Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Executive Summary – Final Version

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary

Introduction

This Executive Summary covers an EC Product Group Study related to the Ecodesign of Energy-related Products (ErP) Directive 2009/125/EC (recast of the former EuP Directive 2005/32/EC) for ENTR Lot 5 Machine Tools and Related Machinery. This study has been contracted to Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (IZM) and Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik (IPK).

This product group study aims to identify and recommend ways to improve the environmental performance of these energy-using products throughout their lifetime at their design phase based on the European Commission Methodology for Ecodesign of Energy-using Products (MEEuP). The information provided by the study will be used to prepare for subsequent phases, including undertaking an impact assessment on policy options and to prepare a paper for the consultation of the forum. Those phases are to be carried out by the European Commission.

Task reports are published at www.ecomachinetools.eu .

Main Findings

TASK 1 – DEFINITION

As there is a limited common understanding of a machine tool and as also standards and legislation do not provide an unambiguous definition of “machine tools”, this study had to come up with a “machine tools” definition. This definition has been based on the engineering consideration that cutting, shaping and joining are typically those technologies employed by machine tools, together with economic classifications, standards on process technologies, and taking into account the existing legal framework (the Machinery Directive, 2006/42/EC). Hence, the definition proposed is as follows:

A machine tool is a stationary or transportable assembly, which is neither portable by hand nor mobile, and which is dependent on energy input (such as electricity from the grid or stand-alone / back-up power sources, hydraulic or pneumatic power supply, but not solely manually operated) when in operation, and consists of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is the geometric shaping of workpieces made of arbitrary materials using appropriate tools and forming, cutting, physico-chemical processing or joining

technologies, the use of which results in a product of defined reproducible geometry, and intended for professional use.

Examples of machine tools comprise those for separating/ cutting and forming of metals, including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse, electrolytic etching, etc., or for turning, drilling, milling, shaping, planing, boring, grinding etc., for soldering, brazing, or welding. Further examples are detailed in the Task 1 report.

Explicitly, machine tools for processing a variety of materials are covered, not only metal working machine tools, i.e. also wood working ones and those for other rigid materials such stones, plastics, glass etc. and welding equipment.

The scope of this study covers also “related machinery” which is *machinery for professional use, which contains components and modules of other machinery, which are similar to those used in machine tools.* In order to be clear, these components and modules might be used in machines which do not fall under the definition of machine tools as provided above.

This broader scope is meant to identify potentially a wider environmental improvement potential in industrial production than only with a focus on machine tools as such.

It is intended to follow a modular approach (i.e. machine modules) in the following environmental analysis, taking the machine tools as the starting point, but also covering through this modular approach other (“related”) machinery.

There are numerous standards which exist for machine tools, covering safety aspects. In Europe, a large number of these standards are implemented through the machinery directive (2006/42/EC). With respect to environmental aspects of machine tools there are only very few relevant standards to date, such as ISO 5170 on lubrication systems and ISO 11204 on noise test methods. The first standard specifically tackling machine tools with regard to environmental aspects is the planned ISO/NP 14955 - Environmental evaluation of machine tools. Taking the current status of approved and published standards as a basis, there are **gaps in standardisation** of machine tools specifically regarding the **eco-design process, marking/ labelling of materials/ components (e.g. identification of hazardous substances), power consumption measurements (machines and modules), power modes, power management, consumption of lubricants (measurements, assessment), consumption of compressed air (measurements), and process waste generation measurement including yield losses**.

The most relevant pieces of EU-level legislation regarding environment, health and safety issues for machine tools are:

- Directive 2006/42/EC on machinery
- Directive 2012/19/EU on waste electrical and electronic equipment (WEEE, re-cast of 2002/96/EC)
- Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS, recast of 2002/95/EC)
- Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors

Within the industry there is as yet no voluntary agreement, but CECIMO (Comité de coopération des industries de la machine-outil) initiated a Self-Regulation Initiative (SRI) in 2009, so far addressing metal working machine tools only.

TASK 2 – ECONOMIC AND MARKET ANALYSIS

The machine tools sales market is subject to huge fluctuations, depending on economic cycles. Due to their long lifetime, the stock (installed base) of machine tools shows much less fluctuation than the sales figures. PRODCOM figures were subject to an extensive plausibility check, and revisions were made accordingly, with the support of the following associations in particular: CECIMO (and member associations), EPTA (European Power Tool Association) and the European Welding Association (EWA). Whereas EuroStat states a production volume of nearly 600.000 metal working machine tools for 2009, our plausibility check shows that an estimated **216.000 metal working machine tools** are sold annually, falling under the definition provided in Task 1 is a much more likely figure. Similarly for wood working machinery, instead of 3.4 million production units sold per year - as stated by EuroStat - a more reasonable figure for wood working machine tools, according to the plausibility check by Fraunhofer, is **130.000** units (2009 data) for larger machinery. Note that these data overlaps with the annual market sales data of **220.000 for light stationary wood working tools**. The market of **welding, soldering, and brazing equipment** covers roughly **1.400.000 units** sold per annum of EU production, regarding units falling under the definition provided above.

A basic technical distinction of machine tools is, whether they are controlled and operated by support of any computer hardware and software (CNC, computerized numeri-

cal controlled, occasionally also called NC, numerical controlled, only), or just manually (referred to as non-NC, or non-CNC in this study).

A stock model set up by Fraunhofer for the major market segments covered by the definition of “machine tools” indicates that currently in the EU 27 there are in operation:

- **3,5 million metal working machine tools**, of which **750.000 are** Computerized Numerical Controlled **machine tools (CNC)**
- **5,8 million wood working machine tools**, of which **1,4 million are larger stationary machinery**
- **7,1 million units of welding, soldering and brazing equipment**, of which **1,5 million are stationary units.**

Due to the long lifetime of stationary machine tools, the stock remains very stable for wood working machine tools and no major changes are to be expected regarding the installed base in the mid-term future. The metal working machine tools market sees an ongoing shift from non-CNC machine tools to CNC: In 2025 a total stock of 2.8 million metal working machine tools is forecast, of which 800.000 are estimated to be CNC machine tools, with an increasing complexity and functionality.

The Life Cycle Cost (LCC) model for machine tools is subject to the broad variety of machine tools, and the fact that many more factors than only purchase price, consumables and spare parts play a role. Running costs over the lifetime in almost all cases seem to be higher than initial investment costs; the costs for electricity and (where applicable) consumables are very relevant, and maintenance costs often play an even more important role.

Reflecting the regions where machine tools are most prominently used, the size of the companies using them, and regional electricity costs, in approximate terms the “typical” electricity price for use of metal working machine tools is 0,11 Euro/kWh, for wood working machine tools it is 0,14 Euro/kWh, but it should be noted that these costs have a broad spread across the EU-27 countries.

The total sales volume for EU-27 for mineral oil-based non-water miscible and water miscible cooling lubricants was roughly 800 million Euros in 2008, indicating the high economic relevancy of coolants.

The total value of tools, workpiece holders and spare parts in 2008 for EU 27 production was **7,6 billion Euros**, compared to a sales volume (sold production) of 26,4 billion Euros for machine tools in the same year.

TASK 3 – USER REQUIREMENTS

Machine tools are **business-to-business products**. Recent survey results and stakeholder feedback show that “energy efficiency” – despite some outstanding initiatives - is only recently becoming important in the marketing of the machine tool manufacturers. The important facts are price, cutting speed and innovative equipment.

Although machine tools users’ interests regarding energy efficiency aspects is growing, technical features and performance criteria still dominate. The growing interest and related marketing initiatives do not yet result in a broad demand for, and implementation of, energy efficient modules in machine tools. This is the case particularly in the woodworking sector, although some manufacturers of machine tools actively promote “green” features of their machine tools. In the metal working sector there is a somewhat higher level of awareness of "green" issues, and interest among the automotive industry and its suppliers, but for most other market segments energy efficiency is not among the most decisive criteria for purchasing a machine tool.

Implementation obstacles regarding new energy efficient solutions on the users' side can be observed. For most machine tool users, the price-profitability relation and therefore the amortisation time of such solutions, as well as limited financial resources, are some of these barriers. The main marketing aspects are still price, cutting speed and the innovative equipment of products. The Total Cost of Ownership approach is realised mainly in large-scale production branches, such as the automotive industry.

Nevertheless, machine tool users are aware of the growing importance of machine tools per se, in realising broader sector-specific environmental aspects, especially energy saving gains..

Retrofitting and refurbishment of machine tools after a certain time in use is very common and reported to take place typically a couple of times throughout the lifetime of a machine tool. Due to the business-to-business nature of the machine tools market and the material value of scrapped machine tools a high recycling quota can be anticipated, although statistical data on this aspect is not available.

TASK 4 – ASSESSMENT BASE CASE

Based on findings for the machine tools market, the **Base Case assessments**, meant to be conscious abstractions of reality, cover one typical type of machinery, for each of the following segments:

- **Base Case 1: Computer numerically controlled (CNC) machining centre,**

- **Base Case 2: numerically controlled (NC) deep drawing or bending machine tool,**
- **Base Case 3: laser cutting machine tool,**
- **Base Case 4: non-numerically controlled (non-NC) metal working drilling machine**
- **Base Case 5: machine tool for woodworking: light stationary table saw,**
- **Base Case 6: machine tool for woodworking; horizontal panel saw,**
- **Base Case 7: machine tool for woodworking: throughfeed edge banding machine,**
- **Base Case 8: machine tool for woodworking: CNC machining center; and**
- **Base Case 9: transportable welding equipment.**

The above choices were based on the rationale that the various levels of machine complexity should be addressed, and that the different processes applied, and the variety of materials processed, should be covered.

The assessments confirm the relevancy of use phase energy consumption. For some impact categories the production of the machine tools also has significance.

Total energy consumption (primary energy) of **CNC metal working machining centres (Base Case 1)** is in the range of **410 PJ per year**, which is much more than for any of the other calculated Base Cases. Further relevant machine tools segments are welding equipment (46 PJ per year), industrial wood working machine tools (36 PJ per year, represented by horizontal panel saws, throughfeed edge banding machines, and CNC machining centres), and CNC laser cutting machine tools (32 PJ per year). The **total energy consumption of all Base Cases is 645 PJ per year**, of which c. **60 kWh is electricity.** Aggregated **Greenhouse Gas emissions** total **28 million tonnes CO_2-equivalents**. The Base Cases cover the most relevant market segments of machine tools covered by this study, but not all segments. Therefore, this approach leads to an underestimation of total impacts; however, the order of magnitude is plausible.

TASK 5 – TECHNICAL ANALYSIS BAT AND BNAT

Task 5 identified numerous Best Available Technologies (BAT), including options which are mostly already introduced on the market. In addition, several very generic Best Not Yet Available Technologies (BNAT) were identified and examined. The presented solu-

tions do not claim certain machine tools as the most energy efficient, and thus the best available, or best not yet available technology. Instead, **there are a large number of energy efficient solutions at the component level** for BAT and potentially as BNAT. Here, the modular system architecture of machine tools has to be taken into account for any eco-design measures. Many of the components are manufactured by suppliers and implemented by the machine tool manufacturers. There are some approaches, which address **non-energy related improvements, including media consumption, mass reduction, and productivity increases**. The energy savings to be realised largely depend on the combination of measures, and the savings potential cannot solely be aggregated, when more than one option is implemented.

The assessment of the various technical eco-design measures has been based on a survey among machinery and component manufacturers, which was complemented by research on technical options. The assessment shows that there is a multitude of options, each with a small energy savings potential in the range of 1%, and that it may be anticipated that a combination of several options could lead to significant total savings. However, the large spread of answers given for most of the options once again confirms that the feasibility and suitability of any option has to be assessed carefully for the intended application.

TASK 6 – IMPROVEMENT POTENTIAL

The analysis of improvement potentials calculates the effects of these design options being implemented consecutively, in terms of their monetary consequences via Life Cycle Costs (LCC) for the user, comparing their environmental costs and benefits, and pinpointing the solution with the Least Life Cycle Costs. This analysis builds on the Base Cases. Although the implementation of options now refers each to “one unit of machine tool”, these are hypothetical cases, and are not meant to represent real-world machine tools. Note that the analysis already includes a consideration of market penetration rates.

For each of the Base Cases a consecutive order of design options between 1 for simple non-NC machine tools up to 22 for highly complex machine tools was identified. The analysis showed that the combination of options can lead to moderate **Total Energy savings potentials at the point of Least Life Cycle Costs**, **in the range of 3%-5% for the most relevant Base Cases**, among them the highly-relevant Base Case 1 on CNC machining centres, but also the Base Cases from the wood working sector. For **welding equipment** a **Total Energy savings potential of 12,2% at Least Life Cycle Costs** was calculated. The sensitivity analysis (variation of use patterns, shift

models, lifetime, energy costs) largely confirms the trends identified in the baseline analysis.

In general, there is no single option with a large environmental improvement potential. **Moderate savings** as stated **can only be realised with the implementation of several individual options, and what could be called "good machinery design"**. As this analysis was meant to address certain archetypal machine tools on a very generic level, it should not be ignored that there might be a much larger savings potential for some machine tools under certain conditions, e.g. for specific applications.

TASK 7 – POLICY AND IMPACT ANALYSIS

For the various market segments covered by this study, several targeted policy options apply. For less complex machine tools, specific requirements can be defined. However, for more complex machine tools, policy measures need to reflect the multitude of improvement options identified, the systems aspect, and productivity considerations. A proposed requirement is the mandatory usage of **Good-design-practice Checklists**, making it obligatory to assess the feasibility of improvement options. The final judgement, whether an option is suitable for a given application would remain with the machinery developer.

Besides such a checklist approach (and closely related to it), **power management and information/ declaration requirements** can be defined. Whereas power management addresses the aspect of reducing power consumption in non-productive times without hampering productivity, standardised information/ declaration requirements create transparency and comparability regarding environmental performance and life cycle costs. In particular, the latter is assumed to have an influence on purchase decisions.

Such measures could be introduced either through an ecodesign **implementing measure** or through one or several **Voluntary Agreements (VAs)**. No such Voluntary Agreement is currently in place, and for both options several standards are still lacking, which – if in force - would allow the unambiguous implementation of such VAs.

Three policy option, assumed to yield a change in the market from 2014 onwards, are assessed against a Business-as-usual-scenario (BAU), to examine their energy savings potentials:

(1) Implementation of a good-design-practice-checklist, accompanied by power management requirements and declaration obligations, leading to machinery improvements which correspond to the point of **Least Life Cycle Costs**. This scenario yields a moderate **saving of minimum 31 PJ in 2025 or nearly 4% compared to BAU**.

(2) An alternative **"optimistic scenario"** anticipates higher savings of good-design-practice. **Fiscal incentives** furthermore are assumed to pay off part of the additional machinery costs for implementing even more improvement options than in the scenario above. This option results in **savings of minimum 38 PJ in 2025** compared to BAU.

(3) A **Voluntary Agreement** with a hypothetically target that all machine tools sold in 2014 and thereafter should be, on average, 10% less energy-consuming than in 2010 in combination with an effective **Product Carbon Footprint label** for light-stationary machine tools, yields a total **saving of 74 PJ in 2025**, or **9% compared to BAU**.

Note that the actual savings potential of all scenarios might be higher, because the Base Cases chosen do not fully cover the scope of the study.

Given the typically long lifetime of the machinery considered, any implemented measure is projected to yield significant overall savings results only over the **medium- to long-term**.

Fraunhofer

Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 1 Report - Definition

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary – Task 1

As there is a limited common understanding of what is a machine tool and as also standards and legislation do not provide an unambiguous definition of “machine tools” this study has to come up with a “machine tools” definition. This definition, based on engineering considerations that typically cutting, shaping and joining technologies are those employed by machine tools, economic classifications (NACE Rev. 2, and industry statistics), standards on process technologies (such as DIN 8580), and the existing legal framework (machinery directive) is as follows:

A machine tool is a stationary or transportable assembly, which is neither portable by hand nor mobile, and which is dependent on energy input (such as electricity from the grid or stand-alone / back-up power sources, hydraulic or pneumatic power supply, but not solely manually operated) when in operation, and consists of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is the geometric shaping of workpieces made of arbitrary materials using appropriate tools and forming, cutting, physico-chemical processing or joining technologies, the use of which results in a product of defined reproducible geometry, and intended for professional use.

Exemplarily machine tools comprise those for separating / cutting and forming of metals, including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse, electrolytic etching, etc., for turning, drilling, milling, shaping, planing, boring, grinding etc., for soldering, brazing, or welding. For further examples see the Task 1 report.

Explicitly, machine tools for processing a variety of materials are covered, not only metal working machine tools, i.e. also wood working ones and those for other rigid materials such stones, plastics, glass etc. and welding equipment.

The scope of this study covers also “related machinery” which is *machinery for professional use, which contains components and modules of other machinery, which are similar to those used in machine tools.* For clarification: these components and modules might be used in machines, which do not fall under the definition of machine tools as provided above.

This broader scope is meant to identify potentially a broader environmental improvement potential in industrial production than only with a focus on machine tools as such.

It is intended to follow a modular approach (i.e. machine modules) in the following environmental analysis, taking the machine tools as the starting point, but covering by this modular approach also other ("related") machinery.

A first screening of environmental parameters unveils a **total annual power consumption of machine tools in the range of 200-300 TWh** in the EU-27 largely attributed to metal working machine tools, and a lower share attributed to wood working machinery, welding, brazing and soldering equipment, and stone, glass, and ceramics working machine tools. The screening of machine tools properties against environmental parameters as listed in Annex I of the ErP Directive indicates **highest relevancy of energy consumption in operational and non-operational modes**, and a **moderate relevancy of lubricants' consumption, ease for reuse and recycling, extension of lifetime, waste generation related to the use phase (production waste), emissions to air (saw dust, welding fume...)**.

There are numerous standards existing for machine tools covering safety aspects. In Europe a huge number of these standards are implemented through the machinery directive. With respect to environmental aspects of machine tools there are only very few relevant standards yet such as ISO 5170 on lubrication systems and ISO 11204 on noise test methods. The first standard tackling specifically machine tools with regard to environmental aspect is the planned ISO/NP 14955 - Environmental evaluation of machine tools. Taking the current status of approved and published standards as a basis, there are **gaps in standardisation** of machine tools specifically regarding the **eco-design process, marking / labelling of materials / components (e.g. identification of hazardous substances), power consumption measurements (machines and modules), power modes, power management, consumption of lubricants (measurements, assessment), consumption of compressed air (measurements), process waste generation measurement including yield losses**.

Most relevant legislation on the European level regarding EHS issues are:

- Directive 2006/42/EC on machinery
- Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)
- Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)
- Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors

Within the industry there is no voluntary agreement yet, but CECIMO initiated a Self-Regulation Initiative (SRI) in 2009, so far addressing metal working machine tools only.

1 TASK 1 – DEFINITION

1.1 Subtask 1.1 – product classification and definition

- **Subject of examination**

The primary subject of this preparatory study is defined as 'machine tools'. The product scope remains being the **only reference framework** for the whole study when discussing economic figures, base cases, improvement options, and the like.

As there are similarities between machine tools and other kinds of machinery and equipment, in a subsequent approach, the scope of this study will cover **equipment related to machine tools** and **modules** of other machinery, which are similar to those used in machine tools. Machineries which contain similar modules will be **not** subject to forthcoming analysis (market data, base cases, etc.) but will be indirectly affected by findings deriving from the machine tool examination (e.g. improvement options for certain modules).

- **Objective of task 1.1**

The main objective of this first task is to set a sound foundation for appropriate study results by **defining and classifying the product scope** for ENTR Lot 5 "machine tools and related machinery". The definition will be based on existing definitions and adaptations of these in order to serve the aim of the study.

In order to select a proper product scope from the existing options (e.g. definitions and scopes deriving from market statistics, technical standards, and labelling schemes[1]) it is necessary to reflect or match the boundaries of this product scope with the task requirements of the whole study. This means that the product scope needs to fit:

- Test standards reflecting environmental issues such a power consumption measurement procedures (task 1)
- Product and technology trends (task 2 and 6)
- Available market data and respective typical market segmentation (task 2 and 4)

[1] Compare suggestions from the tender specifications, EUROPEAN COMMISSION, *ENTR/2009/035*, 2009, p.24.

- Use environments and respective typical use patterns (task 3 and 4)
- Products design characteristics and respective technical parameters (task 4)
- Relevant environmental impacts and expected improvements (task 5)

Against this background the first subtask “product definition” is most critical because it determines to great extent the boundaries of following tasks and the overall result of the study – providing options for ecodesign requirements.

- **Structure and design of task 1.1**

Based on various definitions and classifications of machine tools, as traceable in (specialist) literature, guidelines, directives, studies, and the like the scope regarding machine tools will be defined and also be specified for metal working, woodworking, and welding / soldering / brazing in particular.

Subsequently, the product scope will also be classified in terms of PRODCOM categories, whereby the previous subdivision is taken up, meaning that metal working, woodworking, welding / soldering / brazing, and other machine tools will be examined separately.

Taking into account technological convergences of machine tools with other manufacturing machines, the scope will be extended to those which contain similar modules, which in the following will be addressed as ‘related machinery’.

1.1.1 Existing definitions and product classifications

1.1.1.1 DIN 8580

From the perspective of the manufacturing processes DIN 8580[2] provides a broadly accepted classification and terminology for all kinds of processes, Figure1-1. Concerning the aim of our study, the standard provides no further evidence about the allocation of manufacturing process to the correspondent machine, especially machine tools. In fact, DIN 8580 provides an indication concerning conventionally used technologies in the field of manufacturing.

[2] DEUTSCHES INSTITUT FÜR NORMUNG, *DIN 8580:2003-09 Fertigungsverfahren – Begriffe, Einteilung*, 2003.

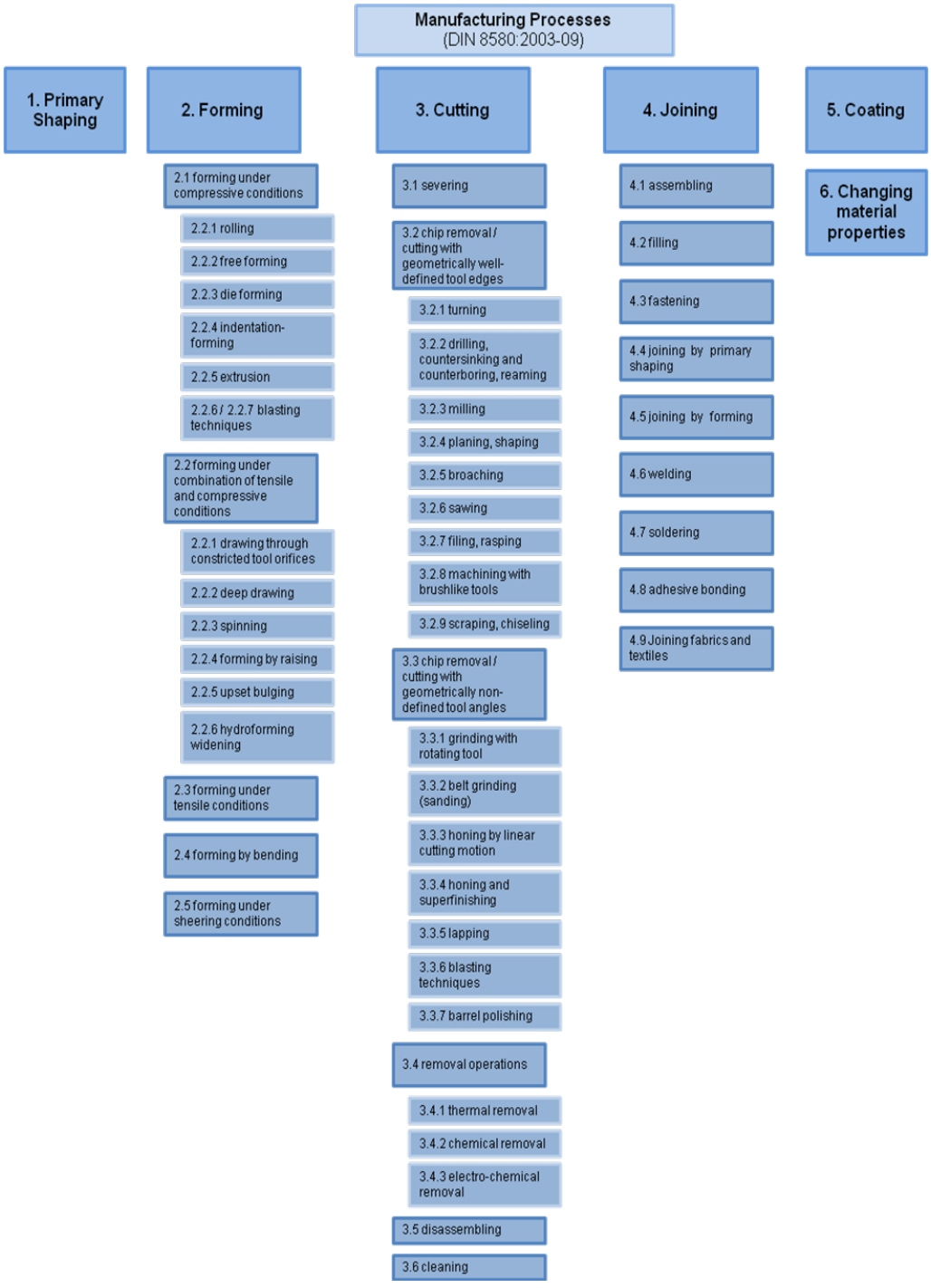


Figure1-1: General Scope – Overview Manufacturing Processes classified according to DIN 8580 (selection)

1.1.1.2 Level of automation of machine tools

Machine tools can be distinguished according to the level of automation, as described in Figure 1-2 (depicted is a scheme reflecting cutting machine tools). A “machine” is characterised by the presence of cutting and feed drives, whereby the sequence of motions as well as tool and workpiece change is carried out by manpower. For the “NC-machine”, a numerical control is incorporated to automatically run the machining of the workpiece. An entire processing of an individual workpiece can be performed in a “centre”, for which several tools can be deployed and changed automatically. Standalone series production for similar workpieces can be applied for a “cell”, in which the complete process of machining is performed automatically, enabled by the extension of automated workpiece change. The highest level is reached in a “system”, where the entire manufacturing process is automated and generally consists of several production machineries, workpiece and tool flow systems as well as supply and waste disposal logistics, controlled by a master computer. [3]

In regard to the ecological performance, it is likely that the increase of automation goes along with rising environmental significance, in particular energy use, considering that manpower is successively replaced by electric current. Automated machine tools are designed for continuous working, which leads to a greater extent of energy consumption during the use phase compared to low tech machine tools. At the same time, raising consumption of electricity causes an increase in heat development, which requires additional cooling. Thus, the degree of automation serves as an ecological indicator, e.g. in regard to the energy demand or manner of use (series production, occasional use, and the like). However, coming along with automation, the productivity of a machine is significantly improved, which should be considered as well. These deliberations are taken into consideration in Figure 1-2.

[3] HIRSCH, A., *Werkzeugmaschinen: Grundlagen: Lehr- und Übungsbuch*, 2000, p. 4.

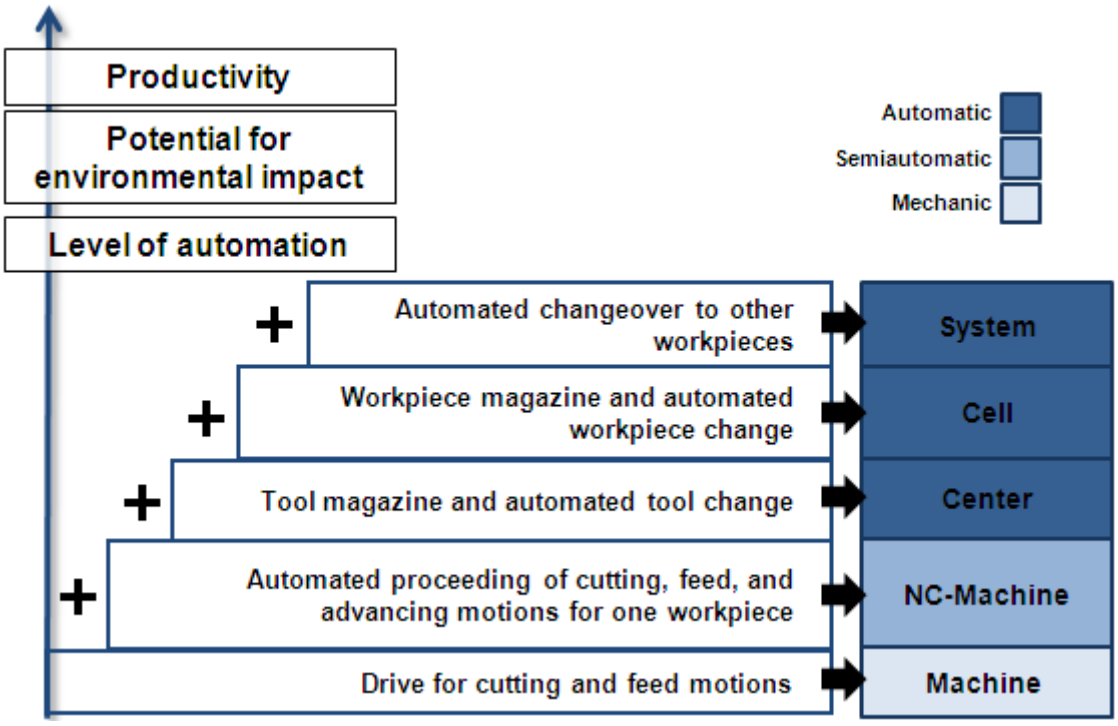


Figure 1-2: Distinction of machine tools according to level of automation.

1.1.1.3 DIN 69651

The drawn back standard DIN 69651[4] deals with the classification of metal working machines and defines machine tools as “mechanised and more or less automated production facilities, which enable the determined shape or transformation of the workpiece through relative motion between tool and workpiece”,[5] thus covering a broad range of working machines. The classification has been performed according to numerous considerations as illustrated in Figure1-3. It is worth to point out that general manufacturing processes for metal working according to this standard are primary shaping, forming, separating, joining, coating, and changing material properties, as

[4] DEUTSCHES INSTITUT FÜR NORMUNG, *DIN 69651 – Werkzeugmaschinen für die Metallverarbeitung*, 1981.

[5] Translation by Fraunhofer, original version in German reads as follows: “*Werkzeugmaschinen sind mechanisierte und mehr oder weniger automatisierte Fertigungseinrichtungen, die durch relative Bewegungen zwischen Werkzeug und Werkstück eine vorgegebene Form oder Veränderung am Werkstück erzeugen.*”, DEUTSCHES INSTITUT FÜR NORMUNG, ref 4, part 1, p. 3.

demonstrated in Figure1-4. The following figures shall illustrate the classification according to this outline:

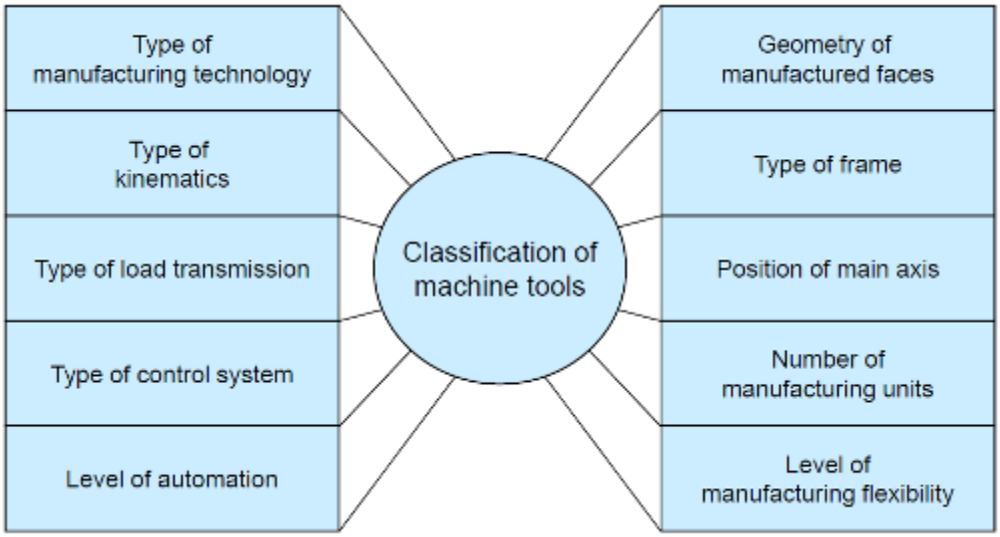


Figure1-3: Classification of machine tools according to DIN 69651

Figure1-4 implies that DIN 69651 can be perceived as an enhancement of DIN 8580 (as described in 1.1.1.1) due to the allocation of technologies and processes to the appropriate machines.

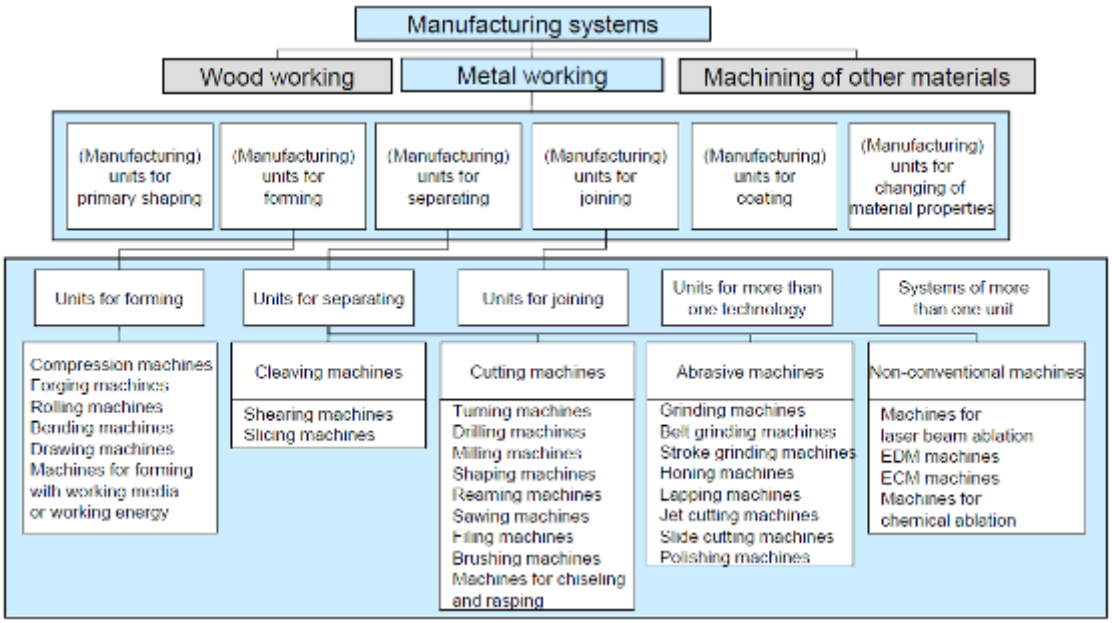


Figure1-4: Machine Tools and manufacturing processes according to DIN 69651

1.1.1.4 Directive 2006/42/EC on Machinery

The revised Machinery Directive 2006/42/EC[6] replaced the former directive 98/37/EC in order to consolidate "the achievements of the Machinery Directive in terms of free circulation and safety of machinery while improving its application".[7] In accordance with Directive 2006/42/EC, the word 'machinery' describes "an assembly, fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application […]". The directive basically deals with safety aspects and the agreement on uniform European standards to avoid extra costs and to prevent from unsafe products in the market. Therefore, it is intended to cover the whole range of all types of machines. Although implicitly addressing machine tools being in the scope of this directive,[8] no further specifications which could indicate a machine tool classification are being made.[9]

1.1.1.5 DIN EN ISO 23125:2010

The draft for DIN EN ISO 23125[10] is a specification of the Machinery Directive concerning safety matters on turning machines. Implementing measures require the classification of machine with certain features into groups, thus turning machines where divided into four groups, according to the following pattern:

Table 1-1: Product classification according to DIN EN ISO 23125:2010

Group No.	Group name	Subdivision in sizes
Group 1	Manually controlled turning machines **without** numerical control	Small and Large
Group 2	Manually controlled turning machines **with limited** numerically controlled capability	Small and Large

6 EUROPEAN COMMISSION, *Directive 2006/42/EC on Machinery*, 2006.

7 EUROPEAN COMMISSION - ENTERPRISE AND INDUSTRY - MECHANICAL ENGINEERING, 2010.

8 Including machine tools accomplished by the exclusion principle, compare ref 6, Article 1, No.2; note: additionally, Machine Tools are excluded from the Low Voltage Directive 2006/95/EC

9 Regarding the aim and the scope, however, this directive does not cope with classification issues at all.

10 NORMENAUSSCHUSS WERKZEUGMASCHINEN (NWM) IM DIN, *DIN EN ISO 23125:2010*, 2010.

Group No.	Group name	Subdivision in sizes
Group 3	Numerically controlled turning machines and turning centres	Small and Large
Group 4	Single- or multi-spindle automatic turning machines	No subdivision

Concerning the size of the turning machine, further distinctions are made:

Table 1-2: Product distinction small and large turning machines according to DIN EN ISO 23125:2010

Criterion	Small turning machines	Large turning machines
Horizontal spindle turning machines and turning centres		
Distance between centres (BC) [mm]	≤ 2000	> 2000
Designed to accept workpiece clamping devices [mm, Outside diameter]	≤ 500	> 500
Vertical turning machines, inverted spindle turning machines including pick-up machines and turning centres		
Designed to accept workpiece clamping devices [mm, Outside diameter]	≤ 500	> 500

1.1.1.6 Nomenclature générale des activités économiques (NACE) Rev. 2

Up to this point of the study, regarding the existing classification introduced thus far, it is apparent that the definitions stated above either do not directly address machine tools as such (e.g. DIN 8580, Machinery Directive) or their field of classifying is restraint to a very specific sub market of machine tools (e.g. DIN EN ISO 23125).

In order to provide a qualitative approach how to categorize and classifying machine tools, the NACE classification can serve as a basis. NACE is the “statistical classification of economic activities in the European Community”[11] in order to create statistical standards for the EU-wide economy. Products which could be considered as machine tools are aggregated in group 28.4 “Manufacture of metal forming machinery and machine tools”, furthermore divided into both classes 28.41 “Manufacture of metal forming machinery“ and 28.49 “Manufacture of other machine tools“. Although a distinction has been made between machine tools for working metal and those for working other materials, a broad range of all varieties of industrial production machineries are covered by the term ‘machine tools’, as summarized in Table 1-3.

11 EUROSTAT, *Methodologies and Workingpapers - NACE Rev. 2 - Statistical classification of economic activites in the European Community*, 2008, p. 7.

Table 1-3: NACE Rev. 2 classification on metal forming machinery and machine tools

28.4 Manufacture of metal forming machinery and machine tools
28.41 Manufacture of metal forming machinery
This class includes: - manufacture of machine tools for working metals, including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse etc. - manufacture of machine tools for turning, drilling, milling, shaping, planning, boring, grinding etc. - manufacture of stamping or pressing machine tools - manufacture of punch presses, hydraulic presses, hydraulic brakes, drop hammers, forging machines etc. - manufacture of draw-benches, thread rollers or machines for working wires This class excludes: - manufacture of interchangeable tools, see 25.73 - manufacture of electrical welding and soldering machines, see 27.90
28.49 Manufacture of other machine tools
This class includes: - manufacture of machine tools for working wood, bone, stone, hard rubber, hard plastics, cold glass etc., including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse etc. - manufacture of work holders for machine tools - manufacture of dividing heads and other special attachments for machine tools - manufacture of stationary machines for nailing, stapling, gluing or otherwise assembling wood, cork, bone, hard rubber or plastics etc. - manufacture of stationary rotary or rotary percussion drills, filing machines, riveters, sheet metal cutters etc. - manufacture of presses for the manufacture of particle board and the like - manufacture of electroplating machinery This class also includes: - manufacture of parts and accessories for the machine tools listed This class excludes: - manufacture of interchangeable tools for machine tools (drills, punches, dies, taps, milling cutters, turning tools, saw blades, cutting knives etc.), see 25.73 - manufacture of electric hand held soldering irons and soldering guns, see 27.90 - manufacture of power-driven hand tools, see 28.24 - manufacture of machinery used in metal mills or foundries, see 28.91 - manufacture of machinery for mining and quarrying, see 28.92

1.1.1.7 Production Communautaire (PRODCOM)

Based on the NACE Rev. 2 structure as mentioned above, the PRODCOM database contains manufacturing data for section B (mining and quarrying) and C (manufacturing), divided into a range of groups from 7.1 to 33.0.[12]

12 Furthermore, categories 399900Z0, 399900Z1, 399900Z3 are included, but will be of less importance for the study.

As mentioned above, regarding the quantity of data material, this database is a unique source when it comes to an economic assessment. Hence, the overall product scope should be complementary and referable to the categories predefined in the PRODCOM database.

As for this study, the decision was made working with PRODCOM and the nomenclature according to NACE Rev. 2. The PRODCOM classes 28.41 and 28.49 will provide the foundation for the study, as they are already predefined as machine tool devices.

1.1.1.8 Study for preparing the 1st Working Plan of the Ecodesign Directive

The EPTA Study[13] based on Article 16 of the Ecodesign Directive 2005/32/EC respectively 2009/125/EC was contracted with the purpose of identifying, which product groups should be listed in the European Commission's EuP Working Plan, and thus potentially subject to an implementation of measures. The methodology that is being used in this study can be described as follows:

- Identification of all Energy Using Products within the scope of the EuP Directive
- Classification of all potential EuPs in product categories[14]
- Identification of priority EuPs and final ranking of the product categories into Priority A EuPs and Priority B EuPs[15]

Due to their findings, they identify machine tools as a relevant class eligible to be examined for improvement potential.[16] A qualitative indication which products ought to be considered as machine tools is listed below:

13 EPTA LTD, *Study for preparing the first Working Plan of the EcoDesign*, 2007.

14 Note: EPTA is using a different nomenclature then PRODCOM to describe similar things (a "category" according to EPTA most likely corresponds with a "group" in PRODCOM).

15 EPTA LTD, ref 13, p. 4.

16 This conclusion derives from an assessment by the means of MEEuP (Methodology study for Ecodesign of Energy-using Products, carried out by VHK in 2005), which will be subject later in this study.

Table 1-4: Machine Tool features and products according to the EPTA Study[17]

Machine Tool features	Products	
Made for Manufacturing & Industrial Use	Lathes - Horizontal lathes - Vertical lathes	Machines for - Milling - Grinding - Bending - Straightening - Folding - Flattening - Cutting - Drilling

The Working Plan Study by EPTA explicitly made a distinction between “machine tools” and equipment for joining processes of metals (“Automatic and Welding Machines”), although from an engineering point, machines for joining processes can be considered “machine tools” too (see DIN 69651 above). Just as machine tools, the product category “automatic and welding machines” is one of the 25 product categories with highest priority (“A”) for inclusion in the Work Plan. Thus, considering the technical convergence of both product groups, automatic and welding machines will be covered by the scope of this study.[18]

1.1.1.9 Technical classification of woodworking machines and auxiliary machines for woodworking

The International standard ISO 7984:1988 ISO 7984:1988 „Woodworking machines – Technical classification of woodworking machines and auxiliary machines for woodworking“ provides an approach for the classification of woodworking machinery from a technological perspective and to some extent in regard to the texture of the end product, additionally considering machines which perform multi-purpose processes. The aim of this standard is to harmonize the designations of different types of woodworking machines in order to overcome language barriers and reduce obstacles to trade. The general definition of woodworking machines provided by ISO 7984 reads as follows:

Woodworking machines, for the purposes of this classification, are stationary or portable machines intended for processing wood, material derived from wood, cork, bone,

[17] EPTA LTD, ref 13, p. 251.

[18] Note: The European Commission evaluated these 25 product categories further to establish a list of 10 product categories in the Work Plan. Whereas machine tools are explicitly listed in the Work Plan, automatic and welding machines are not.

ebonite, plastics and other similar materials (also including assembling, coating machines).

As an outstanding restriction, the definition covers all sorts of machines which are capable to process wood and similar materials. Considering that both stationary and portable machines are addressed, the multitude of small scale handheld woodworking machines is comprised. Compliant with the technological perspective, machines for processing materials having similar properties to wood are covered, so that plastics are included as well. However, the product classification of ISO 7984 goes beyond the definition (e.g. 51.1 Lifting equipment (mobile lifting tables, tilting hoists, etc.), or auxiliary machines such as those for saw blade maintenance (sharpening machines, filling machines, etc.)), which is detailed in Table 1-5.

Table 1-5: Classification of woodworking machines according to ISO 7984:1988

Type of woodworking machine	Specification/Definition
Cutting machines	**Chipless cutting machines**: Cutting machines change the shape or the dimension of a workpiece without the removal of chips
	Cutting machines with the removal of chips or particles: Cutting machines change the shape or the dimension of a workpiece with the removal of chips
Deforming machines	Mechanically change the form and/or physical characteristics of the workpiece by action on its structure
Joining and assembling machines, including coating.	Are for joining two or more pieces, coating machines are for joining a piece ton a coating material (glue, lacquer, etc.)
Equipment for Wood conditioning (seasoning, preserving, etc.).	Modifies the characteristics of the wood by extraction, impregnation or other processes
Auxiliary machines and equipment for the woodworking industry.	Are not strictly woodworking machines but are specifically used by the woodworking industry
Portable machines (hand-held machines) and machining heads	**Portable machines**: Portable machines are power-driven machines, hand-held whilst operating. They include flexible drive and other hand-held machines, e.g. floor sanders, deck planers, etc.
	Machining heads: Machining heads (unit heads) are self-contained production units. They are designed to be mounted on and to supplement existing machines, or, when mounted on a separate base, to form an independent machine.
Multi-purpose machines using various working methods covered by group 1 to 6.	Multi-purpose machines using various working methods covered by groups 1 to 6; in these machines, the workpiece, after initial entry, is fully processed without further manual assistance.
Other machines	Special machines or sets of special machines are designed for the sole purpose of manufacturing particular end products.

1.1.1.10 VDW classification of machine tools ('Red Book')

The "Red Book"[19] issued by the German machine tool Builders' Association (Verein Deutscher Werkzeugmaschinenfabriken (VDW), in the following VDW) provides a precise and detailed overview of distinctive types of machine tools by German manufacturers, along with specific technical details. The index of machine tool types, according to which pattern the classification is being preceded, is subject to Annex I – VDW classification on Machine Tools (Table 3-1, p. 141). The 'Red Book' covers the broad range of machinery for primarily processing metal,[20] whereas machines for processing other materials are not involved, thus not being regarded as a machine tool. The classification also covers periphery systems, e.g. "Control Systems and Software" and "Industrial Plants for Metal Working". Welding and soldering machines, however, are not considered as machine tools.

1.1.1.11 Qualitative definitions for machine tools

In order to set up an approach in engineering terms, the following definition by Kienzle on machine tools gives a basic idea how to border the product scope:[21]

"*Machine tools are machines for the fixed mechanical movement between tools and workpieces. In this regard, tools are processing the workpieces in determined shapes.*"

In general, the perception of Kienzle is that changing the shape of a random component in a definite way is the outstanding feature of a machine tool.

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19 VEREIN DEUTSCHER WERKZEUGMASCHINENFABRIKEN e. V. (VDW), VERBAND DEUTSCHER MASCHINEN- UND ANLAGENBAU e. V. (VDMA), *Machine Tools and Manufacturing Systems from Germany*, 2009. Additional information provided on http://www.vdw.de/web-bin/owa/homepage?p_bereich=leistungsangebot&p_menue_id=1000000022&p_zusatzdaten=dok_zeige_ordner&p_zusatz_id=601&p_sprache=e

20 Note: the Red Book also comprises few very precise niches, such as machines for the precision cutting of diamonds.

21 Translation by Fraunhofer, original version in German reads as follows: "*Werkzeugmaschinen sind Maschinen zur zwangläufigen mechanischen Bewegung von Werkzeugen und Arbeitsstücken. Die Werkzeuge bearbeiten dabei die Arbeitsstücke in bestimmten Formen.*"; KOCH, R., KIENZLE, O., *Handwörterbuch der gesamten Technik und ihrer Hilfswissenschaften Vol. 2*, 1935, p. 731.

By generally defining machine tools as a machine, the definition is compatible with the Machinery Directive as explained in 1.1.1.4. Hence, machine tools can be considered as a particular construction type of a machine in the sense of the Directive.

The use of the term “determined shapes” implicitly imposes several specific requirements onto the workpiece. The word “determined” refers to a fixed, definite, and therefore reproductive way of processing. By comprising the “shapes” into the expression, we conclude that the actual existence of a workpiece’s shape is of crucial significance. In order to provide this feature, the shape has to be existent before, during and after working procedure. To recap our findings: “determined shapes” refer to a reproductive working procedure, in which a particular shape of a workpiece has to be existent before, during, and after the process.

The understanding of workpieces with determined (thus geometric) shapes becomes clearer when comprising the recent definitions on machine tools. An attempt to qualitatively describe machine tools has been phrased by Milberg in the frame of DIN 8580 (see 1.1.1.1). He classifies forming and cutting being the two common applied technologies for machine tools.[22] According to his explanation, machine tools are “working machines for working primarily metallic material with predetermined geometry and appropriate tools”,[23] hence arguing in the sense of the Kienzle definition as stated above.

Comprising a current definition deriving from the DUBBEL, the international acknowledged reference book for mechanical engineering, the significance of geometrical determination of the workpiece is emphasized:

“Due to the relative movement between tool and workpiece and procedural power transmission (separative, transformative), a workpiece of determined elementary shape will be transformed into a predestined shape.”[24]

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22 MILBERG, J., *Werkzeugmaschinen Grundlagen - Zerspantechnik, Dynamik, Baugruppen und Steuerungen*, 1995, p. 2.

23 Translation by Fraunhofer, original version in German reads as follows:“*[Dies sind] Arbeitsmaschinen zum Bearbeiten überwiegend metallischer Werkstoffe nach vorher bestimmter Geometrie unter Verwendung geeigneter Werkzeuge*.“

24 Translation by Fraunhofer, original version in German reads as follows: ”*Durch Relativbewegungen zwischen Werkzeug und Werkstück und verfahrensbedingte Energieübertragung (trennend, umformend) wird ein Werkstück mit bestimmter Grundform in eine vorgegebene Form umgewandelt.*“; WECK, M., *Dubbel - Taschenbuch für den Maschinenbau*, 2005, p. T1.

In order to point out a number of non-distinctive features, the definitions do not claim any restrictive regulation e.g. concerning the processed material, mobility, or the size of the machine, thus opening room for a broad range of various machines which suits the definition.

1.1.1.12 Summary and conclusions

The introduction of the existing categorizing and definition on machine tools revealed that, according to its initial purpose, distinctions among the categories have been made due to different patterns, such as processing and technical features (DIN 8580, ISO 23125, PRODCOM classes), components including their mode of functioning (2006/42/EC), processed material (PRODCOM groups), etc.

Concerning DIN 8580, it is worth noticing, that some of the processes – even from different process classes - might be performed on the same machine tool, e.g. deep drawing (2.2.2) and severing (3.1), just by changing the tool. Therefore this classification according to DIN 8580 does not provide a clear and unambiguous basis to classify machine tools.

The EU directive on machinery at least gives a very broad definition of machinery, but does not provide any guidance, how to distinguish or classify machine tools as a subgroup of machinery. Hence, to resolve this deficiency, the definition on machine tools by Otto Kienzle as stated in 1.1.1.11 can be comprised as framework to gain a more precise picture of the term ‘machine tools’.

PRODCOM provides a clearly arranged view on machine tools and other general machinery which could be subject to this study, besides supplying a multitude of market figures in order to gain a picture of the economic impact for each category. As mentioned afore, due to various facts, PRODCOM remains being an indispensable constituent when analyzing machine tools. However, it should be pointed out that the criterions by which machine tools have been defined as such and put into categories remain unknown,[25] and actually it is up to the manufacturer of machine tools to classify the products according to NACE. In comparison to the ‘Red Book’ issued by the VDW, it is obvious that PRODCOM provides solely aggregated figures for machine tools (given the complexity and multitude of different types of machine tools) which hamper the

[25] Note: Exemplarily, among exclusively cutting and forming machines, class 28.41 contains one casting machine (28.41.33.30 “Presses for moulding metallic powders by sintering [...]”)

identification of environmentally significant machines. Subsequently, an unaltered transfer of the PRODCOM classification to the Product Group Study may lead to inconsistencies among the product scope. In order to cross-check our findings and sharpening the system's boundaries', further external data shall be involved not only for the definition of scope but also throughout the whole study. Additionally, individual data of PRODCOM categories, notably value, sold volume, shall be assessed by measures of quality in order to assess applicability and relevance for this study.

It remains to be emphasized that most existing definitions and classifications do not entirely match our aim to set a sound foundation for the on-going analysis of the study, considering that environmental aspects have not been part to any of them. Some are tailored to small part of machine tools (e.g. DIN EN ISO 23125 for turning machines) which is conflictive considering that it is intended to initially define a broad scope. On the other hand, some are defined in such broad terms (Directive 2006/42/EC on Machinery), for which further specification in reference to machine tools is required.

1.1.2 Definition of machine tools

1.1.2.1 Preliminary restrictions

In the first place, finding the product scope requires several confinements and assumptions. Due to the multitude of definitions and classifications, which differ in the degree if specification and applicability, it is reasonable to start out with a broad and qualitative approach as introduced in 1.1.1.11. Hence, by compiling implicit findings, we are capable to phrase several restrictions which help us defining an appropriate product scope for machine tools.

As argued in 1.1.1.11, the manufacturing process executed by a machine tool is liable to a certain objective, notably changing the geometric shape of a workpiece. In other words, the workpiece is obliged to have a geometric shape before and after the process, which has already been defined in 1935 by Koch and Kienzle and taken up later by Milberg and Weck. Comprising the Machinery Directive introduced in 1.1.1.4, as there is no obvious contrariness with the other qualitative approaches, the Kienzle/Milberg/Weck definition is compatible with this document, too.

- Restriction 1 (technology):

  Deriving from the above definitions, the following technologies subsequently have to be excluded:

- Although providing a geometric shape after the process, **primary shaped** components generally are vaporous, liquid, as well as paste-like or granulated during input, thus lacking a geometric shape. Hence, machinery for primary shaping will not be considered any further as "machine tools".

- Considered on a microscopic level, **surface treatment and coating** as well as procedures **modifying material properties** may lead to a change of the geometric shape of a workpiece, although the intention is different. As this circumstance is rather a side effect of the process, these technologies deviate significantly from those of machine tools in a stricter sense: In the case of **blasting technologies** following considerations lead to the conclusion to exclude blasting technologies from the definition of "machine tools" in a stricter sense: Sandblasting machines are generally equipped for industrial cleaning tasks, such as the removal of contamination or coatings from surfaces. The process media differs with the specific field of application (e.g. suspensions of water, air, process gas and/or abrasives), but the process can also be non-mechanical (lasers). To mention two major differences to those machines which we have regarded so far, blasting machines cannot be considered as production machinery in a conventional sense. The environmental aspects (dust emissions, blasting media consumption and recycling) are different from those being relevant for typical metal working cutting and forming machine tools, hence feature other, very specific characteristics. From the economic perspective industrial cleaning in general becomes more important, however, blasting technologies rather play a minor role (approximately a share of 15% of all cleaning technologies)[26]. Regarding the environmental significance, from the manufacturers' point of view, there is a trend towards clean technologies, expressed by a decline in chlorinated hydrocarbons based cleaning accompanied by an increasing demand for laser technologies,[27] All in all, it should be noted that blasting machinery will not be considered part of the scope, as sufficiently large technological similarities with machine tools cannot be stated

[26] KRIEG, M., *Markt- und Trendanalyse in der industriellen Teilereinigung*, Konferenzbeitrag.

[27] KRIEG, M., ref. 26.

(meaning that no reasonable comparability with other machines is given).

Furthermore, the premise of determined shapes curbs the operating mode of a machine, meaning that the premise of reproducibility has to be preserved. This leads to another restrictive assumption:

- Restriction 2 (product with reproducible geometry):

  Cutting tools for shredding and the like are considered out of scope as they do not grant a determined geometrical result.

The definition also curbs aspects of the workpiece's properties, implying another restriction:

- Restriction 3 (strength of shape):

  Picking up the concept of determined reproducible shapes, the stability of the workpiece remains being an important feature, though leading to the exclusion of **textile as well as rope-making machines** from the product scope, as the processed material is not in a solid, rigid state. This restriction applies to processed material/workpieces which are fluid, soft, very ductile, yielding, and the like, before, during, and after machining, meaning that gravitational, frictional, gripping, or joining forces or torques lead to a deformation in terms of compression, stretching, bending, twist, or volume change in one or several dimensions.[28]

Furthermore, as the focus of this study is meant to be on professional and industrial use of machine tools, DIY ("Do-it-yourself") power tools and the like should be excluded from the scope. DIY tools differ from professional equipment in such a way that they are not placed on the B2B market and cannot be considered as investment goods but rather as consumer goods. As they have to meet other, consumer market specific demands, DIY tools are designed substantially different from professional machine tools and thus are considered out of scope. Investment goods, on the other hand, are highly durable commodities used for creating and processing goods to generate added value. DIY tools do not entirely meet such requirements.

- Restriction 4 (operating a machine tool):

[28] Compare SCHNEIDER, B., *Prozesskettenorientierte Bereitstellung nicht formstabiler Bauteile,* 1999, p. 6. and GÖTZ, R., *Strukturierte Planung flexibel automatisierter Montagesysteme für flächige Bauteile*, 1991, p.21.

Tools portable by hand are usually home-use tools and are characterised by rather short actual operating times.[29] Even those tools portable by hand, which are used by professionals usually are in operation only for few minutes per day, which is a totally different use pattern (and much lower total power consumption) than with large scale stationary machine tools.

Thus, machineries solely featuring one of the above mentioned restrictions will not be considered any further as “machine tools”.

Applying DIN 8580 as introduced in 1.1.1.1, in regard to restriction 1, the scope narrows to a number of few particular technologies. Processes, which are typically performed by machine tools that are those from the process groups 2 Forming, 3 Cutting, and 4 Joining and the respective sub-groups (marked in orange) with some exceptions: Blasting processes (2.2.6, 2.2.7, 3.3.6) are not performed with machine tools and so are disassembly (3.5), cleaning (3.6) and joining fabrics and textiles (4.9) processes, although the cleaning processes might be relevant for the environmental assessment: Required cleaning depends on the way the machine tool operates, e.g. lubricant cooling versus dry processing. There are some more processes, which are typically not performed by machine tools, but could be, such as thermal removal (3.4.1): Here it has to be carefully considered, that the same purpose might be served by machine tools or another kind of industrial equipment. Overlaps with lot 4 (industrial and laboratory furnaces and ovens) might be relevant in a few cases, where machine tools process workpieces under heated conditions. Scope related processes according to the DIN 8580 are shown in Figure1-5.

[29] See also the analysis of charging use patterns for power tools as outlined in Bio Intelligence Service, Fraunhofer IZM, CODDE: EuP Preparatory Study on Battery Chargers and External Power Suppliers, DG TREN Lot 7, 2007



Figure1-5: Machine Tools Scope – Overview Manufacturing Processes classified according to DIN 8580 (selection)

- Restriction 5 (only entire systems): In order to find a sound definition of machine tools, at first, **single components and sub-assemblies** are expelled from the scope (for clarification: single components and sub-assemblies as parts of ma-

chine tools are in the scope when investigating improvement options etc., but not as a distinct definition criterion of what defines a machine tool).[30]

- Restriction 6 (no supply and disposal systems): Besides components, **supply and disposal systems** are out of scope, such as central cooling lubricant systems, as they only affect the periphery of our system. Although being in a functional coherency with machine tools, they should not be covered by the definition of machine tools as they are solely capable to supply border functions in the manufacturing process. Nevertheless, impacts of these supply and disposal systems on machine tools and vice versa will be considered when assessing environmental impacts and systems correlations.

1.1.2.2 Generic definition of machine tools

Summarizing the considerations above, taking the machinery directive as a frame work and Kienzle's technical definition as a straight-forward definition for machine tools, the proposed definition of the scope of this study reads as follows:

A machine tool is a stationary or transportable assembly, which is neither portable by hand nor mobile, and which is dependent on energy input (such as electricity from the grid or stand-alone / back-up power sources, hydraulic or pneumatic power supply, but not solely manually operated) when in operation, and consists of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is the geometric shaping of workpieces made of arbitrary materials using appropriate tools and forming, cutting, physico-chemical processing or joining technologies, the use of which results in a product of defined reproducible geometry, and intended for professional use.

Machine tools comprise exemplarily:

- *machine tools for separating / cutting and forming of metals, including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse, electrolytic etching, etc.*
- *machine tools for turning, drilling, milling, shaping, planing, boring, grinding etc.*

[30] Concerning the PRODCOM database, the sold volume for single components is measured in kg and therefore exacerbating its comparability to other categories, which are usually measured in number of items.

- *stamping or pressing machine tools*
- *punch presses, hydraulic presses, hydraulic brakes, drop hammers, forging machines etc.*
- *draw-benches, thread rollers or machines for working wires*
- *machine tools for working wood, cork, bone, hard rubber, hard plastics, cold glass etc., including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse etc.*
- *stationary machines for nailing, stapling, gluing or otherwise assembling wood, cork, bone, hard rubber or plastics etc.*
- *stationary rotary or rotary percussion drills, filing machines, riveters, sheet metal cutters etc.*

Transportable assemblies are understood to be in operation at changing locations, but parts or the whole assembly are

- *floor standing or*
- *fixed to any other fixed installation (e.g. table top devices)*

while in operation.

“Portable by hand” refers to devices, which are completely carried by the operator when in use.

“Mobile” refers to machinery equipped with a motor

- *to be re-located as a whole or*
- *to process any material while being in motion as a whole*

and are excluded from scope.

Equipment, where only parts of the device are hand-held in operation, but other physically connected parts are stationary, floor standing or fixed to any other fixed installation, are considered stationary or transportable as a whole.

Equipment, being typically powered by internal batteries when being in operation is out of the scope.

The condition "product of defined reproducible geometry" explicitly excludes all machinery processing animal or human material (medical and food processing equipment), textiles manufacturing and processing, and shredding equipment.

"Related machinery" is machinery for professional use, which contains components and modules of other machinery, which are similar to those used in machine tools. For clarification: these components and modules might be used in machines, which do not fall under the definition of machine tools as provided above.

Ecodesign aspects of machine tools and related machinery being in the scope of the study cover also machine external components as far as the operation and design of the machine tool could have an effect on this external equipment (workpiece preparation, centralised lubricant supply, cleaning processes etc.). However, the direct optimisation of these external components is not in the scope of the study.

The following subchapters reflect the definition of machine tools against the common understanding of machinery and equipment in the branches:

- metal working machine tools,
- wood working machinery and
- welding, soldering and brazing machines,

However, this explicitly does not mean a restriction of the scope to these three subbranches only. Others are covered as well by the broader definition provided above.

1.1.2.3 Metal working machine tools

CECIMO, representing national machine tool associations from 15 different nations in Europe, consider machine tools primarily, but not only, as devices for forming and cutting metals.[31] As another outstanding feature, CECIMO defines machine tools as machineries to manufacture products or parts, generally prepared for subsequent treatment in highly complex and sophisticated end-products such as airplanes, medical devices, and the like.[32] Subsequently, the specific scope of metal working machine tools shall be restricted solely to those in the spectrum of the B2B ("business-to-business")

31 See http://www.cecimo.eu/index.php/discover-machine/machinetoolsineverydaylife.html [cited 17.10.2010].

32 See http://www.cecimo.eu/index.php/discover-machine/whatitisamachinetool.html [cited 17.10.2010].

market. In this regard, a CECIMO definition of a metal working machine, which is broadly accepted among the industry, reads as follows:

A metal working machine tool is a power driven, not portable by hand, powered by an external source of energy, designed specifically for metal working either by cutting, forming, physico-chemical processing, or a combination of these techniques.

To stay within the wording of our general definition, aspects deriving from CECIMO's definition shall be incorporated. A corresponding definition tailored to metal working machine tools reads as follows:

A metal working machine tool is a stationary or transportable, but not portable by hand or mobile assembly, connected to the power grid when in operation, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is the geometric shaping of workpieces made of metallic materials either by cutting, forming, physic-chemical processing, or a combination of these techniques, using appropriate tools, resulting in a product of defined geometry.

1.1.2.4 Wood working machines

In analogy to metal machining, manufacturers of **wood working machines** are organized as a self-contained industry sector and are also covered by the scope of this Product Group Study. Woodworking machinery is deployed at all stages of processing wood, beginning with the local cutting of wood of felled trees up to fine machining of single products. Unlike metal working, there is a considerable B2C ("business-to-consumer") market not covered by the scope of the study for wood working machines, primarily a broad range of handheld machines as well as transportable motor operated circular saws and band saws. However, there is a wide range of machines on the B2B market, which use similar technologies (e.g. cutting, planing, milling, grinding) and are equipped with automation. These products are considerably different from B2C products regarding performance, weight, and cost constraints. Subsequently, the definition states the following:

A wood working machine is a stationary or transportable, but not portable by hand or mobile assembly, connected to the power grid when in operation, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is the geometric shaping of workpieces made of wooden materials using appropriate tools and technologies, resulting in a product of defined geometry.

1.1.2.5 Welding, soldering, and brazing machines

Besides using a material related approach to distinguish among industrial branches, it is worthwhile to focus on joining machinery, notably **welding, brazing and soldering machines.** According to Kinkel and Lay,[33] more than two thirds of the German metal and electrical industry are using methods for joining, whereby 60% of these companies expect an increasing importance of the technology for the future. Besides adhesive bonding, welding and soldering are one of the most crucial technologies for industrial manufacturing, whereas the latter is of special importance for electrical engineering and the manufacture of electrical devices. The outstanding role of joining technologies in production processes justifies an isolated analysis, and also due to economic and technological differences compared to metal and woodworking machine tools.

It is acknowledged, that the European Welding Association does consider manual welding equipment not being machinery in the sense of the machinery directive[34]:

- Equipment for manual arc welding and allied processes is intended to be moved by a welder (human force) and therefore is not a machine: The Machinery Directive is not applicable to arc welding equipment for manual welding.
- Equipment for manual arc welding and allied processes intended to be incorporated in a mechanized system is not a „partly completed machine“ but a part of a machine only: The Machinery Directive is not applicable to arc welding equipment to be incorporated in a mechanized system.

However, the machinery directive does not constitute the legal framework of this study, hence other energy-using products, such as manual welding equipment are potentially in the scope of this study.

Following the definition of welding by the American Welding Society (AWS)[35], welding machines are defined as follows:

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33 KINKEL, S., LAY, G., *Technologietrends in der Produktion – Praxis der Anlagenmodernisierung in der deutschen Metall- und Elektroindustrie*, 2006, p.3.

34 Resolution of EWA October 27, 2008

35 Adapted from JEFFUS, L., BOWER, L., *Welding Skills, Processes and Practices for Entry-Level Welders, Book 1*, 2009, p. 4.

A welding machine is a stationary or transportable, but not portable by hand or mobile assembly, connected to the power grid when in operation, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is producing coalescence of arbitrary materials by heating them to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal, using appropriate tools and technologies, resulting in a product of defined geometry.

1.1.3 Classification of product scope

- **Objective**

In accordance with our definition on machine tools and also demanded by the tender specifications for the Product Group Study on machine tools,[36] the scope is ought to be determined in terms of PRODCOM categories. This way, the scope can be specified in terms of particular machines in conjunction with the related annual production figures (average unit value, sold volume, and turnover).

The classification constitutes a significant foundation for on-going analysis, especially in regard to the economic analysis in task 2, which means that a reliable basis needs to be created.

- **Limitations**

In regard to the classification pattern of PRODCOM, there are certain limitations worth to be indicated which are hampering the accurate allocation of categories to the definition. Considering that a broad variety of machines are addressed by our definition, the level of detail for particular types of machines regarding number of categories, comprised machines within one category, specification of the category's description, and the like, is quiet heterogeneous. In some cases, it is not unambiguously acknowledged that the definition fits to the comprised machines of several categories (e.g. 28.99.39.53 "Other machinery for earth, stone, ores, etc., n.e.c.").

This means that although certain categories can be allocated to the aforementioned machines, the selection is ought to be perceived rather as an indication of machines

36 EUROPEAN COMMISSION, ref 1, p. 24f.

included in the product scope, also in regard to that data input is mandatory for the economical assessment coming in task 2.[37]

1.1.3.1 Metal working machine tools

In regard to metal working machine tools, a substantial and differentiated base is provided for the on-going course of the analysis. 59 categories are summarized in class 28.41 “Manufacture of metal forming machinery”.

Using the aforementioned definition of metal working machine tools, PRODCOM class 28.41 “Manufacture of metal forming machinery” will be reviewed in order to find appropriate categories.[38] Hence, **54** out of 59 categories are identified in terms of the definition (see Table 4-1, p. 143). However, certain categories from this class are excluded due to the violation of specific restrictions, which is described briefly in Table 1-6.

Table 1-6: Expelled Categories from class “28.41 - Manufacture of metal forming machinery”

Expelled category	Applicable restriction
28.41.22.33 - Way-type unit heads for working metal by drilling, boring, milling, threading or tapping	5 (Only Entire Systems)[39]
28.41.33.30 - Presses for moulding metallic powders by sintering or for compressing scrap metal into bales	3 (strength of shape not given); 2 (no products/parts being manufactured)
28.41.40.30 - Parts and accessories for metal cutting machine tools (excluding tool holders and self-opening dieheads, work holders, dividing heads and other special attachments for machine-tools)	5 (Only Entire Systems)
28.41.40.50 - Parts and accessories for metal forming machine-tools (excluding tool holders and self-opening dieheads, work holders, dividing heads and other special attachments for machine-tools)	5 (Only Entire Systems)
28.41.40.70 - Parts and accessories for machine-tools operated by ultrasonic processes	5 (Only Entire Systems)

[37] Note: The issue of market data provided by PRODCOM will be raised briefly in the environmental screening and discussed in detail in task 2.

[38] Due to material related restraints as argued in 0, other PRODCOM classes can be excluded a priori.

[39] Note: Single components and sub-assemblies as parts of machine tools are in the scope when investigating improvement options etc.

A non-exhaustive record of typical metal working machine tools affected by the definition stated above is depicted in Table 1-7.

Table 1-7: Non-exhaustive list of comprised metal working machine tools

Metal working industry - comprised machine tools
• Broaching machines • Deburring machines • Draw-benches • Electro-chemical, electron-beam, ionic-beam or plasma arc machines • Electro-discharge machines • Gear cutting/grinding/finishing machines • Grinding machines • Honing machines • Horizontal machining centres • Hydraulic presses • Lapping machines • Laser/light/photon beam machines • Lathes • Multi-station transfer machines • Non-hydraulic presses • Non-numerically controlled bending machines • Non-numerically controlled boring machines • Non-numerically controlled boring-milling machines • Non-numerically controlled cylindrical surface grinding machines • Non-numerically controlled die stamping machines • Non-numerically controlled drilling machines • Non-numerically controlled flat-surface grinding machines • Non-numerically controlled flattening machines • Non-numerically controlled folding machines • Non-numerically controlled forging machines • Non-numerically controlled horizontal lathes • Non-numerically controlled milling machines • Non-numerically controlled notching machines • Non-numerically controlled presses • Non-numerically controlled punching machines • Non-numerically controlled sharpening machines • Non-numerically controlled shearing machines • Non-numerically controlled straightening machines • Numerically controlled automatic lathes • Numerically controlled bending machines • Numerically controlled boring machines • Numerically controlled boring-milling machines • Numerically controlled cylindrical surface grinding machines • Numerically controlled drilling machines • Numerically controlled flat-surface grinding machines • Numerically controlled flattening machines • Numerically controlled folding machines • Numerically controlled grinding machine • Numerically controlled horizontal lathes • Numerically controlled knee-type milling machines

- Numerically controlled milling machines
- Numerically controlled notching die stamping machines
- Numerically controlled notching forging machines
- Numerically controlled notching machines
- Numerically controlled plano-milling machines
- Numerically controlled punching machines
- Numerically controlled sharpening machines
- Numerically controlled shearing machines
- Numerically controlled straightening machines
- Numerically controlled tool-milling machines
- Numerically controlled turning centres
- Planing machines
- Press machines
- Riveting machines
- Sawing/cutting-off machines
- Shaping machines
- Slotting machines
- Spinning lathes
- Swaging machines
- Tapping machines
- Thread rolling machines
- Threading machines
- Turning centres
- Ultrasonic machines for semiconductor devices
- Unit construction machines (single station)
- Vertical machining centres
- Wire producing machines

1.1.3.2 Woodworking machines

Whereas the range of categories for metal working machine tools is comparatively broad, the differentiation of woodworking machines is less detailed, split in only 11 categories, which also include machinery for processing other materials (cork, bone, hard rubber, hard plastic, and others). However, although labelled differently, it is acknowledged by sectoral experts that manufacturers from the plastic and food machinery industry do not report to these categories, therefore they comprise wood and cork machining in their vast majority only. Accordingly, the **11** aforementioned categories substantiate the product scope for woodworking machines (see Table 4-2, p. 145).

A non-exhaustive record of typical woodworking machines affected by the definition stated above is depicted in Table 1-8.

Table 1-8: Non-exhaustive list of comprised woodworking machines

Woodworking industry - comprised machine tools
• Band saws • Bending machines • Boring machines • Circular saws (stationary) • Crosscut machines • Cut-off saws • Drill machines • Drilling machines • Grinding machines • Horizontal band saws (stationary) • Lathes • Milling machines • Mortising machines • Moulding (by cutting) machines • Multi-purpose/universal machines • Panel dimension saws • Panel saw • Paring machines • Planing machines • Polishing machines • Presses • Radial arm saws • Ripsaws • Router machines • Saw benches • Sawing machines • Slicing machines • Spindle moulder/wood shaper • Splitting machines • Surface planer • Tenoners • Thickness planer • Vertical band saws (stationary)

1.1.3.3 Welding, soldering, and brazing machines

Welding, soldering, and brazing equipment is dominated by a multitude of smaller devices, which are typically transportable. Only very few units are actually integrated in a stationary machine. Table 1-9 lists welding, soldering and brazing machinery and equipment following the PRODCOM wording. Several more similar categories are clearly units portable by hand or parts and components. Actually **9** PRODCOM categories are relevant for this study.

Table 1-9: Non-exhaustive list of comprised welding, soldering, and brazing machines

Welding, soldering, brazing industry - comprised machine tools
• Electric brazing or soldering machines and apparatus • Electric machines and apparatus for resistance welding of metal • Fully or partly automatic electric machines for arc welding of metals (including plasma arc) • Manual welding with coated electrodes • Shielded arc welding • Machines and apparatus for spraying of metals • Machines and apparatus for resistance welding of plastics • Machinery and apparatus for soldering, brazing, welding or surface tempering

1.1.3.4 Other machine tools

Besides the types of machines which have been already classified above, further machines can be identified by the aid of the generic definition as stated in 1.1.2.2.

In the course of classifying other machine tools, **10** categories were identified, deriving from several different industry branches (illustrated in Table 1-10). A definition of these in terms of categories only provides little insights concerning the variety of products or the market relevance, which is due to the merging of different types of machineries (e.g. merging of stone, ceramics, glass, and the like) and also the high level of aggregation (e.g. 28.49.11.70 comprises all kinds of machine tools but three specific types). It is striking, that there is a strong similarity to metal working machine tools regarding the manufacturing processes, which are cutting primarily (sawing, grinding, polishing, splitting, etc.) and forming (bending, pressing, etc.). For details, see Table 4-4, p. 146.

Table 1-10: Non-exhaustive list of affected industries for other machine tools (indication).

Comprised other machine tools
Machines for the ceramics industry • General purpose machinery • Grinding machineries • Polishing machineries • Sawing machineries **Machines for the construction industry** • Grinding machineries (stone, concrete, etc) • Polishing machineries (stone, concrete, etc) • Sawing machineries (stone, concrete, etc) **Machines for the glass industry** • Grinding machineries • Polishing machineries • Sawing machineries **Machines for the plastic & rubber industry** • Assembling machineries • Band saws • Bending machineries

- Calendaring machineries
- Circular saws
- Cutting machineries
- Drilling machineries
- Grinding machineries
- Milling machineries
- Morticing machineries
- Moulding (by cutting) machineries
- Multi-purpose machineries
- Multi-purpose machineries
- Paring machineries
- Peeling machineries
- Planing machineries
- Polishing machineries
- Presses
- Rolling machineries
- Sawing machineries
- Size reduction machinery
- Slicing machineries
- Splitting machineries
- Splitting machineries

Machines for the recycling industry

- Scrap metal presses

1.1.3.5 Summary and conclusions

In the course of classifying the product scope, all in all **84 categories** have been identified which substantiate the scope for this study. For the detailed breakdown, see Table 1-11.

Table 1-11: Summary of product scope classification

Type of machine tool	Number of comprised categories		Usability for following tasks[40]
Metal working	54		good usability (detailed breakdown of metal working machine tools (distinction between NC, non-NC; mostly according to manufacturing technology)
Woodworking	11		Specification required (only few categories existent; mixed with other machine tools; no distinction between complex and simple woodworking machines)
Welding, soldering,	9		moderate usability (however, this includes largely

[40] Note: Economic figures are not part of the evaluation.

brazing			a segment of smaller units, partly for integration in other machines, but not machinery as such)
Other machine tools	10		Partly usable (mix of all kind of machines; high level of aggregation; unspecific description of several categories)
Total:	84		

1.1.4 Related machinery

Besides the identification of machine tools, it is additionally intended to follow a modular approach. This is due to the fact that when discussing technological improvement options, the machine sooner or later needs to be regarded in terms of its single modules in order to localize environmentally significant aspects and their corresponding improvement potential. As a consequence for defining the product scope, machines will be included which contain modules similar to those typically used also in machine tools. However, this means that not the whole machine is analysed, but the identified module is subject of further considerations.

1.1.4.1 Modular design of machine tools

In order to reduce the level of complexity, this approach describes machine tools in terms of their single ingredients, in the following referred to as ‘modules’. This approach should improve transparency of the ecological profile of machines and support the identification of improvement potential.

With a view to existing literature, however, there is neither an unambiguous definition for machine tool modules nor a ‘typical set’ of modules.

According to ISO/NP 14955, the view on machine tool components is restricted to those which consume electrical energy. This specific view derives from the intended ISO approach to concentrate on improving the electrical energy efficiency during the use phase. Machine components are defined as “mechanical, electrical, hydraulic, or

pneumatic device(s) of a machine tool, or a combination thereof".[41] The manufacturer who applies ISO/NP 14955 for his products has to specify incorporated modules and select the associated functions individually for each machine. However, it should be mentioned that according to the standard the idea of modules is predominantly functionally-oriented (details provided in section 1.2.6).

In the frame of this study, modules are seen in a broader sense, with the intention to concentrate later on those which contain a significant improvement potential. Thus, in this context, the term modules refer to per se autonomous subsystems which in combination form to a greater system, in which the individual functions (e.g. acceleration, lubrication, vibration damping, etc.) are necessary and contribute to the overall value-adding process (namely the manufacturing of a product). This implies that modules consist of both functional as well as physical features.

The authors of the study support the idea that it is difficult to define a generic set of typical machine tool modules, considering the manifoldness of machine tools as identified in the previous section. However, in order to identify the ecological impact and improvement potential, it is necessary to restrict and generalize 'typical modules' to conduct further analysis. Thus, from a physical point of view, standard modules of machine tools are:

- **frame** (cast iron)
- **guides and bearings** (guides: motion control & adjusting guide (both linear and circular), bearings: hydrostatic, (axial) electrical, etc.)
- **main drives** (electric main drives (e.g. motor spindles for lathes and milling machines, direct current motors, synchronous motors, etc.), hydraulic main drives)
- **feed drives** (hydraulic feed drives for lathes, milling machines, etc.)
- **control device** (CNC applications)
- **hydraulic unit** (continuously variable linear drives)
- **pneumatic unit** (sealing air, workpiece clamping, workpiece holding)

41 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO), *Draft for ISO/CD 14955-1 – Machine Tools – Environmental evaluation of machine tools – Part 1: Design methodology for energy-efficient machine tools,* 2011, p.4.

- **cooling / cooling lubricant unit** (closed circuits for cooling tool and workpiece mainly, using typical lubricants for machine tool processes)
- **process media supply** (welding wire and gas, laser system)
- **Power supply** (electric power transformation)

As far as functionalities of machine tools are concerned, CECIMO in their SRI concept defines the following distinction:

1. Control function
    a. CNC
2. Assisting functions
    a. Process lubrication cooling
    b. Chip removal
    c. Mist removal
    d. Cooling
3. Set up functions
    a. Part handling / part clamping
    b. Tool handling / tool clamping
    c. Process media supply & maintenance
4. Shape of part transformation functions
    a. Manufacturing process integration
    b. Part / tool relative motion
    c. Transforming energy supply

Slightly deviating from this distinction, generalized functions according to ISO/NP 14955 comprises machining (machining process, motion and control), process conditioning and cooling, workpiece handling, tool handling or die change, recyclables and waste handling, and machine cooling/heating.[42] These can be further subdivided into sub functions to detect relevant energy consumers.[43]

Both aspects are important: How to optimise the various components of a machine tool and how to realise certain functions of a machine tool in the most appropriate way. Overarching systems improvement aspects need to be addressed as well. **Table 1-12** correlates physical modules of a machine tool with functional modules of a machine tool. Some physical modules are potentially related with more than one function and vice versa. Some functions might be realised only very occasionally with a marked physical unit (such as the rare use of pneumatics seen in machine tools).

By incorporating the modular approach into the study, the distinction between highly relevant modules from less important ones is facilitated, which is of great significance when identifying BATs for improving the overall environmental compatibility of machine tools. Also a modular approach provides the opportunity to achieve machine-independent findings, considering the fact that most modules can be accommodated in all kinds of energy using products beyond machine tools.

Note, that the above definitions of ‘modules’ is meant to indicate the classification of modules followed in this study. Neither in literature nor in the legislation there is yet a definition of modules available, with qualifies as a definition in legal terms. Such definitions, clarifying in particular unambiguously the system boundaries of each relevant module, still have to be developed, if required for legislative requirements.

[42] ISO, ref 41, p. 9.

[43] ISO, ref 41, p. 12.

Table 1-12: Matrix comparison of machinery modules and functional modules (according to CECIMO SRI)

	Control Function	Assisting functions				Set up functions			Shape of part transformation functions		
	CNC	Process lubrication cooling	Chip removal	Mist removal	Cooling	Part handling / part clamping	Tool handling / tool clamping	Process media supply & maintenance	Manufacturing process integration	Part / tool relative motion	Transforming energy supply
Frame											
Guides and bearings						x	x				
Main drives										x	
Feed drives						x	x				
Control device	x										
Hydraulic unit						x	x			x	
Pneumatic unit						x	x				
Cooling / cooling lubricant unit		x	x	x	x						
Process media supply								x			
Power supply											x
remarks									Systems aspect		

1.1.4.2 Environmental relevancy of selected modules

The modular approach with regard to its single components provides the opportunity to gain a more comprehensive and detailed impression of the environmental relevancy.

The **frame** of a machine tool ensures a stable and precise process and conducts processing forces into the machine frame. Typical frames are castings from gray cast iron and welded steel constructions. For large machines, moreover, the frame has to be anchored on a concrete foundation, in order to balance dynamic forces during operation. In reference to the environmental relevancy, fields of optimisation are solely given in the manufacturing phase, e.g. due to substitution of said materials with alternatives such as metal foam. In regard to material-efficiency, reductions can be achieved e.g. by the use of technologies for analyzing load curves. This way, the overall ecological efficiency of machine tools can be improved due to a lower extent of consumption of material and energy. Considering the concrete foundation, due to a lack of alternatives, less potential for improvement is given.[44]

Guides and bearings are essential to reduce machine-specific motions to a determined set of degrees of freedom. This broadly approached array is of particular significance regarding energy consumption and losses during operation time. The efficiency of motions is primarily hampered by friction, thus low friction, avoidance of stick-slip-effects, and the selection of wear-resistant components have a positive effect on energy efficiency. High friction is also caused by self-locking gearboxes, which are usually applied for many machine tools. Moreover, the acceleration of masses resembles a critical feature, as it significantly contributes to the overall energy consumption. Considering that guides and bearings are of special importance to several components of machine tools (main and feed spindles, work piece table to mention the most relevant), potential for improvement measures and solutions on a broad range can be anticipated.

Main and feed drives for machine tools are usually powered by electric motors, coming to the fore in compressors, pumps, and spindles. In regard to task 1.3, eco efficiency requirements have already been phrased on a legislative level, notably by Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors.

[44] Note: Another approach to reduce emphasis on the foundation would be to find ways to reduce dynamic forces, respectively find other channels for redirection.

However, as the regulation does not cover the full spectrum of motors used in machine tools, it is worthwhile identifying further types of relevant electric motors. Besides raising the electrical efficiency, in reference to CECIMOs' draft on the Self-Regulatory Initiative, however, enhancements can be achieved in the field of regenerative feedback of breaking energy or by upgrading to greater inverter units and motors due to reduced losses.

Accordingly, **control devices, hydraulic units and cooling / cooling lubricant units** provide considerable potential e.g. to elevate the energy efficiency on a higher level. In this regard, CECIMO proposes several options, such as standby modes during non-operation or improved energy-fit modes according to the tangible need of energy for the process.

Pneumatics is occasionally employed in various types of machine tools and production machinery in general, e.g. in the form of sealing air, workpiece or tool clamping. Losses within pneumatic systems occur due to various reasons, in particular during the integration (assembly) of pneumatic systems into greater systems respectively machine tools. These are gas leakages due to improper clipping of air tubes, unnecessary windings and bends of pneumatic feeds, etc. Skilled installation of pneumatic devices, however, significantly increases the efficiency of pneumatics. Application specific design and dimensioning in combination with volume flow monitoring and adaptable operation modes during processing supports a minimized need for electric energy. A decline in flow rate, for example, indicates the occurrence of leakages, which can be fixed short in time if constant monitoring is applied.

Process media supply is relevant for selected processes, such as welding with a welding wire or processes, where process gases are used, welding and laser cutting systems being the most relevant one.

Power supply covers transformation of electric power for the various modules of the machine tool. As every power transformation is related to power losses, the efficiency of the transformer or power electronics components and circuitry under various load conditions is a key aspect for reducing the overall power consumption of the machinery.

Summarizing our findings, though, a distinction between more or less important components is hampered at this stage of study, but can be substantiated in the later course of the study when discussing base cases and options for improvements.

1.1.4.3 Non-exhaustive identification of related machineries

As far as the related machineries are concerned, a non-exhaustive list can be presented, taking into consideration that a complete, definite identification of all machineries which are placed in the market and obtain common machine tools modules is impossible. Later in the study, statements will be made to which extend the findings on the module level can be extrapolated to other machinery segments, or whether there are severe limitations for any such transfer of findings[45]. Hence, by the help of PRODCOM division 28 “Manufacture of machinery and equipment n.e.c.”, an indicative and non-exhaustive list of industrial machinery, which might make use of modules similar to those used in “machine tools” is provided in **Table 1-13**. Machineries have been selected by means of the modules as described above with the exception of frames as well as guides and bearings. Due to the fact that frames can be found in various machines made of arbitrary materials and serving diverse purposes in the context of the product, it would lead to a broad product scope going beyond the capacities of the study. Same argumentation is applicable for guides and bearings, as they are indispensable and provide numerous layouts in every kind of machine.

By means of the Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors, several machineries – which have been solely identified due to main and feed drive likeness and are covered by the Commission Regulation – can be excluded in the first place, namely those falling under NACE class 28.93 “Manufacture of machinery for food, beverage and tobacco processing”.[46] Furthermore, machines which exceed the range of capacity (thus, modules are dimensioned for other loads) typically found in machine tools will be out of focus, such as NACE class 28.22 “Manufacture of lifting and handling equipment” and 28.91 “Manufacture of machinery for metallurgy“. Main and feed drives findable in NACE group 28.3 “Manufacture of agricultural and forestry machinery” do not have any similarity with those in machine tools, due to the fact that combustion engines are generally deployed.

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[45] This transferability depends also on the level of detail regarding specific improvement options identified as a very specific technological improvement might be applicable only to a very limited number of specific cases whereas a rather generic option (example for illustration only: “document measures taken to select motors of optimal size and performance for the intended application”) is transferable to a much broader range of applications

[46] Also categories 28.29.22.30 “Steam or sand blasting machines and similar jet-projecting machines (excluding fire extinguishers, spray guns and similar appliances)”, 28.94.22.50 “Dry cleaning machines”.

A non-exhaustive summary of machines with modular overlaps is depicted in Annex III – Related machinery (identified modules) (non-exhaustive) (**Table 5-1**, p.148). It should be mentioned that category 28.41.33.30, which is excluded from being considered "machine tool" (see Table 1-6) is covered on the module level as a "related machinery" due to similarities in modular design. Despite the fact that machines are being addressed, it should be pointed out that primarily the **manufacturer of system components** are affected by the extension of the product scope.

Table 1-13: Non-exhaustive list of affected industries for related machinery (indication).

Comprised machinery on a modular level
Machines for the chemical industry • Reactive resins machinery • Foam machineries • Floor covering machinery **Machines for the electronic industry** • Boules manufacturing machinery • Circuit machinery • Semiconductor manufacturing machinery • Ultrasonic machinery • Wafers manufacturing machinery • Cable machineries **Machines for the flat panel industry** • Flat panel display machinery **Machines for the glass industry** • Cleaning or drying bottles machinery **Machines for the lamp industry** • Machineries for assembling lamps **Machines for the packaging industry** • Capsuling machinery • Closing machinery • Labelling machinery • Machinery for aerating beverages • Machinery for filling • Packing machinery • Sealing machinery • Wrapping machinery **Machines for the paper & printing industry** • Collating machineries for books • Combined reel slitting cutting machineries • Combined re-reeling cutting machineries • Cross cutting machineries • Flexographic printing machinery • Folding machineries for books • Gathering machineries for books • Gravure printing machinery • Guillotines

- Machineries for making bags, sacks or envelopes
- Machineries for making cartons, boxes, etc.
- Moulding machineries
- Machinery for finishing paper or paperboard
- Paper or paperboard machinery
- Printing blocks and plates machinery
- Pulp making machinery
- Reel fed letterpress printing machinery
- Reel fed offset printing machinery
- Sewing machineries for books
- Slitting machineries
- Stapling machineries for books
- Type-setting machinery
- Unsewn (perfect) binding machineries for books
- Wire stitching machineries for books

Machines for the plastic & rubber industry[47]

- Blow-moulding machineries
- Calendaring machineries
- Extruders
- Injection-moulding machineries
- Sanding machineries
- Thermoforming machineries
- Tyre machinery
- Vacuum-moulding machineries

Machines for the textile industry

- Bleaching machineries
- Circular knitting machinery
- coating machinery
- Cutting machinery
- Doubling machinery
- Drawing machinery
- Dressing machinery
- Drying machinery
- Dyeing machineries
- Extruding machinery
- Finishing machinery
- flat knitting machinery
- Folding machinery (textile fabrics)
- Gimped yarn, tulle, lace, embroidery, trimmings, braid or net machineries
- Impregnating machinery
- Ironing machineries
- Laundry-type Washing machineries
- Nonwoven machinery
- Pinking machinery (textile fabrics)

47 As plastics and rubber machinery constitutes a particularly relevant market segment with anticipated similarities to “machine tools” this market segment was screened to analyse, whether they should be regarded as “machine tools”, “related machinery” or they do not fall under the scope of the study at all. This screening is provided below.

- Presses
- Printing machinery for printing textile materials
- Reeling machinery
- Reeling machinery (textile fabrics)
- Rope machineries
- Spinning machinery
- Stitch-bonding machinery
- Textile fibres machinery
- Texturing machinery
- Tufting machinery
- Twisting machinery
- Unreeling machinery (textile fabrics)
- Warp knitting machinery
- Washing machineries
- Weaving machinery
- Winding machinery
- Wringing machinery

1.1.5 Environmental screening of product scope

1.1.5.1 Working Plan Study – Plausibility Check

The 2007 Working Plan Study by EPTA covered under Machine Tools on the PRODCOM level basically metal working and wood working in one category, stone and ceramics working machine tools in another one, and separately welding equipment and the like.

1.1.5.1.1 Metal and Wood Working Machine Tools

The 2007 Working Plan Study provides an environmental screening of machine tools (named “Tool Machines” in the study), based on MEEuP[48]. For the on-going procedure of this study, especially in regard to our own assessment, comparisons with results of other studies are of particular interest.

The input parameters and the results of the assessment of the Working Plan study are as listed below, including comments from a first screening of the product group by Fraunhofer. Note, that this screening reflects the status of the study findings in a very early stage of the study. Later findings of the study overrule these data. The data below

48 VHK VAN HOLSTEJIN EN KEMNA BV, *Methodology Study Eco-Design of Energy-using Products (MEEuP)*, 2005.

is stated only to document the intermediate state of the study at this point and is NOT used for any further calculations in this study, nor should they be cited as results of the study. More accurate data is to be found in later task reports, see cross-references.

Table 1-14: Working Plan Study Plausibility Check – Metal, Wood and Stone / Ceramics Working Machine Tools[49]

Machine Tools (source: EPTA)		Screening by Fraunhofer (as of Dec 2010)	Data updates in later task reports
Estimated composition of Manufacture	total weight 300 kg - average of 100kg to 500kg; steel, electric motor (75%steel, 15%Cu, 5%Al), Display	This might be correct for some transportable machine tools, but this underestimates the weight of industrial type stationary metal working machine tools	See bill-of-materials for 9 Base Cases in Task 4 (4.1.1)
Stock [1.000 units]	7850,86	Stating a stock of several million units in the EU27 is a plausible order of magnitude Estimates: • Metal working machine tools: 2 – 3 million • Wood working machine tools: 1 – 2 million Other machine tools not considered for this screening	See detailed stock model in Task 2
Estimated electricity consumption [kWh/h]	50	Appropriate for larger metal working machine tools, not for smaller (transportable) ones (frequently wood working and machine tools); rough assumption for typical power consumption: • Metal working machine tools: 25 kW (CNC), 10 kW (smaller units); approximation avrg. 12 kW • Wood working machine tools: 10 kW	See use phase scenarios for 9 Base Cases in Task 4 (4.1.3)
Estimated use time per year [hours]	4240	Appropriate for larger machine tools used e.g. in the automotive industry as one dominating target sector for machine tools, not for those wood working machine tools operated by crafts shops (less working time than 16 hours per day and not running full time during working hours); assump-	See use phase scenarios for 9 Base Cases in Task 4 (4.1.3)
Estimated Use Pattern	16h*265days		See use phase scenarios for 9 Base Cases in Task 4 (4.1.3)

[49] Note: The screening was primarily performed for categories deriving from group 28.4 “Manufacture of metal forming machinery and machine tools”, results were revised based on plausibility check against EuroStat sector consumption data

Machine Tools (source: EPTA)		Screening by Fraunhofer (as of Dec 2010)	Data updates in later task reports
		tions: • Metal working machine tools (1-2 shifts per day): avrg. 3180 h/year, 12h*265days • Wood working machine tools: 4 h/day, 1,000 hours/year	
Estimations electricity consumption use for 1 year [kWh]	$2{,}12*10^5$	• Metal working machine tools: $4*10^4$ kWh/year • Wood working machine tools: $1*10^4$ kWh/year	See Base Case results in Task 4 (4.3)
Total electricity consumption [kWh]	$3{,}14*10^{11}$	Electricity: • Metal working machine tools: $7{,}5\text{-}11*10^{10}$ kWh/year • Wood working machine tools: $1\text{-}2*10^{10}$ kWh/year	See Base Case results in Task 4 (4.5, 4.5.10)

Complementary to Fraunhofer's bottom-up estimates above EuroStat data can be referenced for a plausibility check:

EuroStat provides data regarding energy consumption per industry sector, which allows estimating plausible ranges of electricity consumption related to machine tools (top-down approach). Data for 2008 and 2009 is provided in Table 1-15 with electricity consumption of 1.135 TWh in 2008 for the industry in EU-27, thereof 163 TWh for sectors machinery and transportation equipment, which are those, where metal working machine tools are used, and 28 TWh in sector wood and wood products, covering woodworking machinery. Machine tools in these sectors should consume significantly below 50% of the total energy consumption in these sectors (rather 10-30%), as a major share of electricity is used for thermal processes, infrastructure, material handling, surface treatments and coatings etc.

Table 1-15: Electrical Energy Consumption EU-27, 2008/09

Electrical energy (Final Energy Consumption in kWh)		
	2008	2009
Industry	$1{,}135*10^{12}$	$9{,}81*10^{11}$
Thereof sub-sectors:		
Machinery	$1{,}08*10^{11}$	$9{,}4*10^{10}$
Transport Equipment	$5{,}5*10^{10}$	$4{,}8*10^{10}$
Wood and Wood Products	$2{,}8*10^{10}$	$2{,}5*10^{10}$

Compared to these figures our own estimates are to be considered rather worst-case, but meet a plausible order of magnitude.

The 2011 study to revise the MEEuP methodology (now: MEErP)[50] split the total EU-27 energy consumption among the various consumers (top-down approach) and estimated the annual electricity consumption of "machine tools" with 120 TWh (without providing a distinct definition of their understanding of "machine tools"), which is at the upper range limit of our own screening.

1.1.5.1.2 Welding and Soldering Equipment

The 2007 Working Plan Study provides an environmental screening of welding and soldering equipment (named "Automatic and Welding Machines"), which is covered in this study by the definition of "machine tools", based on MEEuP[51].

The input parameters and the results of the assessment of the Working Plan study are as follows, including comments from a first screening of the product group by Fraunhofer:

Table 1-16: Working Plan Study Plausibility Check – Welding and Soldering Equipment[52]

Welding and Soldering Equipment (source: EPTA)		Screening by Fraunhofer
Estimated composition of Manufacture	Total weight 50 kg - average of 0,5kg to 200kg; steel, plastics, electronics, electrode, possibly gas (argon etc.)	Plausible for the majority of transportable units
Stock [tsd.]	6192,00	Stating a stock of several million units in the EU27 is a plausible order of magnitude, but covers largely transportable units Estimate[53]: • Welding / soldering equipment: 5 – 10 million
Estimated Power consumption [kWh/h]	25,00	Appropriate for larger automated units, but majority of transportable units are rather at 5 kW power consumption
Estimated use time per year [hours]	2120	Appropriate for larger welding machines, but the vast majority of

50 Kemna, R.: Methodology for Ecodesign of Energy-related Products, MEErP 2011, Methodology Report, Part 2: Environmental policies & data, 2011, p. 50

51 VHK VAN HOLSTEJIN EN KEMNA BV, *Methodology Study Eco-Design of Energy-using Products (MEEuP)*, 2005.

52 Note: The screening was primarily performed for categories deriving from group 28.4 "Manufacture of metal forming machinery and machine tools".

53 For detailed figures see Task 2

Welding and Soldering Equipment (source: EPTA)		Screening by Fraunhofer
Estimated Use Pattern	8h*265days	transportable units is used much less frequent, approximately 1-2 h per working day: 1-2 h/day; roughly 250-500 hours/year
Estimations energy consumption use for 1 year [kWh]	53000	1250-2500
Total energy [kWh]	$3{,}28*10^{11}$	$6 – 25*10^{9}$

Table 1-17: MEEuP results for “Automatic and Welding Equipment” (source: Working Plan study, EPTA)

Table . Summary Environmental Impacts EU-Stock 2005, AUTOMATIC AND WELDING MACHINES

main life cycle indicators	value unit
Total Energy (GER)	3446 PJ
of which, electricity	328,2 TWh
Water (process)*	230 mln.m3
Waste, non-haz./ landfill*	4001 kton
Waste, hazardous/ incinerated*	79 kton
Emissions (Air)	
Greenhouse Gases in GWP100	150 mt CO2eq.
Acidifying agents (AP)	887 kt SO2eq.
Volatile Org. Compounds (VOC)	1 kt
Persistent Org. Pollutants (POP)	23 g i-Teq.
Heavy Metals (HM)	59 ton Ni eq.
PAHs	7 ton Ni eq.
Particulate Matter (PM, dust)	19 kt
Emissions (Water)	
Heavy Metals (HM)	22 ton Hg/20
Eutrophication (EP)	0 kt PO4

*=caution: low accuracy for production phase

Presumably the EPTA study overestimated the impact of welding equipment as the stock figures are plausible, but cover in their vast majority transportable units, which consume rather 5 than 25 kWh/h electricity when in operation, but being actually in operation only for 1-2 hours per working day.

This plausibility check indicates that the impact of welding equipment and the like had been rather overestimated by EPTA.

Note, that most of the welding and soldering equipment is included also in the overall sector electricity consumption for metal working as discussed on page 53.

1.1.5.1.3 Stone and Ceramics Working Machine Tools

The 2007 Working Plan Study provides an environmental screening of machines for treatment of stone, ceramics, concrete, referring to the related categories under

PRODCOM 28.49, but as EPTA stated a minor relevancy compared to other energy-using-products for these kind of equipment they were not subject to a MEEuP screening.

Table 1-18: Working Plan Study Plausibility Check – Stone and Ceramics Working Machine Tools[54]

Stone and Ceramics Working Machine Tools (source: EPTA)		Screening by Fraunhofer
Estimated composition of Manufacture	n.a.	Similarities to wood working machine tools expected: Metal / steel parts are dominating, 50 – 500 kg for typical units
Stock [tsd.]	n.a.	estimate[55]: • Stone and ceramics working machine tools: 0.5 - 1 million
Estimated Power consumption [kWh/h]	n.a.	rough assumption for typical power consumption: • Stone and ceramics working machine tools: 10 kW
Estimated use time per year [hours]	n.a.	assumptions: • Stone and ceramics working machine tools: 4 h/day, 1,000 hours/year
Estimated Use Pattern	n.a.	
Estimations energy consumption use for 1 year [kWh]	n.a.	• Stone and ceramics working machine tools: $1*10^4$ kWh/year
Total energy [kWh]	n.a.	Electricity: • Stone and ceramics working machine tools: 0,5-$1*10^{10}$ kWh/year

1.1.5.1.4 Summary

Summarising the plausibility check of the data provided by the Working Plan Study, and referring to power consumption only, the following ranking of market segments regarding their environmental relevancy can be provided:

(1) Metal working machine tools (EU27 electricity consumption 75-110 TWh/year)

(2) Wood working machine tools (EU27 electricity consumption: 10-20 TWh/year)

54 Note: The screening was primarily performed for categories deriving from group 28.4 “Manufacture of metal forming machinery and machine tools”.

55 For detailed figures see Task 2

(3) Welding and Soldering equipment (EU27 electricity consumption: 6-25 TWh/year)

(4) Stone and Ceramics Working Machine Tools (EU27 electricity consumption: 5-10 TWh/year)

Summarising the results of this screening it is evident, that the metal working machine tools are much more relevant in terms of energy consumption – same can be assumed regarding production related material consumption given stock estimates and typical weights per machine - than the other three types of machine tools. Given the uncertainty of the screening it can be concluded, that the impact of wood working machine tools, welding and soldering equipment, and stone and ceramics working machine tools is on an equal level.

1.1.5.2 Further assessments of metal working machine tools

VDW energy efficiency study

The requirement of a much diversified examination becomes evident under the inclusion of other studies dealing with the specific features of machine tools. In 2008, the **VDW** initiated a data acquisition concerning the energy efficiency of machine tools. In a non-representative survey, manufacturers from the German machine tool branch were questioned about several features of their products, such as specific weight, connection power, produced number of items, and power consumption.

As mentioned above, the survey lacks representativeness, but is a useful source to get an impression of the characteristics of machine tools. The following figures illustrate the results of the VDW survey.

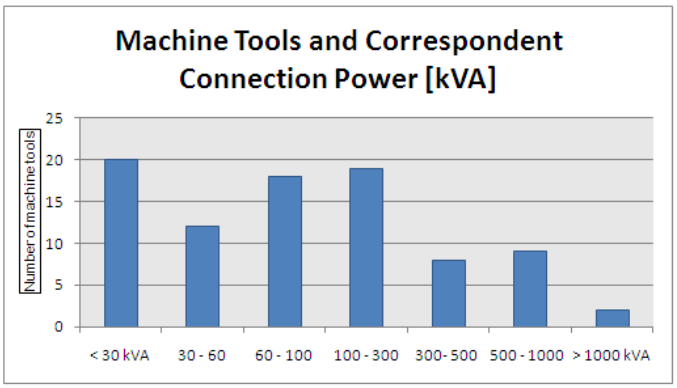


Figure 1-6: Connection Power of Various Machine Tools (VDW Survey)

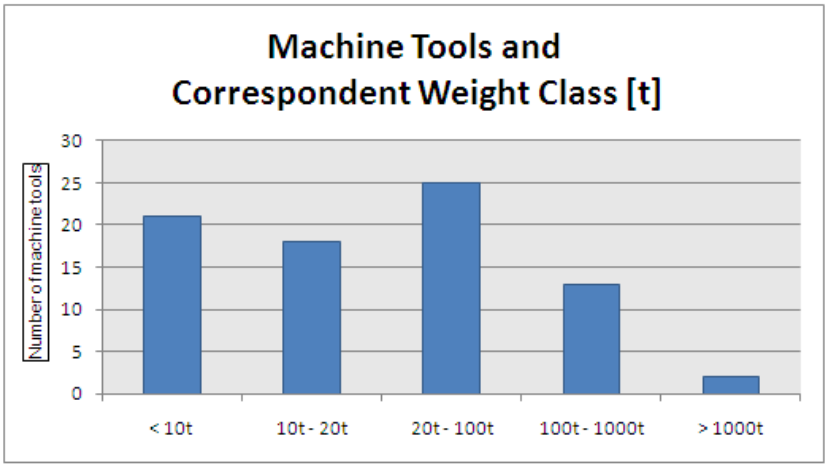


Figure 1-7: Weight of Various Machine Tools (VDW Survey)

Table 1-19: Key data deriving from the VDW survey

Machine Tools	Weight [t]	Produced Items [units]	Connection Power [kVA]
Mean	369,69	19,73	223,41
Sample Variance	3.737.687,54	1.025,98	160.430,44
Standard Mean Error	1.933,31	32,03	400,54

Figure 1-6 and Figure 1-7 illustrate the broad range of connection power and weight for different kinds of metal working machine tools which is supported by the statistical evaluation in Table 1-19. The heterogeneity of the parameters ‘weight’ and ‘connection power’ is expressed in the large deviations from the mean average value. It should be noted, that VDW represents the manufacturer of metal working machine tools, which in terms of connection power and weight are not comparable with wood working machine tools in their majority.

Key data derived from the evaluation of the survey are listed in Table 1-19. Compared with the screening by EPTA, however, we see that the mean for the weight is 369.69 tons, whereas EPTA calculates with an approximate value of 0.3 tons. Similar discrepancies appear regarding the Connection Power. EPTA states, that “the majority operates in the range of 30kW – 60kW, although there are machines of 250kW and 5kW”.[56] The VDW survey gives the impression that the majority of machine tools feature connection powers up to 300 kVA, besides the fact that the range between 30kW and 60kW is less representative.

[56] EPTA LTD, ref 13, p. 258f.

The findings of these two studies and our own horizontal estimates already illustrate, that the product category machine tools cannot be analysed on such a meta level only, but that a distinction is required, addressing the specifics of the various sub-segments.

CECIMO life cycle assessments of machine tools

In preparation of a proposal for a Self-Regulatory Initiative (SRI) **CECIMO** contracted a Life Cycle Analysis[57] (LCA) of two typical types of metal-working machine tools (milling and turning, assessment of 9 individual machine tools) with a clear result that "the use phase dominates the environmental impact in all considered categories. In the use phase the most important influencing factor is the energy consumption." Results are depicted in Figure 1-8, based on the following settings: 100.000 hours productive operating with specific average energy consumption, consumption of 4.000 kg coolant lubricant and of 400 l hydraulic oil.

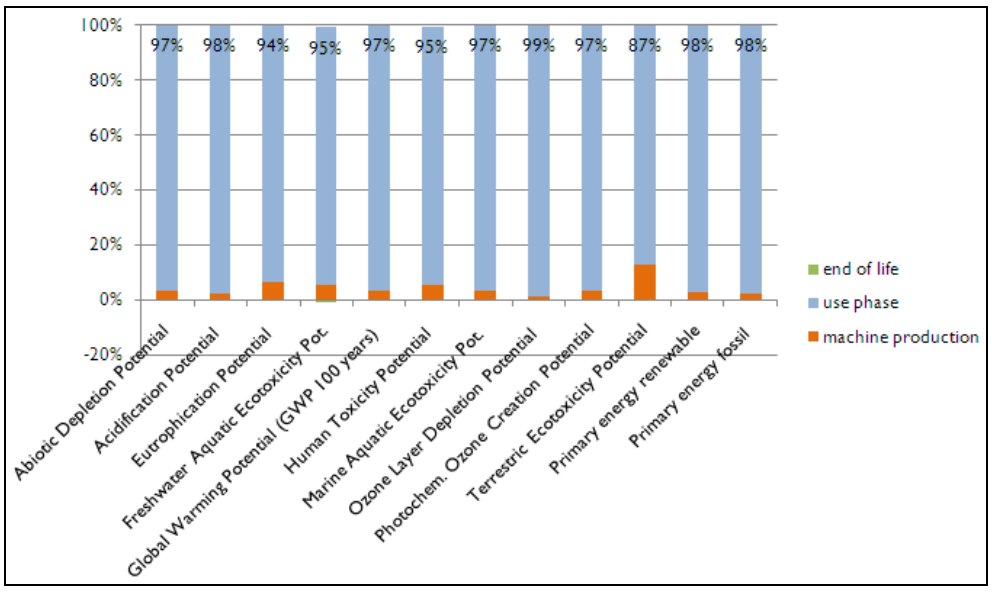


Figure 1-8: Average LCA results for machine tools split into production, use phase and end of life

The consumption of hydraulic oil, lubricant and electric energy of machine tools during the use phase is displayed in Figure 1-9. Electrical energy is dominating clearly, cooling lubricant and hydraulic oil being negligible according to these results.

57 CECIMO, *Concept Description for CECIMO's Self-Regulatory Initiative (SRI) for the Sector Specific Implementation of the Directive 2005/32/EC (EuP Directive)*, 2009.

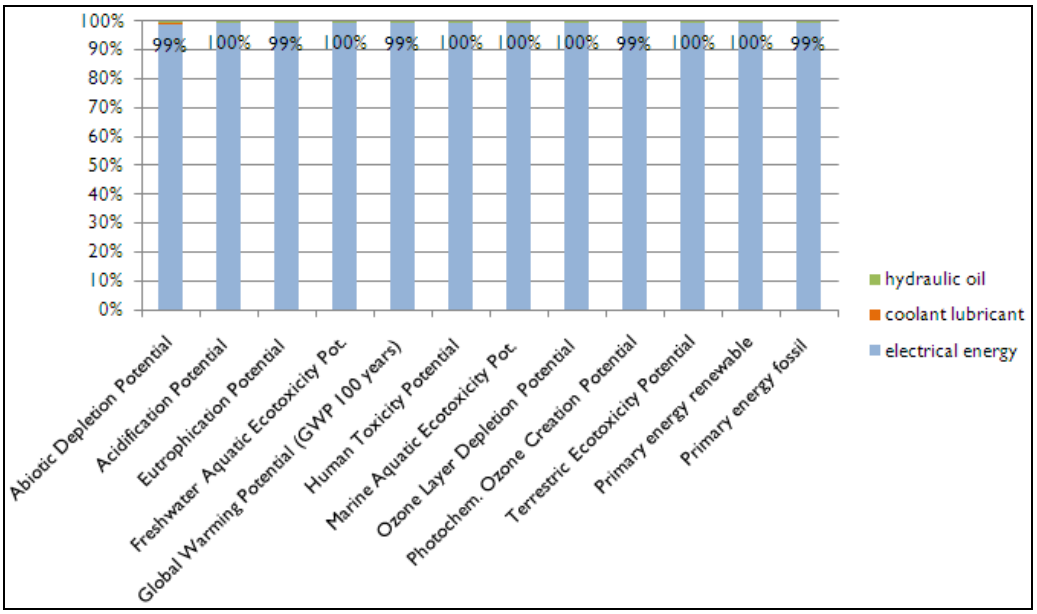


Figure 1-9: Average impact of consumables and energy of machine tools during use phase

The LCAs provided by CECIMO severe for a first orientation, further details are taken into account in the base case assessments in task 4.

Other research

Howard[58] states that Makino pushed efforts to make their machine tools as small and compact as possible and achieved a 40% size reduction for some of their vertical machining centres compared to previous generations. For other machine tools manufacturers similar trends have been observed.

The Minimum Quantity Lubrication (MQL) approach allows to eliminate large volumes of waste water, resulting in positive secondary environmental effects: MQL sprays also can be applied in a manner that eliminates mist, maintenance, and disposal operations associated with water-based cooling lubricants[59]. Clarens et al. published LCA results comparing four alternative systems for metal working fluids, showing clear improve-

58 SCIANNA, M., *Green Machine – Energy efficient, eco-friendly designs now mainstream in machine tools*, 2008.

59 ADLER, D. P. H, W, W.-S., MICHALEK, D. J., SUTHERLAND, J. W., *Examining the role of cutting fluids in machining and efforts to address associated environmental / health concerns,* 2006.

ment potentials when changing over to MQL[60] for some, but not all impact categories (see Figure 1-10). In particular life cycle energy consumption and GWP are increased.

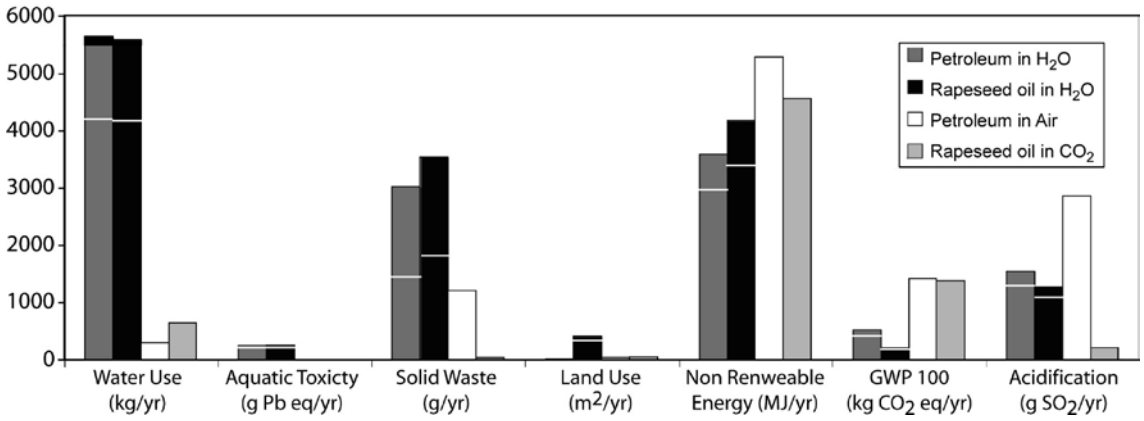


Figure 1-10: Life cycle burdens for the four metal working fluids systems based on expected application conditions

Based on different manufacturing scenarios, Abele et al.[61] assessed the overall energy consumption with special regard to losses due to idle periods, exemplary for a 5-axis machining centre. For a 3-shift operation series production, naturally, only 3% of the total energy use is accounted for the maintenance of the machine during downtime. However, compared to occasional manufacturing, the operational mode is significantly energy intensive, as depicted in Figure 1-11. Occasional manufacturing, on the other hand, is characterized by a share of 43% which are lost due to downtimes. In the latter case, as saving potentials are given in the field of appropriate energy modes during stand-by, energetic optimisation of single modules and the overall machinery can be applied for series production. In this regard, single modules need to be assessed in order to single out energy intensive devices, which are reliant on type of manufacturing, machinery, selection and arrangement of components, and machining task. According to the measurement performed by Abele et al., the hydraulic motor, the power train, and the low pressure cooling lubrication pump were identified holding the major share of energy usage, each of them providing different potential for improvement measures.

60 CLARENS, A.F., ZIMMERMAN, J. B., KEOLEIAN, G.A., HAYES, K.F., SKERLOS, S.J., *Comparison of Life Cycle Emissions and Energy Consumption for Environmentally Adapted Metalworking Fluid Systems*, 2008.

61 ABELE, E., DERVISOPOULOS, M., KUHRKE, B., *Bedeutung und Herausforderungen der Lebenszyklusanalyse am Beispiel Werkzeugmaschine,* 2009, 60.

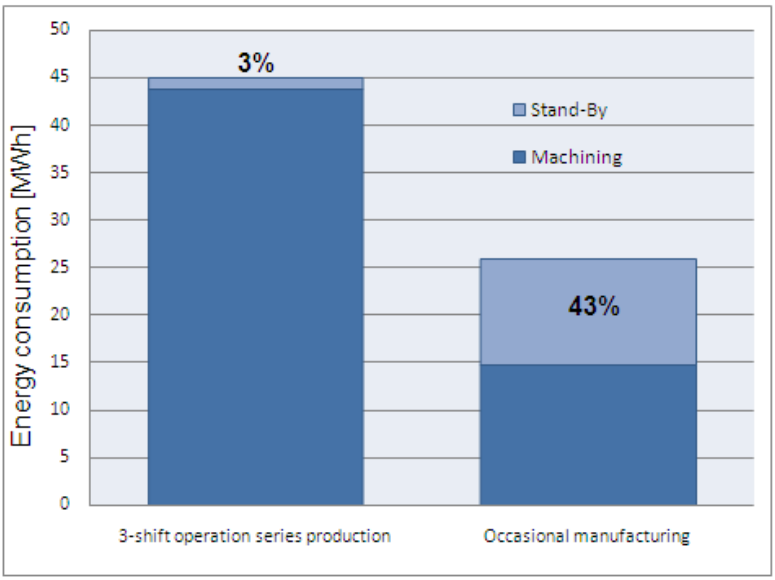


Figure 1-11: Energy consumption and idle losses of machine tools depending on different manufacturing scenarios. Figure adapted from Abele et al.[62]

Relevant power consumers of a machine tool are pumps, drives, chillers, power losses of transformers and power supplies. Figure 1-12 depicts the various consumers of electrical power in a cutting metal-working machining centre according to Pause.[63] Only 20% of the power consumption is directly related to the process as such, 80% is for auxiliary components of the machine tool.

[62] Abele, E. et al.

[63] PAUSE, B., *Energieeffizienz in der Werkzeugmaschinenentwicklung und im –Einsatz*, 2009.

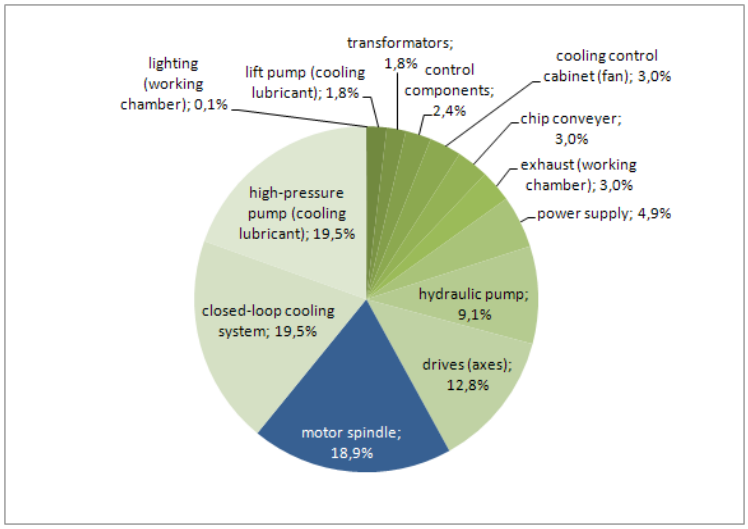


Figure 1-12: Electrical Power Consumption of Machine Tools – Shares of individual consumers

Similar figures are stated by Kuhrke,[64] referencing Volkswagen in Salzgitter (see Figure 1-13), where the grinding spindle consumes 21% of the overall power of the machine tool, and almost all of the remaining power consumption is related to pumps, either for coolants supply and removal or hydraulic oil.

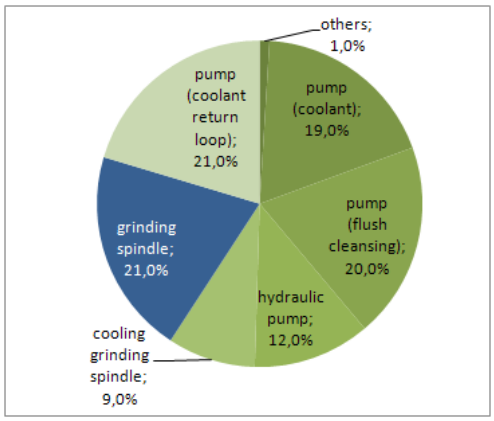


Figure 1-13: Electrical Power Consumption of a grinding machine at Volkswagen

Improvement potentials for a better energy efficiency of machine tools and reduction of lubricants and pressurized air consumption are manifold[65,66] to name only a few:

64 KUHRKE, B., *Ansätze zur Optimierung und Bewertung des Energieverbrauchs von Werkzeugmaschinen*, METAV Trade Fair, 2010.

65 SCIANNA, M.

- optimal dimensioning of motors
- mass reduced slides
- energy-efficient motors
- reduction of warm-up phases (sensor based compensation)
- working chamber design for optimal chip removal (small size, sloped walls...)
- shorter process times through MQL
- implementation of standby modes and shut-off machine tools components in stand-by (cooling lubricants pumps, axes drives, chillers etc.)
- machine turn-off after a set idle time
- automatic lights off when working chamber doors closed
- closed-loop oil bath
- grease system replacing oil lubricants on guideway systems
- dry-cutting (increasing productivity in some cases)
- implementation of “smart” control technologies

In another assessment, Klocke et al.[67] published LCA data for a key component of a **milling machine**: a **tool changing unit** with a weight of 350 kg. Based on an assessment with the Eco-indicator 99 the power consumption in the use phase is confirmed to be the dominating environmental aspect (92,7% of Eco-points over the full life cycle), followed by raw materials production (3,7%) and transports (3,1%), disposal being negligible (0,6%).

As a stakeholder input Reis provided LCA results[68] for a **press-brake**, which indicates, that the production phase of the press-brake, contrary to other LCAs on metal working

66 PAUSE, B.

67 KLOCKE, F.; LUNG, D.; NAU, B., *Umweltorientiertes Lebenszyklusmanagement - Bewertung ökologischer Einflüsse und Kostenbetrachtung im Lebenszyklus von Werkzeugmaschinen*, 2008.

68 Santos, J.P.; Oliveira, M.; Almeida, F.G.; Pereira, J.P.; Reis, A.: Improving the environmental performance of machine-tools: influence of technology and throughput on the electrical energy consumption of a press-brake, Journal of Cleaner Production, (2010), article in press

machine tools (see above) indeed could be relevant in terms of life cycle impacts. Results of their LCA study based on the Eco-Indicator 99 are provided in Figure 1-14. This study will be taken into consideration for the base case assessments in Task 4.

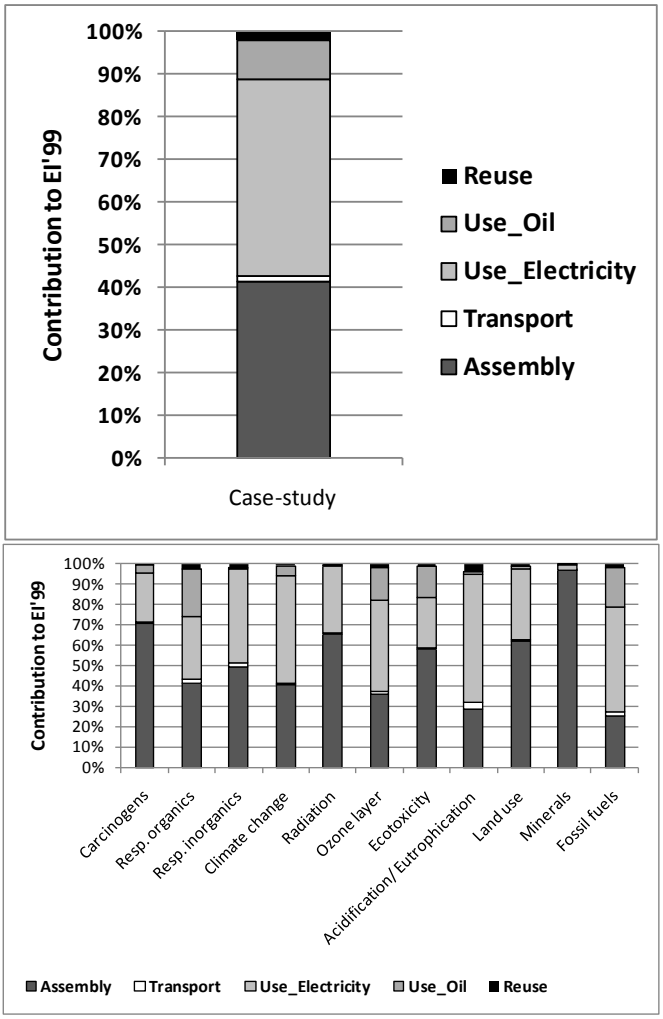


Figure 1-14: Environmental profile and relative contributions of life-cycle phases to the global environmental impact of a press-brake

1.1.5.3 Further assessments of Welding Equipment

Junnila[69] published a Life Cycle Assessment of a metal inert gas (MIG) welding equipment with a hybrid LCA approach. Besides the fact, that the equipment is modelled with a 10 years lifetime, no further details regarding the assumed use scenario

69 Junnila, S.: Life cycle management of energy-consuming products in companies using IO-LCA, International Journal of Life Cycle Assessment (2008), 13, p. 432-439

and specifications are disclosed. However, the results presented in Figure 1-15 indicate, that the sourcing (most likely material acquisition for production of the welding equipment) is relevant for several impact categories, frequently even dominating the use phase. As a consequence for welding equipment the focus of following analyses should not be solely on power consumption in the use phase.

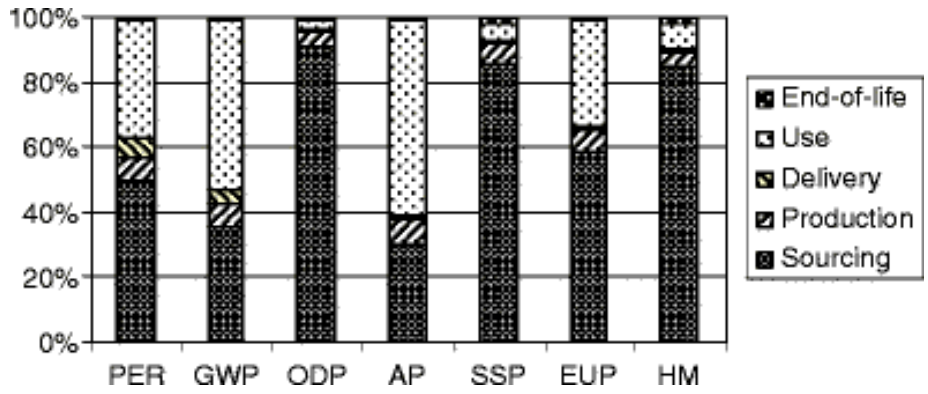


Figure 1-15: Environmental contribution of the main life cycle phases of a MIG welding equipment

1.1.5.4 Environmental Screening of Plastics and rubber machinery

Plastics and rubber processing machinery represents an important market. As the dominating moulding and extrusion processes are primary shaping processes most of the plastics processing machinery do not meet the condition of processing a workpiece of determined shape. Consequently this machinery does not fall under the core definition of a “machine tool”, but might be considered as “related machinery”. Only if plastics and rubber processing machinery is of significant market relevance and environmental improvement potential, and if the modules used in this type of machinery are comparable to typical machine tools, only then plastics and rubber processing machinery will be considered further.

Market Relevance

Although there is a PRODCOM code **28.49.12: Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials; electroplating machinery** according to EUROMAP/VDMA no rubber or plastics processing machinery is reported under this code. Instead, the vast majority of plastics and rubber processing machinery is covered in market statistics under **28.96: Manufacture of plastics and rubber machinery**.

For 2009 EuroStat states an EU-27 production value of 4.65 Billion Euros[70] and in terms of units 133,057 produced machines. A plausibility check of this data by Fraunhofer, which excludes unit figures (obvious over-estimates, likely reporting of low-value consumer products, and obvious misallocation of presumably parts and the like; for details of the plausibility checks see criteria explained in task 2 report), results in lower numbers: **3.85 Billion Euros production volume** and **61,000 produced machines** (see Table 1-20).

Table 1-20: Plastics and rubber machinery - Production Volume 2009 and Plausibility Check

PRODCOM Code 2896..		Volume EU27 according to EuroStat	FRAUNHOFER Plausibility Check	Re-calculation rule	re-calculated EU27 Volume	re-calculated Value in THOUSANDS	re-calculated unit value
1010	Injection-moulding machines for working rubber or plastics or for manufacturing rubber or plastic products	31,200	non-plausible volume for HU at low market share	GER, I, F, ES	6,373	503.440,69	79.002
1030	Extruders for working rubber or plastics, or for manufacturing rubber or plastic products	5,362	market share GER, I, A: 95%, unit value plausible for all relevant countries	no recalculation	5,362	1.020.686,71	190.356
1040	Blow-moulding machines for working rubber or plastics or for manufacturing rubber or plastic products	1,992	relevant market share is confidential, but rest and EU27 unit value plausible	no recalculation	1,992	450.106,17	225.957
1050	Vacuum-moulding machines and other thermoforming machines for working rubber or plastics or for manufacturing rubber or plastic products	4,697	UK relevant volume, but at 3000 Euro unit value	EU27-UK	2,803	159.095,70	56.759
1060	Machinery for moulding or retreading pneumatic tyres...	2,192	most of the market not substantiated with volume; but EU27 unit value is plausible	no recalculation	2,192	228.585,85	104.282
1073	Other presses for moulding or forming rubber or plastics, etc, n.e.c.	1,228	ES at low unit value of 8.500 Euro, GER and I at nearly 90% market share	GER, I	0,992	145.196,96	146.368
1075	Machinery for moulding or forming rubber or plastics, etc, n.e.c.	8,931	huge differences regarding unit values, even among countries with large market share (13.000-290.000 Euro); PL at unit value 1.700 Euro	EU27-PL	8,247	255.810,80	31.019
1082	Machines for processing reactive resins	1,404	I with significant market share in terms of units at 2.700 Euro unit value; no data disclosed from other countries; calculation not verifiable	EU27-I	0,480	106.095,66	221.033
1084	Machines for the manufacture of foam products (excluding machines for processing reactive resins)	0,389	GER 95% market share, others not disclosed (at likely rather low unit value)	GER	0,317	128.627,73	405.766

[70] all of 28.96 except parts

1091	Size reduction equipment for working rubber or plastics	5,068	I at unit value 2.900 Euro, others in the range 6.000-25.000 Euro; small scale equipment covered	EU27-I	4,625	73.707,01	15.937
1093	Mixers, kneaders and agitators, for preparing rubber or plastics	3,371	GER, I 98% of all units	GER, I	3,291	102.372,06	31.107
1095	Cutting, splitting and peeling machines for working rubber or plastics or for the manufacture of products from these materials	4,182	GER, ES, I 90% market share at unit values 24.000 - 40.000 Euro	GER, ES, I	3,413	127.519,41	37.363
1097	Machinery for working rubber or plastics or for the manufacture of products from these materials, n.e.c.	63,041	GER 50% of units, but no value disclosed; EU27 total value rounded; only countries with disclosed unit values > 15.000 Euro taken into account, but uncertainty regarding GER figures is a major shortcoming	DK, I, A, P, FIN, UK	20,776	544.608,81	26.213

Of these 61,000 produced machines roughly 40,000 are of a unit value below 50,000 Euro, the remaining 20,000 units start at roughly 50,000 Euros each, but comprise also categories, such as extruders and blow-moulding machines with average unit values in the 200,000 Euro range.

Import to the EU-27 and export from any EU-27 country to outside EU-27 in terms of monetary value according to figures provided by VDMA for the years 2007-2009 is summarised in Table 1-21.

Table 1-21: Plastics and rubber machinery – EU-27 import and export (billion Euros)

	2007	**2008**	**2009**
Export from EU-27 to other countries	5.47	5.26	3.78
Imports to EU-27 from other countries	1.13	1.12	0.76
for comparison:			
Production (EuroStat, EU-27)	6.98	7.74	4.65
Production (plausibility checked)	5.68	6.07	3.85
Production (plausibility checked)	88,000 units	91,500 units	61,000 units

There is an obvious mismatch between export figures and production figures, as production is only slightly higher than exports, whereas the EU-27 export even neglects the significant EU-27 internal trade between member countries. Even with an assumed significant trade of used equipment either export figures seem to be too high or production too low.

However, taking into account the production figures of PRODCOM (plausibility checked), and the fact, that a major share of the EU-27 production is exported and a comparing smaller number is imported out of roughly 80,000 units manufactured per year (but notice year-to-year fluctuations), the newly installed stock might be in the

range of 40-50,000 units per year. A 2005 survey among plastics processing companies reported an average age of the relevant machinery of 9 years, ranging from 6 years in Germany to 13 years in UK, which illustrates the huge spread even among European countries[71]. Injection moulding, extrusion and compounding machines are in average 6 to 8 years old, transfer moulding machinery and presses are nearly 14 years old in average. Logically, lifetime is longer than average age of any operating machinery: Given a lifetime of 10-20 years this means a range of **400,000 – 1 million units of installed stock of plastics and rubber machinery** in EU-27, thereof 2/3 smaller machinery, e.g. for prototype or laboratory use and the like, and 1/3 for large-scale industrial use. For comparison: Petri[72] states a figure of 55,500 injection moulding machines – being one of the most relevant market segments - installed in Germany based on 2005 sources, which confirms the plausibility of having a few 100,000 industrial plastics processing machines installed in the EU-27.

Use patterns

Roughly 2/3 of the plastics processing enterprises work **24 hours 5 days a week**. Another 15% even 24 hours 7 days a week. Only 20% of the companies work in one or two shifts[73]. Utilization according to the same survey is typically above 60%, but it can be assumed, that this figure is subject to fluctuations with economic cycles. Highest utilization rates are those of extrusion processes, compared to the batch processes of moulding.

As of 2005 28% of the plastics processing enterprises monitored and reviewed the energy usage of each of their machines[74], and a significant share of companies underwent an energy audit or contracted an energy consultant. However, the conclusion is, that energy consumption is an important topic for the plastics processing industry, but

[71] Fraunhofer ICT: Energieverbrauch und Einsparmöglichkeiten in der Kunststoffverarbeitung – Europäischer Vergleich zum Energieverbrauch und Einsatz bestmöglicher Technologien, November 2005, p. 9

[72] Petri, E.: Leistungselektronik, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

[73] Fraunhofer ICT: Energieverbrauch und Einsparmöglichkeiten in der Kunststoffverarbeitung – Europäischer Vergleich zum Energieverbrauch und Einsatz bestmöglicher Technologien, November 2005, p. 11

[74] Fraunhofer ICT: Energieverbrauch und Einsparmöglichkeiten in der Kunststoffverarbeitung – Europäischer Vergleich zum Energieverbrauch und Einsatz bestmöglicher Technologien, November 2005, p. 9

as of 2005 there is still room for improvement regarding transparency of energy consumption and attention paid to this aspect.

Environmental Relevance

Based on a stated average energy consumption of plastics processing of 1.85 kWh/kg and a total estimated consumption of 40 million tonnes plastics in 2005 Fraunhofer ICT[75] estimated a total power consumption of plastics processing of **74 TWh** per year in the EU. Petri[76] states a figure of 24 TWh power consumption for injection moulding in Germany, which looks rather high in comparison to the 74 TWh for plastics processing in EU-27, leading to the assumption that the total power consumption might be even higher.

This is only a rough estimation as the specific energy consumption depends inter alia on the actual type of plastics processed and the type of process: According to the above 2005 survey the site specific energy consumption ranges from below 1 kWh/kg for compounding and fibre extrusion to 3 kWh/kg for injection moulding and compression moulding and 6 kWh/kg for rotational moulding and thermoforming[77]. The average site specific energy consumption was stated with 2.87 kWh/kg, which makes sense in relation to the stated machine specific energy consumption of 1.85 kWh/kg.

What distinguishes plastics processing from e.g. metal working cutting and forming processes is the fact, that the melting of plastics granulates inevitably needs an input of heat to the process. Physically, the melting heat is a fixed value which is not subject to any improvement potentials. However, excessive heat and heat losses could be subject to improvement options.

Fraunhofer ICT stated as a trend, that the site specific energy consumption is lower in newer facilities with newer machines, but could not state with certainty, whether this is related to the newer, more energy efficient buildings or whether machines became more energy efficient - or both.

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75 Fraunhofer ICT: Energieverbrauch und Einsparmöglichkeiten in der Kunststoffverarbeitung – Europäischer Vergleich zum Energieverbrauch und Einsatz bestmöglicher Technologien, November 2005, p. 2 / Prestudy Report EuPlastVoltage January 2010, p. 16

76 Petri, E.: Leistungselektronik, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

77 Note: the *site* specific energy consumption is higher than the *machine* specific energy consumption, as it includes also the site infrastructure, but as it was to possible in the frame of the cited survey to get hold of machine specific data, only site specific data was asked for

Power consumption of machinery in the plastics processing industry is dominated by[78]:

- Motors and drives with a minimum of 0.25 kWh/kg polymer for the drive motor of any machine, that melts plastics
- Process heating, including pre-drying of polymers
- Process cooling (water, air, chillers), to remove all energy that went into the melting process, avoiding any negative impact on product quality; indicatively a minimum for cooling is 0.25 kWh/kg polymer processed

Under optimal conditions the power consumption values could be even lower: Gehring[79] states as a good value of **0.35 kWh/kg** for injection moulding processes under the following conditions: Polypropylene, large machine, high throughput, properly maintained, hydraulics with variable speed drive.

Just as with other machines it has to be kept in mind that power consumption of a plastics processing machine in particular in relation to the output depends on the capacity utilization: Pamminger et al.[80] analyzed for an Austrian plastics processing company the electricity consumption. For a given machine at high utilization ratio of 17 kg/h parts output, the specific consumption is 5 kWh/kg. When utilization ratio is at 5 kg/h the specific consumption rises to 12.5 kWh/kg (Figure 1-16).

78 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 5-6

79 Gehring, A.: Energieeffizienz in der Kunststoffverarbeitung – Potentiale identifizieren und nutzen, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

80 Pamminger, R.; Wimmer, W.; Winkler, R.: Entwicklung von Kriterien zur Kommunikation der Energieeffizienz von Kunststoff verarbeitenden Maschinen, 5/2010 p. 58

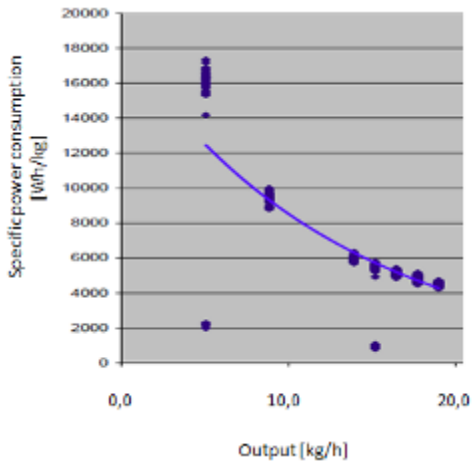


Figure 1-16: Specific energy consumption of an injection moulding machine

Improvement Potential

Based on the findings regarding the power consumption per output correlation Pamminger et al. conclude, that attention should be paid to

- eliminating fixed power consumers.

The RECIPE project identified the following general measures to reduce energy consumption in plastics processing[81]. Regarding the design of the machinery key aspects are:

- appropriate motor dimension / efficiency
- motors with constant or variable speed drive.
- short lines between vacuum pumps/compressors and consumers. Setting the correct pressure and switching off when not needed.

Users have to consider, if:

- motors and machines running in standby
- equipment running when production machines are not in use
- heat insulation is installed

81 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 7

- chillers settings are correct in relation to working temperature and switch off mode
- controlling and reducing leakages in steam, air or water lines

Gehring[82] states an energy savings potential in plastics processing of "not uncommonly 30%".

A 2010 study by Fraunhofer ICT and Fraunhofer ISI[83] calculated three scenarios to demonstrate energy consumption and reduction potential in the plastics processing industry:

- Business-as-usual ("frozen scenario"): development without energy saving measures
- Reference scenario: reduction of energy usage because of increasing fuel costs, production volume and CO_2 costs. Saving options are realized driven by market demands.
- Voluntary agreement scenario: A higher level of diffusion of improvement options is anticipated, due to a commitment by industry, but no indication is given in the study, how such a voluntary agreement could look like, what are the quantified targets and how market surveillance might work, therefore this is a highly abstract scenario.

These scenarios are set up for injection moulding, extrusion and blow moulding as outlined below.

Injection Moulding

The energy consumption of injection moulding machines in particular depends on[84]:

- clamping force, design, size and complexity of the machine module
- use of hot runners, hydraulic cores or inserts

82 Gehring, A.: Energieeffizienz in der Kunststoffverarbeitung – Potentiale identifizieren und nutzen, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

83 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2 , June 2010

84 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 18

- ancillary equipment such as dehumidifiers, dryers and mould heaters
- type of plastic material used as some materials have a higher melt temperature, e.g. to melt polyolefins requires 0,2 kWh/kg, polyaromatics and some nylons require 0,4 kWh/kg[85]
- cycle time dictates the length of time the pump or electric motor is running during injection moulding process

80% of heating energy is dissipated by the cooling system. The other 20% of excessive energy are related to the plastification unit and are dissipated by radiation and convection.

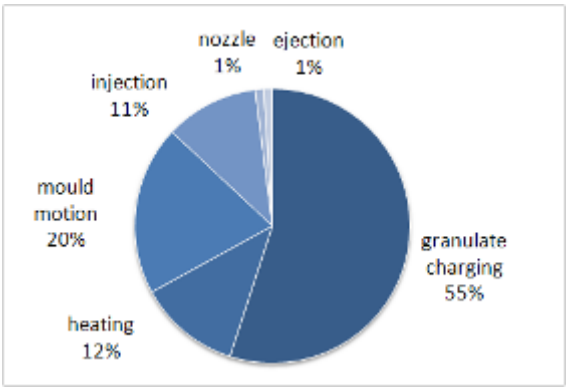


Figure 1-17: Average split of energy consumption of a “standard” injection moulding process

Brettnich[86] states an average split of the power consumption of injection moulding machine as shown in Figure 1-17: Motor and drives for granulate charging are dominating by far, followed by the drive system for mould motion and heating.

Wimmer et al. analysed in detail an exemplary middle size hydraulic injection moulding machine[87]. The energy balance per module is shown in the following table. Power consumption of motors and heating[88] are dominating. Energy, i.e. heat, is basically

85 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 8

86 Brettnich, T.: Energieeffiziente Spritzgießmaschinen, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

87 Wimmer, W.; Pamminger, R.; Winkler, R.E.: Energiedienstleistung zur Steigerung der Energieeffizienz von Spritzgießmaschinen im Kunststoffbereich 55/2009 p. 11, 16, 17, 28

88 higher share than stated by Brettnich above

removed from the process with the cooling cycle connected to the mould and the hydraulic oil.

Table 1-22: Energy consumption of an injection moulding machine for standard applications

INPUT	Average (in kW)	OUTPUT	Average (in kW)
Motor supply	12,5	Hydraulic oil	8,5
Heating	7	Moulding cooling	9,9
Utilities and peripherals	3,5	Convection loss (calculated)	4,6

Wimmer et al point out that it is technically very difficult to recover the energy losses resulting from convection and radiation: An additional housing of the plastification unit might allow a recovery of convection heat to be transferred to pre-heat the plastics granulate before it enters the plastification unit.[89] However, this option would have a direct impact on the injection process. Heat transferred to the cooling water or hydraulic oil could be used, but according to Wimmer et al. externally to the injection moulding machine only and consequently this is not an option for a machine-centric ecodesign measure.

Comparing hydraulic, electric and hybrid machines for injection moulding, the RECIPE European Best Practice Guide states[90],[91]:

- "**Hydraulic** drives normally require continuous operation with minimum start-ups and shut downs making it difficult to improve energy savings. Machine control is vulnerable to hydraulic fluid temperature. Hydraulic system flow and pressure requirements vary throughout the cycle and in many cases excess fluid that is not required by the process is throttled back to the reservoir, wasting motor energy and producing additional thermal load on the cooling system." However, the reference to "many cases" indicates, that this is an improvement option, with which improved hydraulic systems might cope.

89 Wimmer, W.; Pamminger, R.; Winkler, R.E.: Energiedienstleistung zur Steigerung der Energieeffizienz von Spritzgießmaschinen im Kunststoffbereich 55/2009 p.7

90 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 20

91 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2 , June 2010, p. 12, but the wording is exactly the same as in the RECIPE Best Practice Guide. Obviously no technology update since 2006 is taken into account by the study authors

- "**All-electric** machines have the potential to reduce the energy usage in injection moulding by between 30 and 60% depending on the mould and machine used." This improvement potential obviously refers to an assumed 30 to 60% improvement compared to a hydraulic injection moulding machine. "All-electric machines do not require a hydraulic system as the power requirement is provided by the direct electrical drive. All-electric machines eliminate the need for the cooling of hydraulic oils. All-electric machines have lower power consumption at start up leading to lower maximum demand requirements."
- "**Hybrid** machines use both, servomotors and hydraulic pumps. Common configuration is using the hydraulic pump for clamping and the servomotors for the screw movements. Hybrid machines are generally lower in cost than the all-electric machines, however, they are not as energy efficient or as quiet."

Consequently, the EuPlastVoltage study[92] identifies an energy savings potential of **30,000 - 40,000 TJ** for 2020 when replacing hydraulic by electrical machines.

For Germany 2005 data and machine tests indicate that the total energy consumption of injection moulding machines is in the range of 24 TWh and roughly 12 TWh could be saved when shifting from hydraulic systems to all-electric systems[93]. However, a stated savings potential of 50% for drives, despite claiming to be based on real measured values, is in conflict with the fact, that the heating of the plastification unit usually is a major energy consumer, not only the hydraulic system.

Both, the EuPlastVoltage study and the data for Germany neglect the inherent improvement potential of hydraulic systems achievable with advanced state-of-the-art systems[94]. Hence, as of the technical status of 2010 the only improvement option might not be the drastic technological shift to all-electric systems, but also the optimal design of a hydraulic system, which could result in an overall low power consumption per kg plastics processed[95].

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92 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2 , June 2010, p. 32

93 Petri, E.: Leistungselektronik, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

94 The statement of 50% savings potential actually is at least partly based on sources as of 1999, i.e. Wortberg, J.; Michels, R.; Neumann, M.: Energieeinsparpotentiale in der kunststoffverarbeitenden Industrie, 1999

95 See p. 10

Barrel insulation jackets[96,97,98] are an option to reflect radial emitted heat back into the plastification unit. The energy saving of heating elements with this approach can be in the dimension of 40-50%. Advantages can be shorter start up times, reduction of heat losses and operation cost.

Taylor and Aochi[99] states **induction heating** (instead of conventional heating-band heaters) as an option for a more energy saving design of plastification barrels for moulding machines. Depending on the type of plastics processed an average of 58.2% of the heating energy for the barrel could be saved (Figure 1-18) or 10% of the energy consumption of the whole injection moulding machine.

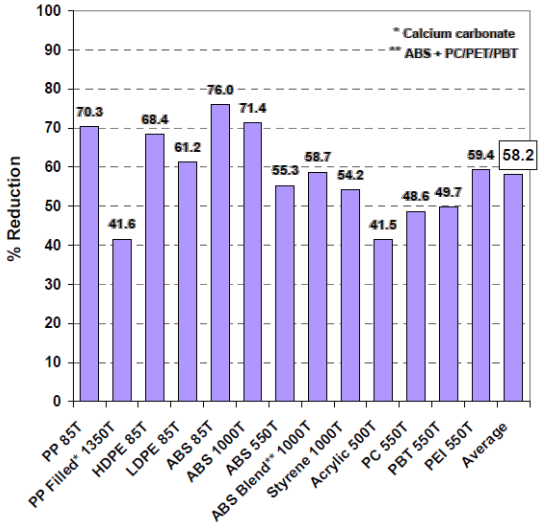


Figure 1-18: Reduction in barrel heating energy through induction heating (Taylor 2008)

Conformal Cooling is stated as a major measure to optimize the cooling process of the mould and the moulded part[100]: Most time of a cycle is needed when molten plastic

96 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 20

97 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 11

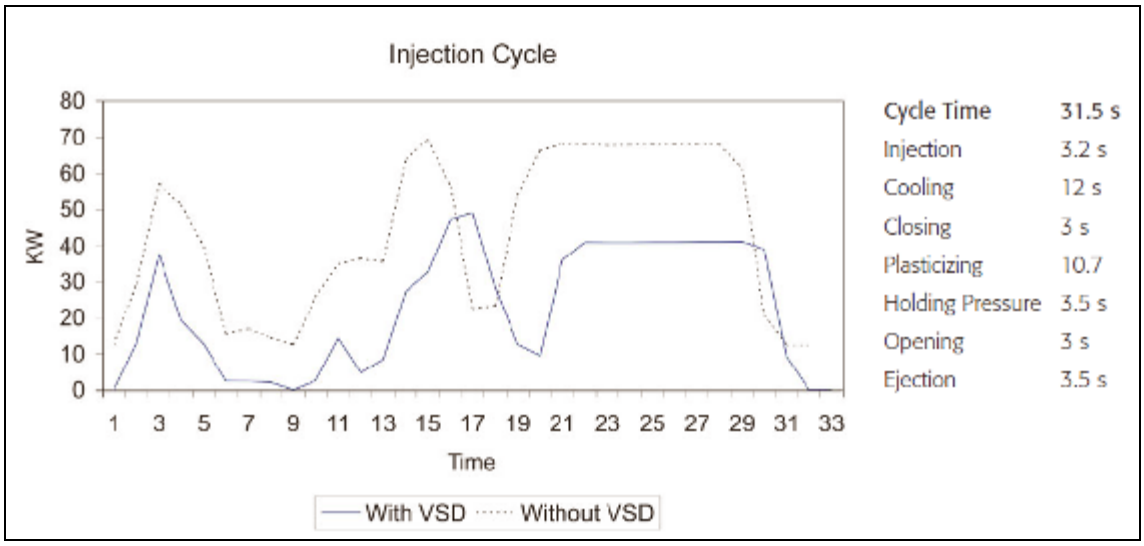
98 Wimmer, W.; Pamminger, R.; Winkler, R.E.: Energiedienstleistung zur Steigerung der Energieeffizienz von Spritzgießmaschinen im Kunststoffbereich 55/2009, p.10

99 Taylor, B.F.; Aochi, Y.: Induction Barrel Heating on Production Molding Machines – Quantifying Energy Savings & Understanding Influencing Factors, 2008, http://www.xaloy.com/pdf/induction_japan_techarticle.pdf

100 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 21

has to chill in the mould before ejecting. The traditional method for cooling moulds is to run water through straight shapes in the mould. As a result there is an irregular cooling of the mould. This causes longer cycle time, as a result of hot and cold spots in the mould. To reduce cycle time and disparities of temperature in the mould, the straight shapes can be changed to conformal shapes. Therefore the cooling channels should have the design of the part cavity. The consequence is a reduction of cooling time and a similar temperature in the mould. This method is reported to improve energy savings by 20-50%, but is related in a stricter sense to the design of the mould, not the injection moulding machine.

Typically injection moulding machines are driven by hydraulic pumps. The efficiency of hydraulic pumps declines, when the maximum oil flow is not needed. Oil is bypassed back to the reservoir. This can be avoided by using a **variable speed drive for the hydraulic pump**. Consequence is a lower oil temperature and less cooling. In addition the motor and cooling parts needs up to 50% less energy[101]. Durability increases, because wear and tear on the motor and related components are reduced. The reported savings potential of 50% for a hydraulic injection moulding machine actually is in contradiction with the statement of the same report as cited above, that energy savings in hydraulic systems for injection moulding can hardly be realized. Taken from the RECIPE Best Practice Guide Figure 1-19 depicts the comparison of an injection moulding machine with hydraulic pump with and without a Variable Speed Drive (VSD). The average power consumption of the machine decreases from 41 to 21 W.



101 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 22

Figure 1-19: Comparative injection cycle with and without variable speed drive

Total savings for the three scenarios developed in the EuPlastVoltage project[102] are summarised in Table 1-23.

Table 1-23: Scenarios for injection moulding (EU energy consumption)

Scenario	2007	2020
Frozen, i.e. Business-as-usual (in TJ)	93,000	114,000
Reference (in TJ)	82,000	60,000
Voluntary agreement (in TJ)	82,000	45,000

In the case of business-as-usual, the energy consumption for injection moulding growth to 114,000 TJ in 2020. A more likely development driven by a consideration of energy costs results in a decreased power consumption from 82,000 TJ down to 60,000 TJ and in case of a more stringent implementation of improvement potentials in 45,000 TJ for the voluntary agreement scenario for the year 2020[103]. Contrary to this huge improvement potential Wimmer et al. [104] state, that in the past 20 years, injection moulding machines where improved regarding energy efficiency. Based on the findings in a typical Austrian plastics processing company, a comparison of injection moulding machines of different ages and with drive systems typical for the year of construction was calculated, showing an improvement of roughly 70% for a machine built in 2005 compared to a similar one with construction year 1983. According to Wimmer et al. European manufacturers develop and sale state-of-the-art machinery – with respect to the drive technology in particular. Given this fact the savings potential on the product level is considered rather minor by Wimmer et al., and further energy savings need to tackle systems aspects instead, i.e. machine external improvements, which are not in the scope of product related ecodesign measures.

Extrusion

The main energy consumers in the extrusion processes are motors, drives, heaters and cooling systems, in particular[105]:

102 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 31-33

103 For details of the calculated scenarios see the EuPlastVoltage report

104 Wimmer, W.; Pamminger, R.; Winkler, R.E.: Energiedienstleistung zur Steigerung der Energieeffizienz von Spritzgießmaschinen im Kunststoffbereich 55/2009 p. 12, 35

105 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 26-28

- Cooling water for refrigeration of the extruder feeding zone
- Heating of the die
- Heating/cooling of the nip rollers
- Compressed air (necessary for blown film extrusion)
- Vacuum supply
- Haul off systems (profile extrusion)
- Cooling the products

Energy losses are related to sub-optimal extruder screw design, drive system efficiency (electrical motors, gears, power electronics, pumps, throttle valves, hydraulic pipes), friction (guides, bearings, sealings), heat losses at non-insulated surfaces[106].

Improvement options in their majority are related to adapted operation patterns, such as optimized and controlled water amount and temperature for cooling, setting the die temperature at the lowest possible level without hampering the process result, and optimising the water circulation system for cooling nip rollers. The machinery design could address these potentials by providing appropriate measurement and control features. Improvement options directly relevant for machinery components are

- motors and other components should be sized to match extruder capacity (avoid oversized and thus inefficient components),
- optimized compressed air supply for blown film extrusion and vacuum supply for profile extrusion.

Insulation of the barrel is not in every case possible, but in average 5% energy can be saved. Also insulation of the melt filtering system can reduce energy consumption. With this measure savings in the range of 700 TJ may be possible[107].

Total savings for the scenarios calculated by the EuPlastVoltage project are summarised in Table 1-24 for extrusion[108]: The more ambitious “voluntary agreement” scenar-

106 Gehring, A.: Energieeffizienz in der Kunststoffverarbeitung – Potentiale identifizieren und nutzen, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

107 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2 , June 2010, p. 13, 37

108 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 35-37

io reduces the total energy consumption only slightly in comparison to the energy cost driven reference scenario. In comparison to a business-as-usual scenario 7,000 TJ savings might be achievable, but approximately half of this potential is achieved with retrofitting measures to improve machinery, which is already in operation.

Table 1-24: Scenarios for extrusion (EU energy consumption)

Scenario	2007	2020
Frozen, i.e. Business-as-usual (in TJ)	79,000	97,000
Reference (in TJ)	78,000	91,000
Voluntary agreement (in TJ)	78,000	90,000

By comparing extrusion machines of different ages at an Austrian extrusion company, it became evident that newer machines have lower specific energy consumption, due to better insulation of cylinders, more efficient drives, optimized internal heating system, and reduction and elimination of ancillary components[109].

Blow Moulding

Major energy consumption of blow moulding is related to[110]

- Compressed air
- Cooling the products
- Hydraulic pumps
- Heating and cooling

60% of the energy consumption in blow moulding machines is related to compressed air supply. Energy can be saved by working with the correct pressure, selecting a well seized compressor and by minimization of leaks. If diverse processes need compressed air, best practice is to take one compressor for several machines – but this recommendation goes beyond the boundaries of the moulding machine as such.

Optimisation of the hydraulic system, in particular measures to adapt energy consumption to the cycle times, is an important field for machinery improvements. Similarly, an

109 Pamminger, R.; Wimmer, W.; Winkler, R.: Entwicklung von Kriterien zur Kommunikation der Energieeffizienz von Kunststoff verarbeitenden Maschinen, 5/2010 p. 70

110 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 35-37

all-electric machine with state-of-the–art energy saving options is stated to result in significant energy savings.

Total savings for the scenarios calculated by the EuPlastVoltage project are summarised in Table 1-25 for blow moulding[111]: The more ambitious "voluntary agreement" scenario reduces the total energy consumption only slightly in comparison to the energy cost driven reference scenario. In comparison to a business-as-usual scenario 5,000 TJ savings might be achievable, but the largest share of this potential is achieved with retrofitting measures to improve machinery, which is already in operation.

Table 1-25: Scenarios for blow moulding (EU energy consumption)

Scenario	2007	2020
Frozen, i.e. Business-as-usual (in TJ)	38,000	47,000
Reference (in TJ)	37,000	43,000
Voluntary agreement (in TJ)	37,000	42,000

Other plastics converting processes

There are several more plastics converting processes with typical power consumption attributes and related improvement potentials, but as injection moulding, extrusion and blow moulding are the most relevant processes, this screening is limited to these three types of processes. Only for illustration some additional aspects are listed here:

- Rotational Moulding: Electrical mould heating is potentially much more efficient than convection ovens[112]
- Thermoforming: Gas versus electricity heating has an impact on heating times, thus throughput, but at a potentially higher total energy consumption[113]

Total Savings Potential in Plastics Processing

In sum plastic converting industry can save energy by about 92,000TJ[114]. The largest potential in energy savings is related to injection moulding, according to findings of the

111 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 38-39

112 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 43

113 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 47

project EuPlastVoltage. However, part of the potential is linked to cross-cutting technologies (e.g. optimized central cooling or pressurized air systems) and is therefore not related to design measures targeting directly at the plastics processing machines. A major share of the potential is also related to retrofitting measures.

As a result of the "frozen" scenario the energy consumption would increase massively to 258,000 TJ in 2020. Taking into account a sensitivity of the market for energy costs, the energy consumption would remain on a stable level ("reference scenario"). Only the scenario of a voluntary agreement[115] results a reduction of energy use by around 19%. From 2010 to 2020 the saving potential is still in the range of 14%.

Table 1-26: Summarised scenarios for plastics processing (EU energy consumption)

Scenario	2007	2020
Frozen, i.e. Business-as-usual (in TJ)	210,000	258,000
Reference (in TJ)	>200,000	>200,000
Voluntary agreement (in TJ)	195,000	158,000

EUROMAP study

Partly in response to the initial discussions on plastics processing machinery, EUROMAP contracted a parallel study to investigate the status quo of these machines and related savings potentials. The following findings have been published by EUROMAP[116]:

"The study looked at the main plastics and rubber processing technologies, i.e. injection moulding, extrusion, blow moulding and thermoforming, which account for around 90 per cent of the total volume processed. (...) production efficiency has almost doubled in 20 years, and plastics machinery's specific energy consumption is down 30 per cent. (...). The demands made on hydraulic systems have resulted in greater efficiency and cut the energy consumption of injection moulding machines by around 40 per cent. The throughput capacity of extrusion machines has also doubled over the same period.

114 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 41-42

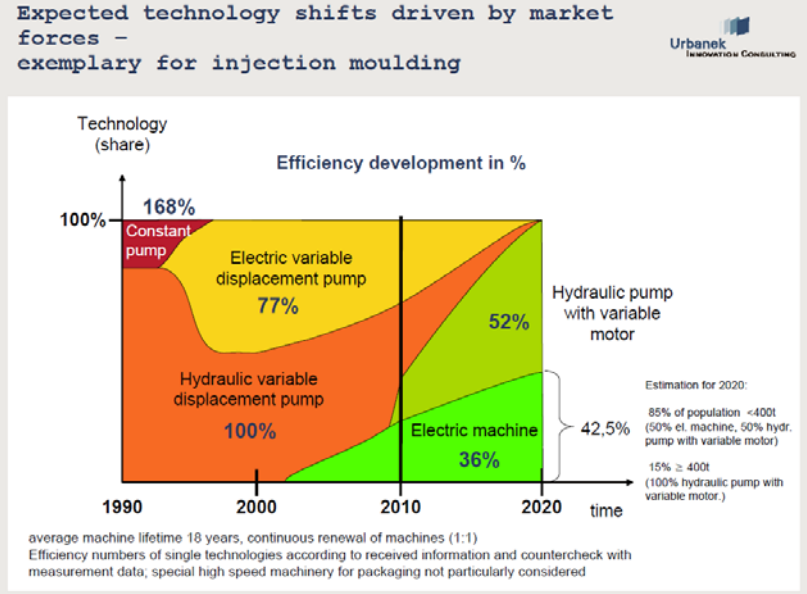
115 To be understood synonymous to any policy measure, that results in an implementation of state-of-the-art technical options at large

116 EUROMAP: study: productivity and energy efficiency go hand in hand, press release, 29 November 2011, and Urbanek, O.: EUROMAP Energy-Efficiency-Study, Summary/Conclusions, 9 June 2011; full study was not available to Fraunhofer, so no verification of claims made can be done

Machine-related energy consumption has been reduced by around 20 per cent. The same is true in compounding: twice the amount of material is being processed with machine-related energy consumption down by 20 per cent at the same time. (...) Increasing use has been made of servo drives in cyclic processes such as injection moulding, blow moulding and vacuum forming technologies for a number of years now. These allow the energy required for motion to be cut by half. Plants with a conventional, central power source and system-related line and control losses are increasingly being replaced. (...) Servo systems now also offer simple solutions for energy recuperation. In injection moulding, for example, during rapid motion of the closing units, the drives are used as generators to produce energy when braking. The same principle is also used with fast-working closing units of blow moulding machines and in thermoforming machines. (...) Looking to the future, there is no doubt that the use of energy-saving and highly dynamic components will provide a significant boost in terms of improving energy efficiency further in the next ten years. Greater use of all-electric drives and servo-hydraulic designs instead of conventional technology will pave the way for further efficiency gains – in some cases as much as 50 per cent. (...) The most important part in improving machinery is played by developments in process engineering: advances in screw technology have brought a significant increase in throughput rates while at the same time improving the quality of the melt. This has allowed extruders and the injection units of injection moulding machines to become smaller and better while maintaining performance. Radiant heater systems show great potential in thermoforming machines. There is also a great deal of potential for combining several processes: this is of particular interest if residual heat from one stage in a process can be used in the following stage with a view to eliminating reheating altogether. (...) Major savings can also be achieved if converters fine-tune processes to minimise energy consumption. Monitoring the flow of energy in machines, installations and in the plant also produces results. It makes the energy requirement transparent, which in turn contributes to tailoring energy consumption to need. (...)"

The main technology trends, which yield significant savings are depicted in Figure 1-20.

Figure 1-20: Expected technology shifts for injection moulding (source: Urbanek)



The total site energy consumption (S-EC) of the European plastic converting industry (thermoplastics, 2008) is stated to be 66,5 TWh. Machinery energy consumption (M-EC) totals in 22,5 TWh[117], which equals 236 PJ Total Energy consumption[118], and which almost exactly corresponds to the figures stated by the EuPlastVoltage project above.

Urbanek concludes that

- *"the 20% EU goal [for energy consumption reduction] will be achieved by renewal of the machine population with the latest state-of-the-art technology.*
- *In order to optimize energy consumption in plastics processing, the complete product-specific production environment around converting machines must be considered and monitored.*
- *There is great potential in the area of heat recovery."*

Given these statements, a significant savings potential for plastics processing machinery can be concluded. The study gives the impression that this development is inherently related to market developments. The information provided by EUROMAP does

[117] Urbanek, O.: EUROMAP Energy-Efficiency-Study, Summary/Conclusions, 9 June 2011

[118] Based on MEEuP indicators: 1 MWh electricity equals 10500 MJ Total Energy

not indicate whether there is any additional savings potential, which would require dedicated policy measures to be realised.

Standardization

The European association EUROMAP developed a standard for **Injection Moulding Machines – Determination of Specific Machine Related Energy Consumption** (EUROMAP 60), i.e. covering roughly a production volume of 6,400 machines in 2009 in EU-27 (see PRODCOM figures above). The current version 2.0, published in June 2009, is currently tested by a couple of machinery manufacturers. The scope of this standard is restricted to "injection moulding machines for thermoplastics with one injection unit with a reciprocating screw, an electrically heated barrel and one horizontal clamping unit without any ancillaries". The standard defines the set-up conditions for measurements and three types of production cycles for thin-walled parts, technical parts and commodity parts / thick-walled parts. In technical documents the following values shall be given:

- Specific machine related energy consumption (kWh/kg)
- Average power consumption (kW)
- Cycle time
- Power factor cos φ

Consequently, for an injection moulding machine the technical documentation should include e.g. the following:

> Specific energy related energy consumption (EUROMAP 60), Cycle II:
> 0,95 kWh/kg; 20 kW; 30 s; cos φ = 0,85

It is worthwhile noticing, that EUROMAP 60 refers to the amount of processed plastics ("per kg"), which is a suitable reference unit for thermal primary shaping processes, such as moulding, but rather not for forming, cutting, joining technologies.

Furthermore, injection moulding is only a sub-segment of the plastics processing industry. For extruding a similar approach is under discussion (EUROMAP 90) and a working group was established, but by now no consensus regarding a feasible energy efficiency measurement standard could be achieved.

Conclusions

This screening leads to the following conclusions for this study:

- Plastics and rubber machinery is an important market segment in terms of installed number of units
- Technically there are major differences compared to “machine tools” as heating and cooling are relevant and process inherent power consuming machine features,
    - which are subject to some significant directly machinery related improvement potentials
    - but typically are not found in “machine tools” and thus could not be tackled with similar approaches.
- Consequently, plastics processing machinery is not considered a “machine tool”
- On the component / module level there are some similarities with “machine tools”, in particular regarding
    - Drives
    - Hydraulic systems
    - Vacuum and pressurized air systems
    - Control systems

  although with some specifics (hydraulic oil is much more subject to a significant heat transfer from the process, pressurized air used for blow moulding has no similar key function in “machine tools”), which need to be taken into account in later steps of the study.
- Consequently, **drives, hydraulic systems, pneumatic systems / vacuum and pressurized air systems, control systems of plastics processing machinery are within the scope of the study on the modular level**.
- Approaches for energy efficiency measurement standards are in place or under discussion for certain market segments, but
    - need further verification regarding feasibility and
    - explicitly follow an approach (referencing the amount of material weight processed), which is not comparable to cutting or forming processes

1.1.5.5 Specification of environmental aspects of machine tools

1.1.5.5.1 Environmental parameters

Taking into account available life cycle data (see above) a first descriptive screening of machine tools regarding environmental parameters as listed in Annex I of the ErP directive is provided in Table 1-27, with further explanations provided below the table.

Table 1-27: Environmental parameters and judgement of relevance

parameters according to Annex I, 1.3 of EuP framework directive	**Relevance**
(a) **weight and volume** of the product	low relevancy
Material consumption mainly determined by mechanical requirements; many machine tools are in the range of several tons, so high consumption per device, but limited improvement potential: There are some approaches to make use of light-weight materials and to reduce weight of moving parts (reducing also the power requirements). Volume of machine tools determined mainly by size of work pieces to be processed, but anecdotally there are machine tools manufacturers claiming to have achieved a significant reduction in machine size. Environmental assessments of 3rd parties indicate a low relevancy of material consumption (and thus weight) of machine tools regarding the whole life cycle. Impact is in the range of few percent of the whole life cycle impact in most impact categories.	
(b) use of **materials issued from recycling activities**;	low relevancy
Metal parts typically made of the usual primary / secondary metals mix as provided by the metals industry.	
(c) **consumption of energy, water and other resources** throughout the life cycle;	Energy: highest relevancy in operational and non-operational modes Water: low relevancy
Environmental assessments of 3rd parties typically identify the use phase consumption of energy as the most relevant environmental aspect of machine tools over their life cycle. Given the high power rating of many machine tools (in the range of up to several 100 kVA, see VDW survey above), long lifetime and long operation times in most manufacturing environments, power consumption is high. Some machine tools, such as machine tools for soldering and welding also operate at elevated temperatures, meaning additional power consumption. Numerous approaches for reducing power consumption of machine tools are stated in literature and are promoted by solution providers, so a significant improvement potential can be assumed. Measures are as follows: power management, efficient motors, etc. Note, that a major share of power consumption depends on the work piece (geometry, precision requirements) and the material to be processed, thus is not subject to machine related improvement options. Consumption of pressurized air could be relevant in terms of power consumption (e.g. for pneumatic tables). Usage of water occasionally as process cooling water and to generate emulsions and solutions of cooling lubricants. (Reduction potential for usage of cooling lubricants see below)	
(d) **use of substances classified as hazardous** to health and/or the environment (...);	Low relevance

parameters according to Annex I, 1.3 of EuP framework directive	Relevance
Hazardous substances used as constituent of machine tools are e.g. lead in solder of electronics components (exempted from RoHS in case of stationary equipment) and mercury in operator panel backlights. Given the trend towards RoHS compliant electronics components in general, availability of non-RoHS compliant components for machine tool applications also is hampered, stimulating a "voluntary" change to leadfree soldering technologies There is no known environmental assessment available indicating any environmental relevancy of hazardous substances contained in parts and components of machine tools. Also given the B2B nature of the machine tools market, uncontrolled release of lead from solders etc. is unlikely.	
(e) quantity and nature of **consumables** needed for proper use and maintenance;	Consumption of lubricants: moderate relevance Consumption of hydraulic oils: low relevance some cooling lubricants contain toxic composites
Although consumption of cooling lubricants and hydraulic oils can be significant, they do not show up as very relevant in 3rd party environmental assessments. Total consumption of cooling lubricants is estimated at several million tonnes per year (emulsions and solutions, see task 2 report, 2.4.3). There is an improvement potential in reducing cooling lubricants consumption by employing minimum quantity lubrication (MQL) or dry processing, but this might affect power consumption of the machine tool adversely. less toxic alternatives available, but not suitable for some dedicated processed metals /alloys	
(f) **ease for reuse and recycling** as expressed through: • number of materials and components used, • use of standard components, • time necessary for disassembly, • complexity of tools necessary for disassembly, • use of component and material coding standards for the identification of components and materials suitable for reuse and recycling (including marking of plastic parts in accordance with ISO standards), • use of easily recyclable materials, • easy access to valuable and other recyclable components and materials; • easy access to components and materials containing hazardous substances;	Moderate relevance
As machine tools represent high-value investment goods reuse usually is done, but availability of suitable control electronics typically is hampered for machine tools > 10 years in operation, but this is rather a problem of spare parts stock, not machine design. As maintenance-friendliness of machine tools in most applications is crucial for reduced down-times, access to key components and possibility for replacement usually is non-critical. Machine tools usually are designed in a modular way easing also disassembly and materials separation at end-of-life. Usage of bulk materials, which are of interest for metals recycling at end-of-life. Amount of metal make it worthwhile typically to dismantle machine tools. Contamination of machines in some applications requires thorough decontamination before material recycling and resale.	
(g) incorporation of **used components**;	Low relevance
Given the long lifetime of machine tools possibilities are limited that components from another machine tool are still usable / state-of-the-art / compatible for a new machine tool	
(h) avoidance of technical solutions **detrimental to reuse and recycling** of	Low relevance

parameters according to Annex I, 1.3 of EuP framework directive	Relevance
components and whole appliances;	
Non-standardised components and interfaces constitute a barrier for reuse of components and whole machines. E.g. proprietary communication protocols can be considered a barrier, but see remarks on reuse of machine tools in general above.	
(i) **extension of lifetime** as expressed through: minimum guaranteed lifetime, minimum time for availability of spare parts, modularity, upgradeability, repairability;	Moderate relevance
Usually machine tools are compliant with essential requirements for lifetime extension as demonstrated also by the huge second hand market for machine tools.	
(j) amounts of **waste** generated and amounts of **hazardous waste** generated;	Moderate relevance
Major wastes generated throughout product usage and disposal are: Cut-offs from workpieces, yield losses of workpieces, emissions from work pieces such as wood particle boards and from processes such as welding fumes and saw dust, waste from cooling lubricants and machine oils, WEEE from electronic components, scrapped tools. Some of these wastes could reach a moderate level of relevance.	
(k) **emissions to air** (greenhouse gases, acidifying agents, volatile organic compounds, ozone depleting substances, persistent organic pollutants, heavy metals, fine particulate and suspended particulate matter) (...);	Moderate relevance
Particle emissions from wood processing (saw dust) constitute a major environmental problem for the workplace, same for welding fumes and the like. The emergence of oil mist and subsequently oil steam is a prevalent observable phenomenon during metal cutting operations under high cutting rates. The discharge of gaseous oil causes significant damage to the immediate environment. Due to the fact that there is existing legislation regulating the maximum admissible concentration, machine tools generally are in possession of an oil mist extraction device. Thus, the environmental relevancy is assumed to be low. Lower relevancy of droplets emitted from cooling lubricants usage. Relevant emissions to air throughout the life cycle are rather related to the power consumption (emissions of power plants).	
(l) **emissions to water** (heavy metals, substances with an adverse effect on the oxygen balance, persistent organic pollutants);	Low relevance
Cooling lubricants are typically classified as water hazard substances, but no release under normal operating conditions. Waste water (containing e.g. residues of cooling lubricants) stems from cleaning of machined parts, thus dry processing could reduce cleaning requirements.	
(m) **emissions to soil** (especially leakage and spills of dangerous substances during the use phase of the product, and the potential for leaching upon its disposal as waste).	Low relevance
No release of any hazardous substances under normal operating conditions to be expected.	

1.1.5.5.2 Criteria for the judgement of the environmental relevancy

As revealed above, according to 3rd party findings, the major environmental impact is induced during the use phase, notably caused by the consumption on electricity. In this respect, the following criteria have been summarized, reflecting the environmental parameters identified above, which are energy consumption, compressed air consumption, consumption of cooling lubricants, cooling water consumption, exhaust air from suction, workspace related air conditioning, and noise pollution.

Energy consumption

In the framework of the environmental screening, the energy consumption of a machine tool is a matter of special importance. In accordance with the Working Plan study, most machine tools are indicated using a great deal of energy during operation time.[119] The majority of metal working machine tools operate in the range of 30KW-60KW, whereas this window might not be reliable considering the multitude of distinctive machine tools in the product scope. Connecting power of other relevant machine tools, explicitly those for working wood are likely to be significantly lower in average. However, energy consumption remains being a central benchmark in the assessment of environmental impacts, including losses due to stand-by mode.

The energy efficiency of a machine tool is likely to be a significant subject matter in this Product Group Study. As 30% of the energy consumption is used for standby-mode (e.g. in order to maintain the process stability),[120] concepts for economic usage are gaining additional attention.

According to a study on environmental machining from 2004, three different types of machine tools where analyzed in regard to the specific energy use under heavy duty.[121] As a result, a rising degree of automation seems to be in correlation to a rising fixed percentage of constant energy consumption:

119 EPTA LTD, ref 13, p. 258f.

120 BUNDESMINISTERIUM FÜR BILDUNG UND FORSCHUNG (BMBF), FRAUNHOFER GESELLSCHAFT (FHG), *Energieeffizienz in der Produktion*, 2008.

121 DAHMUS, J.B., GUTOWSKI, T.G., *An Environmental Analysis of Machining*, 2004.

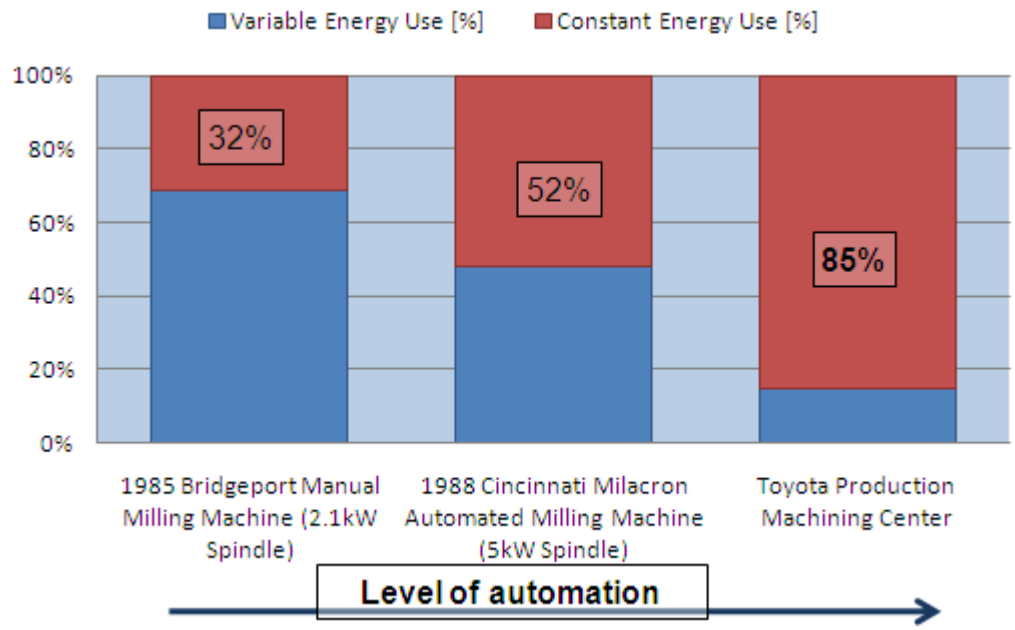


Figure1-21: Ratio of fixed and variable energy consumption for different types of machine tools (selection), figure adapted from Dahmus & Gutowski.

Compressed air consumption

Closely linked to energy efficiency of production systems is the supply and consumption of compressed air. Overall, possible savings can be up to 30% of the current energy consumption.[122]

Consumption of cooling lubricants

By the means of ISO 19378:2003,[123] cooling lubricants for metal-cutting procedures are differentiated as being water-miscible, water-immiscible, or water-mixed fluids. To extend the field of appliance, different lubricants contain several additives in order to make them suitable for the respective kind of metal cutting. The substances can be classified in groups as follows:

- Anti-wear additives which form a lubricating film (AW additives),

122 BUNDESMINSITERIUM FÜR WIRTSCHAFT UND ARBEIT (BMWA), DEUTSCHE ENERGIE-AGENTUR GmbH (DENA), FRAUNHOFER ISI, VDMA KDV, *Druckluft Effizient – Abschlussbericht*, 2005.

123 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, *ISO 19378:2003 - Lubricants, industrial oils and related products (class L) -- Machine-tool lubricants -- Categories and specifications*, 2003.

- High pressure additives, so-called EP additives,
- Anticorrosion additives,
- Foam retarding agents,
- Anti-fog materials,
- Dispersing agents, and
- Surface-active substances.

The ecological range due to the use of cooling lubricants has its impact on several distinctive levels, both in the direct working surrounding as well as in a globally-viewed framework, which is visualized in Figure1-22. Cooling lubricants have a broad ecological range, which is due to presence of hazardous substances for human and environment, especially in form of aerosols, besides causing additional costs and charges. To avoid dissipation of aerosols, auxiliary equipment such as filtration units need to incorporated. Furthermore, specific requirements concerning environmentally compatible recycling are obvious, contributing to an increase in life cycle costs of lubricants.

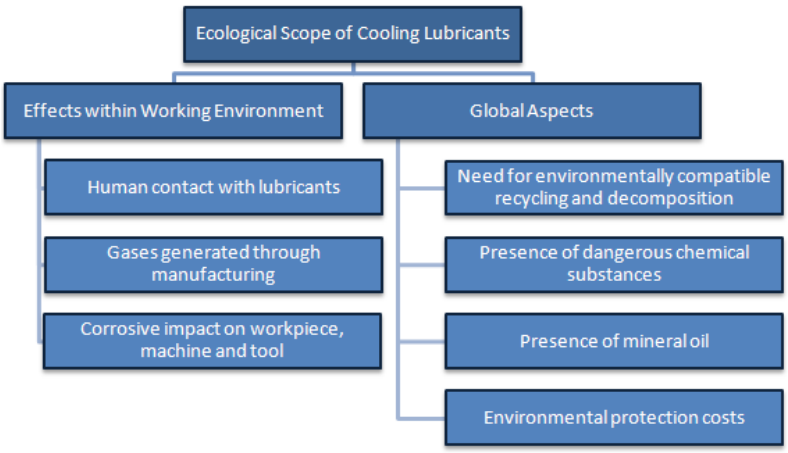


Figure1-22: Ecological scope of cooling lubricants. Figure adapted from Sokovic & Mijanovic.[124]

Cooling water consumption

The assessment of the water consumption adds another component in order to gain an overall picture of the environmental relevancy of machine tools.

124 SOKOVIC, M., MIJANOVIC, K., *Ecological aspects of the cutting fluids and its influence on quantifiable parameters of the cutting processes*, 2001.

Except for the appliance of lubricants, water may be used in several processes as the cooling media during manufacturing. Considering the environmental interaction, we will focus on machines which cooling systems are based upon an open loop mechanism, where a mass transfer across the system boundaries can be quantified. Furthermore, impacts caused by potentially harmful additives contained in the cooling media as well as the dissipated energy content have to be considered.

Exhaust air from suction

As with the previous indicator, the mass transfer caused by the exhaust air of the manufacturing process will be assessed by an energetic as well as a material related consideration. Closely related to water consumption, the quality respectively the composition of accompanying substances (e.g. aerosols deriving from the cooling process) is of great importance, considering that additional modules (e.g. sophisticated filtration plants) need to be taken into account, which in return affects the life cycle assessment of the machine.

Workspace related air conditioning

The additional air conditioning may occur in places where the ambient air temperature is raised by the dissipated energy from the running machines. As an indirect influence considering the efficiency of these devices, further energy consumption for room air-conditioning have to be taken into account for the assessment. The other way around, extra energy is needed to maintain a solid temperature in a working environment. Especially when regarding large scale factories, room ventilation is accounted for as an important expense factor. Empirical evidence is provided in the frame of an energetic analysis carried out at BMW in Leipzig, in which potential savings of 457.000€ per annum were revealed.[125]

Noise pollution

Noise pollution resembles a location based disruptive factor, leading to physiological discomfort and psychological distress of beings that are at close range. With this aspect in mind, machine tools and where appropriate single components such as the spindle and the electric motor needs to be evaluated regarding emitted noise.

125 HAHM, *Verbindung von Energieeffizienz und Energiebezug in produzierenden Unternehmen*, 2010, slide 27.

Due to the fact that noise emission and methods for standardised measurement has long been subject to standardisation, which will be discussed in detail in task 1.2, the subject of noise pollution will not be further regarded in this study. In particular noise is covered under the machinery directive.

1.1.5.6 Prioritising machine tool categories

- **Objective**

In order to conduct a first differentiation of scope related machine tools on the grounds of environmental relevancy, the identified PRODCOM categories are classified in terms of the level of automation (see 1.1.1.2). The screening additionally intends to identify categories of minor market relevance.

- **Preliminary consideration**

Across the entire machine life, complex and highly automated machine tools cause higher cumulated power consumption than “low tech” machine tools. This is due to the fact that highly automated machine tools are most frequently used for series production and the like, whereas “low tech” machine tools more likely are sporadically being operated. In this regard, the price (single value) of the machine is used to draw conclusions concerning its level of complexity.[126] We presume, that a high value reflects a high complexity and thus a higher level of automation of the product. Thus, we estimate that a high level of complexity is correlated to an increasing ecological impact and vice versa. This is confirmed by a screening of connection power correlated with sales prices.[127] A classification in terms of automation is of particular interest when discussing improvement options for these machines. It is acknowledged that the increase of automation goes along with a growth of environmental impact respectively energy demand per machine, considering that more components and different technologies are involved. It is however also acknowledged, that on a “per unit of product” basis a highly automated machining centre is likely to be more efficient, than smaller machine units. This will be reflected in later tasks.

[126] Note: The price classification is not committed to any representative market data but intends to find reasonable groups on the basis of the range of prices as depicted in PRODCOM.

[127] Note: However, it should be considered that on the other hand, automation goes along with a significant raise in productivity.

The basic assumptions are summarized in Figure 1-23.

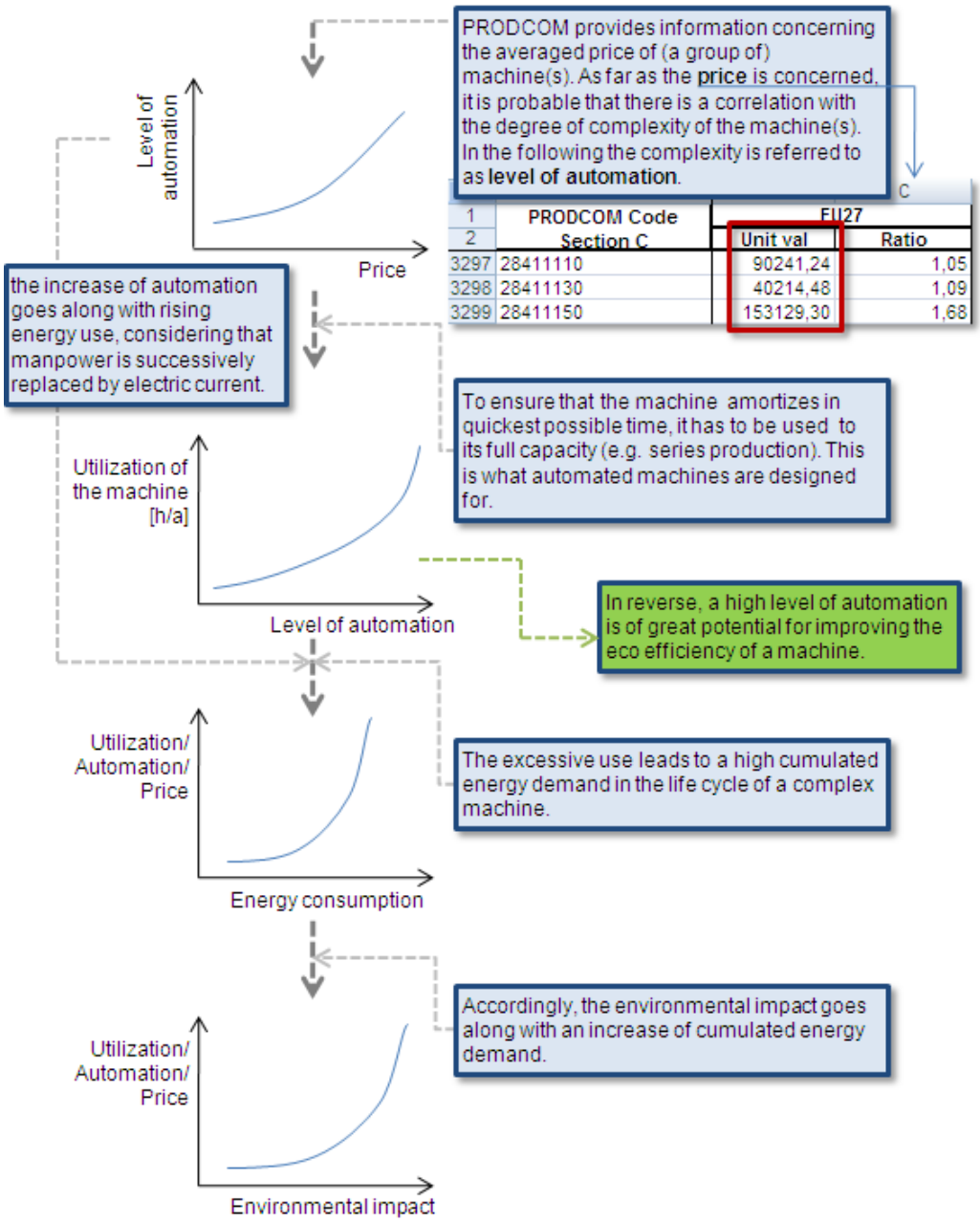


Figure 1-23: Basic assumptions for the first environmental screening.

- **Limitations**

The assessment of metal forming machinery (i.e. NACE code 28.41) is facilitated by the aid of specified information provided by CECIMO which makes it possible to distinguish NC from non-NC. As far as the other types of machine tools are concerned, the

distinction according to automation is additionally being hampered due to several limitations, which are high level of aggregation, unclear descriptions, etc.[128]

It is acknowledged, that several categories are lacking reliability in regard to the economic data and therefore are in need of a review. As far as metal working machine tools are concerned, it should be pointed out that the economic figures (sold volume and unit value) derives from a plausibility check and related revision of PRODCOM data (further explanation is given in task 2). Accordingly, market statistics from the other non-revised machine groups should be used with caution.

- **Means**

The procedure is being performed separately for metal working machine tools, woodworking machines, welding machines, and other machine tools. The screening is not applied on those which are identified as related machineries (see Annex III – Related machinery (identified modules) (non-exhaustive)), considering that only specific modules will be of interest for this study.

Categories which obviously cover machinery and equipment portable by hand (particular low value as an indication) and which are primarily not for industrial use will be not relevant anymore in the ongoing course of the study. In this regard, categories respectively machines which have been recognized as not relevant during the screening are listed separately at the end of each screening.

Considering that PRODCOM categories deriving from classes 28.41 and 28.49 are not unambiguously defined in terms of automation, further criteria need to be considered (see Table 1-28).

[128] Note: For details, see limitations for classifying the product scope.

Table 1-28: Level of automation for the environmental screening – Necessary criteria for identification

Number	Description	Criteria
5	System	Declared as such.
4	Cell	1. Declared as such. 2. If not applicable: If a particular type of machine is addressed, category can be matched to a specific level of automation (further explanation mandatory). 3. If not applicable: Not declared and single value **> 300.000€.**
3	Centre	1. Labelled as such. 2. If not applicable: If a particular type of machine is addressed, category can be matched to a specific level of automation (further explanation mandatory). 3. If not applicable: Not declared and single value **100.000 - 300.000€**.
2	NC-Machine	1. Labelled as such. 2. If not applicable: If a particular type of machine is addressed, category can be matched to a specific level of automation (further explanation mandatory). 3. If not applicable: Not declared and single value **10.000 - 100.000€**.
1	Machine	1. Labelled as non-NC machine by CECIMO. 2. Labelled as such. 3. If not applicable: If a particular type of machine is addressed, category can be matched to a specific level of automation (further explanation mandatory). 4. If not applicable: Not declared and single value **< 10.000€**.
0	No level determinable	See individual comment for each category.

- **Findings for the environmental screening**

The results of the environmental screening in terms of level of automation are summarized in Annex IV – Environmental screening of product scope. Within each level, the PRODCOM categories are in a descending order, according to the sold volume.

Metal working machine tools

The results for metal working machine tools are displayed in **Table 6-1**.

Woodworking machines

The results for woodworking machines are depicted in **Table 6-2**. For simplicity, machines not related to the category are crossed out in the screening.[129]

[129] Note: Explanation is given during the course of classifying woodworking machines (1.1.3.2).

Welding, soldering, and brazing machines

The results for welding, soldering, and brazing machines are depicted in **Table 6-3**.

Other machine tools

The results for other machine tools are depicted in **Table 6-4**.

1.1.5.7 Summary and conclusions

Previous research on the ecological performance of machine tools reveals that the life cycle impact largely derives from the **use phase**, notably **energy consumption**. To some extent, the use of cooling lubricants and hydraulic oil also contributes to the ecological performance. Some studies indicate that under certain use conditions and for certain processes the use phase might be less dominating and the **production phase** of the machine tool, i.e. material consumption for constructing the machine, is relevant as well. The analysis also shows that weight and connection power among machine tools are heterogeneous, meaning that machine tools (also those which share the same PRODCOM category) have very specific ecological impacts and individual improvement potentials.

Based on our findings, the relevance of certain parameters set out by the ErP Directive could be determined.

As a result, machine tools having a comparative high energy demand will be put into focus, e.g. those with a high level of automation (considering that a multitude of modules are involved which contribute to an increased energy demand of the machine) or those which are permanently operated (almost constant energy demand at any time of the day). These types of machine tools are of particular interest for the later base case assessments.

1.1.6 Functional Unit

The functional unit in accordance with ISO14040 on LCAs is “the quantified performance of a product system for use as a reference unit in life cycle assessment study”. A functional unit is meant to allow for a comparison of different products and to provide an unambiguous reference basis for the LCA results of the product assessment.

Given the complexity of potential functions provided by any machine tool (in terms of workpieces to be manufactured) it seems feasible to take “one machine tool over its full life cycle” as functional unit. This approach is also followed by CECIMO in their preparatory LCA work and the SRI developments.

VDMA in a stakeholder comment objects the approach to define the whole machine tool as a “functional unit” as defined in EN ISO 14040 for the following reasons, and questions the possibility to define a functional unit for this broad product range at all: “In principle, VDMA strongly favours the extended product approach that takes into consideration the operating conditions and use patterns of the product involved. By doing so, usually a fixed unit will have to be studied, taking into consideration the actual product, composed of a motor and the control unit. In marketing this unit the manufacturer assumes "overall responsibility". … Metal processing machine tools are complex systems and are marketed as an asset to companies who actively influence the technical characteristics, performance data and equipment characteristics of the machine tool. Therefore, these products are highly unique, influenced by the customer’s requirements with regard to the end product as well as by the organisational and manufacturing involvement in the customer’s production technical environment. In addition, metal processing machine tools encompass an extremely wide range of different processing technologies, with approximately 400 machine groups and around 2000 different types of machines, meaning that any technical/technological comparability between them is extremely difficult. The requirement of EN ISO 14040, to use a “functional unit” for a Life Cycle, is not applicable to a machine tool due to its various application scenarios.”

A more appropriate unit than the machine tool as such for comparisons would be actually the product output. If the product output is not taken into account at all, productivity of a machine tool is neglected. This is not intended by ecodesign as on a highly automised machining centre a high number of machined parts can be produced, but power consumption per machining hour is high, whereas a smaller, less automated machine is likely to run with lower power consumption per machining hour. However, typically power consumption per workpiece produced is typically higher on a smaller machine. This needs to be reflected in the study.

Having said that, the definition of a functional unit for “machine tools and related machinery” per product output in general is not possible, given the manifoldness of manufacturing tasks and the variety of quality criteria to be met. Even more, machine tools are typically meant to manufacture a multitude of different forms and sizes of workpiec-

es throughout their lifetime and a “standard product” can hardly be defined, if production reality should be reflected.

Technical parameters (selection) which are relevant to define the manufactured product comprise:

1. Processed material

2. Type of processing (forming, bending, cutting, drilling etc.)[130]

3. Processing accuracy (failure tolerance etc.)

4. Workpiece dimensions

5. Specific production environment requirements (e.g. processing in clean rooms)

If at all, an output related functional unit can be defined only for certain processes, e.g. possibly for welding “1m welded joint of a given quality for a given geometry” – but this already makes clear, that quality criteria are inevitable for a fair comparison of different machines. For chip removal processes the amount of removed material could be a theoretical functional unit, but as to be complemented by a clear definition of the material to be processed, geometry, and quality criteria, but even then a distinction has to be made for micro machining versus bulk processing, as the latter is meant to remove more material per se, and micro machining is optimised for meeting certain product specifications. The approach to refer to the amount of material processed seems to be feasible only for primary shaping processes (such as injection moulding of plastics, EUROMAP 60, but even in this case comparability of measured performance values is questionable); however, primary shaping is not in the scope of this study. For bending operations Santos et al.[131] propose an exergy reference unit, as the amount of material is considered inappropriate.

In conclusion, for practical reasons this study has to refer to **one machine tool** as a general functional unit, but **productivity** needs to be considered when interpreting the outcomes of the assessments.

130 In machining centers several of these processes are performed consecutively

131 Santos, J.P. et al.: Improving the environmental performance of machine-tools: influence of technology and throughput on the electrical energy consumption of a press-brake, Journal of Cleaner Production (2010)

1.2 Test and other standards

This task should identify the relevant test and other standards relevant for machine tools. Compliant with our previous structure, this task copes with general environmental standards on machinery with particular attention to metal working machine tools, woodworking machines, as well as welding, soldering, and brazing machines. Technical standards – and test standards in particular – are important elements with respect to eco-design requirements and in order to proof compliance.

The objective of this subtask 1.2 is to give an overview of existing test standards, provide short explanations of vital test procedures, and additional information on sector-specific standards (e.g. quality issues) for the product scope defined in task 1.1.

International standards will be taken into consideration for the analysis, comprising e.g. ISO standards, but also those of certain industry branches, which use machine tools, such as the SEMI standards for the semiconductor industry. It is worthwhile noticing, that the semiconductor industry already published a couple of outstanding Environmental, Health and Safety (EHS) standards and guides addressing environmental impacts specifically (namely end-of-life, energy conservation – also with a systems perspective – etc.).

1.2.1 International standards

There are few standards addressing environmental issues on international level, notably in the field of lubricants and lubrication as well as noise measurement procedures. In this regard, there are several standards released on a general as well as on a product specific level. As far as general standards are concerned, **ISO 11204:1997** – ***Noise emitted by machinery and equipment – Measurement of emission sound pressure levels at a work station and at other specified positions – Method requiring environmental corrections –*** provides a method for the determination of sound pressure levels for machineries without the inclusion of specific environmental matters. Methods for noise measurements has been standardised in detail for several specific types of machines, which will be explained later.

1.2.1.1 Metal working machine tools

Lubricants and Lubrication

- **ISO 19378:2003** – ***Lubricants, industrial oils and related products (class L) – Machine-tool lubricants*** – ***Categories and specifications –*** provides information concerning the appropriate use of different lubricants for machine tool operation. However, the allocation of lubricants to the specific application is rather preceded by technological means instead of environmental issues, thus this standard has no direct environmental relevancy for machine tools. In extension to ISO 19378, **ISO 5170:1977** – ***Lubrication systems for machine tools –*** classifies and specifies lubrication systems in relation to the components of a machine in order to maintain a rational use of lubrication. Suppliers are advised to provide appropriate instructions for the correct use of lubricants in accordance to this standard. Although deriving from an applied perspective to reduce expenses due to inefficient lubrication, however, the standard considers toxic effects of lubricants and recommends restricted use of hazardous substances, thus an environmental dimension is provided.

Noise Measurement

- The issue of noise measurement is furthermore adapted by **ISO 230:2009** – ***Test code for machine tools – Determination of vibration levels***. As part 8 of this standard primarily deals with the origins of occurring vibrations due to machine tool operation, part 5 specifies the determination of sound levels, thus providing a pattern for the correct measurement of the emitted sound of a particular machine. In reference to ISO 230-5, determining the noise level of metal-cutting machineries are subject to **ISO 8525:2008 –** ***Airborne noise emitted by machine tools – Operating conditions for metal-cutting machineries.*** The standard focuses on certain machine tools for metal cutting procedures and provides specific introduction for certified noise measurement. By picking up these methods, comparability between similar types of machines shall be granted. It should be pointed out, that solely the test method itself is subject to the standards and hence the environmental aspect of sound emissions is disregarded. Further information, such as limitations of noise levels for different sort of machine tools, are not provided.

1.2.1.2 Woodworking machines

Noise Measurement

- **ISO 7960:1995** – ***Airborne noise emitted by machine tools – Operating conditions for woodworking machines*** – deals with test standard specifications for determining airborne noise emitted by various kind of woodworking machines. The standard provides a detailed instruction for measuring the noise of each specific type of machine. Aside from technical aspects concerning the measurement procedure, ISO 7960 does not relate to environmental relevancy of noise pollution, either.

1.2.1.3 Welding machines

DIN EN 14717:2005 – *Welding and allied processes – Environmental check list* – deals with general considerations for the inclusion of environmental aspects into welding processes. Primarily, it is intended to identify single root causes of environmental pollution triggered by welding processes, machineries and materials. The standard proposes the supervision of fumes, gases, and aerosols as well as the environmentally suitable disposal of substances such as scrap, dust, insulating material, and the like. Additionally, a list of actions to improve the energy efficiency is attached. However, it should be pointed out that DIN EN 14717 remains being on a general and qualitative level, subsequently there is a lack of precision concerning improvement measures (e.g. no specific technical guidance, etc.).

1.2.1.4 Environmental relevancy of safety standards[132]

There are numerous standards affecting safety regulations during design, construction and usage of machine tools on European level. Safety has been subject to standardisation in order to set up admissible working conditions for the operating personnel, especially in the field of metal working machine tools and woodworking machines. To name only a few important ones, such as **EN ISO 14121 – *Safety of machinery – Risk assessment* –** giving a methodology on risk analysis procedures or **EN ISO 12100 – *Safety of machinery – Basic concepts, general principles for design* –** featuring general guidelines concerning product construction matters, many standards provide particular behaviour patterns for secure handling of metal working and woodworking machines (such as DIN EN 692 on mechanical presses, DIN EN 693 on hy-

[132] Note: Due to structural reasons, some safety standards will be dealt with in other sections.

draulic presses, DIN EN 12415 on small numerically controlled lathes, etc.). Overlaps between safety standards and environmental aspects (e.g. as identified in task 1.1) can be assumed but not be acknowledged in detail at this point. However, to grant physical integrity for the operating personnel, safety standards will not be considered as “limits” for environmental implementing measures.

In terms of areal efficiency, **ISO 14122-1 – *Safety Machinery – Permanent means of access to machinery – Choice of fixed means of access between two levels* –** imposes certain rules for the safe access to machines. By defining the arrangement of particular access devices (such as ladders, stairs, ramps), the areal efficiency might be lowered due to this exogenous regulation. Furthermore, design and scaling of access devices cannot be optimized environmentally. However, besides that these circumstances apply rather to a small number of machine tools, the emerging consequences can be assumed as negligible.

ISO 14118:2000 – *Safety of machinery – Prevention of unexpected start-up* – deals with energy dissipation in order to reduce risk of accident from abrupt starts of machine tools and other machines. Therefore, the standard requires the dissipation of stored-energy (such as pressurized air, potential energy of machine tool components, e.g. hammer from a drop forged hammering machine). In doing so, usable energy is discharged and therefore a decrease in efficiency can be denoted. However, it can be assumed that the dissipated energy in comparison to the overall energy consumption is rather small. Certain aspects deriving from ISO 14118 might be of interested in regard to energy management systems which will be subject when analysing BATs in task 5.

As far as woodworking machines are concerned, **DIN EN 12779:2004+A1:2009 – *Safety of woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements* –** provides mandatory safety requirements for the use of stationary large-scale extraction units with air flow rates greater than 6.000 m³/h. The standard covers several issues also relevant from an environmental point of view, i.e. noise emissions, selection of operation modes, and emissions of particles and gases. In regard to noise emissions, DIN EN 12779 recommends certain measures to be picked up during design and construction phase in order to reduce the general noise level of the dust extractor. A list of actions to reduce noise is given by the standard. Besides noise emissions, the document addresses energetic aspects of dust extractors. As a pneumatic system, the extraction vacuum has a major impact on the overall energy consumption. It is furthermore implied that naturally, a reduction of pressure losses in pipelines and tubes increases the energy efficiency. However, taking any measures in the field of energy consumption is not recommended.

Besides in standardisation, safety issues are a significant aspect in legislation. In regard to subtask 1.3, several directives such as 2006/42/EC on Machinery deal with the inclusion of safety issues and its effects on the environment (see also Figure 1-27, p. 126).

1.2.1.5 Machinery components related standards and technical specifications

Among the multitude of standards for the various components and systems of and related to machine tools those on motors are of specific interest:

IEC/EN 60034-30 harmonizes internationally the energy efficiency classes for motors, and is also referenced in Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors (see 1.3.1)

IEC/TS 60034-31 defines the IE4 “super premium” efficiency class of synchronous and asynchronous motors, but solely as a technical specification, not as a standard, as the technology to achieve these efficiency levels is not yet fully established.

Figure 1-24 depicts the IE levels according to IEC/EN 60034-30 and IEC/TS 60034-31 for 4-pole motors.

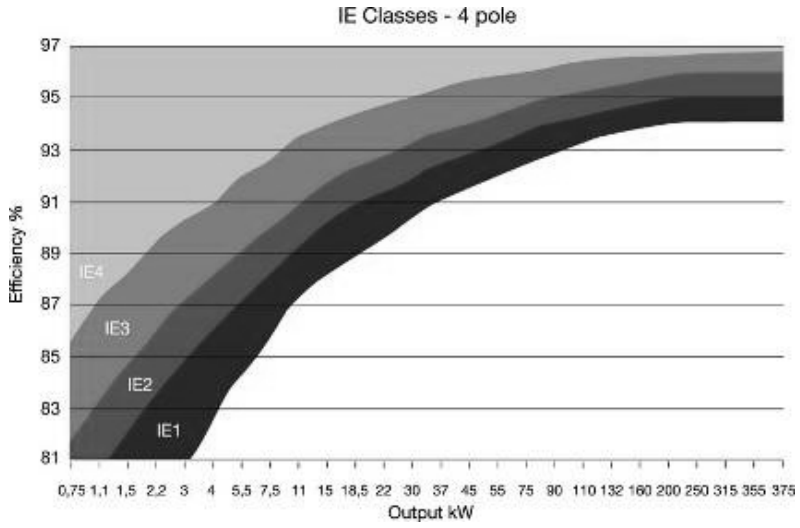


Figure 1-24: IE efficiency classes for 50 Hz 4-pole motors[133]

There is no standard yet for measuring energy efficiency of the combination of motor and variable speed drive, but in 2010 the EC gave a mandate to CEN, CENELEC and

[133] Efficiency regulations for low voltage motors, ABB external presentation, July, 2010

ETSI for standardisation in the field of electric motors, covering procedures and methods of measuring the energy efficiency and associated characteristics for motors, including variable speed drives.

1.2.2 National standards

The national standard **NF E 01-005 – *Mechanical products – Ecodesign methodology* –** provides an ecodesign method for mechanical products, in particular for those manufactured by the mechanical engineering and metalworking industry, thus comprising machine tools as well. According to the standard, the environmental performance relies on the following seven environmental aspects: raw materials, manufacture, use, recyclability, hazardous substances, transportation, and packaging. This document is tailored to small and medium sized enterprises, aiming at a rising awareness for eco aspects in product design and on management level. It is based on five steps as set out below:

- Step 1: Determination of the environmental profile of the product: Determining the environmental profile is supported by a standardised environmental questionnaire. The seven environmental aspects will be ordered by its ecological relevancy.
- Step 2: Selection/ranking of design guidelines:[134] Deriving from the results from step 1, certain design guidelines (which are proposed by the standard) will be selected to improve the overall environmental performance of the product and ranked by the need for implementation. Exemplarily, if transport is the most important environmental aspect, a guideline could be the minimisation of product logistics.
- Step 3: Choice of environmental indicators: Referring to the design guidelines picked in step 2, appropriate indicators will be linked to each guideline. Exemplarily, to reduce product logistics, an indicator could be the number of kilometre involved from raw materials procurements up to putting on the market.
- Step 4: Monitoring of indicators: During the design phase, the adherence of ecodesign is assessed by the monitoring of the predefined indicators.

[134] Note: Design guidelines of NF E 01-005 are basically the same as what we call improvement options.

- Step 5: Assessment – building on experience: Looking back on the completed process, the applied method for implementing ecodesign measures shall be analysed and assessed. In regard to further use and especially optimisation, a knowledge base should be created.

The standard furthermore identifies requirements for the effective implementation of the method. Besides several recommended office tools (e.g. software, analysing methods, etc.), it is assumed that the process is carried out by a multidisciplinary team with the support of all corporate functions (R&D, design office, purchasing, marketing, etc.) and management.

Although being on a generic level for mechanical products, this guide provides an overall improvement management system to implement strategies applicable for machine tools in terms of ecological efficiency. The process is carried by a structured methodology and numerous tools for environmental upgrading of products are provided. However, the provided design guidelines are very general and need to be more product-specific in regard to machine tools. To fill the gap between design guideline (e.g. minimising weight and volume of used materials) and indicator (e.g. weight in kg, volume in l or m^3), substantial product-specific technologies and techniques for implementation need to be provided. The assessment of the environmental profile cannot be used for the comparison of similar products. This is primarily due to the generic nature of the questionnaire, which partly relies on qualitative answers.

The German standard **DIN 33893-2:1997 –** ***Evaluation of the emissions of airborne hazardous substances – Part 2: Pollutant concentration parameter – Stationary woodworking machines –*** deals with the method of determining the concentration of wooden particles from the exhaust air. The procedure is specified for different types of woodworking machines, such as band saws, circular saw benches, planing machines, milling machines, and the like. DIN 33893 exclusively deals with the method of testing, meaning that within the context, no further (environmental) subjects are being addressed. Airborne wooden particles are of great importance regarding occupational safety but do not have great impacts on natural environment and ecosystems, thus they are of minor environmental relevance.

1.2.3 SEMI standards

The semiconductor industry, as mentioned above, published a couple of outstanding environmental standards, which shall be described briefly. As some machine tools are used within this industry, certain segments of the standards are of high relevancy.

- **SEMI S2-0703** – ***Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment*** – is the general guidance concerning prevention strategies for the semiconductor industry. According to the SEMI terminology, the expression equipment refers to “a specific piece of machinery, apparatus, process module, or device used to execute an operation”. Users and suppliers are required to thoroughly consider environmental aspects and seek for improvement potential regarding reduction of resource consumption or the refurbishing or recycling of products.

- **SEMI S12-0298** – ***Guidelines for Equipment Decontamination*** – gives advice for decontaminating hazardous substances from certain products with the intention of further use. This way, the total waste accumulation and the exposure of hazardous substances to the environment shall be minimized.

- **SEMI S16-0600** – ***Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life*** – is a guide providing specific help to minimize the environmental impact during the disposal of equipment from the semiconductor industry. The user is emboldened to take specific measures and to consider the environmental particularities of his product. Besides addressing end-of-life measures, the guide also provides assistance for selecting materials, designs and components for reusability and recyclability during construction phase.

- **SEMI S23-0311 –** ***Guide for Conservation of Energy, Utilities and Materials used by Semiconductor Manufacturing Equipment*** – is a guide intended to be a tool that can be used to analyse energy, utilities and materials conservation on semiconductor manufacturing equipment, but also defines (optional) requirements regarding power management. As the semiconductor industry is the one with the most stringent requirements regarding production accuracy, the requirements set in S23 might serve as a suitable blueprint for a much broader scope of machine tools.

1.2.4 Other standards

Siemens published a couple of company-specific standards dealing with environmental issues during product planning and development. As these standards are generally for company specific use, general validity is not provided.

- The Siemens specific standard **SN 36350-1** – ***Environmentally Compatible Products*** – deals with the inclusion of environmental issues during product planning and the development process. In accordance with ISO Guide 64 (see section 1.2.5), the life cycle thinking shall be comprised during these stages. As the scope of the guideline is used for company products only, whereas Siemens is in charge of producing components for machine tools, it is not exactly clear if machine tools as a whole shall be addressed or not.
- The **Environmental, Health and Safety (EHS) Guidelines** is a bundling of regulations which are meant to be incorporated into an existing management system. According to this guide and in regard to particular environmental loads, problems are initially identified and later confronted with certain measures to minimize the impact. Additionally, the guide imposes certain limits to air emissions and gives qualitative advice how to recognize improvement potentials. According to the industry specific guideline, the primary environmental issues deriving from the manufacturing of metal products are air emissions, wastewater, liquid wastes, and solid waste. The EHS Guidelines originate from an initiative by the World Bank Group, thus it has to be applied if members, which are almost every country in the world, of this group are involved in a project.
- Besides the general EHS Guideline, the **EHS Delivery Specifications (Machinery and installations)** should not remain unmentioned. The document provides an environmental check list for the supplier. Here, certain declarations concerning the environmental compatibility of the product have to be approved.

These measures imply a general sense of acceptance to involve environmental issues into the product planning and development process. The concepts are worth to keep in consideration when implementing machine tool related guidelines with ecological background.

1.2.5 Guidelines for the inclusion of environmental issues

There are several reports addressing the inclusion of environmental issues into the standardisation process. Although these reports are not standards themselves, they indicate the requirement for involving environmental issues. As none of the following guides are product specific (except for the IEC Guide, addressing only electro-technical products), machine tools can be considered being in the scope of the following reports.

- The **ISO Guide 64:2008**[135] – ***Guide for addressing environmental issues in product standards*** – supplies guidance how to comprise environmental issues into the composition of standards and intents to sensitize writers to environmental issues. As a general matter, the guide calls for the "use of life cycle thinking" and encourages the writer to relate to environmental topics and involve experts into the assessment of the standard. Based in the ISO 14000 series of standards, the guide provides numerous environmental criterions, such as energy and material input, water consumption, or emissions, which are ought to be considered during standardisation. Regarding the fact that no further product specifications are implied, all aspects remain important during the implementation of standards on machine tools.

- The **IEC Guide 109:1995** – ***Environmental aspects – Inclusion in electrotechnical product standards*** – is specifically dealing with the inclusion of environmental awareness for standardizing electronic products. In this regard, the report provides instructions for analyzing the environmental impact as well as implementing Ecodesign measures for a product. With respect to this study, the guide also relates to the defined product scope in 1.1., as machine tools generally consist of several electronic components, such as control systems and spindle drives. Furthermore, the IEC was the first committee to issue a guide addressing environmental aspects during product standardisation.

- **Guideline VDI 2243** – ***Recycling-oriented product development*** –, issued by the Association of German Engineers (Verein Deutscher Ingenieure - VDI), provides practical advice for developers and designers to comprise recyclability thinking during strategic, preliminary, and mass-production developing of technical products, covering machine tools as well. By dividing the development process into its core elements, the guide supplies detailed information, instructions and decision support. With the basic aim of optimizing material efficiency, the guide provides a mathematical pattern to calculate whether the component-based material is economically and ecologically recyclable and accordingly reusable or not. However, the guide considers that especially mass- and household products shall be addressed to comprise environmental features, such as appropriate dismantling properties, to their product design. These features are rather secondary in the field of machine tools.

[135] Note: The ISO Guide 64 is equivalent to the European standard CEN Guide 4.

- The **DIN Report 108** – ***Guide for the inclusion of environmental aspects in product standardisation and development*** – is a domestic guide generally based on findings from the ISO Guide 64 and IEC Guide 109. Besides comprising life cycle thinking, adequate labelling and classification of products according to environmental aspects, opportunities and restrictions deriving from the circular flow economy have to be taken into consideration as well. Thus, the DIN Report calls for minimizing mass flows during all stages of a product life cycle.

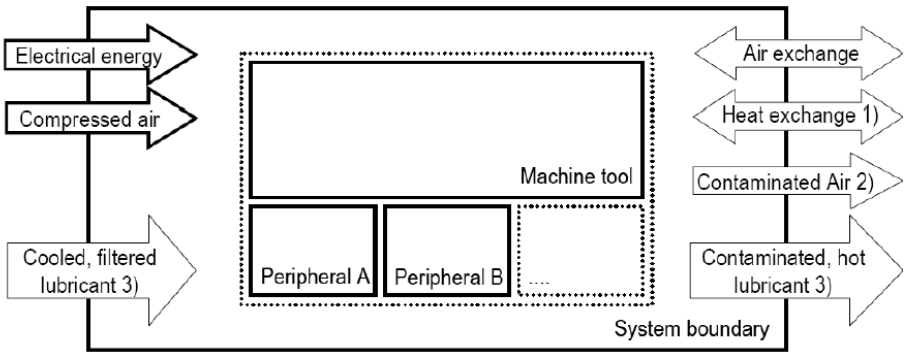
1.2.6 Standards in progress

Currently, the following standards are still in progress:

- **ISO/NP 14955 – *Environmental evaluation of machine tools***. This standard has been in development since December 2009, being motivated also by the Self-Regulatory Initiative of CECIMO, and is intended to describe and standardise an evaluation approach suitable to follow under the SRI, but being also applicable for the evaluation of metal working machine tools. Besides providing a list of improvement options for metal cutting and metal forming machine tools, the standard is structured in four parts, which are:
    - Part 1: Eco design methodology of machine tools
    - Part 2: Testing of energy consumption of modules
    - Part 3: Test pieces and parameters for metal cutting
    - Part 4: Test pieces and parameters for metal forming

  Part 1 provides a sound methodology to analyse the ecological profile of a machine tool. The user of the standard is instructed how to identify and specify functions and relate those to physical components. The analysis gives a hint to energy saving potentials.

  The system boundaries of the evaluated machine tool are depicted in Figure 1-25.



Note: Input of raw parts, new tools, new lubricant, auxillary substances and output of machines parts, used tools, chips and any other aspects not to be considered if it does not represent a relevant energy flow across the system boundary

1) applies to cases with liquid heat exchangers

2) applies to cases without internal mist filtering

3) applies to cases with centralized lubricant management only

Figure 1-25: System boundaries of ISO/NP 14955 - Environmental evaluation of machine tools.[136]

Following the analysis on the current status, Annex A and B provide a list of improvements for components, the overall machine concept as well as guidance for the energy efficient use of machine tools.

The overall methodology for Part 1 can be summarized as shown in the following Figure 1-26:

136 HAGEMANN, D., *Status of ISO/TC39/WG12*, 1st stakeholder meeting "Machine tools and related machinery", Brussels, July 12, 2010, slide 10.

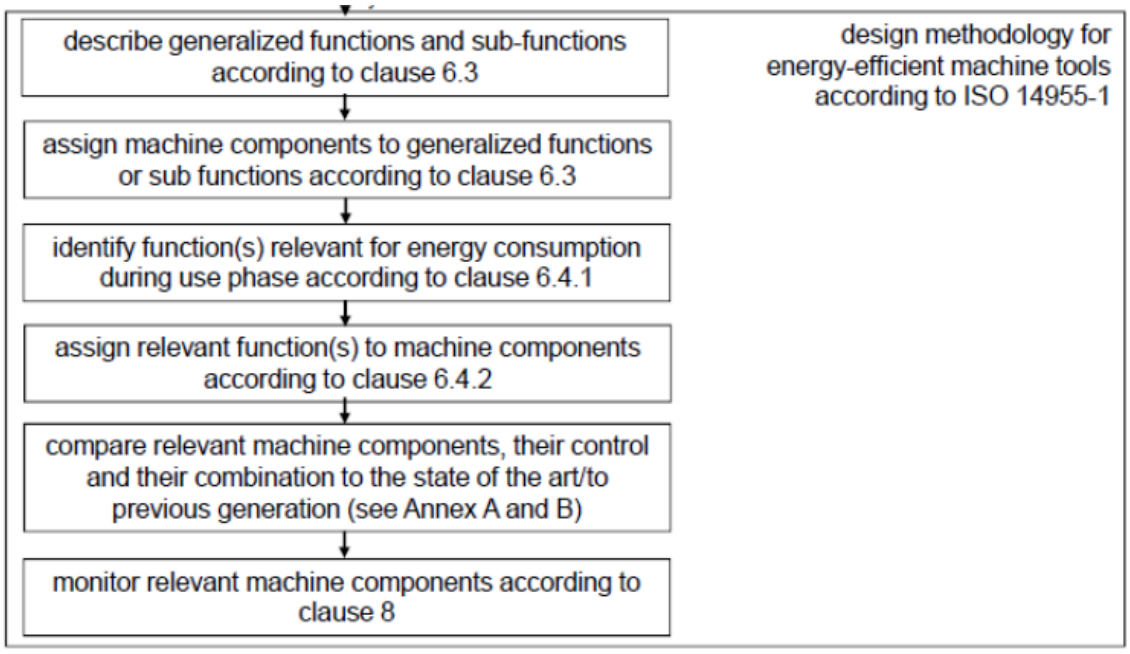


Figure 1-26: Design methodology for energy-efficient machine tools.[137]

- Besides general safety issues, **prEN ISO 28881:2010 – *Machine tools – Safety – Electro discharge machines*** – deals with the noise emission of electro discharge machines, being in a draft status currently.

1.2.7 Summary and conclusions – Gaps in standardisation

- **Metal working machine tools and woodworking machines**

As demonstrated above, there are very few standards primarily tackling environmental aspects, thus creating potential space for new standards for implementing measures. In the range of international standards, it should be pointed out that a sound methodology for noise measurement is provided specifically for metal working machine tools and woodworking machines, which could be used as a link for ecological based standardisation e.g. in terms of imposing limits for noise emission. Similar ecological enhancements are possible in regard to lubricants and lubrications as well, for which a technological foundation has already been established in standardisation for metal working

[137] ISO, ref. 41, p. 17.

machine tools. As far as ancillary equipment of woodworking machines are concerned, the interrelation of certain parameters and its effect on energy consumption has been discussed, which is an approach to arouse ecological awareness. However, internationally viewed, addressing environmental issues in the field of metal working machine tools and woodworking machines have not been subject to standardisation until now.

- **Welding, soldering, and brazing machines**

The environmental check list envisions environmental issues and proposes improvement options, comprising welding procedures, machines, and materials. However, besides the lack of specification in terms of quantitative standard values (e.g. as a fixed upper limit for particular emissions), the improvement options are lacking precise technological descriptions to enable easy application for the user.

- **Gaps in standardisation**

As pointed out above, no specific standardisation which could significantly influence the ecological performance is available for the product scope. Considering our environmental criterions as defined in task 1.1, need for regulation is identified in the field of power consumption, modes, and management as well as on consumption of lubricants, compressed air, water, and on waste. Substantial standards, such as those on noise measurement, reflect a sound basis for environmental upgrades. The aforementioned standard 8525:2008, for instance, demonstrates that the adherence to certain test conditions allows the comparability of specific machine tool features among each other; at least as far as noise emissions are concerned. Thus, defining appropriate test condition parameters to measure the energy consumption, if implementable, would be favourable to gain comparable results in regard to the energy profile of machines. For metal forming and cutting machine tools, such test conditions are currently in progress (ISO/NP 14955). Accordingly, improvement methodologies (namely NF E 01-005 or ISO/NP 14955) can be specified for further types of machinery besides metal working machine tools. Besides on operational level, no standardisation tailored to machine tools has been developed for any other product stage, notably manufacturing, distribution, and end-of-life. At this point, the significance for implementing standards may differ, e.g. as energy efficiency standards on an operational level assumingly dampers the environmental impact to a greater extent than distribution standards. This, however, solely provides a first idea how to integrate environmental issues in standardisation. Identifying the specific need for implementing measures will be investigated later in this study.

1.2.8 Matching standards and guidelines with life cycle stage

As pointed out above, it is evident that there are no standards explicitly addressing environmental aspects of machine tools yet.

There are few standards which can be brought into correlation with environmental relevancy of machine tools, such as ISO 5170 on lubrication systems and ISO 11204 et seqq. on noise test methods. Although based on technological features, ISO 5170 provides measures for the efficient (and correct, in correspondence with ISO 19378) use of lubricants, which is roughly in accordance with ecological requirements. Furthermore, ISO 19378 recommends certain lubricants for different machine tool applications.

Throughout the industry, a rising awareness regarding environmental issues during product life cycles is evident. This attitude is reflected by the guidelines on environmental thinking as described above. However, as they address the broad range of products, machine tools and their specifics are not addressed in detail.

There is no standard yet for machine tools regarding power consumption, or the definition of modes. The upcoming standard ISO/NP 14955 is likely to address these aspects due to the high relevancy of energy consumption for an environmental evaluation of machine tools.

Table 1-29 illustrates the relationship between standards and guidelines and the correspondent life cycle stage(s). Standards, for which the content is under development currently, are written in green (meaning the correlation to life cycle stages has to be preliminary). Reports, such as ISO Guide 64, are written in italic.

Table 1-29 also lists the current gaps in standardisation of machine tools with respect to some major environmental aspects. In case this Product Group Study unveils a high relevancy of these (and other) environmental aspects, it might be advisable to initiate standardisation projects accordingly.

Table 1-29: Allocation of standards to its appropriate life cycle stage

Manufacture / Design	Distribution / Redistribution	Product Usage	End-of-Life
• ***DIN Report 108*** *– Guide for the inclusion of environmental aspects in product standardisation and development* • ***IEC Guide 109:1995*** *– Environmental aspects –*	• ***DIN Report 108*** *– Guide for the inclusion of environmental aspects in product standardisation and development* • ***IEC Guide 109:****1995 – Environmental aspects –*	• ***DIN Report 108*** *– Guide for the inclusion of environmental aspects in product standardisation and development* • *Environmental, Health and Safety (**EHS**)*	• ***DIN Report 108*** *– Guide for the inclusion of environmental aspects in product standardisation and development* • ***IEC Guide 109:1995*** *– Environmental aspects –*

Manufacture / Design	Distribution / Redistribution	Product Usage	End-of-Life
Inclusion in electrotechnical product standards • ***ISO Guide 64:2008*** *– Guide for addressing environmental issues in product standards* • **NF E 01-005** – Mechanical products – Ecodesign methodology • ***SEMI S16-0600*** *– Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life* • ***SEMI S2-0703*** *– Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment* • **SN 36350-1** – Environmentally Compatible Products • ***VDI 2243*** *– Recycling-oriented product development* Metal working machine tools: • **ISO/NP 14955** – Environmental evaluation of machine tools	*Inclusion in electrotechnical product standards* • ***ISO Guide 64:2008*** *– Guide for addressing environmental issues in product standards* • **NF E 01-005** - Mechanical products – Ecodesign methodology Metal working machine tools: • **ISO/NP 14955** – Environmental evaluation of machine tools	*Guidelines* • ***IEC Guide 109:1995*** *– Environmental aspects – Inclusion in electrotechnical product standards* • **ISO 11204:1997** – Noise emitted by machinery and equipment • ***ISO Guide 64:2008*** *– Guide for addressing environmental issues in product standards* • **NF E 01-005** – Mechanical products – Ecodesign methodology Metal working machine tools: • **ISO 19378:2003** – Machine-tool lubricants – Categories and specifications • **ISO 230:2009** – Test code for machine tools – Determination of vibration levels • **ISO 5170:1977** – Lubrication systems for machine tools • **ISO 8525:2008** – Airborne noise emitted by machine tools – Operating conditions for metal-cutting machineries, • **ISO/NP 14955** – Environmental evaluation of machine tools • **prEN ISO 28881:2010** – Machine tools – Safety – Electro discharge machines Welding, soldering, and brazing machines: • **DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	*Inclusion in electrotechnical product standards* • ***ISO Guide 64:2008*** *– Guide for addressing environmental issues in product standards* • **NF E 01-005** – Mechanical products – Ecodesign methodology • ***SEMI S12-0298*** *– Guidelines for Equipment Decontamination* • ***SEMI S16-0600*** *– Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life* Metal working machine tools: • **ISO/NP 14955** – Environmental evaluation of machine tools

Manufacture / Design	Distribution / Redistribution	Product Usage	End-of-Life
		Woodworking machines: • **DIN 33893-2:1997** – Evaluation of the emissions of airborne hazardous substances – Par 2: Pollutant concentration parameter – Stationary woodworking machines • **ISO 7960:1995** – Airborne noise emitted by machine tools – Operating conditions for woodworking machines	
Major environmental aspects not yet covered comprehensively by approved standards for machine tools specifically			
• Eco-design process • Marking / labelling of materials / components (e.g. identification of hazardous substances)		• Power consumption • Power modes • Power management • Consumption of lubricants • Consumption of compressed air • Process waste generation, including yield losses	

The table on the following pages provides an overview of existing standards per environmental aspect for each sub-category of machine tools and separately for the main machine modules. “Not applicable” is stated, where a certain environmental aspect is not linked to a machine or module, “none” marks potentially relevant aspects, for which there is no dedicated standard yet.

Table 1-30: Allocation of standards per machinery type and modules to environmental aspects

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
Machinery / equipment							
Metal working machine tools	**ISO/NP 14955 –** Environmental evaluation of machine tools (in progress)	**ISO 19378:2003** – Lubricants, industrial oils and related products (class L) – Machine-tool lubricants – Categories and specifications (no direct addressing of environmental issues) **ISO 5170:1977 –** Lubrication systems for machine tools **ISO/NP 14955 –** Environmental evaluation of machine tools (in progress)	**ISO/NP 14955 –** Environmental evaluation of machine tools (in progress)	**ISO 11204:1997 –** Noise emitted by machinery and equipment – Measurement of emission sound pressure levels at a work station and at other specified positions – Method requiring environmental corrections (measurement only) **ISO 230:2009 –** Test code for machine tools – Determination of vibration levels (measurement only) **ISO 8525:2008** – Airborne noise emitted by machine tools – Operating conditions for metal-cutting machineries (measurement only)	**none**	**NF E 01-005** – Mechanical products – Ecodesign methodology (generic, not tailored to metal working machine tools) **ISO/NP 14955 –** Environmental evaluation of machine tools (in progress)	**ISO/NP 14955** – Environmental evaluation of machine tools (in progress)
Wood working machine	**DIN EN 12779:2004+A1:2009** – Safe-	**DIN EN 12779:2004+A1:2009** – Safety of	**none**	**ISO 7960:1995 –** Airborne noise emitted by machine tools	**DIN EN 12779:2004+A1:2009** – Safety of	**DIN EN 12779:2004+A1:2009** – Safety of wood-	**none**

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
tools	ty of woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements (relating the energy consumption to specific parameters)	woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements		– Operating conditions for woodworking machines (measurement only) **DIN EN 12779:2004+A1:2009** – Safety of woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements	woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements **DIN 33893-2:1997** – Evaluation of the emissions of airborne hazardous substances – Part 2: Pollutant concentration parameter – Stationary woodworking machines	working machines – Chip and dust extraction with fixed installation – Safety related performances and requirements (system design guidance only) **NF E 01-005 –** Mechanical products – Ecodesign methodology (generic, not tailored to woodworking machine tools)	
Welding equipment	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list (environmental check list only) **NF E 01-005 –** Mechanical products – Ecodesign methodology (generic, not tailored to welding equipment)	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list (disposal of process media only)

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
Other related machinery	**EUROMAP 60 -** Injection Moulding Machines – Determination of Specific Machine Related Energy Consumption	**none**	**none**	**none**	**none**	**NF E 01-005 –** Mechanical products – Ecodesign methodology (generic) **SEMI S2-0703 –** Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment **Guideline VDI** 2243 – Recycling-oriented product development (generic) **DIN Report 108 –** Guide for the inclusion of environmental aspects in product standardisation and development	**SEMI S2-0703** – Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment **SEMI S12-**0298 – Guidelines for Equipment Decontamination (semiconductor equipment) **SEMI S16-**0600 – Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life **SN 36350-1 –** Environmentally Compatible Products (generic, company specific) **Guideline VDI 2243 –** Recycling-oriented

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
							product development
Frame	**not applicable**	**not applicable**	**not applicable**	**none**	**not applicable**	**none**	**none**
Guides and bearings	**none**	**none**	**not applicable**	**none**	**not applicable**	**none**	**none**
Main and feed drives	**IEC/EN 60034-30** - Rotating electrical machines - Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code) **IEC/TS 60034-31** - Rotating electrical machines - Part 31: Selection of energy-efficient motors including variable speed applications - Application guide	**none**	**none**	**none**	**not applicable**	**none**	**none**
Control	**none**	**Not applicable**	**Not applicable**	**Not applicable**	**Not applicable**	**none**	**none**

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
devices							
Fluidic systems (hydraulic, pneumatic)	**ISO 7183:2007 -** Compressed-air dryers -- Specifications and testing (pneumatic dryers measurement)	**ISO 8573** - Compressed air - Part 1: Contaminants and purity classes (quality requirements pressurized air) **ISO 7183:2007 -** Compressed-air dryers -- Specifications and testing (pneumatic dryers measurement)	**not applicable**	**ISO 7183:2007 -** Compressed-air dryers -- Specifications and testing (pneumatic dryers measurement) **Pneurop PN8NTCI** - Noise test code for compressors	**none**	**ISO 8010, ISO 8011, ISO 8012** - Compressors for the process industry -- Screw and related types -- Specifications and data sheets for their design and construction	**none**
Cooling / cooling lubricants units	**None** (for metal working, see above)	**None**	**none**	**none**	**none**	**none**	**none**
Process media supply	**none**	**none**	**none**	**none**	**none**	**none**	**none**
Power supply	**none**	**none**	**not applicable**	**none**	**none**	**none**	**none**

1.3 Existing legislation

This task identifies the relevant legislation and voluntary initiatives for machine tools at EU level, Member State level, and in countries outside Europe.

1.3.1 Legislation and Agreements at European Community level

There are a couple of European Directives that apply to electrical and electronic equipment with respect to health, safety and performance:

- **Directive 2001/95/EC on general product safety (GPSD)**. This directive is on consumer goods and therefore not relevant for this study.
- The **Low Voltage Directive (LVD) 2006/95/EG** lays down the requirements covering all health and safety risks of electrical equipment operating within certain voltage ranges. The LVD in principle covers machine tools[138], but the Guide to application of Directive 2006/42/EC[139] clarifies, that machinery with an electrical supply within the voltage limits of the Low Voltage Directive (i.e. between 50 and 1000 V for alternating current or between 75 and 1500 V for direct current; and not listed among the categories of low voltage electrical and electronic machinery that are excluded from the scope of the Machinery Directive) must fulfil the safety objectives of the LVD.
- The **Electromagnetic Compatibility (EMC) Directive 2004/108/EG** lays down requirements in order to prevent electrical and electronic equipment from generating or being affected by electromagnetic disturbances. The EMC directive requires inter alia compliance with EN61000-3-2, which defines power factor, i.e. harmonic current injection requirements. Machine tools have to comply with the EMC directive.
- The **Pressure Equipment Directive 97/23/EG** is relevant for those machine tools, i.e. parts thereof, operating with fluids and compressed air under certain circumstances, meaning at high pressures – rather untypical for most, but not all machine tools.

138 See: Verein Deutscher Werkzeugmaschinenfabriken: Anwendung der neuen EG-Maschinenrichtlinie 2006/42/EG im Werkzeugmaschinenbau, June 2007

139 Fraser, I. (editor): Guide to application of Directive 2006/42/EC, 1st Edition, December 2009, DG Enterprise and Industry

- The **Directive concerning equipment and protective systems intended for use in potentially explosive atmospheres (ATEX) 94/9/EG** is only relevant for those machine tools intended to operate in certain production environments, e.g. use in the chemical industry could be affected.
- **Directive 2006/42/EC on machinery** is the main European legislation affecting machine tools and setting a couple of dedicated requirements for a broad spectrum of machines and equipment.

All these Directives are based on the principles of the so-called "New Approach", prescribing essential requirements, the voluntary use of standards, and conformity assessment procedures to be applied in order to apply the CE marking.

The Machinery Directive explicitly tackles also some aspects, which are intended to limit environmental impacts (including health impacts on workers), i.e.

- Safety integration
- Materials and products and related design measures must not endanger persons' safety or health
- Airborne noise (and other emissions, such as vibrations, radiation) has to be minimised
- Emissions of hazardous materials and substances have to be reduced through design and construction

On the other hand, some requirements of the Machinery Directive are clearly a compromise between the environment and safety, giving preference to safety, e.g. the requirement of sufficient lighting within the machinery.

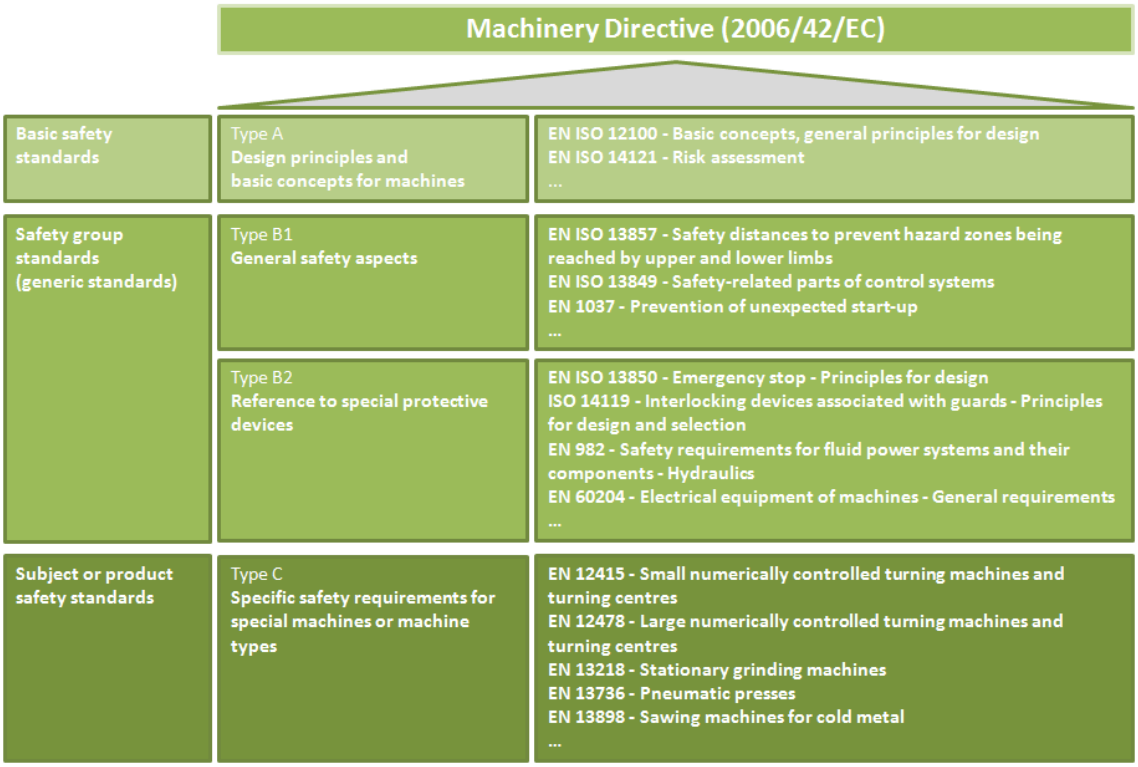


Figure 1-27: Correlation of the Machinery Directive 2006/42/EC with safety norms

When investigating environmental improvement potentials in tasks 5 and 6 of this study, the requirements set by the machinery directive have to be observed. For details and interpretation of the Machinery Directive see the EC's Guide to Application of Directive 2006/42/EC - 1st Edition - December 2009[140].

With regards to the product categories concerned by the study, additional European Union legislation with particular environmental requirements comprises the WEEE/RoHS directive:

- **Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)**
- **Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)**

140 Fraser, I. (editor): Guide to application of Directive 2006/42/EC, 1st Edition, December 2009, DG Enterprise and Industry , http://ec.europa.eu/enterprise/sectors/mechanical/documents/guidance/machinery/index_en.htm

The FAQ document of the European Commission defines “large-scale stationary industrial tools”, which are exempted from RoHS and WEEE as follows:

“machines or systems, consisting of a combination of equipment, systems, finished products and/or components, each of which is designed to be used in industry only, permanently fixed and installed by professionals at a given place in an industrial machinery or in an industrial building to perform a specific task. Not intended to be placed on the market as a single functional or commercial unit.“

To our understanding, most machine tools meet the first sentence of this definition, but as they are intended to be placed on the market as a single commercial unit[141] (with the exception of larger production lines consisting of machine tools and other machinery, which are customized for such kind of interlinked installation[142]). Consequently, following this argumentation machine tools are in the scope of RoHS and WEEE as “Electrical and electronic tools” (no. 6, Annex I A WEEE), including the sub-category “Equipment for turning, milling, sanding, grinding, sawing, cutting, shearing, drilling, making holes, punching, folding, bending or similar processing of wood, metal and other materials”. Exempted from RoHS, but not WEEE are “Monitoring and control instruments” (no. 9), as long as they are independent products used in e.g. an industrial environment. Integrated monitoring and control instruments of a machine tool are part of the machine tool and therefore are subjected to the same regulations under RoHS and WEEE as the machine tool itself.

Some manufacturers of machine tools share the point of view that machine tools do not fall under RoHS and WEEE[143]. According to the German Federal Ministry for the Environment some machine tools fall under the exemption, others do not: Exempted large-scale stationary industrial tools are “e.g. industrial robots, or immobile machinery, such as a stationary saw in a carpenter’s shop, contrary to a mobile circular saw to be used

141 Otherwise also the PRODCOM statistic, which refers to individual units sold, would not be applicable.

142 But even these types of installations are covered in “units” by PRODCOM, see e.g. PRODCOM 28411270 Multi-station transfer machines for working metal

143 See e.g. Kugler: RoHS Konformität – Handlungshilfe zur Kommunikation entlang der Lieferkette über die Einhaltung stoffbezogener Anforderungen aus der Richtlinie 2002/95/EG (RoHS), http://kugler-relaunch.workonweb.de/index.php?action=download&id=320; and: LEAD: Neues ElektroG – was bedeutet das für LEAD Produkte? http://www.lead-online.com/catalog/pdf/Datenblatt_ElektroG_LEAD.pdf; notice, that Kugler and LEAD despite these statements claimed already years ago to apply the relevant substance bans to their products and components

on construction sites, or a stationary drilling machine tool contrary to a handheld drilling machine."[144]

As far as machine tools are concerned, the scope is not changed in the European Commission's recast proposal of WEEE (COM/2008/0810 final) and RoHS (COM/2008/0809 final), but the Committee on the Environment, Public Health and Food Safety of the European Parliament formulated amendments[145] to the recast proposal, explicitly deleting the phrase "(with the exception of large-scale stationary industrial tools)", and consequently, if this version is adopted machine tools will be covered unambiguously.

RoHS restricts the use of the following substances: Lead, mercury, cadmium, chromium-IV, PBB and PBDE. Exemptions from this ban for certain applications apply, such as lead up to a certain level in steel, aluminium and copper alloys to allow for a better workability of these alloys, which is relevant for certain machine elements.

Regarding the WEEE directive, machine tools in their majority count as "WEEE from users other than private households", or in other words: business-to-business e-waste. For such kind of WEEE the producer is responsible for financing the costs for the collection, treatment, recovery and environmentally sound disposal. Actually, machine tool manufacturers have to offer a takeback of obsolete equipment, conditions can be fixed in any sales contract. An IPTS study in 2006 stated, that "Those companies operating in B2B markets do not regard the Directive as impacting upon pricing strategy as implementation of the Directive remains less developed in the B2B area, and many companies already manage their own take-back systems due to the specific high-value nature of B2B used goods."[146] This high-value nature is in particular true for the machine tools market as machine tools are made of valuable metals and alloys and typically do not contain very hazardous substance, which would otherwise add to disposal costs significantly.

There is one EuP implementing measure in place already which tackles a certain type of components of machine tools, the **Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors**.

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144 Federal Ministry for the Environment, Nature Conservation and Nuclear Safety: Elektro- und Elektronikgerätegesetz - Hinweise zum Anwendungsbereich des ElektroG, June 24, 2005

145 2008/0240(COD), 14.12.2009

146 Savage, M.: Implementation of the Waste Electric and Electronic Equipment Directive in the EU, DG JRC, 2006, p.30

The scope of this implementing measure covers “electric single speed, three-phase 50 Hz or 50/60 Hz, squirrel cage induction motor that:

- has 2 to 6 poles,
- has a rated voltage of U_N up to 1 000 V,
- has a rated output P_N between 0,75 kW and 375 kW,
- is rated on the basis of continuous duty operation.”

Such kind of motors are typically used in industrial applications for compressors, pumps etc. From 1 January 2015 motors with a rated output of 7.5-375 kW shall be equipped with a variable speed drive and from 1 January 2017 this requirement is extended to motors in the 0.75-7.5 kW range. Three-phase AC induction motors covered by this implementing measure represent 83.5% of the total European motor market, with a growing market share. The rest of the motor market is represented by various types of DC motors, single phase induction motors, universal and synchronous motors, which are often used in particular applications; many of them are sold in small quantities[147]. However, synchronous motors are used occasionally in machine tools, and also induction motors with a power rating beyond 375 kW are on the market for machine tools specifically[148], which means that Commission Regulation 640/2009 does not cover the full spectrum of motors used in machine tools.

The **EuP implementing measure for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps (245/2009/EC)** explicitly exempts from the scope lamps and luminaires used in products falling under the machinery directive.

The **EuP implementing measure on no-load condition electric power consumption and average active efficiency of external power supplies (278/2009/EC)** covers explicitly only power supplies for household and office appliances, not industrial applications. However, it is worthwhile noticing that in industrial applications there are similar power supply units in use (mainly DIN rail power supplies). Commission Regula-

147 European Commission: Full Impact Assessment - Accompanying document to the Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors, SEC(2009) 1013 final, July 22, 2009

148 See e.g.: Siemens: servomotors brochure, http://www.sea.siemens.com/us/internet-dms/Internet/MachineToolsComm/General/Docs/servomotors.pdf

tion 278/2009 defines maximum no-load power consumption and minimum average efficiency.

The **EuP implementing measure on computers and monitors** (under development currently) might cover also control computers and monitors of industrial equipment, but as of December 2011 no related implementing measure has been adopted.

Similarly, **Energy Star** requirements are in place for computers and monitors. As control units of CNC machines (although not for peripheral devices, such as monitoring and control sensors etc.) technically speaking similar to Personal Computers, same energy requirements might be applicable, but it is important also to recognise the specifics of industrial PCs[149].

Within the industry there is no voluntary agreement yet, but CECIMO initiated a **Self-Regulation Initiative** (SRI) in 2009, which has been presented to the EuP Consultation Forum as a possible alternative to any eco-design implementing measure. CECIMO informs about the progress of this SRI at http://www.cecimo.eu/index.php/ecodesign-eup/selfregulation.html. As CECIMO members are from the metal-working machine tools industry, this SRI in its current status of discussion is meant to address metal-working machine tools only. However, the general approach proposed by CECIMO might be transferrable to other kinds of machine tools as well.

As machine tools are used in industrial environments there is production / company related environmental legislation, which does not address machine tools specifically, but nevertheless might be relevant for the operation of machine tools. Such legislation is for example

- **Regulation 1221/2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS)**, setting the requirements of a voluntary environmental management system, which in case of a metal or wood working enterprise typically requires setting of environmental improvement targets for the operation of machine tools as a core activity of the company.

149 Industrial PCs are normally exceptionally robustly constructed and have a considerably higher level of failsafe design due to environmental influences or electromagnetic interference. As they are operated frequently in harsh environment they need to be protected against dust, humidity etc., which might require adapted fan concepts, filters or specific housings. Similarly, production environments sensitive to vibration might require fan-less designs. All this has an impact also on computer power consumption.

1.3.2 Legislation at Member State level

On member state level the EU directives are implemented by means of national legislation. Partly there is further guidance without legislative order set by other players, such as the employers' liability insurance associations in Germany ("Berufsgenossenschaften"), e.g.:

- BGI/GUV-I 719 - Brand- und Explosionsschutz an Werkzeugmaschinen
- BGI 5003 - Maschinen der Zerspanung - Berufsgenossenschaftliche Informationen für Sicherheit und Gesundheit bei der Arbeit

A number of further information and advice instructions are provided by employers' liability insurance associations oriented to Directive 2006/42/EC on machinery.

Some legislation on member states level covers machine tools under certain conditions: The German **Verordnung zum Umgang mit wassergefährdenden Stoffen (VUmwS)**, currently under development, defines requirements for machinery and installations which contain substances, which are hazardous for the aquatic environment, i.e. including hydraulic fluids and cooling lubricants. Safe guarding measures are required in case certain minimum amount and/or level of hazardousness of contained substances are exceeded.

The Czech eco-label covers **hydraulic liquids**[150], basically requiring a certain level of biodegradability and setting requirements for low ecotoxicity.

1.3.3 Third Country Legislation

There is no known environmental third country legislation tackling only machine tools, but a couple of regulations regarding general production EHS issues.

In **Japan** the Law concerning the Rational Use of Energy[151] implements a comprehensive framework on energy related aspects, including measures for equipment, but these measures target at consumer products including vehicles, not machine tools or other industrial equipment. For factories standards are fixed for a "rational use of energy": For motors and power factors of certain type (and size) of industrial equipment target values are fixed,

[150] Technická směrnice, č. 15 - 2009

[151] See: The Energy Conservation Center, Japan: Japan Energy Conservation Handbook 2008

The target value of power factor at the power receiving end is 95% or more and it is applied to the equipment listed below (those devices relevant for the machine tools market highlighted in bold). Meeting the target value has to be ensured by management the system of the factory.

Table 1-31: Equipment subject to a target value of a power factor of 95% under the Japanese Energy Law

Equipment name	Capacity (kW)
Cage-type induction motor	**more than 75**
Coil-type induction motor	**more than 100**
Induction furnace	more than 50
Vacuum melting furnace	more than 50
Induction heater	more than 50
Arc furnace	-
Flash butt welder (excluding portable type)	**more than 10**
Arc welder (excluding portable type)	**more than 10**
Rectifier	more than 10,000

Japan also introduced a taxation system for promoting investments in the reform of energy supply and demand structures (Taxation System for the Energy Reform). This system entitles a purchaser of any energy efficient equipment to receive either a tax credit that is equivalent to 7% of the reference purchase value or a special depreciation that is not greater than 30% of the reference purchase value, in addition to normal depreciation of the equipment. Among other types of equipment this regulation explicitly covers also “high-efficient composite machine tools”[152].

In **China** the Law on Conserving Energy empowers the administrative department for energy conservation under the State Council to define a catalogue of highly energy-consuming products and equipment to be eliminated (Art. 17), but no machine tools are covered by this catalogue currently. Furthermore, the law sets requirements for so called energy-using units (Art. 20-31), namely energy consumption ratios per unit, but the definition of energy-using units in terms of energy consumption is far beyond the typical range of machine tools, thus not relevant for the scope of this study. Similarly to the European legislation, there are safety measures in place for machine tools (or machinery in general) in numerous countries, to name only a few:

[152] The Energy Conservation Center: Questions& Answers for Application of the Taxation System for Promoting Investment in the Reform of the Energy Supply and demand Structures, Japan 2009

- United States of America: federal regulations implement standards of the Occupational Safety and Health Administration (OSHA). OSHA Standard 29 CFR[153] 1910, Subpart O covers woodworking machinery, abrasive wheel machinery, and mechanical power presses[154]. For woodworking machinery these regulations establish standards and tolerance levels for sawdust, filings, and fumes in the workplace, and cover aspects of machine guarding and personal safety. Workplace safety regulations are often enforced at the state level by state occupational health and safety agencies and by local fire departments. The California Air Resources Board (CARB) has imposed regulations on formaldehyde exposure from composite wood products containing urea-formaldehyde resins which affect machinery operators in woodshops and saw mills. The machinery technology is affected by this legislation as additional equipment to trap residues and wood dust is required.[155]

- Canada, British Columbia: under the Workers Compensation Act, Occupational Health and Safety Regulation are adopted, explicitly setting OHS requirements for power presses, brake presses and shears regarding point of operation safeguarding, design, construction, and reliability of operating controls

- Malaysia: P.U.(A) 113/83 Factories and Machinery (Fencing of Machinery and Safety) Regulation 1970 (revised - 1983); Part IV – Driven Machinery, Regulation 37. Machine tools

There are very few eco-labels in place for industrial equipment, such as the labelling of low-noise construction machinery under the Korean National eco-labelling scheme (KOECO), but none for machine tools. Nevertheless, there is one eco-label of relevancy under the KOECO scheme, namely that on **hydraulic fluids**[156] with the requirement “biodegradable” according to a certain minimum level of biodegradation following any of the test methods listed in the label criteria.

The Thai Green Label Scheme covers **energy-efficient motors** (three-phase induction motors which have a rated output and a voltage not exceeding 375 kW or 500 horse

153 Code of Federal Regulations

154 http://www.osha.gov/SLTC/machineguarding/standards.html

155 Abrahams, E.: Woodworking Machinery – Industry Assessment, International Trade Administration, USA; February 2009, http://www.trade.gov/mas/manufacturing/OAAI/Assess_WoodWorking_Machinery.asp

156 EL601-1993/5/2005-68

power and 1,000 volts, respectively)[157]. The label criteria date back to 1998 and in the meantime the EuP implementing measure for motors (see above) are adopted: Depending on the number of poles and rated output power for certain motor types the EuP IE2 efficiency level is more ambitious than the Thai eco-label criteria, whereas for other motor types (in particular with 6 poles at rated output power below 5.5 kW) the Thai eco-label criteria require an efficiency exceeding the IE3 efficiency level.

Since 2010 a regulation is in place in the US for **small motors**, which is basically relevant for auxiliary motors in machine tools, and for smaller machine tools (light-stationary machine tools in particular):

- US Department of Energy: 10 CFR Part 431 - Energy Conservation Program: Energy Conservation Standards for Small Electric Motors[158]

Minimum efficiency requirements being effective from March 2015 are listed in Table 1-32, but it should be noted, that motors in the US are designed to operate at 110 V (single-phase) and 60 Hz. The standard referenced in the regulation is IEEE Standard 112–2004 (Test Method A and Test Method B), IEEE Standard 114–2001, and Canadian Standards Association Standard C747–94 as test procedures to measure energy efficiency small electric motors.

Table 1-32: Minimum average full-load efficiencies for small motors under the US regulation

Motor output power	Six poles	Four poles	Two poles
STANDARD LEVELS FOR POLYPHASE SMALL ELECTRIC MOTOR			
0.25 Hp/0.18 kW	67.5	69.5	65.6
0.33 Hp/0.25 kW	71.4	73.4	69.5
0.5 Hp/0.37 kW	75.3	78.2	73.4
0.75 Hp/0.55 kW	81.7	81.1	76.8
1 Hp/0.75 kW	82.5	83.5	77.0
1.5 Hp/1.1 kW	83.8	86.5	84.0
2 Hp/1.5 kW	N/A	86.5	85.5
3 Hp/2.2 kW	N/A	86.9	85.5
STANDARD LEVELS FOR CAPACITOR-START INDUCTION-RUN AND CAPACITOR-START CAPACITOR-RUN SMALL ELECTRIC MOTORS			
0.25 Hp/0.18 kW	62.2	68.5	66.6
0.33 Hp/0.25 kW	66.6	72.4	70.5
0.5 Hp/0.37 kW	76.2	76.2	72.4

[157] TGL-15-98 (07-10-98)

[158] Docket Number EERE–2007–BT–STD–0007, Federal Register / Vol. 75, No. 45 / Tuesday, March 9, 2010

0.75 Hp/0.55 kW	80.2	81.8	76.2
1 Hp/0.75 kW	81.1	82.6	80.4
1.5 Hp/1.1 kW	N/A	83.8	81.5
2 Hp/1.5 kW	N/A	84.5	82.9
3 Hp/2.2 kW	N/A	N/A	84.1

1.3.4 International Activities

The international EPD®system is based on a hierarchic approach following among others ISO 9001 (Quality management systems), ISO 14001 (Environmental management systems), ISO 14040 (LCA - Principles and procedures), ISO 14044 (LCA - Requirements and guidelines), ISO 14025 (Type III environmental declarations) upon which the General Programme Instructions are based, as well as instructions for developing Product Category Rules (PCR).



GNC Manufacturing

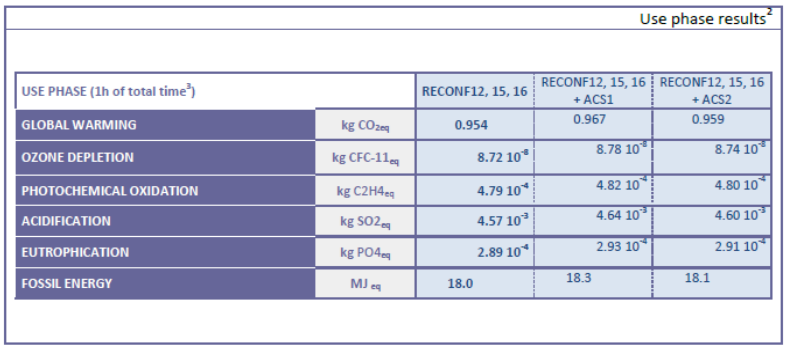
EPD®

Results from the cradle to the client gate

UPSTREAM (1 unit) maximum values		RECONF12	RECONF12 + ACS1	RECONF12 + ACS2	RECONF15, 16	RECONF15, 16 + ACS1	RECONF15, 16 + ACS2	RECONF15, 16 + ACS3
GLOBAL WARMING	kg CO_{2eq}	45 000	47 800	46 200	50 000	52 800	51 200	50 100
OZONE DEPLETION	kg CFC-11_{eq}	197	197	197	197	197	197	197
PHOTOCHEMICAL OXIDATION	kg $C2H4_{eq}$	29.0	30.8	29.8	32.3	34.2	33.1	32.4
ACIDIFICATION	kg $SO2_{eq}$	121	207	194	217	235	222	218
EUTROPHICATION	kg $PO4_{eq}$	27.7	30.6	28.6	32.5	35.4	33.4	32.6
FOSSIL ENERGY	MJ $_{eq}$	885 000	934 000	908 000	974 000	1 020 000	997 000	977 000

EXPEDITION (1 unit) maximum values		RECONF12	RECONF12 + ACS1	RECONF12 + ACS2	RECONF15, 16	RECONF15, 16 + ACS1	RECONF15, 16 + ACS2	RECONF15, 16 + ACS3
GLOBAL WARMING	kg CO_{2eq}	7 550	7 620	7 650	7 980	8 050	8 090	7 980
OZONE DEPLETION	kg CFC-11_{eq}	$1{,}14\ 10^{-3}$	$1{,}15\ 10^{-3}$	$1{,}20\ 10^{-3}$	$1{,}21\ 10^{-3}$	$1{,}22\ 10^{-3}$	$1{,}22\ 10^{-3}$	$1{,}21\ 10^{-3}$
PHOTOCHEMICAL OXIDATION	kg $C2H4_{eq}$	3.39	3.42	3.44	3.58	3.62	3.64	3.58
ACIDIFICATION	kg $SO2_{eq}$	43.0	43.5	43.8	45.5	46.0	46.3	45.5
EUTROPHICATION	kg $PO4_{eq}$	9.76	9.86	9.91	10.3	10.4	10.5	10.3
FOSSIL ENERGY	MJ $_{eq}$	104 000	105 000	105 000	110 000	111 000	111 000	110 000

GATE TO GATE (1 unit) maximum values		RECONF12	RECONF15, 16
GLOBAL WARMING	kg CO_{2eq}	2 330	2 330
OZONE DEPLETION	kg CFC-11_{eq}	$2.15\ 10^{-4}$	$2.15\ 10^{-4}$
PHOTOCHEMICAL OXIDATION	kg $C2H4_{eq}$	1.26	1.26
ACIDIFICATION	kg $SO2_{eq}$	22.7	22.7
EUTROPHICATION	kg $PO4_{eq}$	1.71	1.71
FOSSIL ENERGY	MJ $_{eq}$	42 800	42 900



Use phase results[2]

USE PHASE (1h of total time[3])		RECONF12, 15, 16	RECONF12, 15, 16 + ACS1	RECONF12, 15, 16 + ACS2
GLOBAL WARMING	kg CO_{2eq}	0.954	0.967	0.959
OZONE DEPLETION	kg CFC-11_{eq}	$8.72\ 10^{-8}$	$8.78\ 10^{-8}$	$8.74\ 10^{-8}$
PHOTOCHEMICAL OXIDATION	kg $C2H4_{eq}$	$4.79\ 10^{-4}$	$4.82\ 10^{-4}$	$4.80\ 10^{-4}$
ACIDIFICATION	kg $SO2_{eq}$	$4.57\ 10^{-3}$	$4.64\ 10^{-3}$	$4.60\ 10^{-3}$
EUTROPHICATION	kg $PO4_{eq}$	$2.89\ 10^{-4}$	$2.93\ 10^{-4}$	$2.91\ 10^{-4}$
FOSSIL ENERGY	MJ $_{eq}$	18.0	18.3	18.1

Figure 1-28: EPD for Bed-Type milling machine (extract)

Product Category Rules for the machine tools sector within the context of The International EPD® System and related EPDs have been compiled and published recently:

- August 2011: two EPDs for a range of Bed-Type milling machines, build by N.C. Manufacturing S.A. (Nicolás Correa S.A. Group) – Spain, were published under The International EPD® System (see in Figure 1-28). CTME developed the LCA studies in accordance with the standards UNE-EN ISO 14040 and 14044: 2006 series. (http://www.environdec.com/en/Detail/?Epd=8174).
- January 2012: the product category rules CPC Subclass 44214: Machines-tools for drilling, boring or milling metal v1.0 was published. It was prepared by Nicolás Correa S.A. Group and CTME. This PCR is based on CTME's experience in environmental assessment of capital goods and knowledge acquired in LCA studies of 16 milling machines, according to the ISO 14040 series of standards. (http://www.environdec.com/en/Product-Category-Rules/Detail/?Pcr=7945).

The PCR methodology could be transferred to the remaining products, defined as machine tools, taking into account The General Programme Instructions and the PCR Basic Module for CPC Division 44 Special-purpose machinery.

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3 Annex I – VDW classification on Machine Tools

Table 3-1: VDW Machine Tool Classification

INDEX OF MACHINE TOOL TYPES
Metal Cutting Machine Tools
01 Turning Machines (Lathes) and Turning Automatics
02 Drilling and Boring Machines
03 Milling Machines
04 Planing, Shaping, Slotting and Broaching Machines
05 Sawing Machines
06 Grinding Machines
07 Honing, Finishing, Lapping and Polishing Machines
08 Transfer Machines, Machining Centres, Flexible Manufacturing Cells / Production Systems
09 Units for Machine Tools
10 Gear Cutting Machines and Testing Machines
11 Special Purpose Machines built up from Units for Metal Cutting Operations
Physico-Chemical Process Machine Tools
20 Electrical Discharge Machines (EDM)
21 Electro-Chemical Machines (ECM)
22 Thermal Deburring Machines (TEM)
23 Thermal Beam Processing Systems and Beam Sources
24 Other Physico-Chemical Process Machine Tools
Separating Machine Tools (Punching and Shearing Machines)
25 Shears for Sheet Metal Working
26 Shears for Profiled Materials
27 Blanking Presses
28 Combined Punching, Nibbling, Forming and Beam Cutting Machines
29 Other Machine Tools for Separating
Metal Forming Machine Tools
30 Eccentric presses
31 Crank presses
32 Toggle lever presses
33 Fly presses
34 Other mechanical presses
35 Hydraulic presses
36 Bending and straightening presses
37 Presses for Special Applications
38 Press Lines
39 Flexible Automatic Press Lines and Press Systems
40 Hammers
41 Rolling Mills
42 Bending and Straightening Machines

INDEX OF MACHINE TOOL TYPES
43 Drawing Machines
44 Other Metal Forming Machines
45 Special Purpose Machines for Separating and Metal Forming Operations
Control Systems and Software
46 Control Systems for Machine Tools
47 Components for Machine Tool Controls
48 System and Application Software for Manufacturing Processes
Control Systems and Software
50 Planning, Projection, Realization, Starting up, Training

4 Annex II – Classification of product scope

4.1 Metal working machine tools

Table 4-1: Comprised PRODCOM categories for metal working machine tools

PRODCOM	Description
28.41.11.10	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes
28.41.11.30	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)
28.41.11.50	Machine tools for working any material by removal of material, operated by electro-discharge processes
28.41.11.70	Machine-tools for working any material by removal of material, operated by electrochemical, electron-beam, ionic-beam or plasma arc processes
28.41.11.80	Machine tools for working any material by removal of material, operated by ultrasonic processes, for the manufacture of semiconductor devices or of electronic integrated circuits
28.41.12.20	Horizontal machining centres for working metal
28.41.12.40	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)
28.41.12.50	Unit construction machines (single station) for working metal
28.41.12.70	Multi-station transfer machines for working metal
28.41.21.23	Numerically controlled horizontal lathes, turning centres, for removing metal
28.41.21.27	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)
28.41.21.29	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)
28.41.21.40	Non-numerically controlled horizontal lathes, for removing metal
28.41.21.60	Lathes, including turning centres, for removing metal (excluding horizontal lathes)
28.41.22.13	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)
28.41.22.17	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)
28.41.22.23	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)
28.41.22.25	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)
28.41.22.35	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)
28.41.22.40	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)
28.41.22.60	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)
28.41.22.70	Non-numerically controlled milling machines for working metal (excluding boring-

PRODCOM	Description
	milling machines)
28.41.22.80	Threading or tapping machines for working metal (excluding drilling machines)
28.41.23.05	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm
28.41.23.15	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm
28.41.23.25	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to accuracy >0.01mm
28.41.23.35	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm
28.41.23.45	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm
28.41.23.55	Grinding machines for working metal, any one axis can be set to an accuracy ≥0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines
28.41.23.65	Numerically controlled sharpening (tool or cutter grinding) machines for working metal
28.41.23.75	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal
28.41.23.85	Honing or lapping machines for working metal
28.41.23.95	Machines for deburring or polishing metal (excluding gear finishing machines)
28.41.24.10	Broaching machines for working metal
28.41.24.30	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)
28.41.24.70	Sawing or cutting-off machines for working metal
28.41.24.90	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.
28.41.31.20	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)
28.41.31.40	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)
28.41.31.60	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)
28.41.31.80	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)
28.41.32.20	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)
28.41.32.40	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)
28.41.32.60	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)
28.41.32.80	Non-numerically controlled punching or notching machines for working metal (in-

PRODCOM	Description
	cluding presses, combined punching and shearing machines)
28.41.33.10	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)
28.41.33.20	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)
28.41.33.40	Other hydraulic presses, numerically controlled, for working metal
28.41.33.70	Other non-hydraulic presses, numerically controlled, for working metal
28.41.33.80	Other non-numerically controlled presses for working metal[87]
28.41.34.10	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets
28.41.34.30	Thread rolling machines for working metal, sintered metal carbides or cermets
28.41.34.50	Machines for working wire (excluding draw-benches, thread rolling machines)
28.41.34.70	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal

4.2 Wood working machines

Table 4-2: Comprised PRODCOM categories for wood working machines

PRODCOM	Description
28.49.12.10	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.20	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.33	Band saws for working wood, cork~~, bone and hard rubber, hard plastics or similar hard materials~~
28.49.12.35	Circular saws for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.37	Sawing machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~ (excluding band saws, circular saws)
28.49.12.50	Planing, milling or moulding (by cutting) machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.63	Grinding, sanding or polishing machines for working wood, cork~~, bone, hard~~ rubber, hard plastics or similar hard materials
28.49.12.65	Bending or assembling machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.67	Drilling or morticing machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.75	Splitting, slicing or paring machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.79	Machine tools for working wood, cork~~, bone, hard rubber, hard plastics or similar~~

PRODCOM	Description
	~~hard materials, n.e.c.~~

4.3 Welding, soldering, and brazing machines

Table 4-3: Comprised PRODCOM categories for welding, soldering, and brazing machines.

PRODCOM	Description
28.29.70.90	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)
27.90.31.18	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)
27.90.31.45	Electric machines and apparatus for resistance welding of metal
27.90.31.54	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)
27.90.31.63	Other for manual welding with coated electrodes
27.90.31.72	Other shielded arc welding
27.90.31.81	Machines and apparatus for welding or spraying of metals, n.e.c.
27.90.31.90	Machines and apparatus for resistance welding of plastics
27.90.31.99	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)

4.4 Other machine tools

Table 4-4: Comprised PRODCOM categories for other machine tools.

PRODCOM	Description
28.49.11.30	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass
28.49.11.50	Grinding or polishing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass
28.49.11.70	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)
28.95.11.33	Combined reel slitting and re-reeling cutting machines for paper and paperboard (excluding film cutting machines and apparatus)
28.95.11.35	Slitting and cross cutting machines for paper or paperboard (excluding film cutting machines and apparatus, combined reel slitting and re-reeling machines)
28.95.11.37	Guillotines for paper or paperboard (excluding film cutting machines and apparatus, combined reel slitting and re-reeling machines, slitting and cross cutting machines)
28.95.11.50	Machines for making bags, sacks or envelopes of paper or paperboard
28.95.11.60	Machines for making cartons, boxes, cases, tubes, drums, or similar containers of paper or paperboard (excluding machines for moulding articles)

PRODCOM	Description
28.96.10.91	Size reduction equipment for working rubber or plastics
28.96.10.95	Cutting, splitting and peeling machines for working rubber or plastics or for the manufacture of products from these materials

5 Annex III – Related machinery (identified modules) (non-exhaustive)

Table 5-1: Comprised PRODCOM categories for related machinery (modular approach)

PRODCOM	Description	Main Drives	Feed Drives	Control Device	Hydraulic Unit	Cooling Lubricant Unit
Categories which are lacking specification, though machineries with modular similarities can be anticipated:						
28961073	Other presses for moulding or forming rubber or plastics, etc, n.e.c.	(x)	(x)	(x)	(x)	(x)
28991190	Other book-binding machines	(x)	(x)	(x)	(x)	
28991390	Other offset printing machinery	(x)	(x)	(x)	(x)	
28991490	Other printing machinery, excluding those of the office type, n.e.c.	(x)	(x)	(x)	(x)	
28993905	Machines for treating metal, having individual functions (excluding robots)	(x)	(x)	(x)	(x)	(x)
28993953	Other machinery for earth, stone, ores, etc, n.e.c.	(x)	(x)	(x)	(x)	(x)
28993955	Other machines and mechanical appliances of HS 84, n.e.c.	(x)	(x)	(x)	(x)	(x)
Categories with closer specification regarding comprised machineries, where modular similarities are highly probable:						
28294200	Calendaring or other rolling machines, excluding metal or glass	x		x	x	x
28491287	Presses for the manufacture of particle board or fibre building board of wood or other ligneous materials, and other machines with individual functions for treating wood or cork	x	x	x	x	x
28941100	Machines for extruding, drawing, texturing or cutting man-made textile materials; machines for preparing textile fibres	x	x	x	x	
28292120	Machinery for cleaning or drying bottles or other containers	x	x	x	x	
28292150	Machinery for filling, closing, sealing, capsuling or labelling bottles, cans, boxes, bags or other containers, machinery for aerating beverages	x	x	x	x	
28292180	Machinery for packing or wrapping (excluding for filling, closing, sealing, capsuling or labelling bottles, cans, boxes, bags or other containers)	x	x	x	x	
28413330	Presses for moulding metallic powders by sintering or for compressing scrap metal into bales	x	x	x	x	x
28491283	Machines and apparatus for electroplating, electrolysis or electrophoresis	x	x	x	x	x
28931400	Presses, crushers and similar machinery used in the manufacture of wines, cider, fruit juices or similar beverages	x	x		x	
28941200	Textile spinning machines; textile doubling, twisting, winding or reeling machines	x	x	x	x	
28941300	Weaving machines	x	x	x	x	
28941430	Circular knitting machines	x	x	x	x	
28941450	Flat knitting machines, stitch-bonding machines and warp knitting machines	x	x	x	x	
28941470	Machines for making gimped yarn, tulle, lace, embroidery, trimmings, braid or net, and machines for tufting	x	x	x	x	
28941530	Printing machinery for printing textile materials (excluding offset,	x	x	x	x	

PRODCOM	Description	Main Drives	Feed Drives	Control Device	Hydraulic Unit	Cooling Lubricant Unit
	flexographic, letterpress and gravure printing machinery)					
28942110	Machinery for the manufacture or finishing of felt or nonwovens in the piece or in shapes (including machinery for making felt hats, blocks for making hats)	x	x	x	x	
28942130	Ironing machines and presses (including fusing presses; excluding calendering machines)	x	x	x	x	
28942150	Washing, bleaching or dyeing machines (including wringers and mangles, shaker-tumblers; excluding household or laundry-type washing machines)	x	x	x	x	
28942170	Machines for reeling, unreeling, folding, cutting or pinking textile fabrics	x	x	x	x	
28942180	Machines used in the manufacture of linoleum or other floor coverings for applying the paste to the base fabric or other support; machines for dressing, finishing, wringing, drying, coating or impregnating textile yarns, fabrics or made up textile articles	x	x	x		
28942230	Household or laundry-type washing machines of a dry linen capacity > 10 kg (including machines that both wash and dry)	x		x		
28951113	Machinery for making pulp of fibrous cellulosic material	x	x	x	x	
28951115	Machinery for making paper or paperboard	x	x	x	x	
28951117	Machinery for finishing paper or paperboard	x	x	x	x	
28951170	Machines for moulding articles in paper pulp, paper or paperboard (including packing for eggs, plates or dishes for confectionery or camping, toys)	x	x	x	x	
28951190	Machinery for making up paper pulp, paper or paperboard, n.e.c.	x	x	x	x	
28961010	Injection-moulding machines for working rubber or plastics or for manufacturing rubber or plastic products	x	x	x	x	x
28961030	Extruders for working rubber or plastics, or for manufacturing rubber or plastic products	x	x	x	x	x
28961040	Blow-moulding machines for working rubber or plastics or for manufacturing rubber or plastic products	x	x	x	x	x
28961050	Vacuum-moulding machines and other thermoforming machines for working rubber or plastics or for manufacturing rubber or plastic products	x	x	x	x	x
28961060	Machinery for moulding or retreading pneumatic tyres...	x	x	x	x	x
28961075	Machinery for moulding or forming rubber or plastics, etc, n.e.c.	x	x	x	x	x
28961082	Machines for processing reactive resins	x	x	x	x	x
28961084	Machines for the manufacture of foam products (excluding machines for processing reactive resins)	x	x	x	x	x
28961097	Machinery for working rubber or plastics or for the manufacture of products from these materials, n.e.c.	x	x	x	x	x
28991110	Folding machines for books	x	x	x	x	
28991130	Collating machines and gathering machines for books	x	x	x	x	
28991150	Sewing, wire stitching and stapling machines for books including for manufacturing of cardboard boxes or like excluding stapling machines for office use, for cardboard box manufacture	x	x	x	x	
28991170	Unsewn (perfect) binding machines for books	x	x	x	x	
28991200	Machinery, apparatus and equipment, for type-setting, for preparing	x	x	x	x	

PRODCOM	Description	Main Drives	Feed Drives	Control Device	Hydraulic Unit	Cooling Lubricant Unit
	or making printing blocks, plates					
28991330	Reel fed offset printing machinery	x	x	x	x	
28991410	Reel fed letterpress printing machinery (excluding flexographic printing)	x	x	x	x	
28991430	Flexographic printing machinery	x	x	x	x	
28991450	Gravure printing machinery	x	x	x	x	
28992020	Machines and apparatus used solely or principally for the manufacture of semiconductor boules or wafers	x	x	x	x	
28992040	Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits (excluding machine tools for working any material by removal of material operated by ultrasonic processes)	x	x	x	x	
28992060	Machines and apparatus used solely or principally for the manufacture of flat panel displays	x	x	x	x	
28993915	Machines and mechanical appliances, having individual functions, for mixing, kneading, crushing, grinding, screening, sifting, homogenizing, emulsifying or stirring (excluding robots)	x	x	x	x	
28993920	Machines for assembling electric or electronic lamps, tubes, valves or flashbulbs, in glass envelopes	x	x	x	x	
28993930	Machines for manufacturing or hot working glass or glassware	x	x	x	x	
28993945	Machines and apparatus used solely or principally for a) the manufacture or repair of masks and reticles, b) assembling semiconductor devices or electronic integrated circuits, and c) lifting, handling, loading or unloading of boules, wafers, semiconductor devices, electronic integrated circuits and flat panel displays	x	x	x	x	
28993950	Rope or cable-making machines	x	x			
28993970	Machines for balancing mechanical parts	x	x		x	

6 Annex IV – Environmental screening of product scope

6.1 Metal working machine tools

Sold volumes and unit values are based on PRODCOM 2009 data, plausibility checked by Fraunhofer and data revised where appropriate. For details see Task 2.

Table 6-1: Environmental screening of metal working machine tools

PRODCOM Code	Label	Sold Volume [units]	Unit Value [€]	
Level of automation: 5 (system) Entirely automated manufacturing plant (may consisting of several machines); automated workpiece (different and similar ones) and tool flow systems as well as supply and waste disposal logistics. Highest potential for impact, due to the multitude of employed components.				
28411270	Multi-station transfer machines for working metal	1.550	498.033	
Level of automation: 4 (cell) NC-machines with automated tool change and automated change of similar workpieces. High potential for impact anticipated.				
28412160	Lathes, including turning centres, for removing metal (excluding horizontal lathes)	2.026	377.793	
28412225	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)	1.321	392.468	
28412315	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set	1.158	513.845	

	up to a minimum accuracy of 0.01mm			
28412430	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)	1.057	613.173	
28412240	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	778	628.068	
28412123	Numerically controlled horizontal lathes, turning centres, for removing metal	511	350.000	
28412325	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to accuracy >0.01mm	314	376.829	
Level of automation: 3 (centre) NC-machines with automated tool change. High potential for impact anticipated.				
28411240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	3.943	222.158	
28412127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	2.525	171.242	
28411220	Horizontal machining centres for working metal	2.034	480.286	
28412129	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)	1.879	219.820	
28412305	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	1.061	121.119	
28412217	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)	385	220.729	
Level of automation: 2 (NC-machine) Numerically controlled machines for the automated proceeding of cutting, feed, and advancing motions. Moderate potential for impact anticipated.				
28413360	Non-hydraulic presses for working metal	24.131	16.311	Given the low unit value classification as NC-machine is uncertain
28413120	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	6.146	120.538	

28411110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	5.963	79.017	
28413140	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	5.579	47.553	
28413350	Hydraulic presses for working metal	2.506	207.611	
28412365	Numerically controlled sharpening (tool or cutter grinding) machines for working metal	2.699	39.239	
28412223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	2.538	187.451	
28413240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	2.097	192.397	
28413220	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	1.979	93.489	
28412213	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)	560	185.448	
28411150	Machine tools for working any material by removal of material, operated by electro-discharge processes	517	165.147	
28413310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	342	771.602	
Level of automation: 1 (machine) Machines with cutting and feed drives going without automation. Low potential for impact anticipated.				
28413470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal	57.865	10.464	
28413380	Other non-numerically controlled presses for working metal	40.000	14.166	No revised data available (in task two, no distinction between NC, non-NC)
28412385	Honing or lapping machines for working metal	12.821	14.786	Labelled by CECIMO as NC-machines, but low unit value indicates a significant share of non-NC machines

28413260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	10.457	22.406	
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	9.720	4.606	
28413450	Machines for working wire (excluding draw-benches, thread rolling machines)	6.734	49.114	
28412470	Sawing or cutting-off machines for working metal	6.043	33.454	
28412140	Non-numerically controlled horizontal lathes, for removing metal	5.990	23.927	
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	5.676	35.860	
28412375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal	5.243	4.938	
28413180	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	4.827	16.168	
28412270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)	4.716	11.245	
28412395	Machines for deburring or polishing metal (excluding gear finishing machines)	4.165	44.374	
28411170	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes	2.946	38.485	
28412355	Grinding machines for working metal; any one axis can be set to an accuracy >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines	2.384	25.842	
28411250	Unit construction machines (single station) for working metal	1.647	45.679	
28413410	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets	759	200.464	Not declared as a NC-machine by CECIMO; high single value due to spaciousness, complex and costly

				manufacture of the machine itself, etc.
28411130	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)	637	48.673	
28412490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.	631	55.531	
28412345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	600	58.068	
28412260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	338	109.705	
28412335	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	311	51.808	
28411180	Machine tools for working any material by removal of material, operated by ultrasonic processes, for the manufacture of semiconductor devices or of electronic integrated circuits	297	100.000	
28413320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	290	419.604	No tool change (permanently installed ram hammer or the like); no workpiece change (usually workpieces of diverse geometric shape processed); high single value due to spaciousness, complex and costly manufacture of the machine itself, etc.
28413430	Thread rolling machines for working metal, sintered metal carbides or cermets	228	82.895	
28412410	Broaching machines for working metal	67	438.270	Not declared as a NC-machine by CECIMO, given a much higher reported number of units, which has to be ignored after plausibility check
Out of scope Categories which are out of scope (for reasons, see comments in the right column)				

28412280	Threading or tapping machines for working metal (excluding drilling machines)	16.349	833	Unit value < 1.000 Euro
28413280	Non-numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	11.618	3.377	GER, ES, I: 90% market share, unit values 2.800 - 4.200 Euro; non-industrial use

6.2 Wood working machines[159]

Sold volumes and unit values are based on PRODCOM 2009 data, plausibility checked by Fraunhofer and data revised where appropriate. For details see Task 2.

Table 6-2: Environmental screening of woodworking machines

PRODCOM Code	Label	Sold Volume [units]	Unit Value [€]	Comments
Level of automation: 5 (system)				
---	---			
Level of automation: 4 (cell) NC-machines with automated tool change and automated change of similar workpieces. High potential for impact anticipated.				
28491220	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials~~	9.858	49.196	

[159] Note: Even though indicated by the categories‘ description, plastic and rubber as well as food processing machines are not involved.

Level of automation: 3 (centre)				
---	---			
Level of automation: 2 (NC-machine) Numerically controlled machines for the automated proceeding of cutting, feed, and advancing motions. Moderate potential for impact anticipated.				
28491275	Splitting, slicing or paring machines for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials~~	16.448	13.313	
28491267	Drilling or morticing machines for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials~~	10.548	11.946	
Level of automation: 1 (machine) Machines with cutting and feed drives going without automation. Low potential for impact anticipated.				
28491210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~	5.270	17.228	
28491250	Planing, milling or moulding (by cutting) machines for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials~~	3.568	47.097	
28491265	Bending or assembling machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~	2.194	23.428	
28491235	Circular saws for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~	852	63.847	
Level of automation: 0 Categories for which the level of automation are not determinable (for reasons, see comments in the right column)				
28491279	Machine tools for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials, n.e.c.~~	31.330	9.219	
28491233	Band saws for working wood, cork~~, bone and hard rubber, hard plastics or similar hard materials~~	7.858	7.957	
28491263	Grinding, sanding or polishing machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~	6.375	15.320	
28491237	Sawing machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~ (excluding band saws, circular saws)	Approx. 5.000	Approx. 20.000	

6.3 Welding, soldering, and brazing machines

Sold volumes and unit values are based on PRODCOM 2009 data, plausibility checked by Fraunhofer and data revised where appropriate. For details see Task 2.

Table 6-3: Environmental screening of welding, soldering, and brazing machines

PRODCOM Code	Label	Sold Volume [units]	Unit Value [€]	Comments
Level of automation: 5 (system)				
---	---			
Level of automation: 4 (cell)				
---	---			
Level of automation: 3 (centre)				
---	---			
Level of automation: 2 (NC-machine)				
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	17.367	9.429	
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	8.911	24.964	
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	4.727	28.940	
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	2.713	26.348	
Level of automation: 1 (machine)				
27903154	Fully or partly automatic electric machines for arc welding of metals	277.321	1.188	“automatic” is understood by the reporting com-

	(including plasma arc)			panies typically as automatic feed of welding wire, but welding tool is manually operated
Level of automation: 0 Categories for which the level of automation are not determinable (for reasons, see comments in the right column)				
27903190	Machines and apparatus for resistance welding of plastics	47.323	2.611	High level of uncertainty regarding type of machines covered, no typical welding machines, presumably packaging and laminating machines and the like
27903163	Other for manual welding with coated electrodes	603.299	216	is likely to include also welding equipment for non-professional use
27903145	Electric machines and apparatus for resistance welding of metal	43.656	12.795	
27903172	Other shielded arc welding	326.963	596	

6.4 Other machine tools

Sold volumes and unit values are based on PRODCOM 2008 data unless stated in comments.

Table 6-4: Environmental screening of other machine tools

PRODCOM Code	Label	Sold Volume [units]	Unit Value [€]	Comments
Level of automation: 5 (system)				
---	---			
Level of automation: 4 (cell) NC-machines with automated tool change and automated change of similar workpieces.				

High potential for impact anticipated.				
28951150	Machines for making bags, sacks or envelopes of paper or paperboard	523	366.776	
Level of automation: 3 (centre) NC-machines with automated tool change. High potential for impact anticipated.				
28951135	Slitting and cross cutting machines for paper or paperboard (excluding film cutting machines and apparatus, combined reel slitting and re-reeling machines)	680	235.311	
Level of automation: 2 (NC-machine) Numerically controlled machines for the automated proceeding of cutting, feed, and advancing motions. Moderate potential for impact anticipated.				
28951160	Machines for making cartons, boxes, cases, tubes, drums, or similar containers of paper or paperboard (excluding machines for moulding articles)	14.866	20.180	
28491150	Grinding or polishing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	8.742	26.776	Revised 2009 data, plausibility checked by Fraunhofer
28961091	Size reduction equipment for working rubber or plastics	6.792	19.829	
28951133	Combined reel slitting and re-reeling cutting machines for paper and paperboard (excluding film cutting machines and apparatus)	5.768	51.403	
28961095	Cutting, splitting and peeling machines for working rubber or plastics or for the manufacture of products from these materials	5.622	32.422	
Level of automation: 1 (machine) Machines with cutting and feed drives going without automation. Low potential for impact anticipated.				
28491170	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)	20.054	30.549	Non-professional equipment excluded, revised 2009 data, plausibility checked by Fraunhofer
28491130	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	30.344	6.721	Non-professional equipment excluded, Revised 2009 data, plausibility checked by Fraunhofer
28951137	Guillotines for paper or paperboard (excluding film cutting machines and apparatus, combined reel slitting and re-reeling machines, slitting and cross cutting machines)	47.700	2.088	Only if stationary machines are concerned; low automation anticipated.

28951140	Other cutting machines for paper or paperboard	Approx. 2.000		Only energy-using units considered (former PRODCOM 29551143), based on comments provided by VDMA
Level of automation: 0				
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Fraunhofer

Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 2 Report – Economic and Market Analysis

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary – Task 2

The machine tools market is subject to huge fluctuations, depending on economic cycles. Due to the long lifetime the stock (installed base) of machine tools shows much less fluctuation than the sales figures. PRODCOM figures were subject to an extensive plausibility check and revisions accordingly with the support of associations CECIMO (and member associations), EPTA and EWA in particular. Whereas EuroStat states a production volume of nearly 600.000 metal working machine tools for 2009, our plausibility check unveils, that a figure of **216.000 metal working machine tools** falling under the definition provided in task 1 is a much more likely figure. Similarly for wood working machinery instead of 3.4 million units sold production as stated by EuroStat for wood working machine tools a more reasonable figure according to the plausibility check by Fraunhofer is **130.000 units,** sold production in 2009 for larger machinery, which overlaps with a market of **220.000 light stationary wood working tools** (sales within EU 27). The market of **welding, soldering, and brazing equipment** covers roughly **1.400.000 units** sold EU production, falling under the definition provided above.

A stock model for the major market segments covered by the definition of “machine tools” set up by Fraunhofer and cross-checked by industry representatives indicates that currently in the EU 27 there are in operation

- 3,5 million metal working machine tools, thereof 750.000 CNC machine tools
- 5,8 million wood working machine tools, thereof 1,4 million larger stationary machinery
- 7,1 million units of welding, soldering and brazing equipment, thereof 1,5 million stationary units

Due to the long lifetime of the stationary machine tools the stock remains very stable for wood working machine tools and no major changes are to be expected regarding the installed base in the mid-term future. The metal working machine tools market sees an ongoing shift from non-CNC machine tools to CNC: In 2025 a total stock of 2.8 million metal working machine tools is forecasted, thereof 800.000 CNC machine tools with an increasing complexity and functionality.

The Life Cycle Cost model for machine tools is subject to the broad variety of machine tools and the fact, that many more factors than only purchase price, consumables and spare parts play a role. Actually, running costs over the lifetime in almost all cases

seem to be higher than initial investment, costs for electricity and (where applicable) consumables are very relevant, but even more maintenance costs.

Reflecting the regions where machine tools are most prominently used, size of companies using them and regional electricity costs, roughly the “typical” electricity price for use of metal working machine tools is 0,11 Euro/kWh, for wood working machine tools 0,14 Euro/kWh, but which a broad spread across EU-27.

Total sales volume for EU-27 for mineral oil based non-water miscible and water miscible cooling lubricants was roughly 800 million Euros in 2008, indicating the high economic relevancy of coolants.

The value of tools, work holders and spare parts in total for EU 27 production in 2008 was 7,6 billion Euros, compared to a sales volume (sold production) of 26,4 billion Euros for machine tools in the same year.

2 Task 2 – Economic and Market Analysis

The objective of task 2 is the assessment of trade and sales volumes for machine tools within the EU-27. A clear picture of the product stock available on the EU market should be provided and its growth and replacement rate be forecasted. Insight in the latest market trends so as to indicate the place of possible ecodesign measures in the context of the market structures and ongoing trends in product design should be given. A practical data set of prices and rates to be used in a Life Cycle Cost (LCC) calculation should be provided.

The economic analysis is structured according to the distinctions made in Task 1:

- Metal working machine tools,
- Wood working machine tools,
- Welding, soldering and brazing equipment, and
- Other machine tools.

For "related machinery" no dedicated analysis is provided in this task, as potentially a large variety from numerous sub-sectors falls under "related machinery". As a robust market analysis for all kind of industrial equipment is not feasible due to time and resource constraints, the effects of later findings on "related machinery" will be estimated on a case-by-case basis where relevant.

2.1 Generic economic data

2.1.1 Metal working machine tools

The machine tools market is an explicitly cyclical market, making any predictions for future developments a challenge. Figure 2-1 depicts the the machine tool production in the 15 CECIMO member countries[1] since 1980, showing a downturn nearly every ten years. Due to the economic crisis a sharp decline in production volume by 30% is stated for 2009. From the 2009 figures different scenarios are possible:

- Taking the 2009 figures into account, the average annual growth rate since 1980 is 1,4% per year. A conservative scenario is to extrapolate now from the

[1] Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Italy, The Netherlands, Portugal, Spain, Sweden, Switzerland, Turkey, UK

low 2009 level with a further growth rate of 1,4%. This scenario reflects a situation of a long term impact of the economic crisis on the European production industry and a shift of production to low cost countries.

- Excluding the 2009 crisis from the statistics results in a 3,0% average annual growth rate for the years 1980-2008. A possible scenario therefore is to extrapolate from the 2009 level with such a 3,0% annual growth rate now for the coming years until 2025. This scenario reflects a situation, where the economic crisis has got a long term impact, but coming from a low level the EU sees steady economic growth.
- An optimistic scenario is as follows: The machine tools market sees a rapid recovery from the current status – and as machine tools orders increase significantly again since 4th quarter 2009[2] this is not too unlikely to happen -, reaching the 2008 level again in 2012, followed by a 3, 0% average annual growth rates for the years thereafter, just as it was in the years 1980-2008. This scenario is based on the assumption that the European industry can compete with other regions on the globe and due to cutting edge technology remaining in Europe the economic industrial growth is stable in the EU.

Depending on which scenario is applied (and taking an extrapolation with average growth rates as a basis does not reflect the economic cycles at all), the production volume reached by 2020 might be 22.4 billion, 28.7 billion or even 36.1 billion Euros, i.e. with a spread of a factor of 1.5.

[2] CECIMO Statistical Toolbox - Updated: November 2010

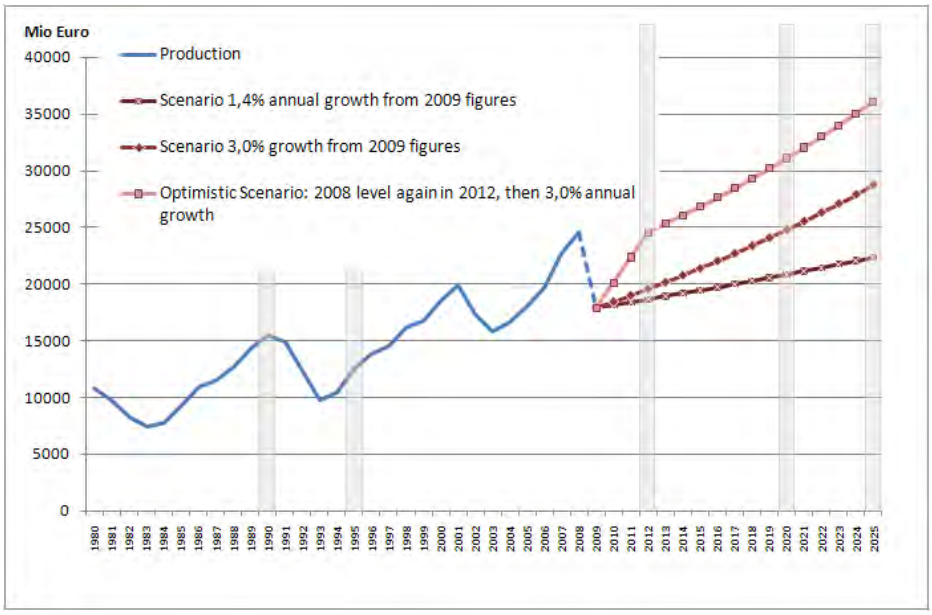


Figure 2-1: Machine tool production in CECIMO countries – totals 1980 - 2025[3]

This model with stable growth rates is a simplified one, due to the inherent dynamics of the machine tools industry: There is a phenomenon called "investment accelerator effect" which in particular is relevant for this industry, just as described by Kouvelis et al.[4]: “For machine tools, there is a fairly stable demand for replacement units, but when durable goods producers invest in anticipation of even a small surge in their demand, this often shows itself as a huge increase in the orders placed with machine tool manufacturers. For example, a plant may use 100 machine tools and replace 5% of them in a typical year. If this firm anticipates a 5% increase in sales, it may plan to buy 10 machine tools this period; 5 new and 5 replacements. Thus, a 5% surge in expected sales at one level becomes a 100% surge for the supplier. This is particularly problematic for machine tools because this pattern is correlated across the entire customer base.” This effect results in a high level of uncertainty for any prediction of future machine tools market developments. Same applies for the scenarios provided above.

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3 Years 1980-2008 based on CECIMO: Last trends in the European Machine Tool industry, http://www.cecimo.eu/index.php/machine-tools/dataastatistics/latesttrend.html, accessed December 17, 2010; 2009: EuroStat data for EU-27, scenarios 2009-2025: own assumptions by Fraunhofer

4 Kouvelis, P.; Chambers, C.; Wang, H.; Supply Chain Management Research and Production and Operations Management: Review, Trends, and Opportunities; Production and Operations Management, October 1, 2006

It should be noted, that the statistics and scenarios on machine tools production outlined above refer to the *economic value* of the market. As there is a trend towards highly integrated, high value machine tools the economic growth does not mean necessarily a growths in terms of units.

The World Machine Tool Output & Consumption Survey by Gardner Publications, Inc.[5] (see Table 2-1) shows global market shares of EU countries in terms of production of machine tools per country: Largest producer in 2010 was Japan, with a slightly higher production than Germany, followed by China, Italy being next. This ranking is confirmed when looking at cutting machine tools only (physicochemical processes, machining centres, lathes, grinding and polishing machines). Considering metals forming machine tools (e.g. presses and benches) Italy is the world market leader, followed by China, Germany, and Japan.

Table 2-1: Production of machine tools in US-$ per country (2010)

		2010 (est.)			2009 (rev.)	change in	change in
	Country	$-Millions	% Cut	% Form	% Form	local currency	U.S. dollars
1.	China, Peoples Rep.	19,980.0	73%	27%	15,300.0	$	31%
2.	Japan	11,841.7	89%	11%	7,007.0	59%	69%
3.	Germany	9,749.9	70%	30%	10,800.1	-5,00%	-10%
4.	Italy	5,166.4	53%	47%	5,242.2	3%	-1%
5.	Korea, Rep. of	4,498.0	69%	31%	2,758.0	$	63%
6.	Taiwan	3,803.3	77%	23%	2,266.4	60%	68%
7.	Switzerland	2,185.4	84%	16%	2,164.5	-3%	1%
8.	United States	2,026.2	72%	28%	2,218.9	$	-9%
9.	Austria	908.9	64%	36%	897.4	6%	1%
10.	Spain	812.0	66%	34%	1,035.9	-18%	-22%
11.	Brazil	714.2	81%	19%	714.2	$	0%
12.	Turkey	555.0	26%	74%	441.3	26%	26%
13.	India	525.0	86%	14%	278.0	89%	89%
14.	France	503.4	70%	30%	557.6	-5%	-10%
15.	Czech Republic	475.6[6]			602.1		
16.	United Kingdom	471.0	72%	28%	438.4	9%	7%
17.	Canada	459.6	62%	38%	434.0	6%	6%
18.	The Netherlands	369.6	20%	80%	369.9	5%	0%
19.	Belgium	316.6	10%	90%	368.5	-10%	-14%
20.	Poland	295.4			326.8		
21.	Sweden	249.7	44%	56%	233.3	1%	7%
22.	Russia	239.7	59%	41%	229.3	0%	5%

[5] Gardner Publications, Inc.: 2010 World Machine Tool Output & Consumption Survey, http://www.gardnerweb.com/consump/survey.html, accessed: November 7, 2011; market shares calculated based on Gardner data

[6] Data by CECIMO

23.	Finland	151.0	10%	90%	153.0	4%	-1%
24.	Mexico	132.5	52%	48%	132.5	$	0%
25.	Australia	129.9	96%	4%	32.0	$	306%
26.	Denmark	76.8	40%	60%	80.6	0%	-5%
27.	Portugal	49.0	8%	92%	62.6	-18%	-22%
28.	Romania	34.7	71%	29%	36.4	0%	-5%
29.	Argentina	33.3	43%	57%	26.7	$	25%
	Total	66,753.9			55,207.6		21%

These market statistics indicate the importance of the European machine tool industry and specifically of Germany and Italy as main machine tool producing, but also using countries: Table 2-2 lists the consumption of metal working machine tools in the various countries, the EU-27 market being slightly larger than China[7].

Table 2-2: Consumption of machine tools in US-$ per country (2010)

	Country	US-$-Millions
1.	China, Peoples Rep.	27,280.0
2.	Germany	5,033.9
3.	Japan	4,445.3
4.	Korea, Rep. of	4,264.0
5.	Italy	2768,7
6.	United States	2,752.3
7.	India	1,740.0
8.	Taiwan	1,505.5
9.	Brazil	1,488.3
10.	Russia	1,246.0
11.	Mexico	1,012.6
12.	Turkey	834.0
13.	Switzerland	824.3
14.	Canada	783.2
15.	France	680.9
16.	Poland	545.8
17.	Spain	494.1
18.	Austria	487.9
19.	United Kingdom	401.5
20.	Netherlands	314.0
21.	Belgium	266.3
22.	Sweden	254.1
23.	Australia	250.8
24.	Romania	204.1
25.	Czech Republic	196.1
26.	Argentina	141.1
27.	Finland	98.0
28.	Portugal	96.7
29.	Denmark	82.1

[7] Gardner Publications, Inc.: 2010 World Machine Tool Output & Consumption Survey, http://www.gardnerweb.com/consump/survey.html, accessed: November 07, 2011

Looking at the production and consumption data for metal processing machine tools for the years 2001-2008 confirms the long-term dominating role of Germany and Italy in Europe for both, production and consumption of machine tools: Production in Germany and Italy since 2002 has been stable at nearly exactly 75% (+/- 1%) of the countries listed, share of consumption of these two countries ranges between 60 and 65% (see Figure 2-2). Germany consumes 41% of all metal working machine tools in the EU 27 (according to 2008 economic figures, Table 2-2).

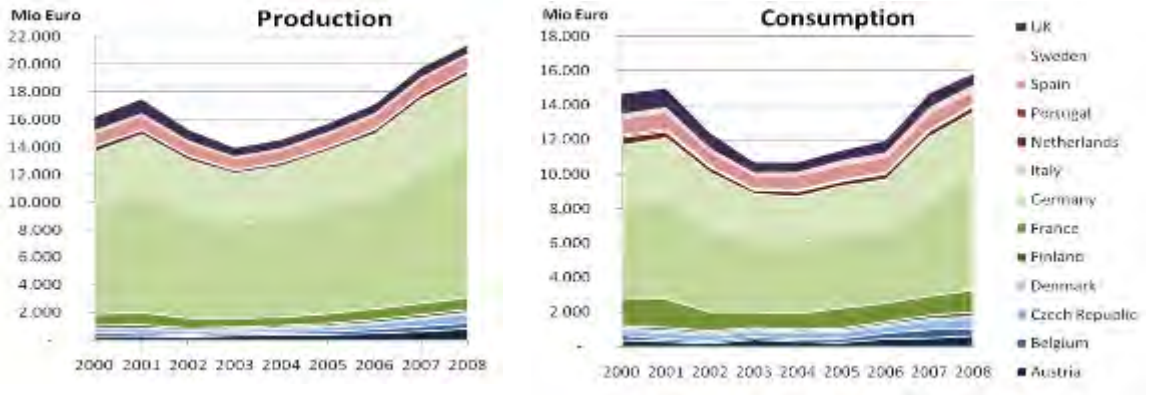


Figure 2-2: Machine tool production and consumption in CECIMO countries – per country 2000 - 2008[8]

Table 2-3: Update data for 2008 to 2011 by CECIMO

	2008	2009	2010	2011
Production (million EUR)	24425	16867	16638	21161
Apparent consumption (million EUR)	17798	10283	9719	n.a.

For the purpose of this study it is essential to provide market data in terms of units, not only economic values. The only publicly available database for such a market study is EuroStat. Fraunhofer analysed the EuroStat/PRODCOM data material in detail and applies a methodological approach to verify and consolidate EuroStat data. The methodology in detail is described in Annex I – Stock model methodology.

The revised PRODCOM 2009 production data for metal working machine tools is provided in Table 2-4. Those machine tools categories marked in red are dominated by CNC machine tools.

8 based on C ECIMO: Last trends in the European Machine Tool industry, http://www.cecimo.eu/index.php/machine-tools/dataastatistics/latesttrend.html, accessed March 11, 2010

Whereas EuroStat states a production volume of nearly 600.000 units for 2009, our plausibility check unveils, that a figure of 220.000 machine tools falling under the definition provided in task 1 is a much more likely figure.

For the UK, SKM Enviros cross-checked the plausibility-checked EU-27 sales figures against estimates for the UK, based on data provided by the Manufacturing Technologies Association (MTA). Total sales in the UK in 2009 according to these figures comprised 8.059 units, which corresponds to 3.5% of all EU-27 sales. SKM Enviros concluded: “In other industrial product areas, such as non-domestic electric motors, the UK market has traditionally been gauged at around 10% of the EU market; an equivalent comparison would suggest that the MTA estimation might be slightly low (or the Preparatory Study data is slightly high).”[9] This indicates that in turn our EU-27 figures still might be slightly overestimated.

[9] SKM Enviros: Estimating the Energy Saving Potential from Small Motors and Machine Tools, Report on Machine Tools Research & Modelling, 11 July 2011, p.15

Table 2-4: EU-27 Production of machine tools under PRODCOM 28.41 (2009, based on PRODCOM, plausibility checked by Fraunhofer)

PRODCOM Code 28.41...	Description	Volume (units) EU27 according to EuroStat	FRAUNHOFER Plausibility Check	Re-calculation rule	re-calculated EU27 Volume	re-calculated Value in THOUSANDS	re-calculated unit value	Re-calculation rule for a 2nd sub-category, where needed	re-calculated EU27 Volume (2nd catego-ry)	re-calculated Value in THOUSANDS (2nd catego-ry)	re-calculated unit value (2nd category)	TOTALS re-calculated EU27 Volume	TOTALS re-calculated Value in THOUSANDS	TOTALS re-calculated unit value
.1110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	5,963	market intelligence indicates a higher unit value for typical industrial units	recalculat-ed with unit value 400 k Euro	1,178	471.180,789	400.000					1,178	471.180,789	400.000
.1130	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufac-ture of semiconductor devices or of electronic integrated circuits)	0,637	seems to be plausible	no recalc.	0,637	31.004,422	48.673					0,637	31.004,422	48.673
.1150	Machine tools for working any material by removal of material, operated by electro-discharge processes	0,517	seems to be plausible	no recalc.	0,517	85.381,022	165.147					0,517	85.381,022	165.147
.1170	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes	2,946	seems to be plausible	no recalc.	2,946	113.375,640	38.485					2,946	113.375,640	38.485
.1180	Machine tools for working any material by removal of material, operated by ultrasonic processes, for the manufacture of semiconductor devices or of electronic integrated circuits	18,161	EU27 unit value of 1.600 Euro not plausible, but no country specific data accessible	rough estimate with 100.000 Euro unit value based on EU27 totals value	0,297	29.669,829	100.000					0,297	29.669,829	100.000
.1220	Horizontal machining centres for working metal	40,000	GER, F, I: 95% market share; remaining 5% market share not substantiated with unit volume	GER; F, I:	2,034	977.119,846	480.286					2,034	977.119,846	480.286
.1240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	3,943	seems to be plausible	no recalc.	3,943	875.968,867	222.158					3,943	875.968,867	222.158
.1250	Unit construction machines (single station) for working metal	1,647	I (with major share in terms of units) @ 10.000 Euro unit value, others (including GER) > 100.000 Euro	I:	1,133	12.964,000	11.442	EU27 w/o I:	0,514	62.269,839	121.148	1,647	75.233,839	45.679
.1270	Multi-station transfer machines for working metal	1,550	seems to be plausible	no recalc.	1,550	771.951,499	498.033					1,550	771.951,499	498.033
.2123	Numerically controlled horizontal lathes, turning	20,000	EU27 unit value of 9.000 Euro	EU27	0,511	178.876,606	350.000					0,511	178.876,606	350.000

	centres, for removing metal		is not plausible; corrected GER data provided by VDW with unit value of 354.000 Euro	totals value divided by 350.000 Euro assumed unit value											
.2127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	2,525	seems to be plausible	no recalc.	2,525	432.386,856	171.242					2,525	432.386,856	171.242
.2129	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)	1,879	seems to be plausible	no recalc.	1,879	413.042,333	219.820					1,879	413.042,333	219.820
.2140	Non-numerically controlled horizontal lathes, for removing metal	5,990	seems to be plausible	no recalc.	5,990	143.325,496	23.927					5,990	143.325,496	23.927
.2160	Lathes, including turning centres, for removing metal (excluding horizontal lathes)	2,026	seems to be plausible	no recalc.	2,026	765.408,664	377.793					2,026	765.408,664	377.793
.2213	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)	0,560	seems to be plausible	no recalc.	0,560	103.850,627	185.448					0,560	103.850,627	185.448
.2217	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)	0,385	seems to be plausible despite a mis-match of EU27 unit value and median	no recalc.	0,385	84.980,847	220.729					0,385	84.980,847	220.729
.2223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	22,021	value for GER corrected	no recalc.	2,538	475.751,005	187.451					2,538	475.751,005	187.451
.2225	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)	1,321	seems to be plausible, large variance, but all in the range of several 100.000 Euros unit value	no recalc.	1,321	518.450,002	392.468					1,321	518.450,002	392.468
.2233	Way-type unit heads for working metal by drilling, boring, milling, threading or tapping	9,760	Considered components											
.2235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	9,720	unit values for most countries @ 2.000 - 7.000 Euro; industrial use questionable	no recalc.	9,720	44.770,133	4.606					9,720	44.770,133	4.606
.2240	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	0,778	seems to be plausible	no recalc.	0,778	488.636,573	628.068					0,778	488.636,573	628.068
.2260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	0,338	units not disclosed for most important countries, but due to overall small number of units and high unit value it is unlikely, that a significant share of non-industrial equipment is covered	no recalc.	0,338	37.080,380	109.705					0,338	37.080,380	109.705
.2270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)	12,965	unit value I: 1.800 Euro; all others > 7.000 Euro	EU27 w/o I	4,716	53.029,715	11.245					4,716	53.029,715	11.245
.2280	Threading or tapping machines for working metal (excluding drilling machines)	16,349	unit value < 1.000 Euro	not relevant	-							-	-	0
.2305	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a	1,061	UK unit value 30.000 Euro; GER, I: 175.000 and 290.000 Euro	UK:	0,432	13.153,523	30.448	EU27 w/o UK:	0,629	115.353,923	183.393	1,061	128.507,446	121.119

	minimum accuracy of 0.01mm													
.2315	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	1,158	seems to be plausible	no recalc.	1,158	595.037,772	513.850					1,158	595.037,772	513.850
.2325	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to accuracy >0.01mm	0,314	seems to be plausible	no recalc.	0,314	118.324,257	376.829					0,314	118.324,257	376.829
.2335	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	3,220	ES unit value < 1.000 Euro	EU27 w/o ES	0,311	16.112,288	51.808					0,311	16.112,288	51.808
.2345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	0,600	only 40% of unit volume disclosed (uncertainty about the rest), but seems to be plausible general	no recalc.	0,600	34.840,718	58.068					0,600	34.840,718	58.068
.2355	Grinding machines for working metal; any one axis can be set to an accuracy >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines	4,200	GER, I 90% market share; UK: low unit values (3.800 Euro)	GER, I:	2,384	61.606,596	25.842					2,384	61.606,596	25.842
.2365	Numerically controlled sharpening (tool or cutter grinding) machines for working metal	4,704	unit value DK 3.900 Euro; GER: 35.000 Euro unit value @ 70% market share	EU27 w/o DK	2,699	105.905,985	39.239					2,699	105.905,985	39.239
.2375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal	24,000	GER 60% market share @ 5.000 Euro unit value; I, UK 25% market share; large number of units not substantiated (obvious overestimate by EuroStat, or large number of parts/non-industrial equip-ment); even for GER, I, UK industrial use questionable	GER, I, UK:	5,243	25.892,492	4.938					5,243	25.892,492	4.938
.2385	Honing or lapping machines for working metal	12,999	market split GER, I 50:50, but unit value in GER: 500.000, I: 6.500 Euro (industrial use questionable)	GER:	0,213	106.708,612	500.979	I:	12,608	82.865,000	6.572	12,821	189.573,612	14.786
.2395	Machines for deburring or polishing metal (excluding gear finishing machines)	60,000	GER, ES, I are all far above median and EU27 unit value, but 90% market share; obvious-ly overestimates by EuroStat	GER, ES, I:	4,165	184.819,452	44.374					4,165	184.819,452	44.374
.2410	Broaching machines for working metal	6,000	GER close to 85% market share, but at rather high unit value compared to others; 99% of sold units not substantiated with disclosed data, most likely overestimate by EuroStat	GER:	0,067	29.364,057	438.270					0,067	29.364,057	438.270
.2430	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broach-ing machines)	30,000	GER close to 95% market share, units provided by VDW	GER, I:	1,057	648.123,960	613.173					1,057	648.123,960	613.173
.2470	Sawing or cutting-off machines for working metal	45,000	unit value: I < 5.000 Euro, A ca.	CZ, DK,	6,043	202.163,497	33.454					6,043	202.163,497	33.454

			380.000 Euro; GER data provided by VDW	GER, A, P, FIN:										
.2490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.	0,657	market dominated by GER, F (both with high unit values) and I (unit value = median; signifi-cant unit volumes); "n.e.c." category = high level of uncertainty	GER, F:	0,083	29.166,659	353.287	I:	0,548	5.849,000	10.673	0,631	35.015,659	55.531
.3120	Numerically controlled bending, folding, straight-ening or flattening machines for working flat metal products (including presses)	6,146	huge differences regarding unit values, even among countries with large market share; 50% of unit volume not disclosed on country level; severe uncertain-ty, but EU27 unit value is plausible	no recalc.	6,146	740.826,950	120.538					6,146	740.826,950	120.538
.3140	Numerically controlled bending, folding, straight-ening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	5,579	seems to be plausible	no recalc.	5,579	265.297,649	47.553					5,579	265.297,649	47.553
.3160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	12,000	GER, ES, I, FIN: 85% market share @ unit values 18.000 - 53.000 Euro; F, PL with relevant unit volumes, but unit value 4.000 Euro	GER, ES, I, FIN, BUL, CZ, DK, P:	5,676	203.540,780	35.860					5,676	203.540,780	35.860
.3180	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	14,617	GER, I: market share 70% @ unit values 15-20.000 Euros, other countries: unit values < 5.000 Euro; UK: high unit value @ 320.000 Euro (but only 20 units)	GER, I, P, FIN:	4,827	78.041,565	16.168					4,827	78.041,565	16.168
.3220	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	1,979	ES: unit value 850.000 Euro (40% market share); GER, I: 75.000/70.000 Euro unit value (50% market share)	ES:	0,084	71.698,091	853.549	EU27 w/o ES	1,895	113.316,383	59.798	1,979	185.014,474	93.489
.3240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	2,371	P: unit value 700 Euro; ES, SWE: rather low 30.000 Euro (NC!), others with unit values > 160.000 Euro	ES, SWE:	0,699	19.643,926	28.103	EU27 w/o ES, SWE, P	1,398	383.812,706	274.544	2,097	403.456,632	192.397
.3260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	11,589	PL: large unit volume @ unit value 250,- Euro	EU27 w/o PL:	10,457	234.296,871	22.406					10,457	234.296,871	22.406
.3280	Non-numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	11,618	GER, ES, I: 90% market share, unit values 2.800 - 4.200 Euro; non-industrial use	not relevant	-							-	-	0
.3310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	1,971	GER 65% market share (with only 47 units); units for other relevant countries not disclosed	GER:	0,047	170.182,721	3.620.909	EU27 w/o GER; based on median value	0,295	93.915,002	318.063	0,342	264.097,723	771.602
.3320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	5,200	GER, I: 93% market share @ large unit values (320.000 / 620.000 Euro); others: few 1.000 Euro unit values	GER, I:	0,290	121.685,302	419.604					0,290	121.685,302	419.604

.3350	Hydraulic presses for working metal	11,156	GER, (F), I, SWE: 95% market share @ unit values 150.000 - 300.000 Euro; ES: large unit volume @ 5.000 Euro unit value	GER, F, I, SWE:	2,506	520.343,538	207.611					2,506	520.343,538	207.611
.3360	Non-hydraulic presses for working metal	42,000	GER, I close to 90% market share @ unit values 14.000-17.000 Euro	GER, I:	24,131	393.611,839	16.311					24,131	393.611,839	16.311
.3410	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets	0,759	seems to be plausible	no recalc.	0,759	152.152,137	200.464					0,759	152.152,137	200.464
.3430	Thread rolling machines for working metal, sintered metal carbides or cermets	0,228	seems to be plausible	no recalc.	0,228	18.900,000	82.895					0,228	18.900,000	82.895
.3450	Machines for working wire (excluding draw-benches, thread rolling machines)	20,000	GER, I: market share 90% @ unit values 41.000 - 65.000 Euro;	GER, I:	6,734	330.734,905	49.114					6,734	330.734,905	49.114
.3470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal	75,843	D, I 75% market share @ 10.000 Euro unit value; DK large unit volume @ low unit values; other countries comparable to GER, I; uncer-tainty: F 10% market share, but no unit volume	EU27 w/o DK	57,865	605.502,272	10.464					57,865	605.502,272	10.464
.4030	Parts and accessories for metal cutting machine tools (excluding tool holders and self-opening dieheads, work holders, dividing heads and other special attachments for machine-tools)													
	Totals 28.41	**598,950**										**216,206**	**14.063.265,418**	**65.046**

2.1.2 Wood working machine tools

The market of **wood working machinery** saw a major drop in sales figures in 2009: VDMA states for the German market a 42% decrease in turnover for 2009 compared to 2008[10]. However, from quarter to quarter, most significantly in the 4th quarter there was a tendency towards a recovery of the market, so a further drop is unlikely. Actually, manufacturers expect for 2010 a growth rate of 10 to 15% compared to the low 2009 level. It is worthwhile noticing, that the 2009 drop in revenue was less dramatic on the domestic market (Germany in this case), as major customers are crafts enterprises, which are less affected by the global crisis, partly even benefit from infrastructure investment programmes.

Table 2-5 lists the verified 2009 PRODCOM production figures for wood working machine tools anticipated to fall under the definition outlined in Task 1. For details of the methodology see 3 Annex I – Stock model methodology. The approach followed here was discussed with VDMA and EPTA, but figures as such were not verified by VDMA and ACIMALL.

10 Press release: VDMA Holzbearbeitungsmaschinen: Umsatzeinbruch von 42 Prozent, Frankfurt am Main, February 17, 2010

Table 2-5: EU-27 Production of machine tools under PRODCOM 28.49 (2009, based on PRODCOM, plausibility checked by Fraunhofer, wood working only)

PRODCOM Code 28.49...	Description	Volume (units) EU27 according to EuroStat	FRAUNHOFER Plausibility Check	Re-calculation rule	re-calculated EU27 Volume	re-calculated Value in THOUSANDS	re-calculated unit value	Re-calculation rule for a 2nd sub-category, where needed	re-calculated EU27 Volume (2nd catego-ry)	re-calculated Value in THOUSANDS (2nd catego-ry)	re-calculated unit value (2nd category)	TOTALS re-calculated EU27 Volume	TOTALS re-calculated Value in THOUSANDS	TOTALS re-calculated unit value
.1210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	15,438	GER, ES, I, A: 90% market share; but at large variation of unit prices (A: 10.000, ES: 82.000); others with lower unit values	GER, ES, I, A:	5,270	90.791,003	17.228					5,270	90.791,003	17.228
.1220	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	9,858	unit value for all market dominating countries @ 38.000 - 160.000 Euro	no recalc.	9,858	484.977,240	49.196					9,858	484.977,240	49.196
.1233	Band saws for working wood, cork, bone and hard rubber, hard plastics or similar hard materials	2.000,000	figure not substantiated by figures of individual countries: GER, ES, F, I, P with 80% market share @ 4.000+ Euro unit value (I only slightly above 4.000); no unit volume for PL (10% market share)	GER, ES, F, I, P:	7,858	62.525,401	7.957					7,858	62.525,401	7.957
.1235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	39,677	ES, F, A, FIN unit values @ 20.000-160.000 Euro (25% market share); D + I @ < 6.000 Euro unit value (70% market share)	ES, F, A, FIN:	0,852	54.420,268	63.847					0,852	54.420,268	63.847
.1237	Sawing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials (excluding band saws, circular saws)	300,000	GER close to 40% market share, but no unit volume (confiden-tial) for 2009; 2008 unit value GER: 1850 Euro (GER 2009 volume recalculated with 1850 Euro); I, A, FIN, SWE comprise another 50% market share with plausible volume. 300.000 units by far over-estimated	I, A, FIN, SWE	3,532	70.300,928	19.904	GER:	26,051	48.193,566	1.850	29,583	118.494,494	4.006
.1250	Planing, milling or moulding (by cutting) ma-chines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	39,889	GER, ES, P unit values > 20.000 Euro (60% market share); I (+ PL) < 3.000 Euro (25% market share) - considered non-industrial use; FIN 7% market share with 21 units @ 1,7 mio each	GER, ES, P	3,568	168.041,369	47.097					3,568	168.041,369	47.097
.1263	Grinding, sanding or polishing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	784,566	GER, I: 90% market share, but huge difference in unit value (9.000 vs. 55.000 Euro); DK @ unit value of 75 Euro	GER	5,490	49.157,049	8.954	I:	0,885	48.509,000	54.812	6,375	97.666,049	15.320

.1265	Bending or assembling machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	2,319	GER + I + ES 70% market share @ 19.000 - 26.000 Euro unit value; FIN 15% market share with 6 units @ 1,5 mio Euro each	GER, ES, I:	2,194	51.400,465	23.428					2,194	51.400,465	23.428
.1267	Drilling or morticing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	10,548	includes countries with unit values down to few 1.000 Euros; GER, I: 90% market share at unit values 19.000 and 9.000 Euro. Figures are plausible, but covers most likely also some non-industrial equipment	no recalc.	10,548	126.004,066	11.946					10,548	126.004,066	11.946
.1275	Splitting, slicing or paring machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	16,448	GER, I, FIN cover 95% market share with unit values of 19.000 down to 6.600 Euros; figures are plausible, but cover also likely non-industrial equipment	no recalc.	16,448	218.972,083	13.313					16,448	218.972,083	13.313
.1279	Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials, n.e.c.	200,000	nearly 90% of the market share covered by GER, ES, F, I (I = 60%), A, PL, FIN, but large spread: I @ 6.600 Euro unit value, FIN @ 260.000 Euro; most units to be assessed as close to non-industrial use	GER, ES, F, I , A, PL, FIN:	31,330	288.817,730	9.219					31,330	288.817,730	9.219
.1287	Presses for the manufacture of particle board or fibre building board of wood or other ligneous materials, and other machines with individual functions for treating wood or cork	17,149	DK irrelevant at unit values of 1.600 Euro; others frequently in the 40.000 Euro range; D @ 500.000 Euro, FIN @ 1.500.000 Euro;	GER, FIN:	1,209	605.691,250	500.985	EU27 w/o DK, GER, FIN:	5,747	185.073,900	32.204	6,956	790.765,150	113.681
	Totals 28.49 wood working	**3.435,892**										**130,840**	**2.552.875,318**	**19.511**

Instead of 3.4 million units sold production as stated by EuroStat for wood working machine tools under 28.49 a more reasonable figure according to the plausibility check by Fraunhofer is **130,000 units** sold production in 2009[11]. The categories saws and planing equipment, for which the recalculated number of industrial units is 42,000 there is an overlap with so-called light stationary wood working tools, which are at a rather low unit value of up to 1,000 Euro:

Light Stationary Wood working Tools

EPTA, the European Power Tools Association, provided market insights for light stationary wood working tools: This sub-sector accounts for approximately € 135 million sales and 220,000 units per annum. The products fall broadly into three categories as listed in Table 2-6.

Table 2-6: EU sales of light stationary wood working tools (source EPTA)

	Table and Radial Arm Saws	Band Saws	Planer Thicknessers
EU sales value	**€ 80 million**	**€ 30 million**	**€ 25 million**
EU sales volume	**110,000 units**	**80,000 units**	**30,000 units**
Calculated unit value	**730 Euros**	**375 Euros**	**833 Euros**

Only 30% of sales in this sector are attributable to EPTA members. There are an unknown number of small independent suppliers, mostly Asian.

This market segment, according to EPTA, can be differentiated from heavier wood working stationary products by three factors:

- Duty – Light Stationary products are typically used intermittently and are almost always manually fed. Heavier duty machines are typically used continuously and are usually automatically fed.
- Motor power – Light Stationary products use induction motors rated mainly between 750 and 3000 watts input power. Heavier duty products are powered by motors usually in excess of 3000 watts.

[11] Given the fact, that the wood working market sees a much higher share of low cost units e.g. for DIY-ers, there is a higher uncertainty regarding the number of units used by professionals, than for the metal working machine tools market.

- Cutting capacity – Light Stationary table and radial arm saws have maximum blade diameters of 350 mm. Light stationary bandsaws have a maximum cutting height / passage width of 280 x 440 mm. Light stationary planer thicknessers have a maximum passage height / width of 180 x 307 whereas heavier duty products have capacities in excess of that.

Typically, because they are light duty, these tools do not have feed systems, hydraulic units or cooling lubricant facilities.

The life cycle of these products is relatively long. It is estimated that **50% of these products will be used longer than 25 years** because they are used intermittently – which would result roughly in an installed stock of 5 million units in EU-27. According to EPTA and their members the majority of users use the products no more than once per day.

Consequently, there were roughly between 90,000 and 130,000 larger, industrial type units produced in EU-27, and 70,000 (30% of EU-27 sales) of light stationary wood working tools.

2.1.3 Welding, soldering and brazing equipment

Table 2-7 lists the verified 2009 PRODCOM production figures for welding, soldering and brazing equipment anticipated to fall under the definition outlined in Task 1. For details of the methodology see 3 Annex I – Stock model methodology. The figures and classifications were discussed with representatives of EWA. The column "plausibility check" also lists further explanations regarding the likely allocation of equipment to a given category. For example, "fully or partly automatic electric machines" is a category to which typically equipment is reported, which is equipped with an automatic welding wire feed, but not highly complex full-automatic welding machines[12]. Those machinery categories, which – after revision – covers mainly CNC machinery is marked in red. Two categories cover equipment in the below 1,000 Euro unit value range, which is smaller transportable equipment. Misallocation of components and parts in this category might have happened, but overall order of magnitude seems to be plausible according to industry experts.

[12] As the data has to be reported individually by manufacturers to the national statistics authorities a judgement by manufacturers and the association to which categories they report which type of equipment is the best indication available to facilitate the interpretation of the data – although naming of PRODCOM codes might be misleading in some cases.

Table 2-7: EU-27 Production of welding, soldering and brazing equipment (2009, based on PRODCOM, plausibility checked by Fraunhofer)

PRODCOM Code	Description	Volume (units) EU27 according to EuroStat	FRAUNHOFER Plausibility Check	Re-calculation rule	re-calculated EU27 Volume	re-calculated Value in THOUSANDS	re-calculated unit value
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	2,713	seems to be plausible, likely to be electronics soldering machines etc., covering solder pots to flow solder machines	no recalculation	**2,713**	**71.483,300**	**26.348**
27903145	Electric machines and apparatus for resistance welding of metal	224,563	volume is not plausible; CZ, GER, ES, SWE, UK: 75% market share at minimum 5000 Euro unit value	CZ, GER, ES, SWE, UK:	**43,656**	**558.596,000**	**12.795**
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	277,321	seems to be plausible: transportable equipment for manual welding with automatic feed of welding wire; GER 25% market share @ 20.000 Euro unit value, all others in the 500 - 2.000 Euro range	no recalculation	**277,321**	**329.375,815**	**1.188**
27903163	Other for manual welding with coated electrodes	630,299	seems to be plausible: transportable equipment for manual welding, low unit values < 400 Euro	no recalculation	**630,299**	**136.152,471**	**216**
27903172	Other shielded arc welding	326,963	seems to be plausible: transportable equipment for manual welding, low unit value 700 Euro	no recalculation	**326,963**	**194.935,172**	**596**
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	17,367	seems to be plausible, covers automatic machinery, i.e. mostly stationary welding units; UK with 5% market share at low 2.500 Euro unit value, others in the 10.000 Euro range	no recalculation	**17,367**	**163.760,510**	**9.429**
27903190	Machines and apparatus for resistance welding of plastics	1.111,507	number and category questionable, not covered by "welding" sector, presumably packaging machines to seal plastic packages; some large units for the automotive sector might be covered here as well; I 35% market share (< 2.000 Euro unit value), F 10% market share(13 Euro unit value - laminating devices?), GER 50% market share (10.000 Euro unit value)	EU-27 w/o F:	**47,323**	**123.569,842**	**2.611**
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	41,999	GER, UK, DK 85% market share	GER, UK, DK:	**8,911**	**222.451,139**	**24.964**
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	672,909	covers inter alia industrial cutting equipment, but number of units is way too high for this; I, FIN with unit values below 100 Euro, F at 1.000 Euro, GER+UK 70% market share	GER, UK:	4,727	136.797,305	28.940
Totals		**3.305,641**			**1359,280**	**1.937.121,554**	

The figures above include soldering equipment, which can be considered industrial ovens (e.g. reflow soldering ovens for printed circuit board assembly), which fall under the scope of Product Group Study Lot 4 - Industrial and Laboratory Furnaces and Ovens[13].

2.1.4 Other machine tools

It is not possible to provide a comprehensive verification of all kinds of other machine tools. Therefore the following figures are restricted to the important sub-segment of stone and ceramics working machine tools. Table 2-8 lists the verified 2009 PRODCOM production figures. For details of the methodology see 3 Annex I – Stock model methodology.

The plausibility check unveiled, that the EuroStat figures are much higher than the actual plausible number of stone and ceramics working machine tools for professional use, parts and components and non-energy related tools excluded. In total the production volume in the EU-27 in 2009 was close to 60,000 units (instead of 430,000 units as listed by EuroStat).

For grinding and polishing machines a distinction of the German, Italian, Spanish and UK market, reporting rather high-value machinery with an average unit value of 85,000 Euros and France and Portugal reporting unit values slightly below 10,000 Euros is provided.

[13] See http://www.eco-furnace.org/

Table 2-8: EU-27 Production of stone and ceramics working machine tools (2009, based on PRODCOM, plausibility checked by Fraunhofer)

PRODCOM Code 28.49...	Description	Volume (units) EU27 according to EuroStat	FRAUNHOFER Plausibility Check	Re-calculation rule	re-calculated EU27 Volume	re-calculated Value in THOUSANDS	re-calculated unit value	Re-calculation rule for a 2nd sub-category, where needed	re-calculated EU27 Volume (2nd catego-ry)	re-calculated Value in THOUSANDS (2nd catego-ry)	re-calculated unit value (2nd category)	TOTALS re-calculated EU27 Volume	TOTALS re-calculated Value in THOUSANDS	TOTALS re-calculated unit value
.1130	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	143,531	EU27 unit value below 2.000 Euro, GER: below 600 Euro; I: 8.500 Euro at 60% market share	EU27 w/o GER	30,344	203.942,051	6.721					30,344	203.942,051	6.721
.1150	Grinding or polishing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	9,948	GER, I: unit values 90.000 Euro (65% market share); F unit value 9.000 Euro (25% market share); others < 1.000 Euro unit value	GER, I, ES, UK:	2,022	172.682,451	85.402	F, P:	6,720	61.390,391	9.135	8,742	234.072,842	26.776
.1170	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)	276,626	ES unit value 150 Euro; GER @ 25.000 Euro; I @ 35.000 Euro; GER + I > 85% market share	GER, I:	20,054	612.630,883	30.549					20,054	612.630,883	30.549
Totals		**430,105**										**59,140**	**1.050.645,776**	**17.765**

2.1.5 Summary

The production figures from the Eurostat PRODCOM statistics, which underwent a plausibility check by Fraunhofer, were discussed with market experts at the industry associations and with market leaders for some segments, and were subject to revision based on the findings are summarised in the table below.

Grand totals of the EU 27 production market of machine tools according to these figures is 19.6 billion Euros, and 1. 77 million units (but largely dominated by welding equipment).

Table 2-9: EU-27 Production of machine tools – Summary (2009, based on PRODCOM, plausibility checked by Fraunhofer)

Category	Initial PRODCOM production figures (units, 2009)	**TOTALS re-calculated EU27 Production Volume**	**TOTALS re-calculated Value in Euro**	**TOTALS re-calculated unit value**
Metal working machine tools	**598.950**	**216.206**	**14.063.265.418**	**65.046**
Wood working machine tools	**3.435.892**	**130.840**	**2.552.875.318**	**19.511**
Light stationary woodworking tools	**n.a.**	**70.000**	**n.a.**	**< 1.000**
Welding, soldering and brazing equipment	**3.305.641**	**1.359.280**	**1.937.121.554**	
Stone and ceramics working machine tools	**430.105**	**59.140**	**1.050.645.776**	**17.765**
Totals (w/o light stationary wood working machine tools)	**7.770.588**	**1.765.466**	**19.603.908.066**	

2.2 Market and stock data

2.2.1 Base Data for the Stock Model

2.2.1.1 Metal working machine tools

As there are no dedicated statistics available regarding the installed stock of machine tools, such figures have to be derived from sales figures with qualified assumptions. Average technical and economic product life is one of these key parameters:

The large Japanese machine tool manufacturer Mori Seiki Co. estimates an average lifetime of **15 years** for machine tools[14].

According to a VDMA index, average lifetime of **NC-controlled machine tools** is **9.5 years**, average lifetime of **non-NC controlled machine tools 18.6 years**[15].

An indication about age of machine tools being still in use or at least considered usable is the market for used machine tools. An evaluation of more than 3,400 machine tools offered mid-March 2010 at one of the leading internet platforms MM Maschinenmarkt Börse online unveils the broad age spread of machine tools offered for reuse: Actually reuse starts right from day zero. These very early reuse cases obviously stem from companies cancelling orders or facing bankruptcy after having ordered machinery. The huge fluctuations in the design year[16] of offered machine tools reflects nearly exactly the economic cycles: If in a certain year less machine tools have been manufactured, rather logically a lower number of machine tools from that respective year is offered now as used machinery. The design year with most used machine tools traded is 1989, indicating that a machine tools' lifetime of more than 20 years is not uncommon at all. There is a remarkable number of machine tools build in the 1960s and 1970s still offered on this trade platform.

This platform is particularly popular for metal working machine tools.

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[14] See Interview with Dr. Rüdiger Kapitza, CEO Gildemeister AG, and Dr. Masahiko Mori,CEO Mori Seiki Co., Ltd., in: Die Zukunft der Werkzeugmaschinen-Industrie, Produktion Nr. 24, 2007

[15] VDMA-Kennzahlen Fertigung und Montage 2006

[16] For clarification of terminology: "design year" refers to the year when an individual machine tool is produced, not the year when the layout of a certain model series of machine tools was designed for the first time

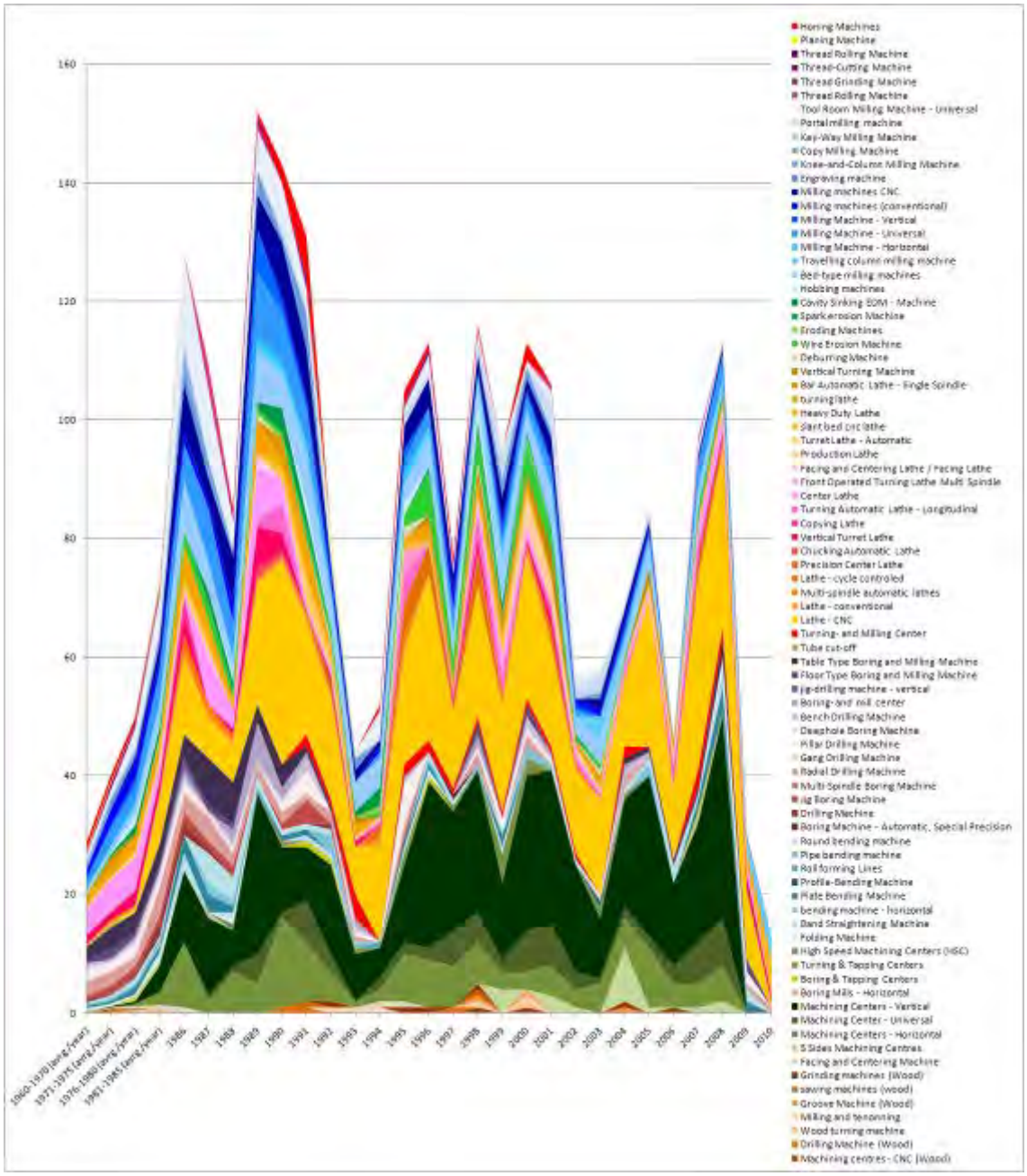


Figure 2-3: Year of Design of Second Hand Machine Tools – Absolute Numbers (as of March 2010)

Looking at those machine tools traded at MM Maschinenmarkt Börse online, which bear in the category name a reference to numerical controlled or machining centre gives an indication about the age of numerical controlled machine tools specifically.

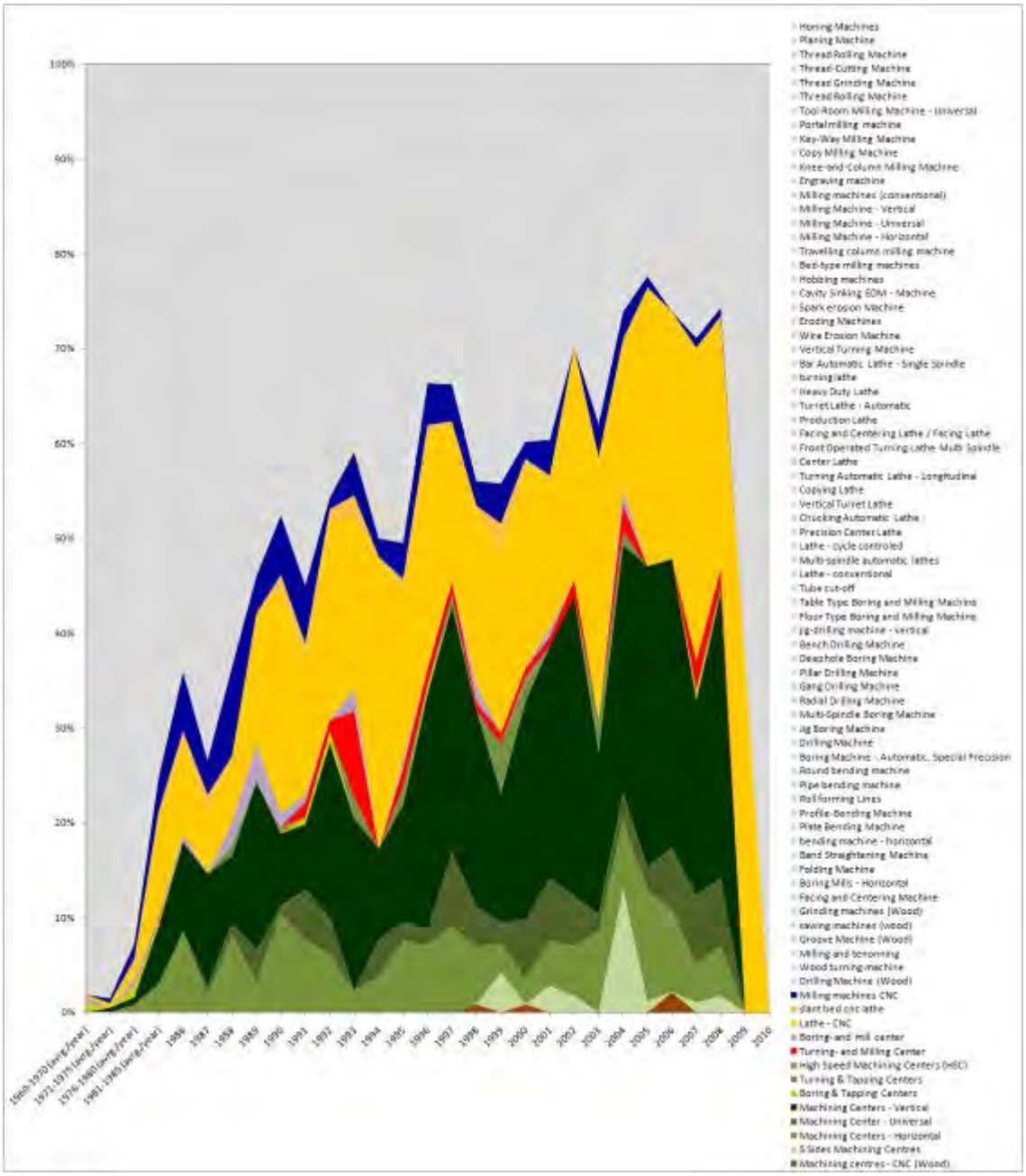


Figure 2-4: Year of Design of Second Hand Machine Tools – Percentage – numerical-controlled and machining centres highlighted[17]

[17] Not that the distinction of NC / non-NC is not that clear in the statistics and categories of this second hand platform as it seems to be in this graphical illustration; there are NC-controlled machine tools also included occasionally in the greyed categories

In Figure 2-4 all categories are greyed out, which do not bear CNC or machining centre in the category name: It is confirmed, that as a tendency, numerical-controlled machine tools traded as second hand machinery have a higher representation in the reuse market of younger machines. The figure of 9.5 years average lifetime of NC-controlled machine tools stated by VDMA (see above) nevertheless is likely to underestimate the real lifetime when looking at the second hand statistics provided below. On the other hand it should be not ed, that the market share of new machine tools shifted from non-numerical controlled machine tools to CNC machine tools anyway, so the statistics of second hand machinery provided in the figure below might rather be a reflection of the market situation of the given year of design (more non-NC controlled machine tools available from earlier years, more NC-controlled machinery available from more recent years).

Table 2-10 lists the average age of machine tools traded at MM Maschinenmarkt Börse online. Only categories with more than 40 units offered as of March 2010 (and stating a year of design) are listed. At minimum the average age of machine tools showing up on this platform is 11 years in case of universal machining centres, and at maximum in the range of 30 years for table type boring and milling machines, centre lathes, and conventional milling machines.

Table 2-10: Average Age of Machine Tools offered as Second Hand Equipment

	Units offered (Totals)	Avrg. age (years)
Machining Centres - Horizontal	149	15
Machining Centre - Universal	77	11
Machining Centres - Vertical	422	12
Round bending machine	42	20
Radial Drilling Machine	89	29
Pillar Drilling Machine	63	29
Table Type Boring and Milling Machine	111	30
Lathe - CNC	475	13
Vertical Turret Lathe	73	28
Centre Lathe	158	31
turning lathe	83	25
Wire Erosion Machine	42	14
Bed-type milling machines	132	20
Milling Machine - Universal	140	24
Milling machines (conventional)	67	30
Milling machines CNC	97	19

	Units offered (Totals)	Avrg. age (years)
Knee-and-Column Milling Machine	41	25
Tool Room Milling Machine - Universal	129	25
Honing Machines	48	29

According to a recent survey by VDW[18] the age of machine tools at end-of-life is **frequently above 25 years** (43% of the replies), the remaining machine tools reach their end-of-life mostly between 16 and 20 years of age, some already at 10 to 15 years (see Task 3.3 for more details).

An inquiry among market experts through CECIMO at their member associations lead to experts' estimates regarding average lifetimes of metal working machine tools. Estimates were made by experts from Italy and France, the German data on average age was taken with the assumption, that the lifetime is roughly twice the average age of the machine tools found in operation.

Table 2-11: Estimates of Average Lifetime of Metal Working Machine Tools

PRODCOM	Description	Average lifetime (years)			
		Italy	France	Germany	average
		Estimate	Estimate	VDMA, 2006	
28411110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	10	17	9,5	**12**
28411130	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)		17	18,6	**18**
28411150	Machine tools for working any material by removal of material, operated by electro-discharge processes	14	17	9,5	**14**
28411170	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes		17	18,6	**18**
28411180	Machine tools for working any material by removal of material, operated by ultrasonic processes, for the manufacture of semiconductor devices or of electronic integrated circuits		17	18,6	**18**
28411220	Horizontal machining centres for working metal	8	17	9,5	**12**

18 Verein Deutscher Werkzeugmaschinenfabriken e.V.: Art und Umfang von Retrofit-/Refurbishing-Maßnahmen (R/R) an Werkzeugmaschinen, survey, February 2010

28411240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	12	17	9,5	**13**
28411250	Unit construction machines (single station) for working metal		17	18,6	**18**
28411270	Multi-station transfer machines for working metal	8	17	9,5	**12**
28412123	Numerically controlled horizontal lathes, turning centres, for removing metal	10	17	9,5	**12**
28412127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	8	17	9,5	**12**
28412129	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)	10	17	9,5	**12**
28412140	Non-numerically controlled horizontal lathes, for removing metal		17	18,6	**18**
28412160	Lathes, including turning centres, for removing metal (excluding horizontal lathes)	30	17	9,5	**19**
28412213	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)	20	17	9,5	**16**
28412217	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)	15	17	9,5	**14**
28412223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	12	17	9,5	**13**
28412225	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)	15	17	9,5	**14**
28412233	Way-type unit heads for working metal by drilling, boring, milling, threading or tapping				**n.a.**
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)		17	18,6	**18**
28412240	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	20	17	9,5	**16**
28412260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)		17	18,6	**18**
28412270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)		17	18,6	**18**
28412280	Threading or tapping machines for working metal (excluding drilling machines)		17	18,6	**18**
28412305	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	8	17	9,5	**12**
28412315	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	8	17	9,5	**12**

28412325	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to accuracy >0.01mm	12	17	9,5	**13**
28412335	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm		17	18,6	**18**
28412345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm		17	18,6	**18**
28412355	Grinding machines for working metal; any one axis can be set to an accuracy >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines		17	18,6	**18**
28412365	Numerically controlled sharpening (tool or cutter grinding) machines for working metal	6	17	9,5	**11**
28412375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal		17	18,6	**18**
28412385	Honing or lapping machines for working metal	5	17	18,6	**14**
28412395	Machines for deburring or polishing metal (excluding gear finishing machines)		17	18,6	**18**
28412410	Broaching machines for working metal		17	18,6	**18**
28412430	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)	10	17	9,5	**12**
28412470	Sawing or cutting-off machines for working metal		17	18,6	**18**
28412490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.		17	18,6	**18**
28413120	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	15	17	9,5	**14**
28413140	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	12	17	9,5	**13**
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)		17	18,6	**18**
28413180	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)		17	18,6	**18**
28413220	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	12	17	9,5	**13**
28413240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	12	17	9,5	**13**
28413260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)		17	18,6	**18**

28413280	Non-numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)		17	18,6	**18**
28413310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	30	17	9,5	**19**
28413320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)		17	18,6	**18**
28413350	Hydraulic presses for working metal	25	17	9,5	**17**
28413360	Non-hydraulic presses for working metal	25	17	18,6	**20**
28413410	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets				**15**
28413430	Thread rolling machines for working metal, sintered metal carbides or cermets				**15**
28413450	Machines for working wire (excluding draw-benches, thread rolling machines)				**15**
28413470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal				**15**

The huge spread in estimated and calculated lifetimes indicates that machine lifetime (and thus the stock calculated on this basis) is subject to a high level of uncertainty.

2.2.1.2 Wood working machine tools

There is no lifetime data available for wood working machine tools. Taking the stated lifetime for other larger machinery of indicatively 15 - 25 years as an approximation, and noticing the EPTA statement that 50% of light stationary products will be used longer than 25 years it is considered appropriate to **calculate with roughly 20 years lifetime** for wood working machinery, but this is subject to a high level of uncertainty.

2.2.1.3 Welding, soldering and brazing equipment

As there is no robust statistic the average lifetime of welding, soldering and brazing equipment was estimated by an industry expert[19], and confirmed at an EWA association meeting.

[19] P. Couderc, Air Liquide

Table 2-12: Estimates of Average Lifetime of Welding, Soldering and Brazing Equipment

PRODCOM	Description	Average lifetime (years)
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	**20**
27903145	Electric machines and apparatus for resistance welding of metal	**15**
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	**7**
27903163	Other for manual welding with coated electrodes	**5**
27903172	Other shielded arc welding	**5**
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	**20**
27903190	Machines and apparatus for resistance welding of plastics	**20**
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	**20**
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	**20**

The low cost units in particular are estimated to be at a rather short lifetime of 5 years, whereas the larger production equipment, being high value investment goods are typically used much longer, indicatively 20 years.

2.2.1.4 Other machine tools

For the large variety of other machine tools and application fields no robust figures regarding average lifetime can be stated. The only statement that can be made, is that the lifetime as for other investment goods is in the range of several years to few decades. For the segment of stone and ceramics working machine tools similar lifetimes as for metal and wood working can be anticipated in the range of 10-25 years. Estimates below will be based on 20 years lifetime.

2.2.2 Installed base (EU-27 stock)

2.2.2.1 Metal working machine tools

Actually, it has to be noticed that average machine tool lifetime changes with the economic cycle and does not keep stable over time. However, these dynamics in detail are not known.

Having said this, the stock model for metal working machine tool product categories (NACE codes) is as listed in the table below for 1995 as Kyoto reference year and 2009 as most recent year, for which Eurostat data is available[20].

[20] as of early 2010

Table 2-13: Metal working machine tools - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28411110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	4.818	18.978
28411130	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)	3312	8762
28411150	Machine tools for working any material by removal of material, operated by electro-discharge processes	22964	33246
28411170	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes	64263	114266
28411220	Horizontal machining centres for working metal	17137	33965
28411240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	34986	99614
28411250	Unit construction machines (single station) for working metal	13862	40955
28411270	Multi-station transfer machines for working metal	11949	22828
28412123	Numerically controlled horizontal lathes, turning centres, for removing metal	15104	34214
28412127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	18451	38005
28412129	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)	27577	44347
28412140	Non-numerically controlled horizontal lathes, for removing metal	148116	100104
28412160	Lathes, including turning centres, for removing metal (excluding horizontal lathes)	21708	53745
28412213	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)	17673	34743
28412217	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)	4891	6859
28412223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	12886	36197
28412225	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)	11030	23858
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	408178	320900
28412240	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	8420	23136
28412260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	6393	3636
28412270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)	49576	36325
28412280	Threading or tapping machines for working metal (excluding drilling machines)	200661	141190
28412305	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	3823	11152
28412315	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	5209	10852
28412325	Other numerically controlled grinding machines in which the	2680	5987

	positioning in any one axis can be set up to accuracy >0.01mm		
28412335	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	**8299**	**4668**
28412345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	**383**	**2024**
28412355	Grinding machines for working metal; any one axis can be set to an accuracy >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines	**72575**	**49332**
28412365	Numerically controlled sharpening (tool or cutter grinding) machines for working metal	**19068**	**43005**
28412375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal	**43058**	**21950**
28412385	Honing or lapping machines for working metal	**461841**	**290527**
28412395	Machines for deburring or polishing metal (excluding gear finishing machines)	**56163**	**49371**
28412410	Broaching machines for working metal	**1358**	**916**
28412430	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)	**2478**	**6401**
28412470	Sawing or cutting-off machines for working metal	**175033**	**137080**
28412490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.	**24693**	**16187**
28413120	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	**34504**	**76542**
28413140	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	**9899**	**33993**
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	**42817**	**48355**
28413180	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	**not applicable**	**not applicable**
28413220	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	**16901**	**37512**
28413240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	**9266**	**17591**
28413260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	**144300**	**146934**
28413280	Non-numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	**367638**	**185759**
28413310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	**3036**	**5290**
28413320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	**224**	**291**
28413330	Presses for moulding metallic powders by sintering or for compressing scrap metal into bales	**4741**	**3221**
28413340	Other hydraulic presses, numerically controlled, for working metal	**32697**	**37583**

28413350[21]	Hydraulic presses for working metal	**not applicable**	**1869**
28413360	Non-hydraulic presses for working metal	**not applicable**	**17658**
28413370	Other non-hydraulic presses, numerically controlled, for working metal	**2553**	**5823**
28413380	Other non-numerically controlled presses for working metal	**638271**	**395426**
28413410	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets	**9287**	**7570**
28413430	Thread rolling machines for working metal, sintered metal carbides or cermets	**19753**	**14334**
28413450	Machines for working wire (excluding draw-benches, thread rolling machines)	**187144**	**187384**
28413470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal	**345445**	**319683**
	Totals	**3.871.087**	**3.464.152**

Total installed stock of metal working machine tools is depicted in Figure 2-5.

21 In 2009 PRODCOM codes 28413340 and 28413370 were replaced by codes 28413350 and 28413360, which explains why no data is reported for 1995, as these were covered by other categories at that time

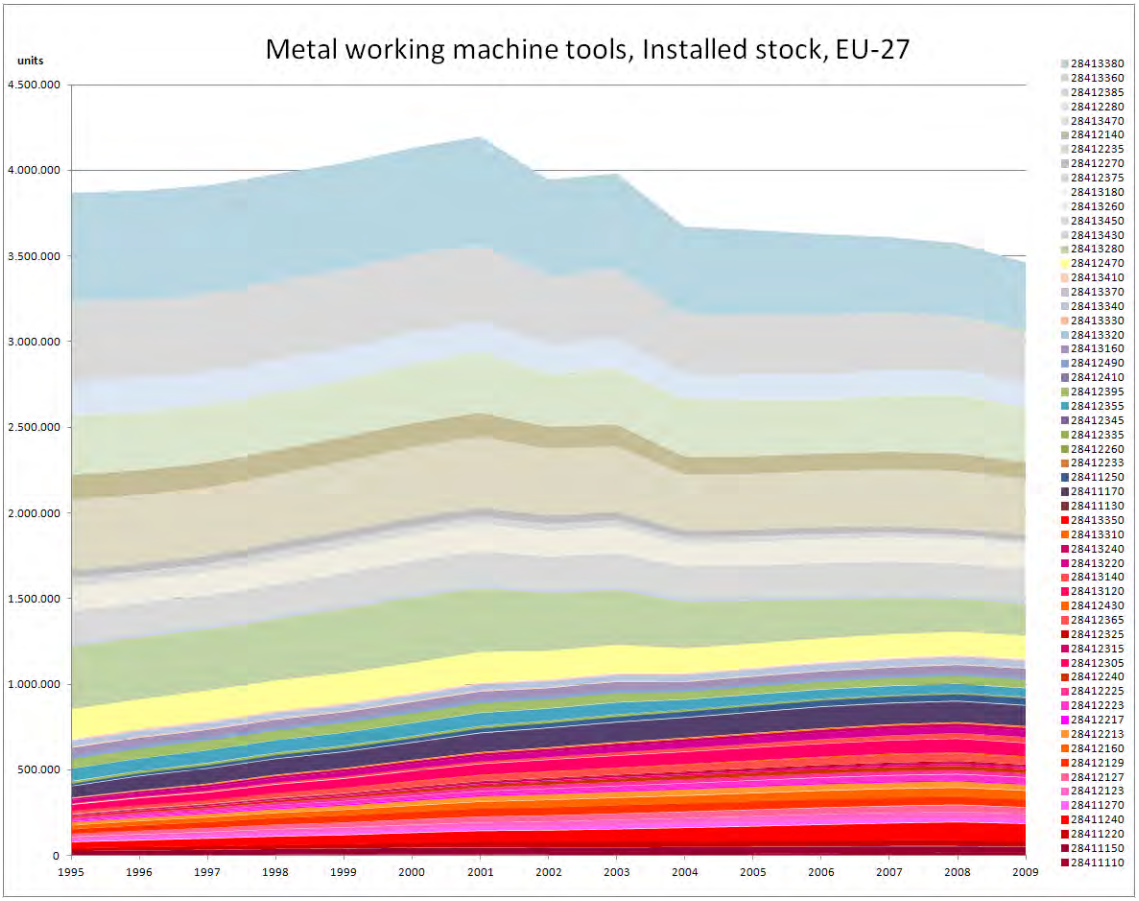


Figure 2-5: Installed Stock – Metal Working Machine Tools Categories – Development 1995 - 2009

The machine tools categories covering (or at least are dominated by) CNC machine tools are coloured in reddish in Figure 2-5. The number of **CNC machine tools** according to this stock model is on a 2009 level of **750.000 units in the EU27**. Considering all machine tools categories with plausible unit values **above 25.000 Euro** per machine tool, the totals are at **1.3 million machine tools** in operation in EU-27. Of these categories only for one there is a rather low plausibility of the data (marked in yellow). Another **2.1 million machines** (greyish in the figure) are in categories with reported (but largely plausible or revised) unit values **below 25.000 Euros**, hence these types of non-CNC machinery are rather expected in workshops, partly also equipment for semi-professional use might be covered, but units portable by hand are rather not covered as they have been ruled out in the plausibility check. In a few of these categories a very limited number of high-value, CNC machine tools might be allocated, but this share is likely to be negligible for this economic analysis.

Regarding the totals there is a slight decrease between 1995 and 2009. Given the stock model calculations the number of CNC machines in operation increased from 350.000 units in 1995 to 750.000 units in 2009 1995 whereas the stock of non-CNC categories above 25.000 Euro remained on the same level as it was in 1995: 500.000 units. Including also the lower value non-CNC machine tools the stock of all non-CNC machine tools decreased from 3.5 million units in stock in 1995 to 2.7 million units in 2009.

The total values seem to be roughly correct in relation to a survey provided by CECIMO for France: There were 230.000 [metal working] machine tools in 1998, where 60% of them were metal cutting. 50% of the population were NC machines. Similarly, market surveys (installed stock) in Germany in 1995 and in Italy in 2005 indicate an installed stock in the CECIMO countries of 1.5 – 4.4 million units[22], taking all three countries France, Italy and Germany as a basis, total stock is estimated with 2.4 million metal working machine tools in CECIMO countries[23], see Table 2-14 (calculation provided by CECIMO), compared to a figure of 3.5 million metal working machine tools in EU 27 according to our stock model.

Table 2-14: Metal Working Machine Tools – CECIMO estimate regarding installed stock in CECIMO countries

Estimation of machine tool stock

Share in CECIMO apparent metalworking machine tools consumption in 2010:

Item / Country	Germany	Italy	France	Total
Share in CECIMO app. consumption in € (%, 2010)	39,10%	21,50%	5,30%	65,90%
Number of machine tools ('000, acc. to the survey)	1040,0	324,5	232,0	1596,5
Year of the survey	1995	2005	1998	

Source: German, Italian and French surveys on machine tools installed stock

Implied CECIMO stock ('000)	000 units
Implied stock based on German data	2660
Implied stock based on Italian data	1509
Implied stock based on French data	4377
Total CECIMO stock weighted by consumption	**2423**

22 Lower boundary of this range based on extrapolation of data for Italy, upper boundary on data for France

23 Turkey and Switzerland included, some EU-27 countries excluded (such as Poland, Romania, and Slovakia)

CECIMO provided also historic survey data regarding the installed stock as outlined and analysed in Table 2-15. As this data spotlights only the situation in two countries and for selected years on a hi ghly aggregated level our stock model cannot directly build on these figures, but was adapted to reflect the change in total units and distinct for CNC / non-CNC: The annual growth rate in CNC stock for Germany was applied for the EU-27 to extrapolate from the calculated 1995 s tock backwards (new stock installed in former years).

Table 2-15: Metal Working Machine Tools – Stock survey in selected years and countries

	Germany		***Italy***	
	1985	*1995*	*1985*	*2005*
Total stock	*1.238.095*	*1.040.000*	*550.000*	*324.500*
CNC share	*6%*	*21%*	*4%*	*27%*
	74.286	218.400	22.000	87.615
annual increase	11,4%		7,2%	
Non-CNC machine tools	1.163.810	821.600	528.000	236.885
annual decrease	-3,42%		-3,93%	
Theoretical replacement rate non-CNC by CNC (number of CNC entering the stock for each non-CNC leaving the stock)	0,4211		0,2254	

(Data in italics as provided by CECIMO, all other calculated by Fraunhofer)

Given the fact, that the stock model demonstrates a rather stable level of installed metal working machine tools[24], the forecasts and scenarios presented in 2.1.1, which are based on economic figures and not on a unit basis, do not have much influence on the installed stock.

Based on historical data and surveys – which only provide snapshots of the situation in individual years in individual countries it is evident that the total stock of metal working machine tools is decreasing significantly. This is confirmed by our revised stock model.

A closer look at the EuroStat data unveils the fact that the unit value of CNC machine tools under most PRODCOM codes raised significantly since 1995. This trend is depicted in Figure 2-6. These data make clear indirectly, that CNC machine tools became more and more complex over time, which means, that not only the stock of CNC ma-

[24] Which, however, is in contradiction to a statement of CECIMO: According to some national market surveys in Germany (1985/1995) and Italy (1985/2005) the total stock decreased in the last few decades. Although this trend is plausible (trend towards more complex machine tools replacing a multitude of simpler ones), the EuroStat data, even after a plausibility check, did not confirm this trend. As there is no other robust data on the EU-27 level including robust historic figures, the stock model cannot be adjusted.

chine tools grew, but is composed today of machine tools of much higher complexity than years ago.

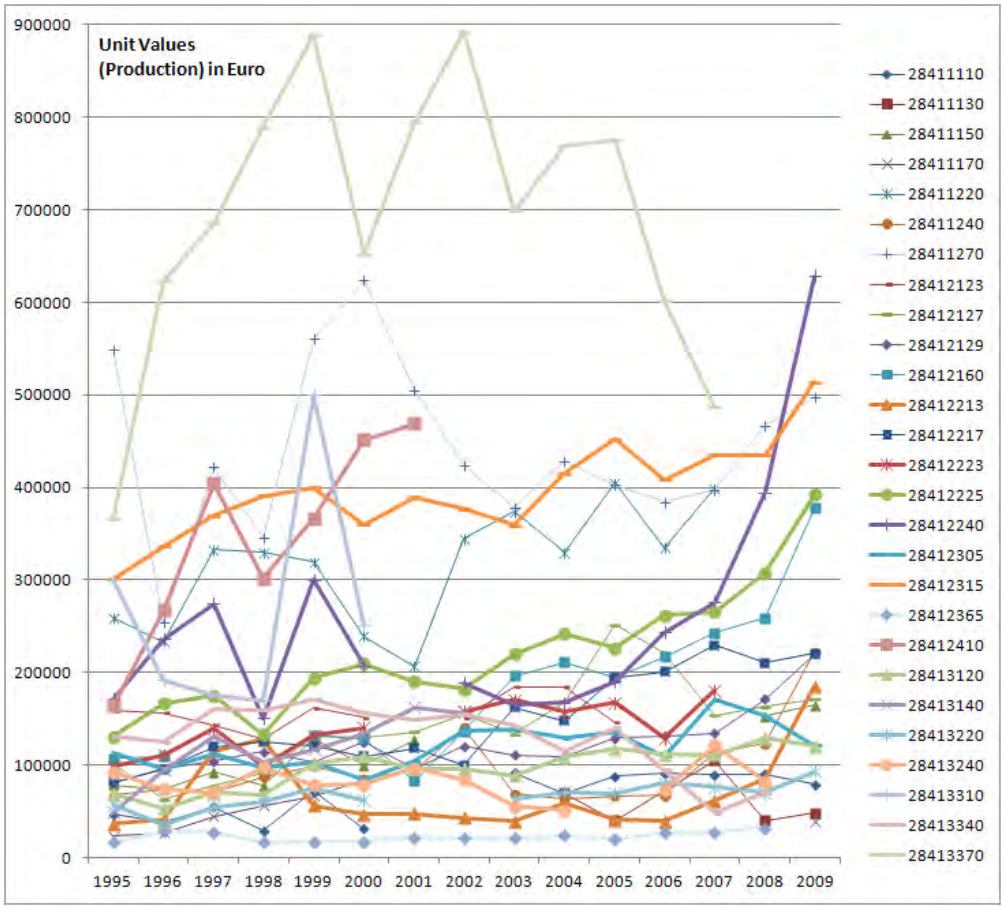


Figure 2-6: Unit values (Production) of CNC machine tools– Development 1995 - 2009

Given these trends in the market the stock model forecast is based on following assumptions:

- For each PRODCOM code the growth rate of "new stock"[25] of the periods 1995-1999 and 2005-2009 is compared and applied as an annual (positive or negative) growth rate for future "new stock", starting with the average of 2007-2009.
- PRODCOM categories with an annual growth rate of more than 5% (2005-09 vs.1995-99) are calculated with max. 5% growth rate to take into account inher-

[25] i.e., production + imports - exports

ent growth limitations, and from 2020 onwards the maximum growth is capped at 3% (reflecting likely market saturation for formerly fast growing markets)

These assumptions result in a stock development of metal working machine tools as depicted in Figure 2-7: The total stock will reach 2.8 million units by 2020 and will remain on this level also in 2025. The share of CNC machine tools will slightly exceed 800.000 units, but complexity and productivity of these will increase further.

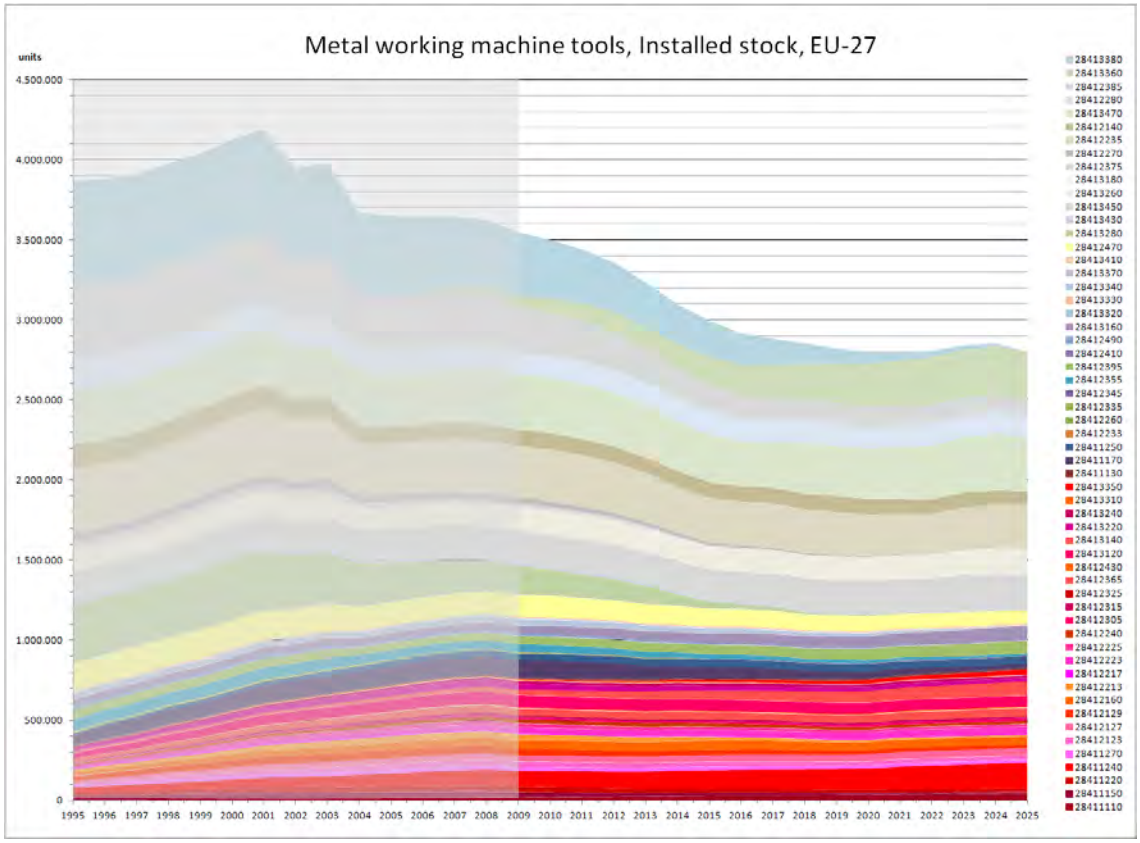


Figure 2-7: Installed Stock – Metal Working Machine Tools Categories – Forecast 2010 - 2025

Calculations of aggregated new installed stock since 2010 for the forthcoming years until 2025 are listed in Table 2-16 and Table **2-17**. Based on these calculations in **2020 2.2 million metal working machine tools will be units sold in 2010 and later**. In

2025 2.8 million metal working machine tools will have been replaced since 2010, and only **20.000 units in stock will be those constructed before 2010**[26].

[26] These figures are subject to the above disclaimers regarding plausibility of the stock model: Figures are appropriate for CNC machine tools, but might overestimate non-CNC machine tools

Table 2-16: Metal working machine tools – Aggregated new installed stock since 2010 (replacement sales) - 2010 - 2017

PRODCOM	Description	2010	2011	2012	2013	2014	2015	2016	2017
28411110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	2.450	5.022	7.723	10.559	13.537	16.663	19.946	23.393
28411130	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)	495	999	1.512	2.034	2.565	3.106	3.657	4.218
28411150	Machine tools for working any material by removal of material, operated by electro-discharge processes	1.210	2.309	3.308	4.216	5.040	5.789	6.470	7.089
28411170	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes	2.395	4.630	6.717	8.664	10.483	12.180	13.765	15.244
28411220	Horizontal machining centres for working metal	2.227	4.420	6.582	8.711	10.808	12.874	14.910	16.915
28411240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	9.116	18.660	28.652	39.112	50.063	61.527	73.528	86.093
28411250	Unit construction machines (single station) for working metal	2.565	5.164	7.797	10.467	13.171	15.912	18.690	21.505
28411270	Multi-station transfer machines for working metal	2.012	3.993	5.943	7.862	9.751	11.611	13.442	15.244
28412123	Numerically controlled horizontal lathes, turning centres, for removing metal	2.132	4.256	6.373	8.484	10.587	12.683	14.772	16.854
28412127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	4.065	8.131	12.199	16.268	20.339	24.411	28.485	32.561
28412129	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)	2.828	5.527	8.101	10.557	12.900	15.136	17.269	19.304
28412140	Non-numerically controlled horizontal lathes, for removing metal	7.301	14.466	21.499	28.401	35.176	41.826	48.352	54.758

28412160	Lathes, including turning centres, for removing metal (excluding horizontal lathes)	2.964	5.918	8.863	11.798	14.724	17.640	20.546	23.443
28412213	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)	832	1.607	2.330	3.005	3.633	4.220	4.767	5.277
28412217	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)	394	760	1.100	1.416	1.709	1.981	2.233	2.468
28412223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	3.064	6.237	9.521	12.922	16.442	20.087	23.860	27.766
28412225	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)	1.432	2.822	4.173	5.485	6.759	7.996	9.198	10.366
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	18.675	37.327	55.958	74.567	93.153	111.718	130.261	148.782
28412240	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	1.026	2.071	3.137	4.224	5.331	6.461	7.612	8.785
28412260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	133	249	349	436	511	576	633	682
28412270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)	596	1.159	1.690	2.191	2.663	3.109	3.530	3.927
28412280	Threading or tapping machines for working metal (excluding drilling machines)	10.187	20.325	30.414	40.453	50.444	60.386	70.279	80.125
28412305	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	1.052	2.156	3.316	4.533	5.812	7.154	8.563	10.043
28412315	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	995	1.989	2.982	3.975	4.967	5.958	6.948	7.937
28412325	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to	293	578	855	1.126	1.389	1.645	1.895	2.138

	accuracy >0.01mm								
28412335	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	0	0	0	0	0	0	0	0
28412345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	332	663	995	1.327	1.658	1.990	2.322	2.653
28412355	Grinding machines for working metal; any one axis can be set to an accuracy >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines	1.869	3.605	5.217	6.716	8.107	9.401	10.602	11.718
28412365	Numerically controlled sharpening (tool or cutter grinding) machines for working metal	4.423	8.912	13.468	18.093	22.788	27.553	32.390	37.299
28412375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal	0	0	0	0	0	0	0	0
28412385	Honing or lapping machines for working metal	15.878	31.152	45.844	59.976	73.570	86.646	99.225	111.324
28412395	Machines for deburring or polishing metal (excluding gear finishing machines)	4.446	9.007	13.688	18.492	23.420	28.478	33.667	38.992
28412410	Broaching machines for working metal	53	105	156	206	256	304	352	399
28412430	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)	626	1.270	1.932	2.614	3.314	4.035	4.776	5.539
28412470	Sawing or cutting-off machines for working metal	7.275	14.353	21.239	27.937	34.455	40.795	46.964	52.965
28412490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.	577	1.130	1.660	2.168	2.656	3.123	3.571	4.001
28413120	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products	5.428	10.821	16.179	21.502	26.792	32.047	37.269	42.457

	(including presses)								
28413140	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	4.825	9.891	15.211	20.796	26.661	32.819	39.285	46.074
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	4.257	8.726	13.419	18.346	23.520	28.953	34.657	40.647
28413180	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	0	0	0	0	0	0	0	0
28413220	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	2.272	4.508	6.707	8.870	10.998	13.091	15.151	17.177
28413240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	1.516	3.011	4.484	5.936	7.366	8.776	10.166	11.535
28413260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	9.411	19.138	29.191	39.583	50.324	61.425	72.900	84.759
28413280	Non-numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	827	1.494	2.034	2.469	2.821	3.106	3.335	3.521
28413310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	139	264	376	476	566	646	718	783
28413320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	18	37	55	74	92	111	129	148
28413330	Presses for moulding metallic powders by sintering or for compressing scrap metal into bales	241	476	706	930	1.150	1.365	1.574	1.779
28413340	Other hydraulic presses, numerically controlled, for working metal	0	0	0	0	0	0	0	0

28413350	Hydraulic presses for working metal	1.869	3.737	5.606	7.475	9.343	11.212	13.080	14.949
28413360	Non-hydraulic presses for working metal	17.658	35.316	52.974	70.632	88.289	105.947	123.605	141.263
28413370	Other non-hydraulic presses, numerically controlled, for working metal	0	0	0	0	0	0	0	0
28413380	Other non-numerically controlled presses for working metal	0	0	0	0	0	0	0	0
28413410	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets	685	1.359	2.024	2.679	3.324	3.960	4.586	5.204
28413430	Thread rolling machines for working metal, sintered metal carbides or cermets	198	378	541	689	824	946	1.056	1.157
28413450	Machines for working wire (excluding draw-benches, thread rolling machines)	12.774	25.813	39.124	52.712	66.583	80.743	95.198	109.953
28413470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal	21.381	43.508	66.408	90.107	114.634	140.017	166.287	193.473
	Totals	**199.417**	**399.449**	**600.332**	**802.271**	**1.005.468**	**1.210.138**	**1.416.476**	**1.624.686**

Updated data for 2010 based on PRODCOM production, import and export figures for 2010 are reported in in the Annex.

Table 2-17: Metal working machine tools – Aggregated new installed stock since 2010 (replacement sales) - 2018 - 2025

PRODCOM	Description	2018	2019	2020	2021	2022	2023	2024	2025
28411110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	27.013	30.813	34.728	38.760	40.463	42.168	43.873	45.575
28411130	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)	4.789	5.370	5.962	6.564	7.177	7.802	8.437	9.084
28411150	Machine tools for working any material by removal of material, operated by electro-discharge processes	7.651	8.162	8.626	9.047	9.430	8.568	7.785	7.074
28411170	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes	16.624	17.913	19.116	20.240	21.288	22.267	23.180	24.033
28411220	Horizontal machining centres for working metal	18.890	20.836	22.754	22.415	22.082	21.754	21.431	21.113
28411240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	99.246	113.017	127.200	141.809	147.740	153.695	159.667	165.649
28411250	Unit construction machines (single station) for working metal	24.358	27.248	30.178	33.147	36.155	39.204	42.293	45.424
28411270	Multi-station transfer machines for working metal	17.018	18.764	20.483	20.163	19.848	19.538	19.232	18.932
28412123	Numerically controlled horizontal lathes, turning centres, for removing metal	18.929	20.998	23.059	25.113	25.029	24.945	24.862	24.778
28412127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	36.638	40.717	44.797	44.814	44.831	44.849	44.866	44.883
28412129	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)	21.246	23.098	24.865	26.551	25.332	24.168	23.058	21.998
28412140	Non-numerically controlled horizontal lathes, for removing metal	61.045	67.215	73.272	79.216	85.050	90.777	89.096	87.447

28412160	Lathes, including turning centres, for removing metal (excluding horizontal lathes)	26.331	29.209	32.078	34.937	37.787	40.628	43.459	46.281
28412213	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)	5.752	6.196	6.609	6.995	7.355	7.690	8.003	7.463
28412217	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)	2.685	2.888	3.075	3.250	3.412	3.168	2.941	2.731
28412223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	31.810	35.997	40.309	44.751	46.261	47.801	49.370	50.969
28412225	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)	11.500	12.602	13.672	14.711	15.720	15.269	14.831	14.405
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	167.281	185.758	204.214	222.647	241.059	259.449	259.143	258.837
28412240	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	9.982	11.201	12.445	13.712	15.004	16.322	17.665	18.008
28412260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	724	761	793	821	845	866	750	651
28412270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)	4.301	4.654	4.988	5.302	5.599	5.879	5.546	5.233
28412280	Threading or tapping machines for working metal (excluding drilling machines)	89.923	99.673	109.375	119.031	128.639	138.201	137.529	136.861
28412305	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	11.597	13.229	14.909	15.589	16.267	16.944	17.618	18.288
28412315	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	8.925	9.913	10.900	10.891	10.882	10.873	10.864	10.856
28412325	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to accuracy >0.01mm	2.374	2.605	2.829	3.047	2.967	2.889	2.813	2.739
28412335	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis	0	0	0	0	0	0	0	0

	can be set up to a minimum accuracy of 0.01mm							
28412345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	2.985	3.317	3.648	3.980	4.312	4.643	4.643	4.643
28412355	Grinding machines for working metal; any one axis can be set to an accuracy >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines	12.755	13.718	14.613	15.445	16.217	16.935	15.733	14.616
28412365	Numerically controlled sharpening (tool or cutter grinding) machines for working metal	42.282	47.341	48.052	48.774	49.507	50.251	51.006	51.773
28412375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal	0	0	0	0	0	0	0	0
28412385	Honing or lapping machines for working metal	122.963	134.158	129.049	124.134	119.406	114.859	110.484	106.277
28412395	Machines for deburring or polishing metal (excluding gear finishing machines)	44.457	50.064	55.817	61.721	67.779	73.995	75.928	77.912
28412410	Broaching machines for working metal	445	490	535	578	621	664	652	641
28412430	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)	6.323	7.130	7.960	8.813	9.065	9.324	9.591	9.865
28412470	Sawing or cutting-off machines for working metal	58.803	64.483	70.009	75.385	80.615	85.703	83.378	81.116
28412490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.	4.413	4.808	5.187	5.550	5.898	6.232	5.976	5.730
28413120	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	47.611	52.733	57.821	62.877	67.900	67.463	67.029	66.597
28413140	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	53.202	60.687	68.397	76.338	79.692	83.050	86.408	89.760
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products	46.936	53.539	60.341	67.346	74.562	81.994	85.392	88.808

	(including presses)							
28413180	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	0	0	0	0	0	0	0	0
28413220	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	19.170	21.130	23.059	24.956	24.550	24.151	23.758	23.372
28413240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	12.885	14.215	15.526	16.818	16.574	16.335	16.098	15.865
28413260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	97.018	109.688	122.738	136.180	150.025	164.286	169.563	174.965
28413280	Non-numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	3.671	3.792	3.889	3.968	4.032	4.084	3.332	2.665
28413310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	841	892	939	980	1.018	1.051	1.081	1.108
28413320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	166	185	203	222	240	259	259	259
28413330	Presses for moulding metallic powders by sintering or for compressing scrap metal into bales	1.980	2.176	2.367	2.554	2.737	2.916	2.850	2.786
28413340	Other hydraulic presses, numerically controlled, for working metal	0	0	0	0	0	0	0	0
28413350	Hydraulic presses for working metal	16.818	18.686	20.555	22.424	24.292	26.161	28.029	29.898
28413360	Non-hydraulic presses for working metal	158.921	176.579	194.237	211.895	229.552	247.210	264.868	282.526
28413370	Other non-hydraulic presses, numerically controlled, for working metal	0	0	0	0	0	0	0	0
28413380	Other non-numerically controlled presses for working metal	0	0	0	0	0	0	0	0

28413410	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets	5.812	6.412	7.002	7.584	8.158	8.723	9.144	8.470
28413430	Thread rolling machines for working metal, sintered metal carbides or cermets	1.249	1.332	1.407	1.475	1.537	1.594	1.493	1.314
28413450	Machines for working wire (excluding draw-benches, thread rolling machines)	125.016	140.393	156.089	172.113	188.470	205.167	222.212	213.799
28413470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal	221.609	250.727	280.718	311.610	332.692	343.548	354.617	330.090
	Totals	**1.834.963**	**2.047.512**	**2.241.394**	**2.427.243**	**2.575.673**	**2.706.312**	**2.771.836**	**2.774.167**

2.2.2.2 Wood working machine tools

Actually, it has to be noticed that average machine tool lifetime – which is quite uncertain as such - changes with the economic cycle and does not keep stable over time. However, these dynamics in detail are not known.

Having said this, the stock model for wood working machine tool product categories (NACE codes) is as listed in the table below for 1995 as Kyoto reference year and 2009 as most recent year, for which Eurostat data is available. This covers explicitly also what is called "light stationary" machinery by EPTA (see Task 1), which is in the terminology of this study rather "transportable" equipment.

Table 2-18: Wood working machine tools - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28491210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	80.874	85.973
28491220	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	95.377	134.938
28491233	Band saws for working wood, cork, bone and hard rubber, hard plastics or similar hard materials	150.692	171.091
28491235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	1.256.347	1.265.651
28491237	Sawing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials (excluding band saws, circular saws)	1.774.961	2.252.145
28491250	Planing, milling or moulding (by cutting) machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	682.899	857.192
28491263	Grinding, sanding or polishing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	166.293	159.022
28491265	Bending or assembling machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	56.602	51.460
28491267	Drilling or morticing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	143.810	144.628
28491275	Splitting, slicing or paring machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	213.330	284.247
28491279	Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials, n.e.c.	248.868	378.955
	Totals	**4.872.048**	**5.787.311**

Total installed stock of wood working machine tools is depicted in Figure 2-8.

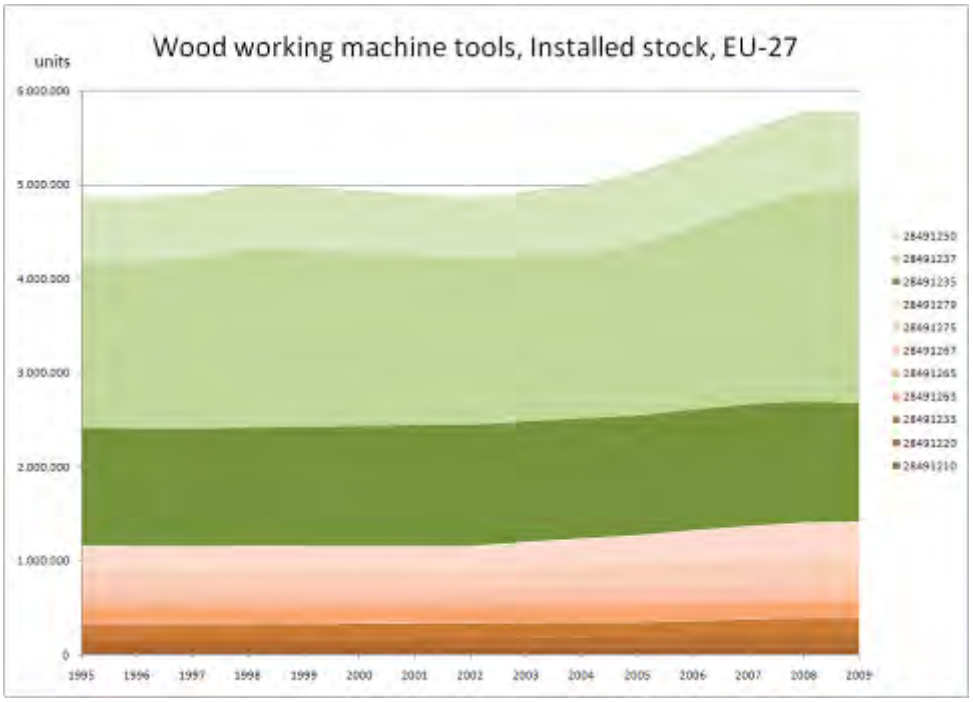


Figure 2-8: Installed Stock – Wood Working Machine Tools Categories – Development 1995 - 2009

The 3 wood working machine tools categories covering (or at least are dominated by) "light stationary", i.e. low value transportable tools are coloured in green in Figure 2-8. The **number of larger stationary machinery** according to this stock model is slightly increasing over the years, totalling in **1.4 million units in the EU27** currently. Considering all wood working machine tools categories, including the "light stationary" ones, the totals are at **5.8 million wood working machine tools** in operation in EU-27. For some of the covered categories in some years non-plausible figures are reported by EuroStat, which could be corrected only with rather rough assumptions. Hence, the stock model is less reliable than for the metal working machine tools.

Regarding the totals there is a slight increase between 1995 and 2009. Even the economic crisis 2008/09 with an effect on the newly installed stock, which significantly dropped for several product categories in 2009, does not result in a visible decrease of total installed stock. This effect is due to the long anticipated machinery lifetimes and presumably due to the fact that the wood working sector partly benefitted from economic recovery packages investing in building and construction.

Given the stable basis of crafts shops in the EU, usage of wood working machinery for domestic building and construction and a s till strong furniture industry in Europe despite partial shift of production to low cost countries, there is little evidence that the

trend in installed units will change drastically in coming years. Hence, in **2025** as a rough estimation the installed stock of wood working machinery is likely to be on the same level as today.

For later calculations of achievable improvements on the EU-27 level the future stock is assumed to remain on the same level as calculated for 2009, and all new wood working machine tools installed are replacement sales. Consequently, depending on the estimated lifetime a certain share of machine tools will be newly installed. The resulting annual replacement rate is listed in Table 2-19 and applied in the following stock forecasts.

Table 2-19: Wood Working Machine Tools – Replacement rate for stock forecasts

PRODCOM	Description	annual replacement rate
28491210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	5%
28491220	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	5%
28491233	Band saws for working wood, cork, bone and hard rubber, hard plastics or similar hard materials	5%
28491235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	5%
28491237	Sawing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials (excluding band saws, circular saws)	5%
28491250	Planing, milling or moulding (by cutting) machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	5%
28491263	Grinding, sanding or polishing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	5%
28491265	Bending or assembling machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	5%
28491267	Drilling or morticing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	5%
28491275	Splitting, slicing or paring machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	5%
28491279	Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials, n.e.c.	5%

Calculations of aggregated new installed stock since 2010 for the forthcoming years until 2025 are listed in Table 2-20 and Table 2-21. Based on these calculations in **2020 3.2 million wood working machine tools will be units sold in 2010 and later**. In **2025 4.6 million wood working machine tools will have been replaced since 2010**, and the remaining **1.2 million units in stock will be those constructed before 2010**.

Table 2-20: Wood working machine tools – Aggregated new installed stock since 2010 (replacement sales) - 2010 - 2017

PRODCOM	Description	2010	2011	2012	2013	2014	2015	2016	2017
28491210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	4.299	8.597	12.896	17.195	21.493	25.792	30.091	34.389
28491220	Multi-purpose machines where the workpiece is automat-ically transferred between operations for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	6.747	13.494	20.241	26.988	33.734	40.481	47.228	53.975
28491233	Band saws for working wood, cork, bone and hard rubber, hard plastics or similar hard materials	8.555	17.109	25.664	34.218	42.773	51.327	59.882	68.436
28491235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	63.283	126.565	189.848	253.130	316.413	379.695	442.978	506.260
28491237	Sawing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials (excluding band saws, circular saws)	112.607	225.214	337.822	450.429	563.036	675.643	788.251	900.858
28491250	Planing, milling or moulding (by cutting) machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	42.860	85.719	128.579	171.438	214.298	257.157	300.017	342.877
28491263	Grinding, sanding or polishing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	7.951	15.902	23.853	31.804	39.755	47.706	55.658	63.609
28491265	Bending or assembling machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	2.573	5.146	7.719	10.292	12.865	15.438	18.011	20.584
28491267	Drilling or morticing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	7.231	14.463	21.694	28.926	36.157	43.388	50.620	57.851
28491275	Splitting, slicing or paring machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	14.212	28.425	42.637	56.849	71.062	85.274	99.486	113.699
28491279	Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials, n.e.c.	18.948	37.896	56.843	75.791	94.739	113.687	132.634	151.582
	Totals	**293.564**	**582.829**	**872.095**	**1.161.358**	**1.450.624**	**1.739.887**	**2.024.856**	**2.314.120**

Table 2-21: Wood working machine tools – Aggregated new installed stock since 2010 (replacement sales) - 2018 - 2025

PRODCOM	Description	2018	2019	2020	2021	2022	2023	2024	2025
28491210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	38.688	42.987	47.285	51.584	55.883	60.181	64.480	68.779
28491220	Multi-purpose machines where the workpiece is automat-ically transferred between operations for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	60.722	67.469	74.216	80.963	87.709	94.456	101.203	107.950
28491233	Band saws for working wood, cork, bone and hard rubber, hard plastics or similar hard materials	76.991	85.545	94.100	102.654	111.209	119.763	128.318	136.872
28491235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	569.543	632.826	696.108	759.391	822.673	885.956	949.238	1.012.521
28491237	Sawing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials (excluding band saws, circular saws)	1.013.465	1.126.072	1.238.680	1.351.287	1.463.894	1.576.501	1.689.109	1.801.716
28491250	Planing, milling or moulding (by cutting) machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	385.736	428.596	471.455	514.315	557.174	600.034	642.894	685.753
28491263	Grinding, sanding or polishing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	71.560	79.511	87.462	95.413	103.364	111.315	119.266	127.217
28491265	Bending or assembling machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	23.157	25.730	28.303	30.876	33.449	36.022	38.595	41.168
28491267	Drilling or morticing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	65.083	72.314	79.545	86.777	94.008	101.240	108.471	115.702
28491275	Splitting, slicing or paring machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	127.911	142.123	156.336	170.548	184.760	198.973	213.185	227.397
28491279	Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials, n.e.c.	170.530	189.478	208.426	227.373	246.321	265.269	284.217	303.164
	Totals	**2.603.386**	**2.892.651**	**3.181.916**	**3.471.181**	**3.760.444**	**4.049.710**	**4.338.976**	**4.628.239**

Updated data for 2010 based on PRODCOM production, import and export figures for 2010 are reported in in the Annex.

2.2.2.3 Welding, soldering and brazing equipment

Actually, it has to be noticed that average machinery lifetime changes with the economic cycle and does not keep stable over time. In particular, it can be assumed that during the economic crisis in 2008/2009 a significant share of welding equipment might have been kept in stock or operation respectively instead of being replaced by new equipment. However, these dynamics in detail are not known.

Having said this, the stock model for welding, soldering and brazing equipment product categories (NACE codes) is as listed in the table below for 1995 as Kyoto reference year and 2009 as most recent year, for which Eurostat data is available.

Table 2-22: Welding, soldering and brazing equipment - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	87.474	76.626
27903145	Electric machines and apparatus for resistance welding of metal	1.038.241	1.014.599
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	1.678.333	1.271.472
27903163	Other for manual welding with coated electrodes	1.688.136	1.868.230
27903172	Other shielded arc welding	1.000.348	1.406.819
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	219.543	209.110
27903190	Machines and apparatus for resistance welding of plastics	892.322	1.087.628
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	87.450	139.121
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	51.321	59.533
	Totals	**6.745.163**	**7.135.147**

Total installed stock of welding, soldering and brazing equipment is depicted in Figure 2-9.

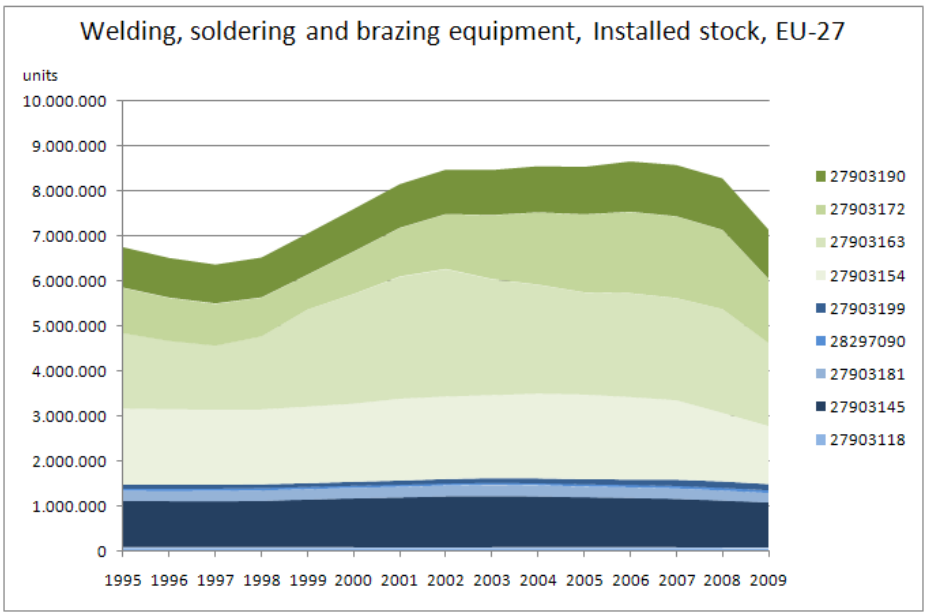


Figure 2-9: Installed Stock – Welding, Soldering and Brazing Equipment Categories – Development 1995 - 2009

The categories covering (or at least are dominated by) rather stationary equipment (indication is a unit value of 10.000 Euro and above) are coloured in blue in Figure 2-9. Smaller, transportable units are those coloured in green. As the transportable units have a shorter lifetime than the installed stationary ones fluctuations in the economic cycles and production figures result also in much higher year-to-year variations according to the simplified stock model. The number of **stationary units** according to this stock model is on a stable level at roughly **1.5 million units in the EU27**. This includes roughly 60.000 soldering machines (PRODCOM 28297090), which are likely to be covered by the scope of the Product Group Study Lot 4 - Industrial and Laboratory Furnaces and Ovens**.** There are another estimated **5.5 – 7 million smaller transportable units**, frequently in the range of a few 100 Euros unit value.

Despite the year-to-year fluctuation there is nearly no difference between 1995 and 2009.

Future developments of the stock are subject to the long-term effect of the 2008/2009 economic crisis and the general trend to shift production to low cost countries – the latter being irrelevant for the consumption of welding equipment to be used on-site (construction sites). A closer look at the newly installed stationary units per year gives the impression, that there was a peak in 2003 and thereafter a downward trend in terms of new equipment installed (unit based), and even the economic growth years

2006-2008 do not fully reverse this trend (Figure 2-10). In particular electric machines and apparatus for resistance welding of metal (PRODCOM 27903145) determine this tendency. The trend observed for metal working machine tools, that there is a shift from lower value industrial machines to rather high value automated (but fewer) machines, is not confirmed for the welding sector by EuroStat figures. In case the observed trend continues this might reduce the number of **installed stationary units** from 1.5 million units currently to roughly **1 - 1.2 million units in 2025** in EU-27.

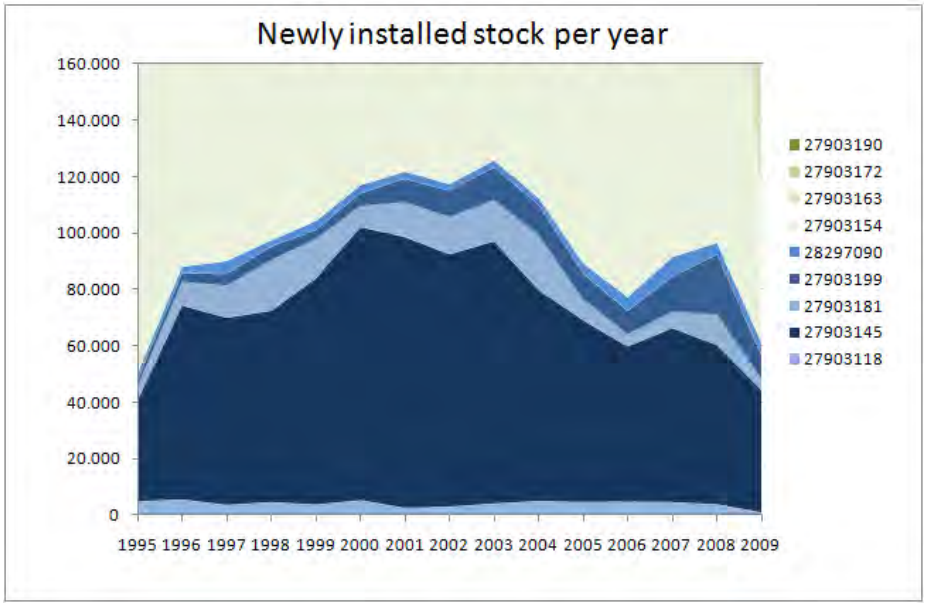


Figure 2-10: Newly Installed Stock per Year – Welding, Soldering and Brazing Equipment (Stationary Units) – Development 1995 - 2009

In developed economies, such as the EU-27, growth of the welding industry and thus consumption of welding equipment is closely related to industrial production. Consumption sectors of particular growth are the energy sector including wind turbine constructions as well as repairs and maintenance of machinery. According to a recent report by Global Industry Analysts, Inc. adopting newer technologies has emerged as the single-most significant trend in the market, whereby numerous segments have given up traditional welding methodologies in favour of modern ones. There has been a sharp decline in the demand for metal welding equipment, with a shift to plastics and other synthetic materials[27]. Furthermore, advancements in welding technology and greater automation will set the momentum for future growth in the industry.

[27] Global Industry Analysts, Inc.: Welding Machinery: A Global Strategic Business Report, October 25, 2010, San Jose

Taking into account these economic trends a rather stable stock of transportable units in forthcoming years can be anticipated.

For later calculations of achievable improvements on the EU-27 level the future stock is assumed to remain on the same level as calculated for 2009, and all welding, soldering and brazing units installed are replacement sales. Consequently, depending on the estimated lifetime a certain share of this kind of equipment will be newly installed. The resulting annual replacement rate is listed in Table 2-23 and applied in the following stock forecasts.

Table 2-23: Welding, soldering and brazing equipment – Replacement rate for stock forecasts

PRODCOM	Description	annual replacement rate
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	5,0%
27903145	Electric machines and apparatus for resistance welding of metal	6,7%
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	14,3%
27903163	Other for manual welding with coated electrodes	20,0%
27903172	Other shielded arc welding	20,0%
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	5,0%
27903190	Machines and apparatus for resistance welding of plastics	5,0%
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	5,0%
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	5,0%

Calculations of aggregated new installed stock since 2010 for the forthcoming years until 2025 are listed in Table 2-24 and Table 2-25. Based on these calculations in **2020 6.2 million units of welding, soldering and brazing equipment will be units sold in 2010 and later**. In **2025 6.8 million welding, soldering and brazing units will have been replaced since 2010**, and the remaining **300.000 units in stock will be those constructed before 2010** (larger installed units with longer lifetimes).

Table 2-24: Welding, Soldering and Brazing Equipment – Aggregated new installed stock since 2010 (replacement sales) - 2010 - 2017

PRODCOM	Description	2010	2011	2012	2013	2014	2015	2016	2017
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	3.831	7.663	11.494	15.325	19.156	22.988	26.819	30.650
27903145	Electric machines and apparatus for resistance welding of metal	67.640	135.280	202.920	270.560	338.200	405.839	473.479	541.119
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	181.639	363.278	544.916	726.555	908.194	1.089.833	1.271.472	1.271.472
27903163	Other for manual welding with coated electrodes	373.646	747.292	1.120.938	1.494.584	1.868.230	1.868.230	1.868.230	1.868.230
27903172	Other shielded arc welding	281.364	562.728	844.091	1.125.455	1.406.819	1.406.819	1.406.819	1.406.819
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	10.455	20.911	31.366	41.822	52.277	62.733	73.188	83.644
27903190	Machines and apparatus for resistance welding of plastics	54.381	108.763	163.144	217.526	271.907	326.288	380.670	435.051
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	6.956	13.912	20.868	27.824	34.780	41.736	48.692	55.649
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	2.977	5.953	8.930	11.907	14.883	17.860	20.837	23.813
	Totals	**982.889**	**1.965.780**	**2.948.667**	**3.931.558**	**4.914.446**	**5.242.326**	**5.570.206**	**5.716.447**

Updated data for 2010 based on PRODCOM production, import and export figures for 2010 are reported in in the Annex.

Table 2-25: Welding, Soldering and Brazing Equipment – Aggregated new installed stock since 2010 (replacement sales) - 2018 - 2025

PRODCOM	Description	2018	2019	2020	2021	2022	2023	2024	2025
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	34.482	38.313	42.144	45.975	49.807	53.638	57.469	61.301
27903145	Electric machines and apparatus for resistance welding of metal	608.759	676.399	744.039	811.679	879.319	946.959	1.014.599	1.014.599
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	1.271.472	1.271.472	1.271.472	1.271.472	1.271.472	1.271.472	1.271.472	1.271.472
27903163	Other for manual welding with coated electrodes	1.868.230	1.868.230	1.868.230	1.868.230	1.868.230	1.868.230	1.868.230	1.868.230
27903172	Other shielded arc welding	1.406.819	1.406.819	1.406.819	1.406.819	1.406.819	1.406.819	1.406.819	1.406.819
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	94.099	104.555	115.010	125.466	135.921	146.377	156.832	167.288
27903190	Machines and apparatus for resistance welding of plastics	489.432	543.814	598.195	652.577	706.958	761.339	815.721	870.102
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	62.605	69.561	76.517	83.473	90.429	97.385	104.341	111.297
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	26.790	29.767	32.743	35.720	38.697	41.673	44.650	47.627
	Totals	**5.862.688**	**6.008.930**	**6.155.169**	**6.301.411**	**6.447.652**	**6.593.892**	**6.740.133**	**6.818.735**

2.2.2.4 Other machine tools

EuroStat figures for other machine tools are of limited accuracy. For the segment stone and ceramics working machine tools the export value in some years exceeded the production value (PRODCOM code 28491150), which could be the case, if imports are re-exported, but is rather unlikely and leads to the assumption, that systematically export statistics cover more machinery types than the production statistics. These inconsistencies could not be verified, and the resulting stock figures are subject to a high level of uncertainty.

Having said this, the stock model for stone and ceramics working machine tools and the like product categories (NACE codes) is as listed in the table below for 1995 as Kyoto reference year and 2009.

Table 2-26: Stone and ceramics working machine tools - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28491130	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	488.852	656.877
28491150	Grinding or polishing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	105.601	108.832
28491170	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)	127.710	178.201
	Totals	**724.158**	**945.919**

Total installed stock of stone and ceramics working machine tools as one major segment of “other machine tools” is depicted in Figure 2-11. The number of installed machine tools rose from **720.000 units** in 1995 to nearly **950.000 units** in 2009 according to this stock model. The economic crisis of 2009 is not visible in this stock model: Although sales volume went down significantly the newly installed stock was in a similar range as 20 years before (the anticipated average lifetime) which leads to a stable stock according to the simplified model.

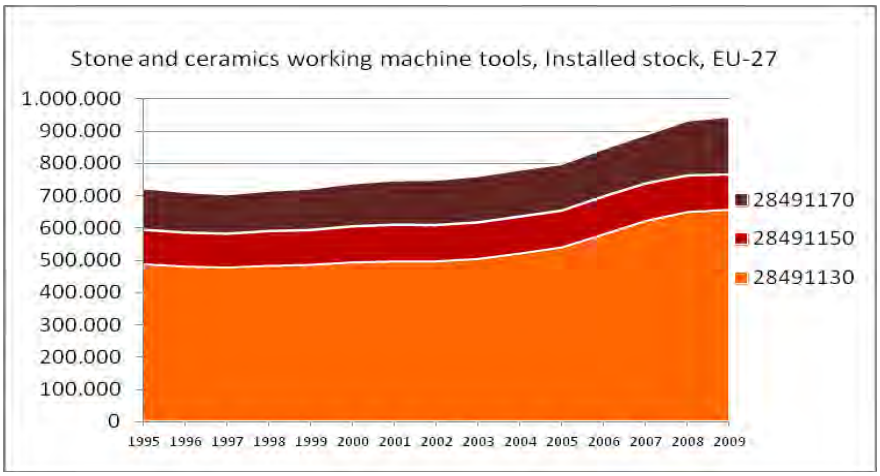


Figure 2-11: Installed Stock – Stone and Ceramics Working Machine Tools Categories – Development 1995 - 2009

For future years it is assumed, that the installed stock remains on a stable level.

Calculations of aggregated new installed stock since 2010 for the forthcoming years until 2025 are listed in Table 2-27 and Table 2-28. Based on these calculations in **2020 520.000 stone and ceramics working machine tools will be units sold in 2010 and later**. In **2025 750.000 stone and ceramics working machine tools will have been replaced since 2010**, and the remaining **200.000 units in stock will be those constructed before 2010**.

Table 2-27: Stone and ceramics working machine tools – Aggregated new installed stock since 2010 (replacement sales) - 2010 - 2017

PRODCOM	Description	2010	2011	2012	2013	2014	2015	2016	2017
28491130	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	32.844	65.688	98.532	131.375	164.219	197.063	229.907	262.751
28491150	Grinding or polishing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	5.442	10.883	16.325	21.766	27.208	32.649	38.091	43.533
28491170	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)	8.910	17.820	26.730	35.640	44.550	53.460	62.370	71.280

Updated data for 2010 based on PRODCOM production, import and export figures for 2010 are reported in in the Annex.

Table 2-28: Stone and ceramics working machine tools – Aggregated new installed stock since 2010 (replacement sales) - 2018 - 2025

PRODCOM	Description	2018	2019	2020	2021	2022	2023	2024	2025
28491130	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	295.595	328.439	361.282	394.126	426.970	459.814	492.658	525.502
28491150	Grinding or polishing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	48.974	54.416	59.857	65.299	70.741	76.182	81.624	87.065
28491170	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)	80.190	89.101	98.011	106.921	115.831	124.741	133.651	142.561

2.2.3 Summary

Based on a comprehensive stock model an installed number of machine tools as listed in the following table can be estimated.

Table 2-29: EU-27 installed stock – Summary (stock model by Fraunhofer)

Category	Installed stock (units, EU-27, 1995)	Installed stock (units, EU-27, 2009)	Installed stock (units, EU-27, 2025)	thereof newly installed between 2010 and 2025 (units, EU-27)
Metal working machine tools	**3.9 million**	**3.5 million**	**2.8 million**	2.8 million
Thereof numerical-controlled	***0.35 million***	***0.75 million***	***0.8 million***	
Wood working machine tools	**5 million**	**5.8 million**	**5.8 million**	4.6 million
thereof larger stationary woodworking tools	***1.2 million***	***1.4 million***	***1.4 million***	
Welding, soldering and brazing equipment	**6.7 million**	**7.1 million**	**7.1 million**	6.8 million
thereof stationary units	***1.5 million***	***1.5 million***	***1.5 million***	
Stone and ceramics working machine tools (as sub-segment of "other machine tools")	**0.72 million**	**0.95 million**	**0.95 million**	0.75 million
Totals	**16.3 million**	**17.4 million**	**16.7 million**	15 million

The major share of the stock will be replaced between 2010 and 2025. Given the long lifetime of industrial equipment a larger number of machine tools constructed before 2010 will be still in operation in 2025.

2.3 Market channels and production structures

The objective of the task 2.3 is the analysis of general market structure and respective trends.

2.3.1 Market Players and Production

2.3.1.1 Metal working machine tools

The main producers of machine tools in Europe are Germany (with a share of almost 50%) and Italy (26%), see Figure 2-12[28]. All other European countries are much less important. Similarly, within the European Union 41% of all machine tools were sold within or to Germany, 24% within or to Italy (see Figure 2-17).

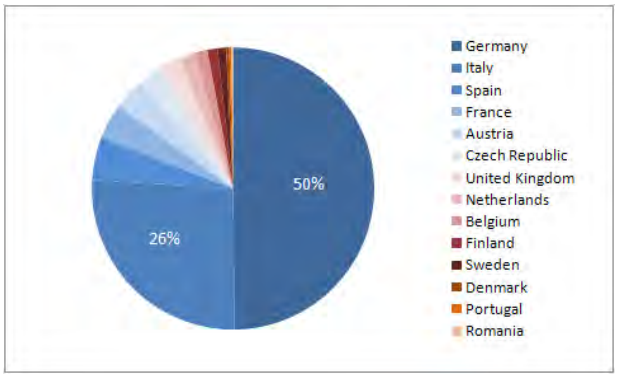


Figure 2-12: Machine tool production share of most relevant EU countries (2008, in monetary units)

Table 2-30 lists the major companies relevant for the machine tool market and the country, where these companies are based. This shows again the strong position of the European machine tool market. Among the top 50 there are 19 manufacturers from the EU-27, thereof 13 from Germany.

There is a trend towards market concentration in the machine tools business, which is driven by the general trend towards globally distributed industrial production: Setting up a production at various locations requires from machine tool providers also a global representation, and customers want a broad spectrum of machine tools they can

[28] Based on: Gardner Publications, Inc.: 2009 World Machine Tool Output & Consumption Survey, http://www.gardnerweb.com/consump/survey.html, accessed: March 11, 2010

choose from, which can be provided rather by machine tool manufacturers exceeding a turnover of at least 1 billion Euro per year. The prediction, that the 20 leading machine tools manufacturer might represent more than 50% global market share mid-term is confirmed by experts[29] (up from below 35% in 2008, see Table 2-30).

Table 2-30: Top 50 Machine Tool Manufacturers Worldwide[30]

	Company Name	Country	Machine tool revenue US $-Mill.	Major Brands
1.	Trumpf	Germany	2,770.3	Trumpf, TruPunch, TruBend, TruLaser
2.	Yamazaki Mazak	Japan	2,525.0	Mazak
3.	Gildemeister	Germany	2,507.9	Gildemeister, Deckel Maho, Gildemeister Italiana
4.	Amada	Japan	2,099.0	Amada, Amada Wasino
5.	Okuma	Japan	1,877.4	Okuma
6.	MAG	U.S.A.	1,654.0	Cincinnati, G&L, Fadal, Cross Hueller, Lamb, XLO
7.	Shenyang	China	1,626.7	Shenyang, Schiess, Liaoning Precsn, Yunnan CY
8.	Mori Seiki	Japan	1,572.0	Mori Seiki, Dixi, Mori Seiki Hitech
9.	Dalian	China	1,525.7	Dalian, Ingersoll Production Systems, BoKo
10.	Jtekt	Japan	1,524.6	Toyoda, Koyo
11.	Schuler	Germany	1,452.9	Schuler, Müller-Weingarten, SMG, Gräbener, Hydr
12.	GF AgieCharmilles	Switzerland	1,000.6	Charmilles, Agie, Mikron, ActSpark
13.	Haas	U.S.A.	880.0	Haas
14.	Doosan Infracore	So. Korea	856.3	Doosan, Daewoo
15.	Makino	Japan	782.8	Makino
16.	Emag	Germany	758.0	Emag; SW; NaxosUnion
17.	Wia	So. Korea	726.0	Hyundai-Kia
18.	Körber Schleifring	Germany	715.1	Blohm, Ewag, Jung, Mägerle, Studer, Walter
19.	Bystronic	Switzerland	690.3	Bystronic, Beyeler, AFM Tianjin.
20.	Index	Germany	675.8	Index, Traub
21.	Komatsu NTC	Japan	609.1	NTC, Nippei Toyama
22.	Aida	Japan	606.8	Aida, Manzoni, Rovetta
23.	Chiron	Germany	598.8	Chiron, STAMA
24.	Rofin-Sinar	Germany	575.3	Rofin, PRC, Lee
25.	A-TEC Industries	Austria	544.5	Emco-Maier, -Mecof, -Famup, Intos, Dorries
26.	Gleason	U.S.A.	542.4	Gleason, Gleason-Pfauter, -Hurth, -M&M
27.	Prima	Italy	540.4	Prima, Convergent Laser, Laserdyne
28.	Heller	Germany	515.8	Heller
29.	Grob	Germany	510.5	Grob
30.	Komatsu Press	Japan	502.1	Komatsu, Komatsu Maypres
31.	Hermle	Germany	409.6	Hermle
32.	Danobat	Spain	400.2	Danobat, Soraluce, Estarta, Overbeck, Newall
33.	Sodick	Japan	389.9	Sodick
34.	Liebherr	Switzerland	375.2	Liebherr, Sigma Pool
35.	Star Micronics	Japan	353.9	Star Micronics
36.	Hardinge	U.S.A.	345.0	Hardinge, Kellenberger, HTT, Bridgeport

[29] See Interview with Dr. Rüdiger Kapitza, CEO Gildemeister AG, and Dr. Masahiko Mori,CEO Mori Seiki Co., Ltd., in: Die Zukunft der Werkzeugmaschinen-Industrie, Produktion Nr. 24, 2007

[30] Metalworking Insiders' Report, Machine Tool Scoreboard, updated July 24, 2009

	Company Name	Country	Machine tool revenue US $-Mill.	Major Brands
37.	Feintool	Switzerland	341.0	Feintool, Schmid, Hydrel
38.	Citizen	Japan	332.3	Citizen Cincom
39.	Nachi-Fujikoshi	Japan	312.0	Nachi
40.	Finn-Power	Finland	306.3	Finn-Power
41.	Comau	Italy	298.5	Comau, PICO, Renault Automation
42.	Mitsubishi H.I.	Japan	292.8	Mitsubishi
43.	Niles-Simmons	Germany	291.0	Niles-Simmons, Hegenscheidt-MFD
44.	StarragHeckert	Switzerland	284.3	Starrag (Rigid), Heckert, SIP
45.	Fagor Arrasate	Spain	270.7	Fagor Arrasate, Ona Pres
46.	Toshiba	Japan	252.9	Shibaura, Toshiba
47.	Autania	Germany	251.1	Elb, WFL Millturn, Profiroll, Wirth & Gruffat, Sieber
48.	OKK	Japan	247.7	OKK
49.	Romi	Brazil	245.1	Romi
50.	Tornos	Switzerland	243.6	Tornos

Table 2-31: Machine tool production in Germany, 2008

Segment	Million Euro
Laser-, ion beam-, ultrasonic machines	473,0
Electrical discharge machines	74,2
Machining centres, flexible systems	1.913,4
Unit construction machines, transfer machines	566,4
Turning machines, turning centres	1.561,9
Drilling machines, boring machines, boring-milling machines	208,6
Milling machines	1.090,2
Grinding, honing, lapping and polishing machines	1.225,6
Gear cutting and finishing machines	748,3
Sawing and cutting-off machines	267,6
Other metal cutting machine tools	85,6
Metal cutting machine tools	**8.214,8**
Forging machines and hammers (incl. presses)	148,7
Bending, folding and straightening machines (incl. presses)	542,6
Shearing, punching, notching machines (incl. presses)	432,9
Other presses	615,8
Wire working machines	299,4
Other metal forming machine tools	462,1
Metal forming machine tools	**2.501,5**
Total machine tools	**10.716,2**
Parts, accessories	2.537,4
Installation, repairs etc.	925,1
Machine tools incl. parts and accessories, installation, repair, maintenance	**14.178,8**

The economic structure of one of the major producing countries for machine tools in Europe – Germany – is listed in Table 2-31[31].

[31] Verein Deutscher Werkzeugmaschinenfabriken: Werkzeugmaschinen-Produktion Deutschland nach Maschinengruppen, 2009

Machine tools production in Italy as the second large player in EU-27 is dominated by small- and medium sized enterprises, meaning a much more fragmented market than in other countries, according to UCIMU[32],[33]: There are roundabout 500 machine tools manufacturer in Italy, considering the manufacturer base of *metal working* machine tools. Most of them do not have more than 70 employees – which is less than in Germany and Japan -. and are family-owned and -managed. According to 2007 data 60,3% of the Italian machine tools companies employ less than 50 people, 16,4% are in the range of 50 – 100 employees, and 23,3% are with more than 100 employees[34]. Export orientation is important even for the smallest machine tools manufacturers; however the export orientation among the larger Italian companies is even more important, see Figure 2-13.

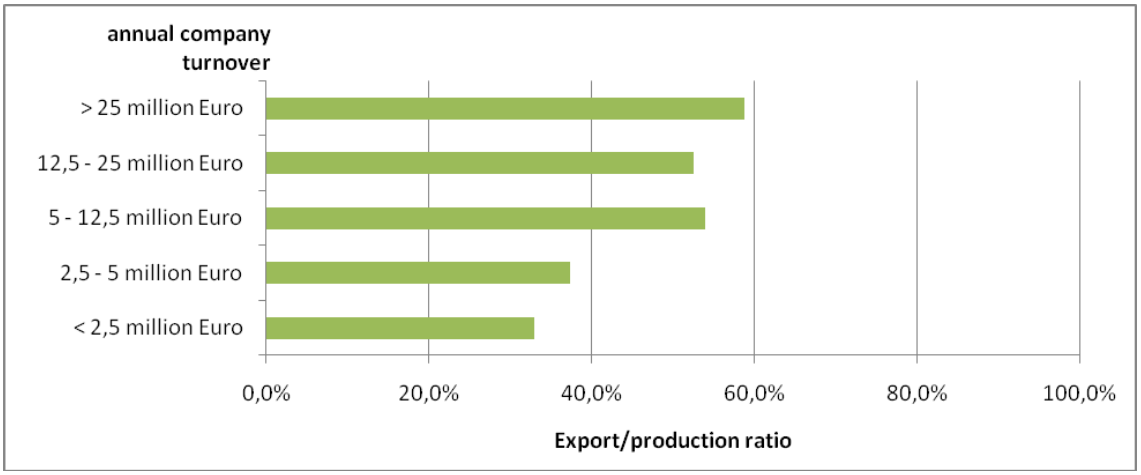


Figure 2-13: Exports/ production ratio of Italian metal working machine tools manufacturers (2007)[35]

32 UCIMU: The Sector Italian Machine Tool: A worldwide success, http://www.ucimu.it/ucimu/eng/index.cfm?id=19

33 Bates, C.: Italian Machine Tools: A Family Affair, IndustryWeek, November 24, 2009, http://www.italianmachinetools.com/news2.asp?id=135

34 UCIMU: 2008 Rapporto di Settore

35 Adapted from: UCIMU: 2008 Rapporto di Settore

2.3.1.2 Wood working machine tools

Wood working machine tools manufacturing is dominated by a multitude of SMEs, exemplarily the situation in Italy and Spain is as follows:

The Italian sector of wood working machinery and tools comprises 300 companies with 40 employees in average[36].

In Spain over 600 companies manufactured wood working machines in 2006 in which SMEs represent 90% of this business sector[37]. Major products of the Spanish market are machine tools like milling machines, classic CNC lathes, production lines for pellets, UV production lines and CNC turning lathes. The industry is concentrated in the three major regions Catalonia (30%), Basque region (23%) and Valencia (22%).

2.3.1.3 Welding, soldering and brazing equipment

According to 2009 PRODCOM figures Germany has a monetary market share in welding, soldering and brazing equipment production of about 55%. As shown in Figure 2-14[38] Germany, Italy, Sweden and France produce more than three quarter of this type of equipment in EU. Other countries in EU27 have no significant relevance.

[36] According to ACIMALL Italian Woodworking Machinery and Tool Manufacturers Association

[37] Instituto Español de Comercio Exterior: Branchenreport – Spanien: Maschinen und Werkzeuge für die Holz- und Möbelbearbeitung, May 2007

[38] Eurostat: PRODCOM 2009 released 12.07.2010

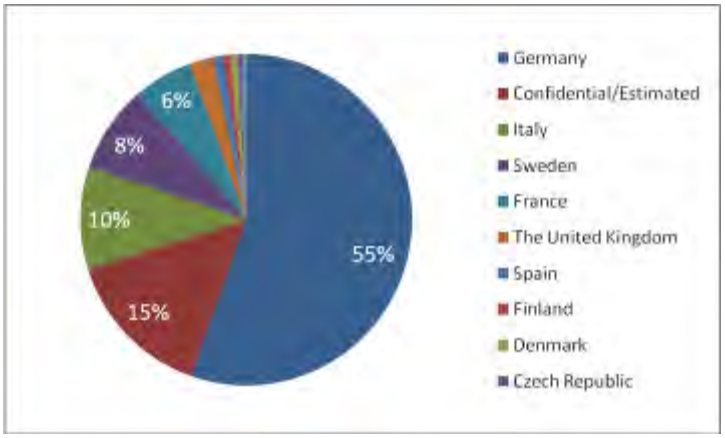


Figure 2-15: Welding, soldering, brazing equipment production share of most relevant EU countries (2009, in monetary units)

France and Italy hold two third of market value of production in category "Other for manual welding with coated electrodes". In terms of units – not economically - this category stands for half of the welding machines.

There is a limited number of companies manufacturing this type of equipment: In Germany for example maximum 10 to 15 companies report into each of the relevant 9 PRODCOM categories[39].

According to EuroStat figures[40] there is an EU-27 production value of roughly 3 billion Euros per year, thereof a value of 1.26 billion exported to non-EU countries and another 360 million Euros value in welding, soldering and brazing equipment imported from non-EU countries.

DVS Deutscher Verband für Schweißen und verwandte Verfahren e.V. (German Welding Society) regularly surveys the market for joining technologies, and states higher production values for the EU, based on 2007 data, than what is identified by our EuroStat evaluation. DVS covers devices, machines and systems[41]: Around one third of the European production of joining technology devices originates from Germany. In 2007, goods with a production value of € 7.5 billion were manufactured in Europe,

39 Statistisches Bundesamt: Produzierendes Gewerbe - Produktion des Verarbeitenden Gewerbes sowie des Bergbaus und der Gewinnung von Steinen und Erden - 2009, Fachserie 4 Reihe 3.1, May 11, 2010

40 years 2005-2009 in average

41 Middeldorf, K.: The Economic Importance of Welding and Joining in Europe Production Values, Values Added and Employees, DVS, July 24, 2009

thereof almost € 2.6 billion in Germany. Other important manufacturers of these devices are Italy with a production value of nearly € 1.2 billion and France with € 320 million, but no information about the laser production in these countries was available. Therefore, their actual production could turn out to be even somewhat higher. In Europe, welding technology devices account for around € 3.9 billion of the production values amounting to € 7.5 billion. This corresponds to a proportion of 52 %. Germany is also the most important welding technology producer in Europe. Almost 43 % of the European welding technology production originates from Germany, 18 % from Italy and 6 % from France.

2.3.2 Target markets: Countries and Sectors

In terms of numbers of enterprises using (potentially) machine tools the target market is very diverse: Machine tools constitute an important part of the production processes in the following sectors:

- DD20: Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
- DH252: Manufacture of plastic products
- DI2612: Shaping and processing of flat glass
- DI2615: Manufacture and processing of other glass, including technical glassware
- DI262: Manufacture of non-refractory ceramic goods other than for construction purposes; manufacture of refractory ceramic products
- DI267: Cutting, shaping and finishing of ornamental and building stone
- DJ28: Manufacture of fabricated metal products, except machinery and equipment
- DK29: Manufacture of machinery and equipment n.e.c.
- DL31: Manufacture of electrical machinery and apparatus n.e.c.
- DL32: Manufacture of radio, television and communication equipment and apparatus

- DL33: Manufacture of medical, precision and optical instruments, watches and clocks
- DM34: Manufacture of motor vehicles, trailers and semi-trailers
- DM35: Manufacture of other transport equipment
- DN36: Manufacture of furniture; manufacturing n.e.c.

These sectors in total represent 1.373 million enterprises in the EU-27 (Eurostat, 2007), see below.

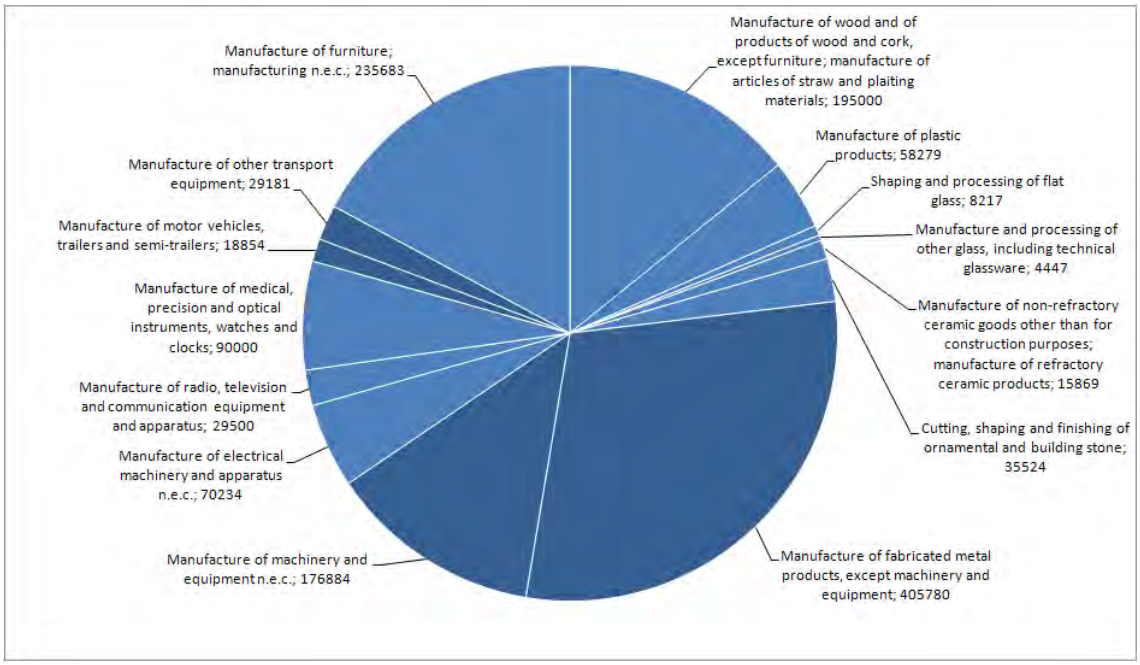


Figure 2-16: Number of enterprises in the target sectors for machine tools (EU-27, 2007)

In some of these sectors almost all companies use machine tools as a core part of the process chain. These sectors alone comprise 640,000 companies in EU-27 (DJ28, DK29, DM34, DM35), most of them small and medium-size enterprises, partly even micro-enterprises. For the other sectors the penetration rate with machine tools is much more uncertain, but widespread use of machine tools can be assumed, although in most enterprises only for few process steps among many other processes. Having this in mind, the **number of machine tools using companies in EU-27 can be estimated at roughly 800,000 – 1,200,000 enterprises**.

Looking at the country split for the most relevant sectors unveils that for both “manufacture of fabricated metal products, except machinery and equipment” and “manufacture of machinery and equipment n.e.c.” the country with the most enterprises is Italy, next are Spain, Germany and France, followed by Poland and the United Kingdom. This reflects also the industry structure in the countries as Italy is characterized by a huge number of micro-scale enterprises.

2.3.2.1 Metal working machine tools

Main consumers of metal processing machine tools in Europe are Germany and Italy, followed by France. The main consumer market in France is the automotive sector.

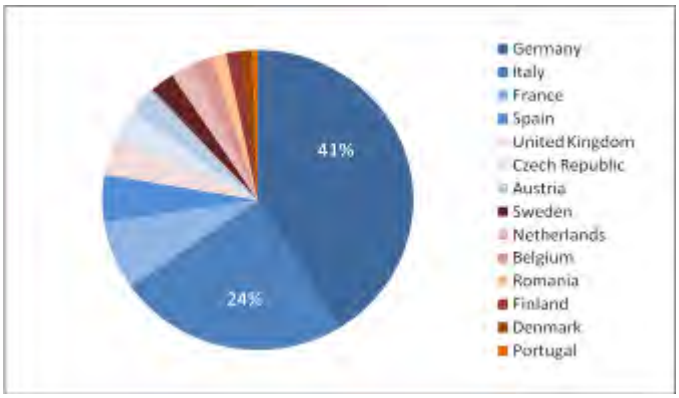


Figure 2-17: Metal working machine tool procurement share of most relevant EU countries (2008, in monetary units)

The automotive sector, although being the most important customer for metal working machine tools in terms of economic value (see below), comprises much less companies as SMEs play a minor role compared to large automotive brands. The large automotive manufacturers each have installed thousands of machine tools, whereas the micro-scale enterprises in manufacture of fabricated metal products might work with only one or two rather simple machine tools.

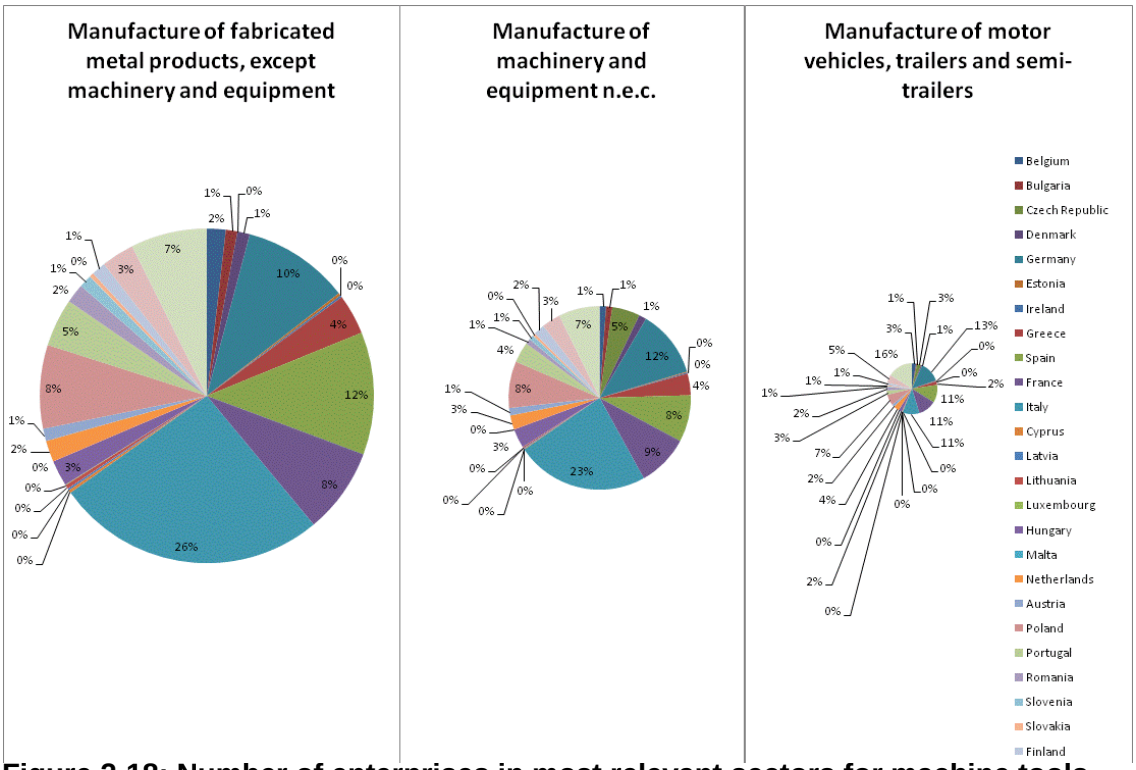


Figure 2-18: Number of enterprises in most relevant sectors for machine tools, per country (2007)

The German project "Werkzeugmaschinen-Initiative 20XX" researched in detail the market for machine tools in Germany, having in mind the metal processing machine tools, and classified the user groups of machine tools as structured in the matrix below[42]. Clearly, the automotive sector is the most important customer for the machine tools industry. Furthermore, the machine tools industry itself actually is in both positions, supplying machine tools, but also being a very important customer. The market segment of manufacturing products of limited complexity as single parts or maximum in small batches is dominated by tool and mould construction. Automotive suppliers clearly dominate the segment of producing less complex products in mass production.

42 Gausemeier, J.; Kinkel, S.: Strategische Technologieplanung mit Zukunftsszenarien - Methoden, Hilfsmittel, Beispiele, VDMA Verlag GmbH, 2008, p. 12

Table 2-32: Most important machine tools users (market share according to machine tools turnover)

		Complexity of products	
		Simple products	Complex products
Number of units per lot	Single part or small-series production	Total: 11%  dominated by **tool and mould construction** (59%)	Total: 14%  dominated by **machine tool building** (33%)
	Medium-size lots or mass production	Total: 28%  dominated by **automotive suppliers** (75%)	Total: 35%  dominated by **automotive manufacturing** (91%)

Increasingly, the European machine tools manufacturers produce for a global market, exporting an increasing share of machine tools abroad. This holds true not only for the larger machine tools manufacturers, but is stated also for the SME dominated machine tools manufacturers from Italy[43].

2.3.2.2 Wood working machine tools

As the sectors depicted above rather represent the target market for metal working machine tools it is worthwhile to look at the target markets for wood working machine tools as well, although in the aggregated sectors “Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials” and “Manufacture of furniture; manufacturing n.e.c.” (Figure 2-19) the penetration rate of machine tools might be slightly lower: Again, the number of enterprises is highest in Italy. Now, also the Czech Republic is very relevant. Other countries with a significant share comprise France, Poland, Spain and Germany.

[43] Bates, C.: Italian Machine Tools: A Family Affair, IndustryWeek, November 24, 2009, http://www.italianmachinetools.com/news2.asp?id=135

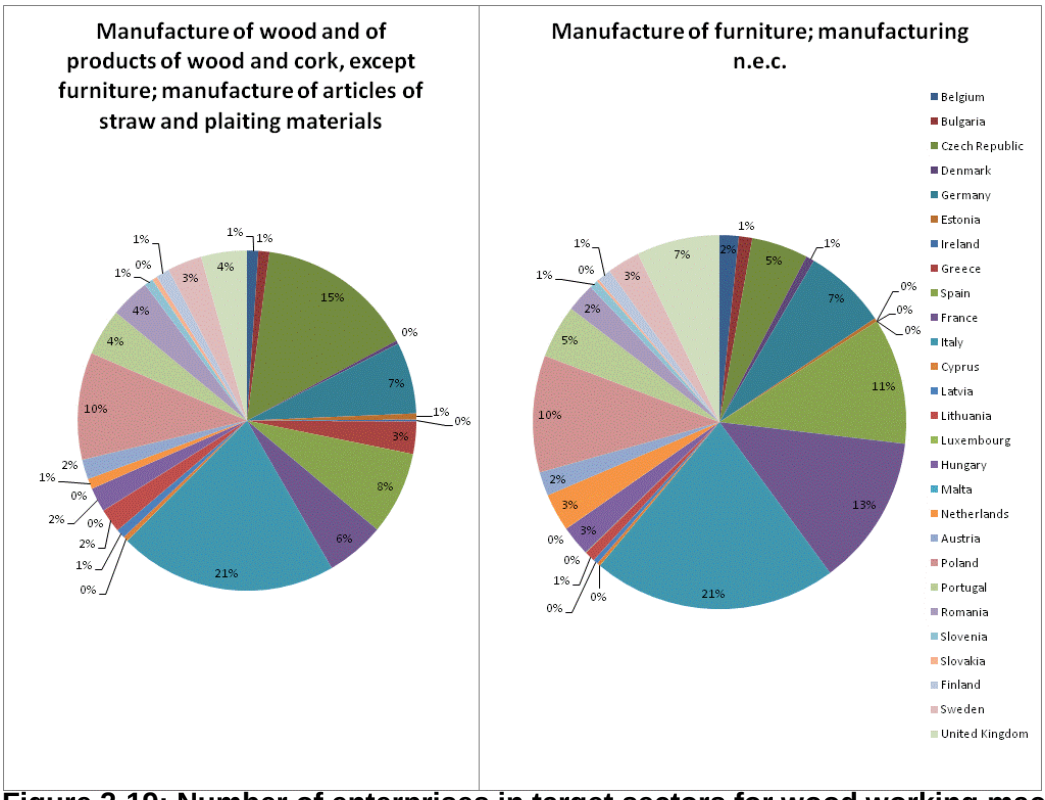


Figure 2-19: Number of enterprises in target sectors for wood working machine tools, per country (2007)

Wood working crafts shops and furniture industry each represent roughly 1/3 of the turnover of the wood working sector in Germany, building and construction parts, and saw mills represent a much smaller economic market share. Among the saw mills there is a trend towards fewer, but larger facilities. In Germany more than 50% of the turnover is generated by only 2% of the saw mills[44]. Most likely this results also in an increasing demand for rather larger, automated wood working machinery.

2.3.2.3 Welding, soldering and brazing equipment

Key target markets for welding equipment comprise the following[45]:

- Automotive sector, where a technology shift is observed from steel to aluminium welding due to the demand for light-weight vehicles

[44] Fraunhofer Institut für Produktionstechnik und Automatisierung: Delphi-Studie "Holzbearbeitungstechnologien 2015", 2005

[45] Chauhan, A.: Will the Energy and Repairs and Maintenance Industry Drive the Global Welding Market Out of Recession? Frost & Sullivan, August 4, 2009

- Aerospace industry, including building new aircrafts and maintenance of existing ones.
- Shipbuilding
- Heavy machinery building
- Energy and power industry, in particular manufacturing of wind turbines, which sees a steady and stable growth against the trend of the economic crisis. (the energy generation market currently occupies a share of 11 per cent in the total global welding market)
- Repair and maintenance in various sectors, frequently done by small enterprises.

2.3.3 Production Structures and Trends

2.3.3.1 Metal working machine tools

There are a couple of indicators and trends with potentially important effects for the machine tools industry, influencing the specifications and market conditions:

- Batch size
- Product size
- Precision requirements
- Product cycles

The *batch size* is a very important factor for configuration and use patterns regarding machine tools and frequently there is a trend mentioned towards “one piece flow”, which has been confirmed as being relevant in a comprehensive survey of Fraunhofer ISI, Heinrich-Nixdorf Institut and VDW among German users of machine tools back in 2003 (covering 1,450 companies) [46], but not as a dramatic change: In total 24% of the companies from the metalworking and electrical industry stated, that the number of variants required by their customers increased significantly, 51% stated a slight increase in number of variants, 22% stated no changes. The sub-sector with the strongest trend towards an increased number of variants is the vehicle construction (i.e. dominated by the automotive manufacturing industry; 32% - significant increase, 55% - slight increase). Whether an increased spectrum of variants also results in smaller batches produced depends on further conditions, e.g. process planning and order management. The survey revealed, that actually at 10% of the companies in the metalworking and electrical industry the manufactured lot size shrunk significantly, 24%

46 Gausemeier, J.; Kinkel, S.: Strategische Technologieplanung mit Zukunftsszenarien - Methoden, Hilfsmittel, Beispiele, VDMA Verlag GmbH, 2008, p. 18-21

stated a slightly shrinking lot size in average, whereas among 42% of the companies lot sizes remained the same, 20% and 5 % even stating a trend towards larger and much larger lot sizes. Gausemeier and K inkel conclude, that industry did not (yet) broadly implement a “one piece flow”, nor is it likely to happen short- to mid-term; usage of machine tools is likely to remain **dominated by mid-size lots and mass production**, although **more flexible machine tools configurations** are required for a couple of applications. Recently the VDW published another survey among member companies regarding lot sizes of machine tools production[47]: At maximum 150 machine tools of a given model are produced per year, stated by one of the large manufacturers, whereas most models are produced in less than 50 units per year, frequently even below 10 units per year, indicating the high level of customisation among metal working machine tools.

Product size matters for the dimension of machine tools. Both developments are observed, the trend towards smaller, miniaturised objects and processing of larger units the survey of “Werkzeugmaschinen-Initiative 20XX” identified, that product dimensions have been considered to remain roughly the same by 63% of the users of machine tools, and from the remaining, more state a trend towards larger products than smaller ones. The trend towards smaller product dimensions is clearly dominating in the sector “manufacturing of electrical machinery and apparatus” (10% report a significantly reduced size, 18% a slight size reduction), whereas the adverse trend towards larger objects is most significant in vehicles construction (15% report significantly increased product sizes, 23% a slight increase) [48].

Precision requirements are an important quality criterion for machine tools, but also for process stability, and thus influence the use patterns for machine tools in the production environment. More than one quarter of those machine tools users replying to the survey under the “Werkzeugmaschinen-Initiative 20XX” stated, that precision requirements increased significantly, another 44% state a slight increase[49]. In particular those sectors which are major consumers of machine tools (tool and mould construction, automotive manufacturing) are characterized by increasing precision requirements.

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47 Hagemann, D.: Die energieeffiziente Werkzeugmaschine – Rahmenbedingungen und Lösungen für eine nachhaltige Fertigungstechnik, Symposium „Energieeffiziente Werkzeugmaschinen“, Düsseldorf, February 24, 2010

48 Gausemeier, J.; Kinkel, S.: Strategische Technologieplanung mit Zukunftsszenarien - Methoden, Hilfsmittel, Beispiele, VDMA Verlag GmbH, 2008, p. 24-25

49 Gausemeier, J.; Kinkel, S.: Strategische Technologieplanung mit Zukunftsszenarien - Methoden, Hilfsmittel, Beispiele, VDMA Verlag GmbH, 2008, p. 26

Product cycles have an impact on investment decisions: The more frequently a production line has to be changed to produce new products, the shorter the return on investment time span has to be. Changing product portfolios might also require more flexibility for machine tools configurations, i.e. modularity and adaptability. However, a survey regarding the product cycles of products manufactured with machine tools revealed, that in the metalworking and electrical industry only 13% of the revenue stems from products introduced within the last 3 years, another 53% from products introduced first up to 10 years ago and nearly one-third of the product revenue is even from products introduced more than 10 years ago[50].

The sub-segment of special purpose machinery manufacture lost market shares in the past despite the increasing demand for customized solutions: 72% of the machinery investment of the metalworking and electrical industry is spent for machinery, which is based on standard equipment. 14% of investments is spent for machinery developed specifically for a given application, and 13% is spent for internal machinery developments[51]. Obviously, the market of "standard" machine tools became more diverse, more flexible to address specific customer requirements with a given machinery platform.

The production structures of Gildemeister are somewhat typical for the European market[52]: Material is sourced inter alia in Russia, Romania and Poland. Due to the high wages in Germany, only the machining of key components and high-quality assembling takes place there. Actually Gildemeister manufactures high-tech machine tools in Germany, so-called "entry" machine tools are manufactured in Poland and China, machine tools according to specific customer requirements in Italy.

2.3.3.2 Wood working machine tools

The wood working machine industry is currently undergoing a major change, which focuses on fully automated equipment and the topic of sustainability and energy efficiency gains importance. The furniture production sector represents the most important

50 Gausemeier, J.; Kinkel, S.: Strategische Technologieplanung mit Zukunftsszenarien - Methoden, Hilfsmittel, Beispiele, VDMA Verlag GmbH, 2008, p. 28-29

51 Gausemeier, J.; Kinkel, S.: Strategische Technologieplanung mit Zukunftsszenarien - Methoden, Hilfsmittel, Beispiele, VDMA Verlag GmbH, 2008, p. 40

52 See Interview with Dr. Rüdiger Kapitza, CEO Gildemeister AG, and Dr. Masahiko Mori,CEO Mori Seiki Co., Ltd., in: Die Zukunft der Werkzeugmaschinen-Industrie, Produktion Nr. 24, 2007

driver for those changes. Even the international market describes a trend to fully automated equipment with the furniture industry as major driver for mass production. Conferences and industry fairs in the business sector recently integrate topics like sustainable production and energy efficient products. Medium sized and large-scale enterprises drive those topics.

Technology trends

Regarding the general trend of higher automated products a 2005 report on future technology trends in the woodworking machine sector identified a growing usage of industrial robots for load and unloads operations.[53] The industry estimated that wood as raw material is more and more industrial produced with improved material properties. This means that there is a change to improved raw materials with chipped wood as basis and the development of new surface treatment and finish treatment for solid wood. Those trends of new and improved raw materials require new and adapted machines for transforming processes. In Europe, particularly in Germany or Spain there is an upcoming trend for “one piece flow” production in the furniture sector. Concerning this changed user demand the traditional use of single machines switch to the use of modular systems with a central control system. Existing machines gets upgraded with computer controlled information systems to integrate them into a new central controlled system. The advantage of this system trend is a better integration of power management for all connected machine modules. It is possible to send each module individually into a standby mode after the defined task is finished. A manual power on and –off becomes obsolete. The potential disadvantage of the additional power consumption by the integrated ICT components could be disregarded related to the energy savings of a well-integrated power management system.

The growing use of laser technology for improved differentiation and positioning of machine tools stands for a potential aspect for increased energy consumption. Laser technology in woodworking is used increasingly for edge gluing, where laser technology could save energy compared to usage of conventional hot melt adhesives[54], or engraving, but also for wood cutting of finely wrought workpieces. Compared to processing other types of materials, laser applications for wood working are a rather minor

[53] Fraunhofer Institut für Produktionstechnik und Automatisierung: Delphi-Studie "Holzbearbeitungstechnologien 2015", 2005

[54] HOMAG Group: ecoPlus – Technology that really pays off, Schopfloch

segment of the whole laser market[55]. No information is available regarding market growth of laser processing for wood in particular.

The use of nanotechnology is an innovation that affects the wood industry in two different aspects. First, the development of wood coatings particular for UV absorbing and penetration requires new machines for coating processes. Second, the increased durability of both, machine parts and tools with the application of nano-modified materials will have effects on the configuration and sustainability of wood working machines. Today nano technologies affect are widely present in research activities. In 2005 experts expected the implementation into the product design for woodworking machines by 2010[56].

2.3.3.3 Welding, soldering and brazing equipment

Given the fact, that joining technologies are cross-sectorial technologies, which are applied in multiple sectors, large industry and small enterprises, as well as for infrastructure, this industry is considered relatively resistant to economic cycles.

Technology Trends

Important changes in the welding branch are related with emerging new and advanced technologies and changes regarding materials to be processed – which are closely related to technology changes: The trend towards lightweight construction, joining of coated sheets and in general modularization of fabrication among other trends leads to a competition between joining technologies. The dominating thermal joining processes are challenged by low-heat and cold joining processes, such as adhesive bonding[57]. This might result in a general power consumption reduction for joining processes, but this is a question of proper technology choice, not of the equipment as such. Combined, hybrid technologies such as the combination of gas-shielded metal-arc welding

55 LaserFocusWorld: Annual Review and Forecast: Skies may be clearing, but fog still lingers, January 1, 2011, http://www.laserfocusworld.com

56 Fraunhofer Institut für Produktionstechnik und Automatisierung: Delphi-Studie "Holzbearbeitungstechnologien 2015", 2005

57 Grote, K.-H.; Antonsson, E. K. (Eds.): Springer Handbook of Mechanical Engineering, Springer, 2009, pp. 660-662

and laser welding gain ground and are subject to intensive research work. Miniaturization drives the trend towards micro joining technologies. Research in joining technologies currently focuses on highest-strength steel, light metals (aluminium and magnesium alloys) and mixed joints. Grote et al. state the following major trends regarding individual technologies:

- Gas-shielded arc welding retains a dominant position, but is likely not to grow as quickly as in the past years
- Resistance welding processes will hold a dominant position among joining processes given the high productivity and process performance, but will be replaced for certain applications by mechanical joining technologies and adhesive bonding
- Laser beam welding processes are likely to gain increasing importance

Expectations for future technology development and application stated by companies surveyed by the German DVS are depicted in Figure 2-20, confirming the trends stated above.

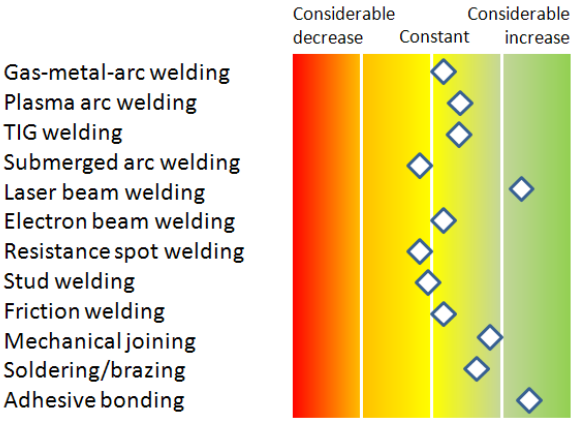


Figure 2-20: Prospective development of joining processes

The forecasted increase in laser beam welding stems from improvements of the laser beam source: With an increase in the maximum power output, and improvements in the ability to focus the laser beam, new applications emerged in particular in the automotive sector, shipbuilding, and apparatus construction[58].

58 Grote, K.-H.; Antonsson, E. K. (Eds.): Springer Handbook of Mechanical Engineering, Springer, 2009, pp. 668

2.3.4 Suppliers

System components for machine tools are of importance when investigating the industry structure of the machine tools industry. Key technology components comprise control technology, pneumatic and hydraulic systems, spindles, drives, motors, bearings, gears, pumps, compressors, taps and valves. Iron and steel are typically the most relevant supply materials.

As most machine tools manufacturers are small and medium sized enterprises, they are not capable of having all the technology know-how in-house for all the components and have to rely on numerous suppliers for key components and modules. Some machine tools manufacturers even rather operate as a type of engineering company, assembling customized machines from components sourced from suppliers.

There are only a very limited number of relevant hardware suppliers for **control technology**, i.e. Computer Numerical Controller (CNC): The market is dominated by Siemens, with global market share of 33,3 % in 2006, followed by Fanuc and Mitsubishi Electric with 32 % and 12,4 % respectively. Total global market size is 4,5 billion US-$[59]. A couple of smaller companies are also active in some market niches as suppliers of CNC technology, but their number and market share is rather limited[60]. A survey among CNC users in Germany revealed in 2007 the current usage of CNC systems: Being asked, what is the CNC system you are working most frequently with, 40,5% gave Heidenhain as a reply, another 28,8% Siemens[61], see Figure 2-21.

[59] Tsakiridou, E.: The Buzz About Automation, Pictures of the Future, Fall 2007, p. 19

[60] The leading German directory of suppliers „wer liefert was?“ lists as suppliers of control technology for machine tools in total 23 companies (as of March 2010)

[61] Strutzke, A.: CNC-Marktstudie zeigt Anwenderwünsche, Marktstudie: MM Maschinenmarkt, Internetforum CNC-Arena, Whitepaper, October 8, 2007, 1338 respondents covered with this survey, http://www.maschinenmarkt.vogel.de/index.cfm?pid=1610&pk=95048&icmp=aut-artikel-artikel-80

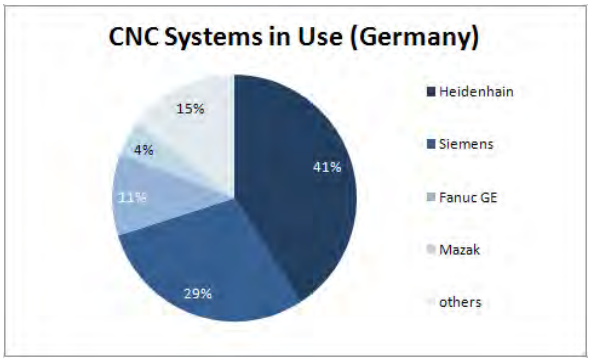


Figure 2-21: CNC Systems in Use in Germany (2007) according to recent surveys

In the broader programmable logic controllers (PLCs) business with a size of 8,9 billion US-$ globally the hardware, software, and services market share of Siemens is 31,3 %, followed by Rockwell with 22,1 % and Mitsubishi with 12,7 %[62,63], see Figure 2-22: 8 companies cover nearly 90% of the global market.

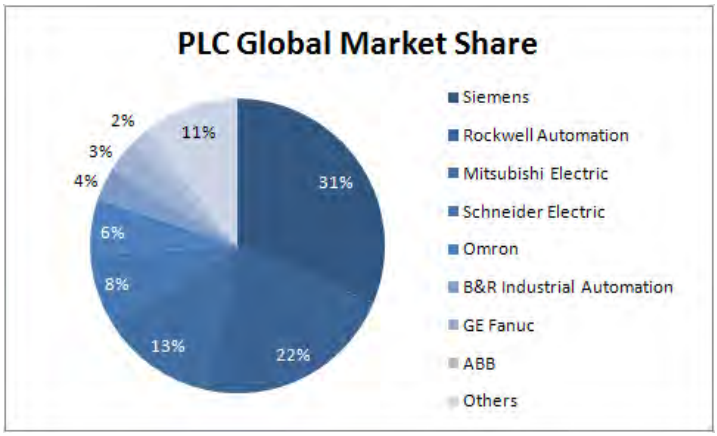


Figure 2-22: PLC Global market shares (2007)

The market for **cooling lubricants** is also dominated by few companies, among them Rhenus Lub with a 2009 production volume of 14.000 t (compare to totals of consumption as stated below), Fuchs, Henkel, SKF. Many of the manufacturers of cooling lubricants are based in the EU-27.

62 ARC Advisory Group, referenced in Rick Zabel: State of Manufacturing & Automation in the U.S. Looks Good, July 30, 2008, automation.com, http://www.automation.com/content/state-of-manufacturing-and-automation

63 These figures refer to the PLC market in general, not only the machine tools market

The machine tools industry furthermore is a supplier of its own: Machine tools are key to the manufacture of machine tools and components. The broad spectrum of specialized machine tool manufacturers constitutes therefore also the base of investment good suppliers to this branch.

2.4 User expenditure base data

The objective of this subtask is to gather base data about user expenditure which will be used to calculate Life Cycle Costs (LCC).

There is no robust, comprehensive single source on life cycle costs for machine tools, but some exemplary calculations, indicating cost relations for some metal working machine tools (but not to be considered as representative for the whole range of machine tools).

LCC of a vertical machining-centre (3 axes)

The CO$TRA project by PTW published an exemplary LCC calculation for a machining centre with following settings and assumptions[64]:

- Initial investment (purchase price, installation, start-up, initial set of tools and spare parts, training of operators): 198,000 Euro
- 2-shifts operation at 224 days/year (3,584 h/year)
- Product: simple milled part, processing time 145 s, annual output 85,000 units
- Assumed yield 99,99%, resulting in a machine running time of 2,928 h/year, remaining time (656 h/year) in standby
- Power consumption (average, including cooling lubricant supply, exhaust system): 22kW during operation, 11kW in standby.
- Free warranty: 12 months, response time of service personnel: 12 hours
- Unscheduled down times calculated with 75 Euro/hour (corresponding to the hourly rate of an operator)
- The calculation covers a period of 10 years

Total life cycle costs under these conditions are stated at 582,000 Euro, thereof 34% initial investment, 20% maintenance and planned overhauling, 15% unscheduled overhauling, 17% energy costs, 5% pressurized air, 5% occupancy costs (building), 4% expenses for capital commitment. Costs for yield losses, tools and setup time are explicitly not taken into account, furthermore the calculation does not state costs for material, personnel costs during operation and for cooling lubricants.

64 Dervisopoulos, M.: CO$TRA – Life Cycle Costs Transparent, Abschlussbericht, Kurzfassung, PTW, Technische Universität Darmstadt, 2008, p. 26-27

Life cycle costs are largely dependent on the individual use patterns. As a first approximation Abele et al.[65] consider initial investment representing roughly 30% of total life cycle costs for a machine tool as appropriate, 10 years lifetime assumed.

Another exemplary cost calculation by PTW for a machine tool states the following cost relations[66]:

- Initial investment: 100,000 Euro
- Annual running costs: 39,000 Euro, thereof
    - 8% expenses for capital commitment
    - 37% planned maintenance
    - 8% unscheduled overhaul
    - 6% occupancy costs
    - 21% electricity costs
    - 3% pressurized air
    - 16% cooling lubricant

Failure reasons for downtimes of machine tools have been analysed by Fleischer[67]: An analysis of representative field data unveiled, that that there are basically four main component groups responsible for most downtimes, in declining order of importance:

- drive axes,
- spindle and tool changer,
- electronics and
- fluidics

As every downtime is a cost issue, maintenance and repair of these assemblies constitutes a major cost factor in terms of life cycle costs of machine tools.

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65 Abele, E.; Dervisopoulos, M.; Kuhrke, B.: Bedeutung und Anwendung von Lebenszyklusanalysen bei Werkzeugmaschinen, in: Schweiger, S. (Edt.): Lebenszykluskosten optimieren – Paradigmenwechsel für Anbieter und Nutzer von Investitionsgütern, Gabler, Wiesbaden, 2009

66 Abele, E.: Begrüßung und Einstimmung, Symposium „Energieeffiziente Werkzeugmaschinen“, Düsseldorf, Germany, February 24, 2010; remark by Abele: 21% electricity costs rather to be seen as a maximum value, not average

67 Fleischer, J.; Broos, A.; Schopp, M.; Wieser, J.; Hennrich, H.: Lifecycle-oriented component selection for machine tools based on multibody simulation and component life prediction, CIRP Journal of Manufacturing Science and Technology, Volume 1, Issue 3, 2009, p.179-184

In the welding business workpiece related costs are determined by multiple factors. Some of these are related to investment and consumables, but in addition for the user it is important to consider other process related costs as listed in [68].

Table 2-33: Welding cost parameters

Preparatory costs	Process and equipment related costs	Post-core-process costs
■ Time for joint preparation. ■ Time to prepare the material for welding (blasting, removal of oils, etc.). ■ Time for assembly. ■ Time to preheat the joint (when required). ■ Time for tack-up. ■ Time for positioning.	■ Welding equipment invest. ■ Time for welding. ■ Time for changing electrodes. ■ Time to move the welder from one location to another. ■ Time to change welding machine settings. ■ Cost of electrodes. ■ Cost of shielding materials. ■ Cost of electric power. ■ Cost of fuel gas for pre-heat (when required).	■ Time to remove slag (when applicable). ■ Time to remove spatter. ■ Time for inspection. ■ Time to repair or re-work defective welds. ■ Costs associated with any required stress relief.

2.4.1 Electricity, fuel and interest and inflation rates

Eurostat provides data on electricity prices. Most recent ones for industrial customers are compiled for the second half of 2009 by EU-27 member state in Table 2-34.

The EU-27 average electricity price for industrial customers was 0.0952 Euro/kWh in 2009.

Electricity prices in the no. 2 machine tools consuming country Italy are significantly above the EU-27 average, partly by 30% and more, in Germany as no. 1 machine tools consuming country electricity tariffs are roughly 10% above average, similarly in Spain (no. 4), in Italy by even more than 30%. In the number 3 machine tools consuming country France the electricity tariffs are well below the EU-27 average. Between France and Italy there is a factor of more than 2, demonstrating the significant spread of electricity prices across Europe.

Smaller crafts enterprises for wood working (carpenter's shops and the like) are in the 20 – 500 MWh/a range, the large brand name automotive manufacturers consume typ-

[68] adapted from D.K. Miller: Determining the Cost of Welding, Welding Design & Fabrication, March 1, 2004

ically more than 150 000 MWh in their main production countries. A larger metal-working company such as Heidenhain with 3,000 employees and a production facility in Traunreut, Germany – actually also an important supplier for the machine tools industry itself – is in the 20 – 70 GWh range. The majority of small and medium sized metal and wood working companies can be assumed to be in the range of 500 – 2 000 MWh. In the case of Italy, there is a tendency towards even smaller companies, and thus an even lower power consumption range.

Table 2-34: Electricity Prices for Industrial Customers in EU-27, 2nd half 2009

	Band IA : < 20 MWh	Band IB : 20 - 500 MWh	Band IC : 500 - 2 000 MWh	Band ID : 2 000 - 20 000 MWh	Band IE : 20 000 - 70 000 MWh	Band IF : 70 000 - 150 000 MWh	Band IG : > 150 000 MWh
EU-27	0,1632	0,1198	0,1023	0,0911	0,0833	0,0758	:
Belgium	:	:	:	:	:	:	:
Bulgaria	0,0767	0,0721	0,0639	0,0583	0,0516	0,0476	0,0476
Czech Republic	0,1720	*0,1398*	0,1122	0,0978	0,0912	0,0916	:
Denmark	0,1800	0,0967	0,0927	0,0900	0,0820	0,0806	:
Germany	0,1888	*0,1323*	**0,1134**	0,1007	0,0901	0,0861	:
Estonia	0,0815	0,0693	0,0645	0,0572	0,0460	0,0461	:
Ireland	0,1688	0,1406	0,1175	0,0971	0,0888	0,0788	:
Greece	0,1540	0,1159	0,0936	0,0811	0,0729	0,0636	0,0595
Spain	0,1770	*0,1335*	**0,1120**	0,0934	0,0823	0,0709	0,0499
France	0,1158	*0,0824*	**0,0656**	0,0621	0,0628	0,0532	:
Italy	0,2384	***0,1530***	**0,1370**	0,1224	0,1081	0,0888	0,0845
Cyprus	0,1563	0,1574	0,1494	0,1362	0,1221	0,1217	:
Latvia	0,1161	0,0967	0,0893	0,0835	0,0767	0,0712	:
Lithuania	0,1057	0,0921	0,0790	0,0666	0,0622	:	:
Luxembourg	0,1986	0,1312	0,1158	0,0936	0,0655	:	:
Hungary	0,1271	0,1226	0,1297	0,1146	0,1055	0,0877	0,0952
Malta	0,1460	0,1425	0,1291	0,0860	0,0860	0,0860	0,0860
Netherlands	0,2010	0,1450	0,1110	0,1010	0,0940	0,0920	0,0740
Austria	:	:	:	:	:	:	:
Poland	0,1455	*0,1115*	0,0933	0,0842	0,0803	0,0731	0,0779
Portugal	0,1613	0,1148	0,0944	0,0827	0,0692	0,0544	:
Romania	0,1020	0,0970	0,0828	0,0714	0,0625	0,0571	:
Slovenia	0,1641	0,1276	0,0962	0,0798	0,0748	0,0758	:
Slovakia	0,2180	0,1673	0,1403	0,1263	0,1094	0,1011	0,0903
Finland	0,0837	0,0773	0,0683	0,0664	0,0552	0,0525	:
Sweden	0,1166	0,0780	0,0689	0,0601	0,0560	0,0502	:
United Kingdom	0,1379	0,1160	0,1012	0,0900	0,0867	0,0869	0,0781

In Table 2-34 the most important countries / segments are market in **bold** for metal working companies and in italics for *wood working* companies. Roughly the "typical" electricity price for use of **metal working machine tools** is **0,11 Euro/kWh**, for **wood working machine tools 0,14 Euro/kWh**.

For **welding, soldering and brazing equipment** a typical electricity price is much more difficult to state as the target sectors and enterprises cover an even broader spectrum from small-size to large industrial. Hence, the EU-27 average can be taken as an approximation with rounded **0,10 Euro/kWh**.

Interest minus inflation is given as the discount rate, for which (currently) the value 4% is applied in line with Commission impact assessment practice.

2.4.2 Purchase Price

As a distinction of purchase prices for the various machine tools types the unit values as stated by EuroStat in the PRODCOM statistics and checked for plausibility by Fraunhofer are the best available approximation for "typical" purchase prices of machine tools.

These unit values are listed in 2.1 Generic economic data:

- Metal working machine tools: Table 2-4, p. 12
- Wood working machine tools: Table 2-5, p. 18, and Table 2-6, p. 20
- Welding, soldering and brazing equipment: Table 2-7, p. 22

Despite all uncertainties of the EuroStat data this approach at least allows to estimate the order of magnitude for average purchase prices in each category. The unit values for some important product categories, indicating also the broad spread of machine tools and equipment, are as follows:

- Horizontal machining centres for working metal: 480,000 Euro
- Lathes, including turning centres: 380,000 Euro
- Hydraulic presses for working metal: 210,000 Euro
- Non-numerically controlled horizontal lathes for working metal: 24,000 Euro
- Multi-purpose machines where the workpiece is automatically transferred between operations for working wood: 50,000 Euro

- Band saws for working wood: 8,000 Euro
- Machinery for soldering, brazing, welding or surface tempering: 30,000 Euro
- (Other) shielded arc welding equipment: 600 Euro

For the various major branches, average unit values for machine tools (revision after plausibility check) are as follows:

- Metal working machine tools (NACE 28.41): 64,000 Euro
- Wood working machine tools (industrial stationary ones, NACE 28.49): 20,000 Euro
- Wood working machine tools ("light stationary", i.e. transportable, NACE 28.49): 600 Euro
- Welding, soldering and brazing equipment (NACE 27.90, 28.29): 1,400 Euro
- Stone and ceramics working machine tools (NACE 28.49.11): 18,000 Euro

2.4.3 Consumables

2.4.3.1 Cooling lubricants

Consumption of cooling lubricants constitutes a major share of life cycle costs of many machine tools. Following a top-down-approach consumption is derived national from sales statistics: Table 2-35 lists the use of cooling lubricants in Germany in tonnes, based on data by the German BAFA[69]. These data show a high impact of the economic cycles, specifically of the drastically reduced number of productive hours in 2009, resulting in a decreasing amount of cooling lubricant usage by 35-40% compared to 2008, although the stock of installed machine tools did not decrease in a similar way. Therefore, the 2008 data is closer to representativeness for consumption and costs of cooling lubricant use (and machine tools usage in industry in general) than the more recent year 2009.

[69] Bundesamt für Wirtschaft und Ausfuhrkontrolle: Amtliche Mineralöldaten, BAFA Ref. 423

Table 2-35: Use of Cooling Lubricants in Germany – BAFA data – mineral oil based

	2009	2008	2007	2006	2005	2004
all lubricants [t]	**862.381**	**1.109.383**	**1.149.432**	**1.173.850**	**1.023.044**	**1.039.680**
of those, cooling lubricants [t]	**42.029**	**65.777**	**72.308**	**67.821**	**75.701**	**73.856**
non-water miscible CL [t]	24.779	38.370	41.532	38.339	45.094	46.846
water miscible CL (concentrate) [t]	17.250	27.407	30.776	29.482	30.607	27.010
emulsions and solutions created from water-miscible CL [t][70]	790.000	1.260.000	1.410.000			
total amount of cooling lubricants used [t]	815.000	1.300.000	1.450.000			

Given the fact that cooling lubricants are mainly used for metal working machine tools[71] and that Germany consumes 41% of all metal working machine tools in EU 27, the consumption for EU 27 can be estimated based on the assumption, that the ratio of cooling lubricant usage in other EU 27 countries correlates in a similar way with the installed value of machine tools[72]. In 2009 the EU-27 usage of cooling lubricants for metal working machine tools is estimated at 161.000 t, thereof 94.000 t non-water miscible cooling lubricants and 67.000 t water-miscible cooling lubricants. The latter total roughly 3.1 million tonnes of emulsions and solutions.

Table 2-36: Use of Cooling Lubricants in EU-27 - estimate – mineral oil based

	2009	2008	2007	2006	2005	2004
all lubricants [t]	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**
of those, cooling lubricants [t]	**102.000**	**161.000**	**176.000**	**165.000**	**185.000**	**180.000**
non-water miscible CL [t]	60.000	94.000	101.000	94.000	110.000	114.000
water miscible CL (concentrate) [t]	42.000	67.000	75.000	72.000	75.000	66.000
emulsions and solutions created from water-miscible CL [t]	1.900.000	3.100.000	3.400.000			
total amount of cooling lubricants used [t]	2.000.000	3.200.000	3.500.000			

70 Domrös, R.; Spieß, G.; Mehr, G.: Sustainable Production – using minimal quantity lubrication, SKF Evolution online, 2009; estimate for 2007, figures extrapolated for other years

71 Ratio of cooling lubricants usage per type of processed material is unknown, use for metal processing is widespread, usage for processing of other hard materials, such as stone, ceramics, glass is relevant as well

72 i.e. multiplying the German consumption figures with 1/0,41. This approach neglects the economic differences in the various EU countries regarding degree of capacity utilization, types of production (e.g. volume production vs. single-part production, types of metals processed etc.), and the actual differences in distinct machinery installed.

Typical prices for cooling lubricants (concentrates) are in the range of 3 – 8 Euro/l, depending on type, specification and order volume, package size. Assuming a price of 5 Euro/kg, the total sales volume for EU-27 for **non-water miscible cooling lubricants** was **470 million Euros** in 2008, and for **water miscible cooling lubricants** another **330 million Euros**.
As cooling lubricants are typically used for processing of hard materials, such as metals, stone, ceramics, the related costs are relevant for these two segments only.
The total value of these machine tools categories for the 2009 sales (not stock), is 15 billion Euro. Compared to this figure a total sales volume of 800 million Euro for mineral oil based cooling lubricants seems reasonable. This also corresponds to industry sources[73], stating that the proportion of costs in production for conventional cooling lubricants is in the range of 14-18% depending on the complexity of the components and that on average 10 % of workpiece-related costs are cooling lubricant costs respectively. A survey by Astakhov[74] revealed, that metal working fluids (including the handling of these, such as supply system and disposal of residues etc.) are correlated with 8-10% of the manufacturing costs in such sectors as the automotive industry.

A typical CNC machine may use 10 to 10,000 l/h of cooling lubricant or related emulsion depending on application. Whilst much is reconditioned and recycled, due to natural wastage as aerosol spray into the atmosphere and adherence to swarf, overall losses can amount to between 3 and 15 l/h[75].

Other auxiliary substances, such as deep drawing lubricants and hydraulic oil for machine tools are not yet considered, and so are the additional costs of lubricant management (logistics, OHS measures, and disposal).

2.4.3.2 Welding, soldering and brazing consumables

Supplies, consumables and services for the joining industry, including welding filler materials, adjuvants, gases, protective clothing, testing machines and training services

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73 See e.g: BILZ: General Information MQL, http://www.bilz.de/MMS_Vorteile.pdf; Domrös, R.; Spieß, G.; Mehr, G.: Sustainable Production – using minimal quantity lubrication, SKF Evolution online, 2009

74 Astakhov, V.P.: Ecological Machining: Near-dry machining, in: Davim, J.P. (Edt.): Machining: Fundamentals and Recent Advances, Band 10, Springer, 2008

75 Hughes, J.: Minimum quantity cooling lubricants for CNC machinery, November 6, 2009, TheDailyEngineer.com

constitute a 12.5 billion Euros production value in the EU-27 as of 2007[76]. Germany has the highest production value (€ 2.1 billion) closely followed by Italy (€ 1.8 billion) and France (€ 1.5 billion). Germany, France and Italy stand out with high production values for the manufacture of welding consumables (€ 576 million in Germany, € 312 million in France and € 303 million in Italy). The production values of welding gases are in the same order of magnitude in these countries.

Comparing the production value of devices and complementary joining technology goods for welding, soldering and brazing there is a relation of 12,5 billion Euros for consumables and the like to 7.5 billion Euros for devices, indicating also the fact, that in terms of total life cycle costs consumables for joining technologies are significantly higher than the actual initial investment in equipment.

Welding gases comprise helium, argon, oxygen, nitrogen, hydrogen, carbon dioxide and hydrocarbons, such as acetylene, ethene, propene, propane, butane, methane. These constitute a relevant share of welding equipment usage costs, but vary broadly depending on type of gas and amount purchased.

Electrodes and welding wires respectively can be considered consumables, but it should be noted, that the material makes it into the final product. Depending on process, technology and application the deposition efficiency is a cost relevant factor: The deposition efficiency is the relationship of the electrode used to the amount of the weld metal deposited.

2.4.4 Tools, Work Holders, Spare Parts

EuroStat provides data for production of tools and parts for machine tools, which can be considered basically as initial sets of tools, spare parts and replacement parts. Not all of these parts are relevant for all types of machine tools. Table 2-37 provides a matrix where some major machine tool categories are correlated with the potentially corresponded parts according to NACE nomenclature.
The value of these **parts and components** in total for EU 27 production in 2008 is **7,6 billion Euros**, compared to a sales volume (sold production) of 26,4 billion Euros for machine tools in the same year. This sounds reasonable, but it is clear, that costs for tools vary broadly, depending on the complexity of the product: Astakhov[77] states a

[76] Middeldorf, K.: The Economic Importance of Welding and Joining in Europe Production Values, Values Added and Employees, DVS, July 24, 2009

[77] Astakhov, V.P.: Ecological Machining: Near-dry machining, in: Davim, J.P. (Edt.): Machining: Fundamentals and Recent Advances, Band 10, Springer, 2008

share of the tool costs for advanced power train plants to be in the range of 12-15% related to the high cost of gear manufacturing, and for simpler automotive plants dominated by turning and milling processes, such as shaft production, a cost range of direct tooling of 5-7% of manufacturing costs.

For welding equipment the nozzles are relevant in particular as these are subject to wear and tear.

Table 2-37: Major Machine Tools Categories and Corresponding Parts

		EU27 Value in EUR (Production, 2008)	Selection of Machine Tools categories 28.41 / 28.49																				
			28491233	28491140	28491263	28491279	28491237	28491170	28491130	28412233	28412235	28412470	28412270	28411270	28491235	28491250	28412223	28412395	28412375	28412490	28412160	28491287
28414030	Parts and accessories for metal cutting machine tools (excluding tool holders and self-opening dieheads, work holders, dividing heads and other special attachments for machine-tools)	2.728.072.081								x	x		x	x			x	x	x	x		
28414050	Parts and accessories for metal forming machine-tools (excluding tool holders and self-opening dieheads, work holders, dividing heads and other special attachments for machine-tools)	1.650.000.000										x									x	
28414070	Parts and accessories for machine-tools operated by ultrasonic processes	125.789.508																				
28492110	Arbors, collets and sleeves for machine-tools and hand tools	334.364.885	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
28492130	Tool holders for lathes (excluding arbors, collets and sleeves)	206.806.155				x		x		x				x								
28492140	Tool holders, self-opening dieheads and workholders of a kind used solely or principally for the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays	58.264.769																				
28492150	Tool holders, n.e.c.	415.006.839	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
28492170	Self-opening dieheads for machine-tools and hand tools	6.183.170								x				x								
28492230	Jigs and fixtures for specific applications, and sets of standard jig and fixture components for machine-tools and hand tools	660.585.706	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
28492250	Work holders for lathes (excluding jigs and fixtures for specific applications, and sets of standard jig and fixture components)	321.898.858				x		x		x				x								
28492270	Work holders for machine-tools and hand tools (excluding jigs and fixtures for specific applications, and sets of standard jig and fixture components, those for lathes)	156.539.954	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
28492350	Dividing heads and other special attachments for machine-tools and hand tools	380.874.896	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
28492450	Parts and accessories for machines of HS 84.65	561.542.384	x		x	x	x	x	x						x	x						x
	Totals	**7.605.929.205**																				

3 Annex I – Stock model methodology

As no robust, detailed data on installed stock of machine tools, reflecting the definition of “machine tools” as provided in Task 1, for the relevant reference years 1995, 2009 and 2025 is available, the stock model has to be based on available statistical data regarding production, sales, imports and exports, verified with additional evidence, and checked for plausibility.

3.1 Production

Starting point for the stock model are the PRODCOM production figures for 2009 as published by EuroStat.

- The plausibility check intends to **identify the number of sold units, which are stationary or transportable units falling under the definition of “machine tools” as stated in Task 1 and to rule out all consumer products, misallocated parts and cases, where estimates by EuroStat result in non-plausible amounts of units**
- A similar unit value for different countries serves as indication, that there is a similar understanding of the machinery grouped in this product class.
- In case the unit value differs among the countries, those market shares (economic value, not unit based) with a very low unit value (indicatively below 4.000 Euro for metal working machine tools) are not taken into account, as they presumably do not represent industrial, stationary or transportable types of machinery (but DIY, handheld, mobile units, parts). This approach does not allow for distinctions within one country, where possibly a huge diversity of machinery types are allocated to the same product class. In case there are larger differences regarding the unit value among the market leading countries (indicatively difference of a factor of 4 or more) this is taken as an indication, that in these countries different types of machinery are allocated to this product class, and it might be needed to subdivide this product class in two, reflecting the specifics of the different manufacturing markets. This split is depicted in the production figures only, but not subject to distinction in the stock model.
- If the EU-27 totals - in terms of units sold - are based on EuroStat estimates, it is checked whether non-confidential data from those countries with highest market shares justify roughly the EU-totals. Where the EU-27 totals are significantly higher than the aggregated value of the market leading countries, only the market share of these market leading countries is taken into consideration.

This should result in a market coverage of at least 80% (economic value) for any given machine category.

- It is checked, whether the unit value (corrected, non-plausible market shares ruled out) reflects the likely sales prices of the machine tools likely to be covered in this group. For this check, common understanding of the machine tools category and the indication numerically controlled / non-numerically controlled is the basis.
- Largest uncertainties remain, where major market shares are confidential (no economic value, no sold volume for important countries stated). The approach for these cases is to divide the EU27-total sold volume by estimated typical price (experts estimate or median value or similar). This approach works well for product categories, which are economically dominated by high value machines, but is critical, if only a few high value machines are reported by the companies to these categories and the majority of total economic value is made up by low value units. Following the above approach of dividing the total economic volume by likely sales prices of "machine tools in scope" leads to an overestimate of total machine tools in the scope, neglecting that this total category leads to an underestimate of the total machine tools in scope.
- The resulting "level of plausibility" for each category is listed in the revised production tables and for clarity marked with the following colour code:

EU27-totals plausible as is
adjustments of EU27-totals made or data uncertainties are obvious, but data base does not allow for a correction
additional estimates required to fill data gaps / to rule out inappropriate data

This plausibility check by Fraunhofer was communicated with the relevant associations, inviting their market experts to counter-check the revised figures and to provide clarifications on specific categories and country figures.

3.2 Import and Export – Installed New Stock

The calculation of installed new stock intends to **quantify, how many machine tools in any given year are taken in operation in the EU-27**.

Import and export figures are derived from the EU-27 figures provided by EuroStat. Data following NACE Rev. 2 are available for years since 1995. However, the figures for number of units of imported and exported are frequently implausible and thus in general not suitable to calculate the installed new stock in EU-27. For several catego-

ries reported exports (in terms of units) are much higher than imports and production, which is not logic at all. Hence, the new stock installed is re-calculated as follows:

- For the years 1995 – 2002 only EU-15 figures are reported. No extrapolation to EU-27 is applied for these years.
- Import and export figures are likely to include also larger numbers of used equipment, but this cannot be verified and is not taken into account.
- Production value plus import value minus export value is the anticipated economic value of newly installed machine tools in the EU-27
- For each year 1995-2009 the calculated economic value of newly installed machine tools is divided by the production unit value. This approach neglects that exported machine tools are likely to be of a higher average value than imported ones, thus leading rather to an underestimate of installed new stock. Referring to a calculated production unit value individually for each year takes into account, that the production unit value is not constant, but subject to a trend towards more complex machine tools of higher value
- Following criteria are checked to verify, whether the resulting newly installed stock is plausible:
    - Export value (significantly) smaller than production and import value for most years
    - Overall low export and import figures, which means the more reliable production figures constitute the major share of newly installed stock, thus overall results are more robust
    - Production quantity figures changes from year to year are plausible
    - Resulting new stock value corresponds with economic cycles without major inconsistencies, new stock value year to year changes are not subject to excessive fluctuations
    - New stock quantity roughly plausible in most years in relation to verified 2009 production data
    - Production unit values plausible for most years (i.e. in the range of the 2009 figures, potentially with a tendency towards increasing unit values from year to year)

- Due to a check against these criteria, occasionally adaptations where made to enhance plausibility of the data. These corrections include
    - taking a plausible unit value also for years where reported unit values are implausible,
    - taking a plausible production quantity where reported quantity does not match with data from other years
    - for remaining cases approximation of newly installed stock with data from other years (potentially with an correction reflecting economic cycles)

For illustration, Table 3-1 provides the data subject to the plausibility check and verification for “28.41.21.40 Non-numerically controlled horizontal lathes, for removing metal”.

Further adaptations have been made to approximate the economic conditions:

- EuroStat data is available on the EU15 level only up to 2002. Based on the data provided for 2003 and consecutive years for EU 15 and EU 27 correction factors are introduced for some categories, where a major additional production, export to or import from the new member countries is evident.

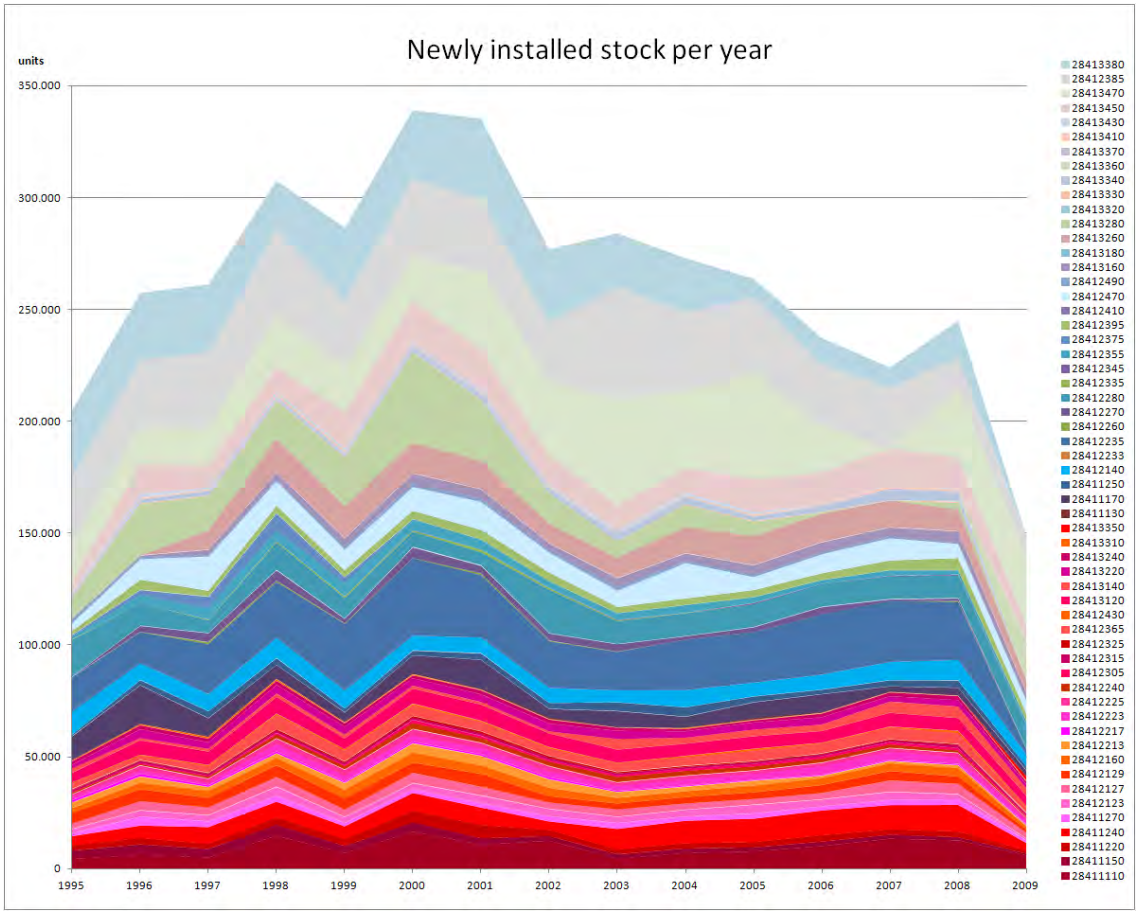


Figure 3-1: Metal working machine tools – newly installed stock 1995 - 2009

The newly installed stock of metal working machine tools exemplarily is depicted in Figure 3-1: The number of newly installed machine tools roughly remains stable, with a sharp decline in 2009 due to the economic crisis. The economic down-turn years 2002-2004 are also visible with this model. The particularly low values in 1995-1997 can partly be related to the economic situation, but even more to the fact, that 2 major product categories are not reported for these years (28.41.33.80 in greyish-blue, 28.41.23.85 in grey), thus not covered by the statistics. These findings confirm that the model for newly-installed stock is plausible and fluctuations are explainable.

Table 3-1: Plausibility Check New Installed Stock "28.41.21.40 Non-numerically controlled horizontal lathes, for removing metal"

PRODCOM EuroStat data „as is"								Calculation and plausibility check Fraunhofer				Data quality check Fraunhofer											
PERIOD_LAB	EXPQNT	EXPVAL	IMPQNT	IMPVAL	PRODQNT	PRODVAL	PROD unit value	new STOCK quantity	new STOCK value	new STOCK quantity based on Production unit values	Correction	Quota IMPVAL/PRODVAL	Quota EXPVAL/PRODVAL	2009 PROD plausible	EXPVAL < 60% in 12 years	EXPVAL < 45% in all years	IMPVAL < 40% in 12 years	IMPVAL < 25% in all years	new STOCK value corresponds with economic cycles	new STOCK value year to year changes w/o major inconsistencies	new STOCK quantity roughly plausible in several years	PROD unit values plausible in 12	TOTAL data quality no adjustments required
1995	7995	73933000	31384	69508380	10609	181489039	17107	33.998	177.064.419	**10.350**		38%	41%										
1996	6437	75129130	14213	72534220	7397	206477431	27914	15.173	203.882.521	**7.304**		35%	36%										
1997	26646	69072900	22408	80535710	7147	173260692	24242	2.909	184.723.502	**7.620**		46%	40%										
1998	4465	69949930	23982	102327040	7552	192074680	25434	27.069	224.451.790	**8.825**		53%	36%										
1999	5158	58444290	18289	87277100	6631	213378397	32179	19.762	242.211.207	**7.527**		41%	27%										
2000	4305	68819040	4019276	88987900	5793	204780910	35350	4.020.764	224.949.770	**6.364**		43%	34%										
2001	9261	68304830	18433	94918010	17649	169561922	9607	26.821	196.175.102	***6.942***	PRODQNT estimate: 6,000	56%	40%	1	1	0	0	0	1	1	0	1	0	**5**
2002	4331	58608280	17001	73712500	6047	140633821	23257	18.717	155.738.041	**6.696**		52%	42%										
2003	10891	77799740	30530	48305250	9171	164184678	17903	28.810	134.690.188	**7.524**		29%	47%										
2004	37216	65925900	22883	57745490	10508	147865481	14072	-3.825	139.685.071	**9.927**		39%	45%										
2005	20293	69589130	27851	62309510	8460	149976369	17728	16.018	142.696.749	**8.049**		42%	46%										
2006	9236	69762720	25430	56723430	8957	187925710	20981	25.151	174.886.420	**8.336**		30%	37%										
2007	19743	78057640	73561	73115780	10027	227085195	22647	63.845	222.143.335	**9.809**		32%	34%										
2008	59866	69736080	31369	83281410	10060	224730386	22339	-18.437	238.275.716	**10.666**		37%	31%										
2009	3732	36611660	20365	34187170	5990	143325496	23927	22.623	140.901.006	**5.889**		24%	26%										

3.3 New Stock Totals

Above calculations result in the verified newly installed stock for each of the years 1995 – 2009. The accumulated stock has to consider also historic data before 1995 due to the long lifetime of machine tools. For simplification, newly installed stock before 1995 is calculated with the average of the following 10 years, i.e. the data for 1994 is based on the average of the years 1995-2004 (which represents one economic cycle). For CNC machines newly installed stock is set at 0 for all years before 1975 as this technology was introduced in the mid-70s.

This “retrospective extrapolation” results in a newly installed stock, exemplarily for metal working machine tools, as depicted in Figure 3-2.

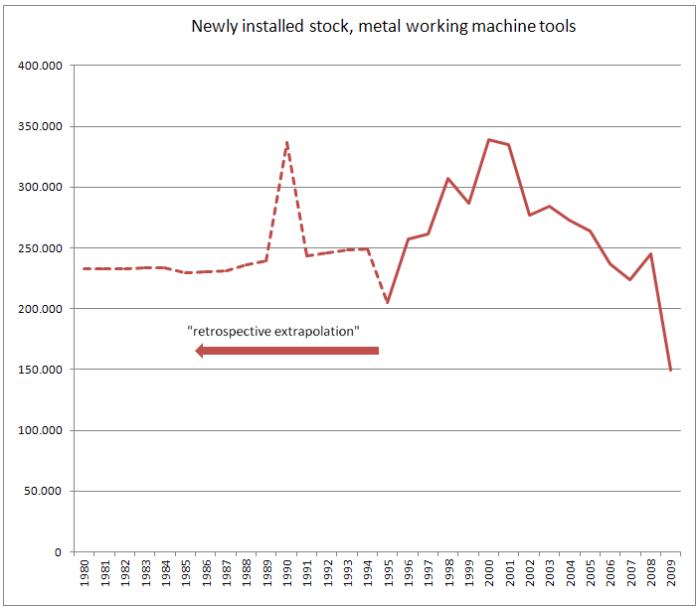


Figure 3-2: Metal working machine tools – newly installed stock 1980 - 2009

Based on the lifetime estimates, the stock model follows a scenario that 100% of the machine tools stay in operation the stated lifetime and are completely taken out of operation once this lifetime expired. This is a simplification, as there will be a phase-out stretching over several years, partly even over 1 to 2 decades. However, given the long lifetime – and thus rather small share of stock being mathematically exchanged in any given year – this approach is accurate enough for the purpose of the study.

The results of this stock model show a rather stable number of installed units, which leads vice versa to the conclusion, that a more distinct phase-out model stretching of several years phase-out time would not add any value to the findings.

Further adaptations have been made to approximate the economic conditions:

- Given the steady replacement of non-CNC machine tools by CNC machine tools in recent decades it was assumed, that the lifetime of non-CNC machine tools in the economic recession 2002-2004 was reduced by 3 years (by taking over capacity machine tools out of operation)
- As an approximation of the historic development of installed CNC machine tools before 1995, for which no EuroStat data was extracted, an annual growth rate of 11,4% (according to German machine tools surveys in 1985 and 1995) was anticipated
- The economic boom of the late 1980s / early 1990s is addressed with a factor of 1,5 applied to the new stock installed in 1990 (adaptation of the retrospective extrapolation of stock data)

3.4 PRODCOM 2010 update

In the course of the study, new PRODCOM data became available for 2010 production, imports and exports. Table 3-2 lists in the right column the new calculated stock for 2010 based on the aforementioned stock model, which takes into account real PRODCOM data until 2009, and the 2010 data based on recently reported PRODCOM figures (calculating new stock based on reported 2010 production, import and export data; rules for plausibility checks apply). It is obvious that there are major deviations due to the inherent limitations of the Eurostat data, but in general the order of magnitude is confirmed. For metal working machine tools in most categories the PRODCOM based figures are 20-60% lower, which is not surprising, as 2010 has been affected by the economic crisis. Hence, new stock is logically lower than the estimation based on the Fraunhofer stock model, which does not consider the economic cycles (as these cycles cannot be predicted with a 2025 horizon, in any case).

Table 3-2: Machine tools – new installed stock in 2010 according to PRODCOM figures and according to the stock forecast model

PRODCOM	Description	2010	2010
		Applying stock model methodology to 2010 PRODCOM data	Fraunhofer stock model based on extrapolation of historic trends (data used for calculations)
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	4.080	3.831
27903145	Electric machines and apparatus for resistance welding of metal	108.590	67.640
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	41.658	181.639
27903163	Other for manual welding with coated electrodes	503.139	373.646
27903172	Other shielded arc welding	264.297	281.364
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	9.095	10.455
27903190	Machines and apparatus for resistance welding of plastics	not available	54.381
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	not available	6.956
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	obvious data reporting error (296.812)	2.977
28411110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	6.990	2.450
28411130	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)	541	495
28411150	Machine tools for working any material by removal of material, operated by electro-discharge processes	718	1.210
28411170	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes	3.044	2.395
28411220	Horizontal machining centres for working metal	1.290	2.227
28411240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	4.573	9.116
28411250	Unit construction machines (single station) for working metal	1.885	2.565
28411270	Multi-station transfer machines for working metal	1.577	2.012
28412123	Numerically controlled horizontal lathes, turning centres, for removing metal	1.376	2.132

28412127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	2.837	4.065
28412129	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)	1.032	2.828
28412140	Non-numerically controlled horizontal lathes, for removing metal	4.442	7.301
28412160	Lathes, including turning centres, for removing metal (excluding horizontal lathes)	1.580	2.964
28412213	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)	456	832
28412217	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)	210	394
28412223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	1.708	3.064
28412225	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)	1.644	1.432
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	5.454	18.675
28412240	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	272	1.026
28412260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	60	133
28412270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)	3.548	596
28412280	Threading or tapping machines for working metal (excluding drilling machines)	10.237	10.187
28412305	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	540	1.052
28412315	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	437	995
28412325	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to accuracy >0.01mm	42	293
28412345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	256	332
28412355	Grinding machines for working metal; any one axis can be set to an accuracy >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines	2.087	1.869

28412365	Numerically controlled sharpening (tool or cutter grinding) machines for working metal	3.596	4.423
28412375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal	7.797	not plausible
28412385	Honing or lapping machines for working metal	6.252	15.878
28412395	Machines for deburring or polishing metal (excluding gear finishing machines)	3.142	4.446
28412410	Broaching machines for working metal	50	53
28412430	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)	287	626
28412470	Sawing or cutting-off machines for working metal	6.672	7.275
28412490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.	87	577
28413120	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	3.799	5.428
28413140	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	2.273	4.825
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	9.142	4.257
28413180	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	- 217	n.a.
28413220	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	1.943	2.272
28413240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	1.364	1.516
28413260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	23.410	9.411
28413280	Non-numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	7.266	827
28413310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	189	139
28413320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	not available	18
28413350	Hydraulic presses for working metal	2.205	1.869

28413360	Non-hydraulic presses for working metal	21.185	17.658
28413410	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets	not plausible	685
28413430	Thread rolling machines for working metal, sintered metal carbides or cermets	122	198
28413450	Machines for working wire (excluding draw-benches, thread rolling machines)	14.287	12.774
28413470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal	51.247	21.381
28491130	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	not available	32.844
28491150	Grinding or polishing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	not available	5.442
28491170	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)	83.005	8.910
28491210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	8.404	4.299
28491220	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	9.252	6.747
28491233	Band saws for working wood, cork, bone and hard rubber, hard plastics or similar hard materials	11.221	8.555
28491235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	36.274	63.283
28491237	Sawing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials (excluding band saws, circular saws)	53.525	112.607
28491250	Planing, milling or moulding (by cutting) machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	29.735	42.860
28491263	Grinding, sanding or polishing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	32.684	7.951
28491265	Bending or assembling machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	not plausible	2.573

28491267	Drilling or morticing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	4.768	7.231
28491275	Splitting, slicing or paring machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	19.503	14.212
28491279	Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials, n.e.c.	20.405	18.948

Fraunhofer

Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 3 Report – User Requirements

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary – Task 3

Machine tools are **business-to-business products**. Recent survey results show, that "energy efficieny" – despite some outstanding initiatives - is not very important in the marketing of the machine tool manufacturers. The important facts are price, cutting speed and innovative equipment.

Although machine tools users' interest regarding energy efficiency aspects is growing, technical features and performance criteria are dominating. The growing interest and related marketing initiatives do not result in a broad demand for and implementation of energy efficient modules in machine tools. This is the case particularly in the wood-working sector, although some manufacturers of machine tools actively promote "green" features of their machine tools. In the metal working sector there is a somewhat higher level of awareness and interest among the automotive industry and its suppliers, but for most other market segments energy efficiency is not among the decisive criteria for purchasing a machine tool.

Implementation obstacles regarding new energy efficient solutions on the users' side can be observed. For most machine tool users the price-profitability relation and therefore the amortisation time of such solutions as well as limited financial resources are some of these barriers. Still, the main marketing aspects are price, cutting speed and the innovative equipment of products. The Total Cost of Ownership approach is realised mainly in large-scale producing branches such as in the automotive industry.

Nevertheless, machine tool users are aware of the growing importance of realising environmental, especially energy saving aspects in machine tools.

Retrofitting and refurbishment of machine tools after a certain time in use is very common and reported to take place a couple of times throughout the lifetime of a machine tool. Due to the business-to-business nature of the machine tools market and the material value of scrapped machine tools a high recycling quota can be anticipated although statistical data on this aspect is not available at all.

3 Task 3 – User Requirements

3.1 User information

Machine tools are typical business-to-business products. The user is therefore not a single (private) consumer (user), but an enterprise. This enterprise could be a manufacturing company of varying size (e.g. small, medium or large). Within this entity product related (user) information are necessary on various levels. This ranges from technicians and production managers working with the machine tool to financial administration and desk personnel responsible for procurement of a machine. These corporate users have different information requirements with respect to the products technical and environmental performance.

With respect to eco-design, relevant information for the corporate user of machine tools would include at best an environmental footprint or life cycle performance data of the product, detailed information regarding specific energy and material consumption during use phase including varying configurations and modes, as well as specific information concerning maintenance and the end-of-life treatment.

The objective of this task is to provide references for the current status of environmentally related product information disclosure in the market. The investigation is focusing on determining the types and availability of environmental product information in the sales/procurement situation (e.g. power consumption, consumable efficiency). The goal is to collect evidence as an input for later tasks. An analysis of the available user information including shortcomings in that respect is a secondary task.

3.1.1 Metal working machine tools

- **Product information supplied by machine tool manufacturers**

A brief investigation showed that is justified to say that today's communication between manufacturers of machine tools and their customers (users) is usually limited to technical product data and service information. The study investigated exemplarily, product information provided by machine tool manufacturers including the following machinery:

- 5-axis machining centre by Roeders, Soltau,
- 3+2-axis milling machine by Deckel Maho, Seebach,

- turning-milling centre by Gildemeister, Bielefeld,
- 4-revolver turning machine by Traub, Reichenbach,
- profile grinding machine by Blohm, Hamburg, and
- die sinking EDM machine by Zimmer & Kreim, Brensbach.

All surveyed offers are related to machine tools with CNC. The machine tools have common working space for stand-alone solutions of between 300 mm and 1250 mm per linear axis. The use for workshops as well as line manufacturing was taken into account. The product description includes all means, e. g. main drive, feed drives, working space, control system, meeting customer demands on the output of the machine tool. This also includes displaying power and torque against rotational speed of main drive, acceleration and maximum velocity of feed drives, electricity supply data, the flow-rate of lubrication, hydraulic system and pneumatic system as well as noise emission.

Further technical information available for machine tools comprises mostly description of components. Manuals include information on standardized interfaces such as for tool holders according to ISO 12164[1] or for electrical safety according to EN 60204[2]. The standardized accuracy of machine tools is pointed out according to ISO 230[3] or other related international, European or national standards. All hardware and software parts of machine tool are usually well described.

The service aspects are explained too. Here, transport from manufacturer to customer site, transport conditions, packaging, insurance and travel costs, initial set-up, warranty claims and customer training are all addressed. The availability is guaranteed by guidelines such as VDI 3423[4].

Despite this sufficient technical information there is limited environmental information available from the machine tool manufacturers. Most eco-information is related to waste management and substances regulations such as the environmentally compliant

1 ISO 12164-1:2001 (2008): Part 1-4: Hollow taper interface with flange contact surface.

2 EN 60204-1:2006+A1:2009: Safety of machinery. Electrical equipment of machines. General requirements.

3 ISO 230:1996 (2010): Part 1-9 Test code for machine tools.

4 VDI 3423:2002: Technical availability of machines and production lines - Terms, definitions, determination of time periods and calculation.

using of coolant and lubrication. There are also few indications with respect to the recycling of machine components and take-back. Aspects such as material and energy consumption or efficiency are mentioned rather incidentally if all. A stakeholder comment from CECIMO argues that energy consumption is part of productivity, quality and life cycle costs. CECIMO therefore concludes that it is not correct to ask for energy consumption on top of those other factors.

The following table sums up the product information provided for the user by machine tool manufacturers. The numbers were collected from the survey of this study[5].

Table 3-1: Machine Tool Information for the Users

Parameters	Yes		No
Technical	100 %		0 %
Ecological (for the use phase)	75 %		25 %
		Mainly environmentally compliant using of coolant and lubrication	
Ecological (End of life behaviour)	62.5 %		37.5 %
		mainly recycling of machine components	
Maintenance clearance (e g. by reason of abrasion)	87.5 %		12.5 %
Spare part availability (e. g. time)	87.5 %		12.5 %

- **Ecodesign related marketing of machine tool manufacturers**

According to our survey and literature analysis the most dominant issue in the communication between manufacturer and the customer is the productivity that can be achieved with the machine. A survey at the EMO 2003 unveiled, which sales arguments were most relevant at that time[6]: The top three aspects are:

- Machine quality,

5 Online survey and direct contact; Questionnaires answered: nine; Countries: Germany, Italy, Japan; Machinable material: metal, wood

6 Sample size: 1.573 experts

- Qualification and availability of service technician,
- Services and availability of spare parts[7].

Environmental aspects (green machine) were not mentioned. However, the rubric “Innovation power of providers” (rank 7) included innovation in relation to environmental improvement.

A more recent survey was carried out by the Institut für Werkzeugmaschinen und Fabrikbetrieb (IWF) at TU Berlin at the METAV 2010[8]. This survey focused on marketing aspects and safety of metal working machine tools. According to this survey, energy efficiency is becoming an important marketing strategy in the near future. The study concluded that internal and external corporate communication of eco-efficiency labels and solutions leads to improved corporate identity. But in the actual sales situation eco-efficiency is currently not a strong argument for a purchasing decision.

The results of the survey are still very similar to the survey of the EMO 2003. Over the past decade eco-design has gained only limited importance in the market. Relevant for marketing are price, technical performance (such as cutting speed) and other innovative features of the product. The top priorities for the customers are similar. They are high quality performance and an acceptable price. Energy saving or the design of “green machines” are considered of secondary importance.

There are nevertheless a few initiatives and trends that indicate a growing recognition of environmental performance and energy efficiency in particular in the machinery industry today. Important initiatives with respect to energy efficiency are:

- 2008: The German Machine Tool Builder Association (VDW) developed the label “Blue Competence”.
- 2009: Presentation of the label "Blue Competence" at the EMO.
- 2010: Funding of the German innovation platform “Resource Efficiency in Production” (German: “Effizienzfabrik”), founded by the German Federal Ministry of Education and Research (BMBF).

7 Kapitza, R. (2004): Erfolgreiches Marketing im Werkzeugmaschinenbau. In: Backhaus, K.; Voethe M. (Hrsg.): Industriegütermarketing, Wiesbaden: Gabler, 2004, S. 1105-1121.

8 Sample size: 35 machine tool manufacturers; international SMEs and major enterprises

- 2010: 15 companies addressed "Blue Competence" at the METAV and the additional symposium “The energy efficient machine tool” [in German: “Die energieeffiziente Werkzeugmaschine”] and 27 companies at the AMB.
- 2011: The Association of Italian Manufacturers of Machine Tools, Robots, Automation Systems and ancillary products, UCIMU, developed the label “Blue Philosophy”. “Blue Competence” is operated by VDMA, and addresses mechanical- and plant construction.
- 2012: “Blue Competence” is operated by CECIMO, and addresses metal working machine tool manufacturers and their suppliers throughout Europe.

Eco-design and eco-performance is a growing marketing aspect (this has been indicated by the well frequented workshops and events on energy efficiency of machine tools in 2010), but energy saving measures are mainly driven forward by large-scale producing branches such as the automobile industry. Major enterprises implement life-cycle oriented energy saving measures increasingly, whereas SME remain reserved and sceptical due to the indistinct financial benefit that they perceive, regarding eco-solutions.

In the survey conducted by the authors of this study, it was explicitly asked for eco-design measures. The survey included a ranking regarding sales information in general. The manufacturers were asked to rank twelve aspects using a scale from 1 (most important) to 5 (not very important). According to the survey’s results the productivity, quality, accuracy and availability ranked with an average value of 1.0 to 1.4 constitute the most important points. In contrast, life cycle costs, brand image, energy consumption and design of machine tools are less important and were ranked with an average value of 3.2 to 3.7 (see figure below). Detailed explanation will be given in Chapter 3.2.

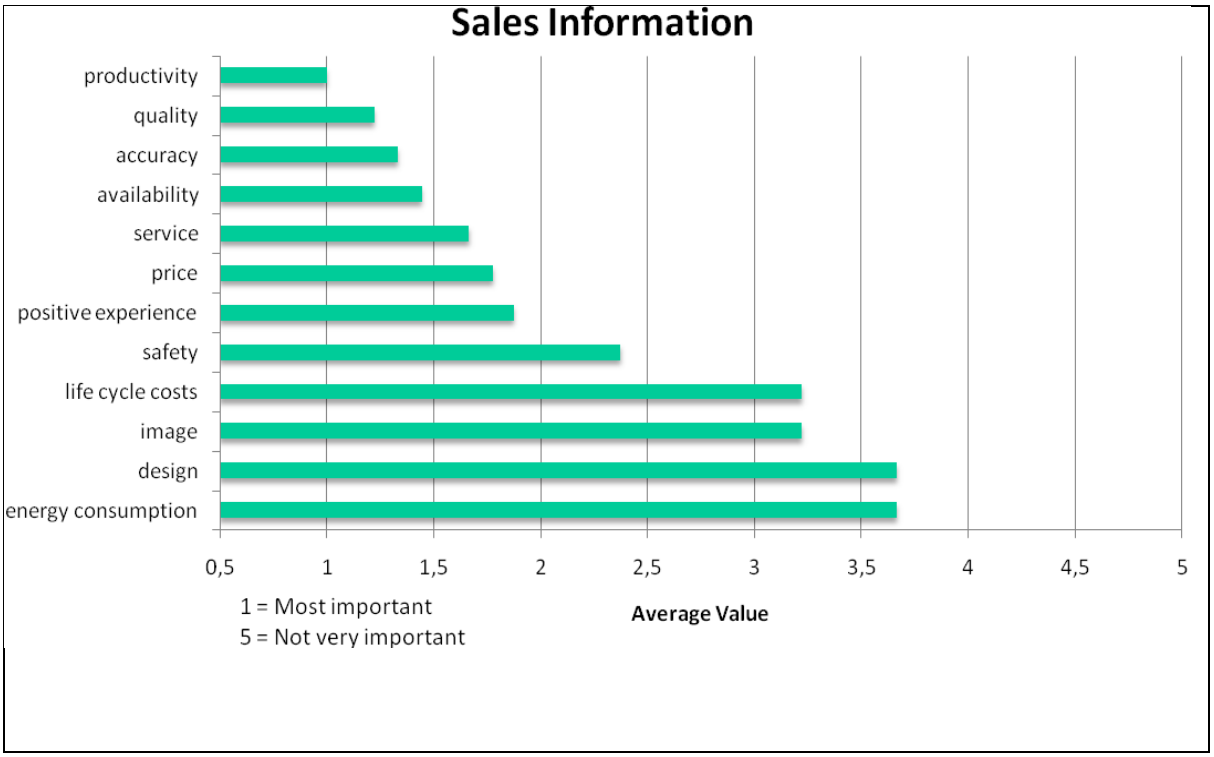


Figure 3-1: Important Sales Information

The results of our survey is furthermore supported by other (some older) studies.

Core customer demands regarding machine tools comprise the following[9]:

- Productivity, quality, flexibility (verified through the survey of this study)
- Process oriented machine tools
- High availability and reliability
- Exploitation of the machines' full capacity
- Cost transparency at purchase and use

Figure 3-2 illustrates the results of a survey by University of Hannover (IFW) among 11 machine tool users of different company size / branch (each with 5-1500 CNC-machine tools in use) regarding the importance of certain factors for investment decisions.

[9] B. Denkena, A. Harms: Life-Cycle Oriented Development of Machine Tools, LCE Congress, Leuven, 30/05/2006.

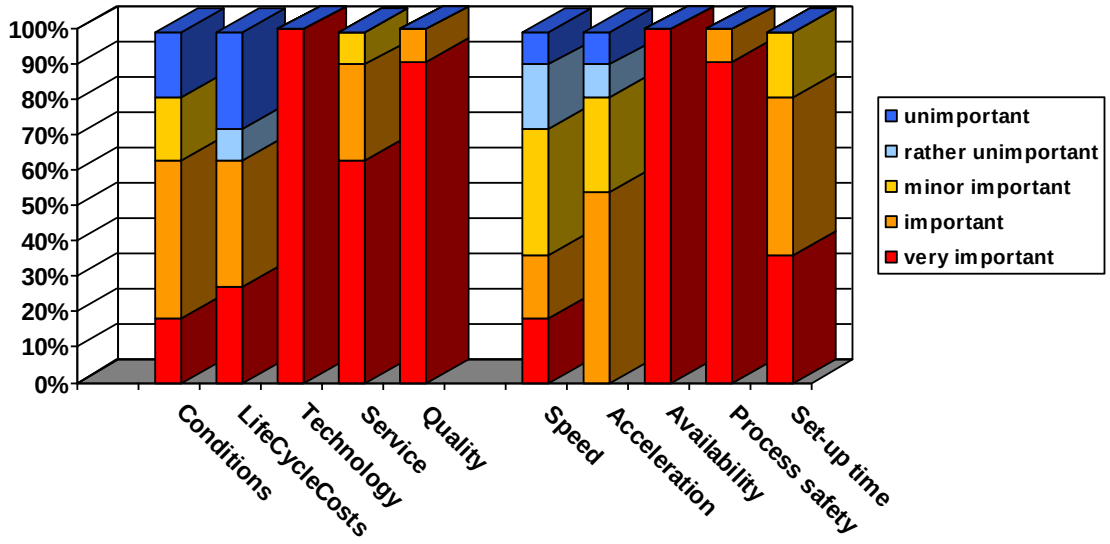


Figure 3-2: Survey among machine tools users

Figure 3-3 shows the cost structure of the producing industry. This is a very interesting statistic because it indicates two important aspects with respect to eco-design. First of all, the total material costs are with just over 46 % the most important (absolute dominant) cost factor. The improvement of material efficiency should be therefore of highest concern. This would also benefit the environmental performance. A stakeholder comment from CLASP points out that the ratio of output value (46% x 5) to energy (1.8%) is 130:1. Although very crude, this illustrates the over-riding importance of throughput compared to energy consumption, according to CLASP.

We have to notice therefore the rather low cost factor of energy with only 1.8 %[10]. That figure might change however with rising energy prices and also vary from enterprise to enterprise. According to a German source the energy costs will increase from 4.3 % in 2003 to 7.6 % in 2013 in relation to the total annual costs of producing companies[11].

10 Statistisches Bundesamt: Kostenstruktur im Produzierenden Gewerbe (2007).

11 http://www.karlsruhe.ihk.de/produktmarken/innovation/Verborgene_Dateien_Innovation_und_Umwelt/Anlagen_Innovation_und_Umwelt/Umwelt/Energiepreise_und_Unternehmensentwicklung_in_Baden-Wuerttemberg.pdf. Access on 01/06/2010.

Similar trend can be seen according to a survey by Thamling et al.[12] one third of the companies from producing industry estimate their energy consumption at more than 5 % and one seventh at more than 10 % of total production costs.

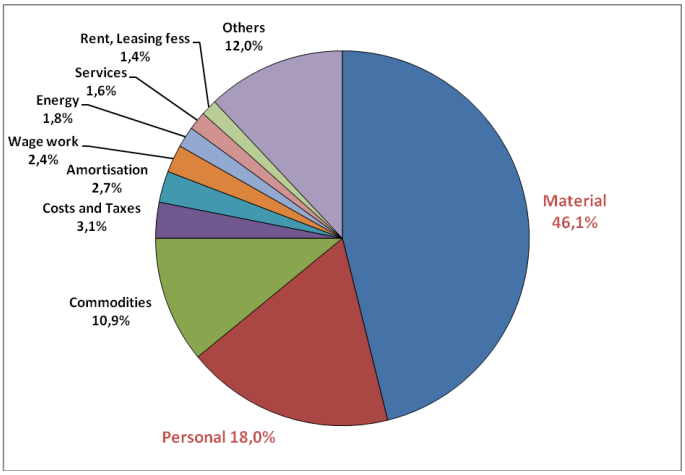


Figure 3-3: Cost structure of producing industry in Germany in 2007

Machine tools manufacturers are mostly part of the first third. The long amortization times and the limited financial resources are to be named as obstacles for implementation of energy reducing measures. The focus is rather on facility related energy savings measures, than on the production equipment.

Nevertheless the main impact in terms of energy and material appears during use phase of machine tools. The potentials for cost reductions regarding improved energy efficiency are estimated between 5 % and 20 % according to Thamling et al. The machine tool related energy efficiency measures of SME are mainly situated in a mean range of up to 5 %. 15 % to 35 % of SME estimate machine tool related energy efficiency measures between 11 % and 30 %.

- **Environmental requirements in procurement specifications**

Only very occasionally customers – mostly large enterprises of the automotive or woodworking branch – ask in a systematic way for EHS (environmental, health and safety) aspects of the machinery they purchase. One such example is the SKF EHS

12 Thamling, N.; Seefeldt, F.; Glöckner, U.: Rolle und Bedeutung von Energieeffizienz und Energiedienstleistungen in KMU. Report of Prognos AG on behalf of the KfW Bankengruppe, Berlin, 05/02/2010, p. 8

Delivery Specifications[13]. It was designed as a comprehensive guide to the EHS Management System in a check list style. The guide is used by the company's procurement to evaluate supplier of purchased products and parts. The components of the SKF EHS Delivery Specifications include not only environmental aspects, but also Industrial safety, machinery safety, fire safety regulations and plant protection. An exemplary segment from this specification is shown in Figure 3-4, actually addressing environmental protection issues. The main focus is the proper substance and waste handling.

Pos.	SKF EHS Delivery Specifications	not applicable	accepted
2	**Environmental protection**		
2.1	Use of substances listed under http://www.gadsl.org is prohibited. Declarable substances have to be reported.	☐	☐
2.2	Components must exit the machine in such a dry condition that they do not contaminate the subsequent transport, processing and test systems.	☐	☐
2.3	During operation, no negative influence or pollution from machines or plants should interfere with the direct surrounding field. Legal limits should be under run as far as possible according to the state of the art.		
2.4	Machine oil must not be able to mix with the processing medium.	☐	☐
2.5	The use of FCKW or CKW as a cleaning or degreasing agent or as an active substance is not permitted.	☐	☐
2.6	When using water to cool various media (oil, emulsion, etc.), only safety heat exchangers may be used.	☐	☐
2.7	If the unauthorised use of SKF waste containers or SKF storage surfaces is observed, disposal will be arranged at the cost of the polluter.	☐	☐
2.8	Any kinds of liquid waste with the exception of household waste water or pure surface water must not be disposed of in the sewage system.	☐	☐
2.9	Any containers provided by the Contractor for the above purposes must be clearly labelled to guarantee the properly sorted collection of waste.	☐	☐
2.10	Used packaging will be taken back own expense and under proper disposal.	☐	☐
2.11	Labelling of electrical and electronic equipment according to EU directive 2002/96/EC (WEEE).	☐	☐
2.12	REACH / GHS conformal EU-safety data sheets for all materials supplied and used by the Contractor on site must be handed to SKF before (upon) delivery and start of work / use of these materials. The materials shall be approved for use by SKF.	☐	☐
2.13	In case of dusty and noisy activities, effective measures for prevention are mandatory in agreement with SKF.	☐	☐
2.14	Integration of containment with sufficient slope for machines using liquid medias?	☐	☐
2.15	Nomination of an on-site official responsible for environmental protection.	☐	☐

Figure 3-4: SKF EHS Delivery Specifications for Procurement

13 http://www.skf.com/files/882847.pdf. Access on 03/06/2010.

Furthermore, table 3-2 indicates the percentage of machine tool manufacturers applying EHS guidelines and delivery specifications according to the study's survey. The results show most of the asked companies actually apply EHS guidelines.

Table 3-2: Applying EHS

	Yes	No
Does your company apply "Environmental, Health and Safety (EHS) Guidelines"?	87.5 %	12.5 %
Does your company apply EHS Delivery Specifications (Machinery and installations)?	87.5 %	12.5 %

- **Measuring environmental product parameters**

One of the main problems, why unambiguous information on environmental aspects rarely can be stated by machine tools manufacturers is the lack of appropriate standards to come up with comparable measurements of e.g. power consumption. Furthermore the power consumption is a function of the use mode the most energy is used in the production process.[14] Therefore it is difficult to receive comparable values. The stakeholder CLASP commented: "It is stated that there is no common way to assess the energy performance of a machine tool. CLASP agrees with this finding, and we would support more work being done in this Preparatory Study and by testing organizations and CECIMO to develop appropriate, accurate and repeatable energy measurement methods for this equipment." The authors of this study recommend that readers should crosscheck comments and statements on standardization in Task 1.

The definition of energy efficiency as the ratio of benefit and use of energy provides a possible approach to consistent determination and evaluation of energy consumption. Herein the benefit is represented for example by added value of a production line or turnover of a company depending on the observed object.[15]

14 Abele, E.; Kuhrke, B.: Impulsvortrag – Produktionsorientierter Umweltschutz im Maschinenbau und in der Metallbearbeitung. Fachtagung Hessen-Umwelttech 2009, 25.03.2009

15 Reinhart, G.; Karl, F.; Krebs, P.; Reinhardt, S.: Energiewertstrom – Eine Methode zur ganzheitlichen Erhöhung der Energieproduktivität. ZWF 105 (2010) H. 10, S. 870 ff

An alternative to quantify electrical energy consumption in the use phase is proposed by Gutowski et al.[16], based on a more academic approach from the U.S.: The approach taken is based on thermodynamics to account for material transformations, including the conversion of raw working materials into products, wastes, and emissions, and the conversion of fuels into heat and usable work, wastes, and emissions. The concept can also incorporate all other energy sources. Machine tools include in addition to the basic function of shaping work pieces a wide variety of functions including tool and work piece clamping and handling, lubrication and chip removal. All these additional functions can often dominate energy requirements. This is shown in Figure 3-5 for an automotive machining line. In this case, the maximum energy requirement for the actual machining is only 14.8 % of the total. At lower production rates the machining contribution is even smaller.

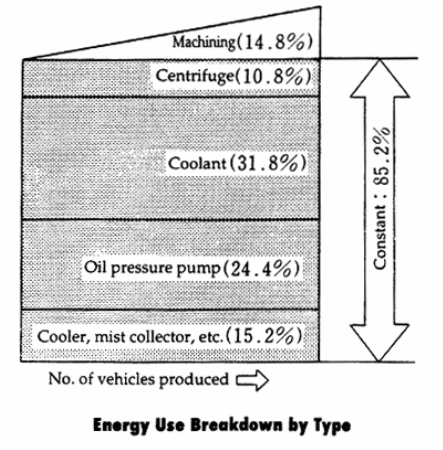


Figure 3-5: Energy used as a function of production rate for an automobile production machining line[17]

Other processes show a similar behaviour. In general, there is a significant energy requirement to start-up and maintain the equipment in a “ready” position. Once in the “ready” position, there is then additional power consumption proportional to the quantity of material being processed.

16 Gutowski, T.; Dahmus, J.; Thiriez, A.: Electrical Energy Requirements for Manufacturing Processes. In: Proceedings of the 13th CIRP Int. Conf. on Life Cycle Engineering, 2006.

17 Gutowski, T., Murphy, C., Allen, D., Bauer, D., Bras, B., Piwonka, T., Sheng, P., Sutherland, J., Thurston, D., Wolff, E.: Environmentally Benign Manufacturing: Observations from Japan, Europe and the United States, Journal of Cleaner Production 13 (2005), pp 1-17.

Gutowski et al. proposed the specific electrical energy per unit B_{elect} in kJ/cm^3 as calculated variable in order to determine the energy efficiency.

$P = P_0+k*v'$
with P total power in kW,

P_0 idle power in kW,

k constant in kJ/cm^3, specific cutting energy, closely related to mechanical properties of material to be machined

v' rate of material processing in cm^3/s

the formula is transformed into $B_{elect} = P_0/v' + k$ [kJ/cm^3]

The relation of idle power and machining power is improved with an increase of the material removal rate. However, the throughput of material depends on frame conditions such as required precision, scale effects and the complexity of shape to be manufactured. These effects need to be taken into account for different manufacturing processes as depicted in Figure 3-6. The highest process rates at lowest electrical energy consumption are stated for injection moulding and machining[18]. As B_{elect} can be determined for a well-defined process and material, but not on a generic level for machine tools as such, a standardization of the process, work piece (type and quality), material would be required to make B_{elect} measurable in a comparable way. Such an approach might mean, that an exemplary process might be reflected, but not the real life application of a machine tool.

18 Gutowski, T.; Dahmus, J.; Thiriez, A.: Electrical Energy Requirements for Manufacturing Processes. In: Proceedings of the 13th CIRP Int. Conf. on Life Cycle Engineering, 2006.

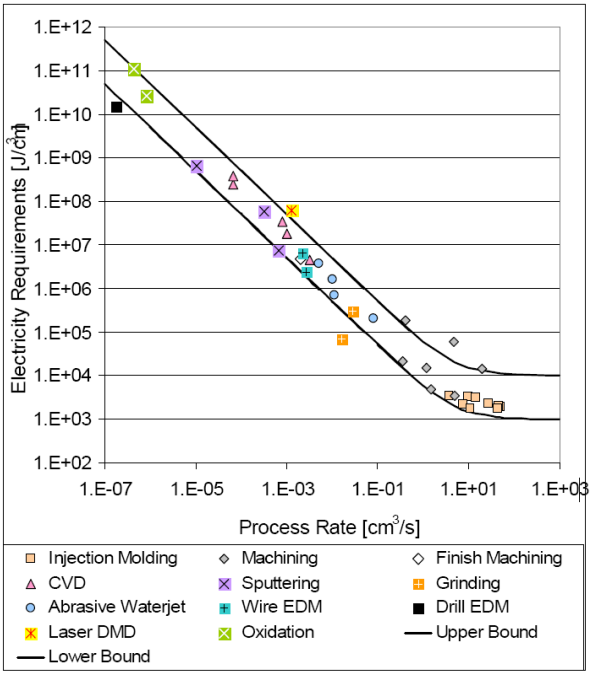


Figure 3-6: Specific electricity requirements for various manufacturing processes as a function of the rate of material processed (Source: Gutowski et al)

The scope of the ISO/TC39/WG12 Environmental evaluation of machine tools is the definition of the environmental performance of machine tools regarding design, use and end of life phases. Based on a list of positive environmental features which can be built into a machine tool, the performance of this product shall be evaluated to quantify the environmental improvements achieved over a defined period. The project will take care of environmental impacts like energy consumption, CO2 output, materials used, and operating materials and precision tools during the use phase. Besides the design and engineering of machine tools also the utilization of these products will be addressed in this project[19].

3.1.2 Wood working machine tools

Although the wood working branch was invited to participate in the survey among users and manufacturers of machine tools and related machinery there was not sufficient feedback from this sector for a statistical evaluation. Anecdotally it is confirmed, that

19 Hagemann, D.: Stakeholder meeting Lot 5 EuP. Status of ISO/TC39/WG12. 02.07.2010

manufacturer of wood working machinery typically provide information on the technical specification, maintenance instructions and about spare parts availability, but not on environmental performance criteria or disposal instructions.

Resource efficiency has been one of the focal topics at the 2009 LIGNA trade fair, but refers rather to increasing productivity for on-site wood harvesting and technologies to minimize the resource consumption for furniture and other wood products rather than to the efficiency of the machinery as such.

There is no known joint marketing initiative for eco-efficient wood working machinery similar to the Blue Competence initiative for the metal working sector. However, there is a moderate tendency among individual manufacturers of wood working machinery to promote particularly energy efficient equipment, such as manufacturer Holzma, presenting their ecoLine technology for cutting processes in 2009.

- **Environmental requirements in purchase specifications**

Only very occasionally there are dedicated environmental purchase specifications – beyond legal compliance aspects - for wood working machinery. In the wood working and furniture manufacturing branch one of the examples where at least on a general level environmental aspects are specified is IKEA's IWAY standard "Minimum Requirements for Environment and Social & Working Conditions when Purchasing Products, Materials and Services"[20]: This standard specifies, which criteria have to be met by suppliers of IKEA, i.e. the users of wood working machinery. Although it is an obligation to pass down these IWAY requirements also to sub-suppliers, those who "provide production equipment e.g. machinery or tools" are explicitly excluded from this requirement. However, there is a generic requirement to reduce environmental impacts of production constantly, including energy consumption: Suppliers "shall measure and record energy consumption for all buildings and processes. Targets for reductions shall be set annually." This requirement might be met by investing in energy efficient equipment, including wood working machinery. Furthermore, IKEA provides long-term strategic support for suppliers including[21]:

- Technical consultations to master new product-technology

20 IKEA Supply AG: IWAY standard - Minimum Requirements for Environment and Social & Working Conditions when Purchasing Products, Materials and Services, edition 4, 2008

21 Ivarsson, I.; Alvstam, C.G.: Supplier Upgrading in the Home-furnishing Value Chain: An Empirical Study of IKEA's Sourcing in China and South East Asia, World Development, Volume 38, Issue 11, November 2010, pp. 1575-1587

- Provision, advice or financial assistance to obtain machinery and equipment
- Technical consultations to master new production-technology

As the major supplier basis of IKEA is in Europe, these supply chain requirements have a particular impact on a few hundred enterprises in the wood working branch in Poland, Italy, Sweden and Germany[22].

3.1.3 Welding, soldering and brazing equipment

The growing need to pay attention to the energy consumption of most processing methods including thermal joining processes is shown in figure 3-7. It is obvious that most parts of the introduced overall performance are not used for the actual processing (e.g. heating to melting temperature T_S or fusing).

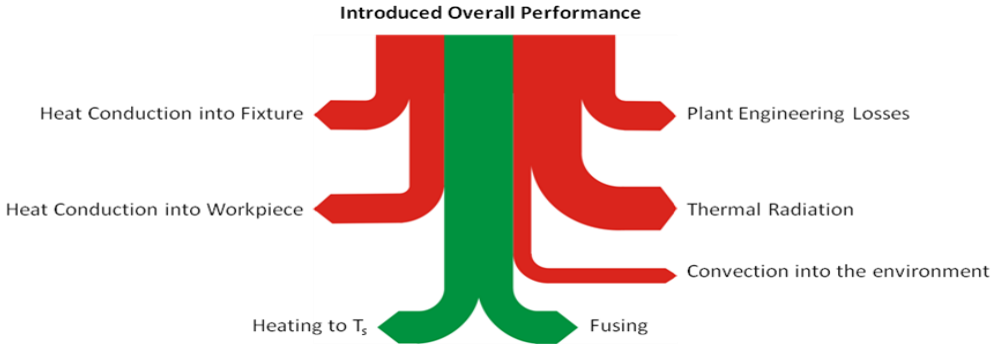


Figure 3-7: Thermal joining process

Some manufacturers of welding equipment promote environmental aspects of their products actively, pointing out e.g. energy efficiency and power factor correction[23] or following an approach called “Green Automation”, which is meant to allow in particular a much more efficient welding and cutting through robotics[24].

22 In 2009, almost two-thirds of IKEA’s global purchasing was in Europe. The top countries included Poland (18%), Italy (8%), Germany (6%) and Sweden (5%) according to IKEA, Facts and figures 2009. Total number of suppliers was 1,220 worldwide, a significant share of this likely to come from the wood working sector.

23 See ESAB: Produktkatalog, 2010, www.esab.de/de/de/support/upload/Produktkatalog_PE_2010.pdf

24 See Reis Robotics: Reis Robotics engagiert sich für Umweltschonung, press release May 10, 2010, http://www.reisrobotics.cz

Manuals for transportable units typically address worker safety aspects at length, including noise, fume emissions, electric shock and arc rays etc. As smaller non-stationary units fall under the WEEE directive disposal advices are given in the manuals. Stated technical data relevant for the environmental performance of the welding equipment typically are[25] (but not stated by all manufacturers in their manuals)

- Power factor at maximum current
- Efficiency at maximum current
- Constant A-weighed sound pressure

Anecdotally, there are some examples of closer B2B interaction to increase eco-efficiency of welding operations, such as Thermacut's refund and recycling system for used tungsten-based plasma cutting nozzles, which is economically motivated, but promoted as a measure for resource efficiency as well[26].

Looking at the German language daily journal of the 2009 "Schweißen & Schneiden" trade fair it is evident, that welding equipment and components are very occasionally promoted with pointing out the resource efficiency of a given product, which is typically related to higher productivity and better yield rates, but also material-reduced nozzles[27]. Energy efficiency is occasionally a promotional argument for selling welding power sources. As the core business of some enterprises are the consumables – corresponding with the customers welding costs - and the equipment is just an add-on business also the marketing focuses on efficient use of consumables, tools and parts.

3.1.4 Other machine tools

Given the fact, that other machine tools cover a broader spectrum of machines, partly niche markets, the user perspective can hardly be generalized. For some of the other machine tools the industrial worker is the typical user, such as glass and ceramics working machine tools. Stone working machine tools are used by both, industrial enterprises and in the construction sector, where craftsmen are among the users.

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25 See for example: ESAB Instruction manual, Arc 150i / Arc 200i, Origot A32, 0459 261 227

26 Gießler, S.: Thermacut - Verdreifachte Standzeiten von Plasmaschneiddüsen, Welding and Cutting Today, September 19, 2009

27 Trommer, G.: Fronius - Verschleißbedingte Einflüsse im Kontaktrohr beim MIG/MAG-Schweißen kontrollieren, Welding and Cutting Today, September 19, 2009

In the ceramics and glass processing industry energy is a highly relevant cost category, but this is related rather to other types of machinery, namely for glass melting and ceramics sintering ovens. See also the parallel DG ENTR Lot 4 Preparatory Study on Industrial and Laboratory Furnaces and Ovens[28].

For other machine tools used in industrial environments technical performance, such as throughput, i.e. productivity is of highest priority when deciding for a machine.

Other machine tools used in the construction sector, such as stone saws have to be very robust and durable when being used on-site, but also mobile. Safety aspects of such equipment used on construction sites is similarly important.

Instruction manuals for such smaller units typically include installation and operation instructions, safety guidelines, advice regarding suitable tools to be used with this machine and frequently also a components list and explosion drawing to facilitate repair and spare parts ordering.

3.2 User requirements in the use phase

As has been stated earlier in the report, it is expected that the energy related costs will increase considerably in relation to the total annual costs of producing companies[29]. This trend is likely to draw more and more attention to energy saving measures. A calculation by AUDI for example compares the relation of energy costs for a transfer line and a table machine with tool costs while machining a swivel bearing. It is assumed that costs for electrical energy during primary processing time, down time and idle time as well as costs for pressurized air outperform tool costs of 0.19 € with 0.20 € of the table machine and 0.28 € with the transfer line[30]. Energy saving measures are going to be more important in general and especially in the German machine tool sector in

[28] Reports for download at http://www.eco-furnace.org/

[29] http://www.karlsruhe.ihk.de/produktmarken/innovation/Verborgene_Dateien_Innovation_und_Umwelt/Anlagen_Innovation_und_Umwelt/Umwelt/Energiepreise_und_Unternehmensentwicklung_in_Baden-Wuerttemberg.pdf. Access on 01/06/2010.

[30] E. Abele: Rahmenbedingungen und Lösungen für eine nachhaltige Fertigungstechnik. Proceedings of Symposium „Die energieeffiziente Werkzeugmaschine“ METAV Fair 2010, 24 February.

metal working production. The energy demand of these machines is estimated to be 15 % of the whole electric power consumption in Germany[31].

The following figure underlines the percentage of energy costs of the value of manufactured goods for the production industry[32].

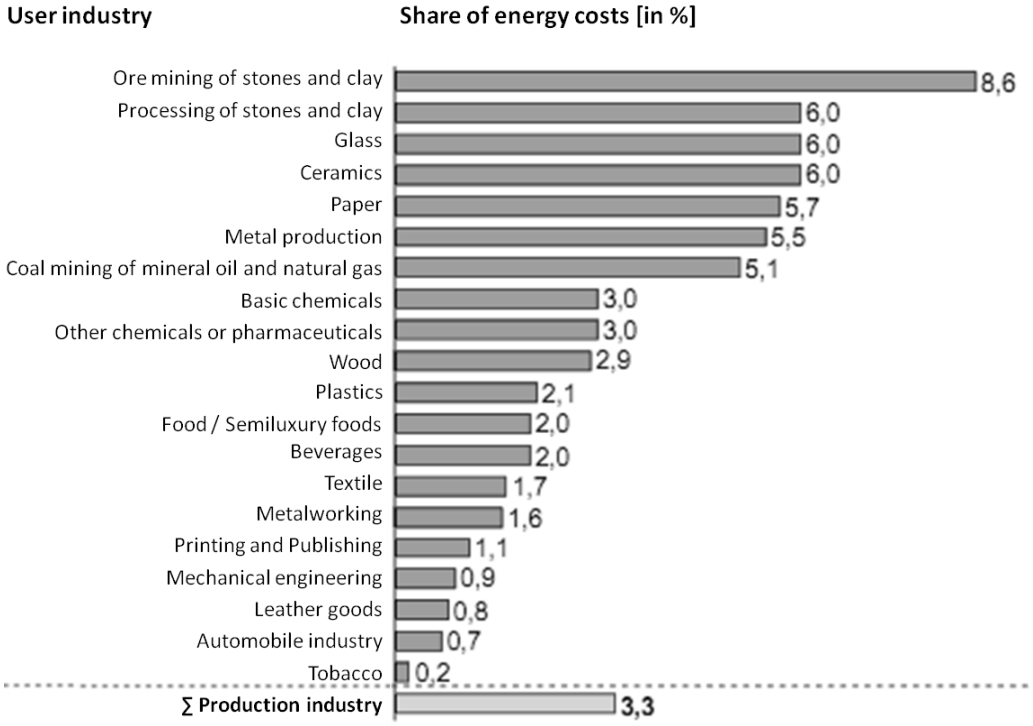


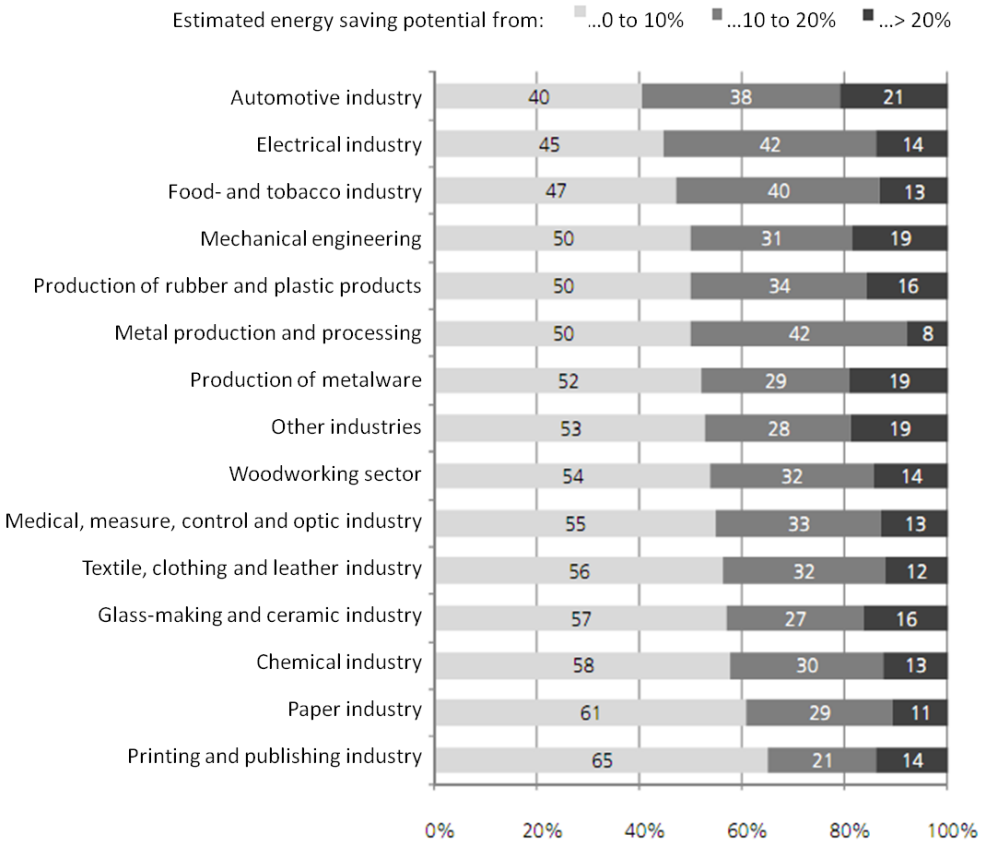
Figure 3-7: Share of energy costs in the production industry

In addition, according to a study undertaken by Thamling et al., the importance of energy efficiency is positively correlated with the company's size. The larger the company's size, the higher the significance of energy efficiency. Moreover, Thamling et al. state that especially bigger and more energy-intensive companies realize energy saving measures or see great potential in doing so. The reasons for implementing energy saving measures are to 93 % the reduction of energy costs and only to 21 % the opti-

31 Kuttkat, B.: Energiesparfüchse sind am Werk. Sonderausgabe Maschinenmarkt METAV Journal 2010, p. 24-26

32 Henzelmann, T., Büchele, R.: Der Beitrag des Maschinen- und Anlagenbaus zur Energieeffizienz. Report of Roland Berger Strategy Consultants on behalf of VDMA, 2009

mization of processes and production[33]. About 50 % of companies in mechanical engineering consider regardless of the size of the company the potential for energy savings in the production to at least 10 % (Figure 3-8). Mechanical engineering is thus in the first third of manufacturing firms that see a very high potential to reduce energy costs. Other branches of manufacturing industry that use machine tools see some significant energy savings potentials as well. The most energy-intensive companies, such as the chemical, glass and ceramic industry and the pulp, paper, printing and publishing industry, which mostly use a much smaller amount of machine tools, represent the last third in the survey. They see little or no energy saving potentials[34].



33 Thamling, N.; Seefeldt, F.; Glöckner, U.: Rolle und Bedeutung von Energieeffizienz und Energiedienstleistungen in KMU. Report of Prognos AG on behalf of the KfW Bankengruppe, Berlin, 05/02/2010.

34 Schröter, M.; Weißfloch, U.; Buschak, D.: Energieeffizienz in der Produktion –Wunsch oder Wirklichkeit? Energieeinsparpotenziale und Verbreitungsgrad energieeffizienter Techniken. In: Modernisierung der Produktion. Mitteilungen aus der ISI-Erhebung 51 (2009)

Figure 3-8: Energy saving potentials in the production industry

Furthermore, it is also stated that 61 % of asked companies realized energy saving measures in general in the last three years. 26 % of these companies are currently implementing energy saving measures. In total, 87 % of the surveyed companies were or are realizing those measures including not only in the production but also heating systems and insulation of buildings[35]. It has to be mentioned that the highest potential in energy saving and in implementing energy saving measures is to be seen in the range of water heating systems, heating systems in general and insulation of buildings. These results however were essentially lower in the production and assembly (see figure 3-9)[36].

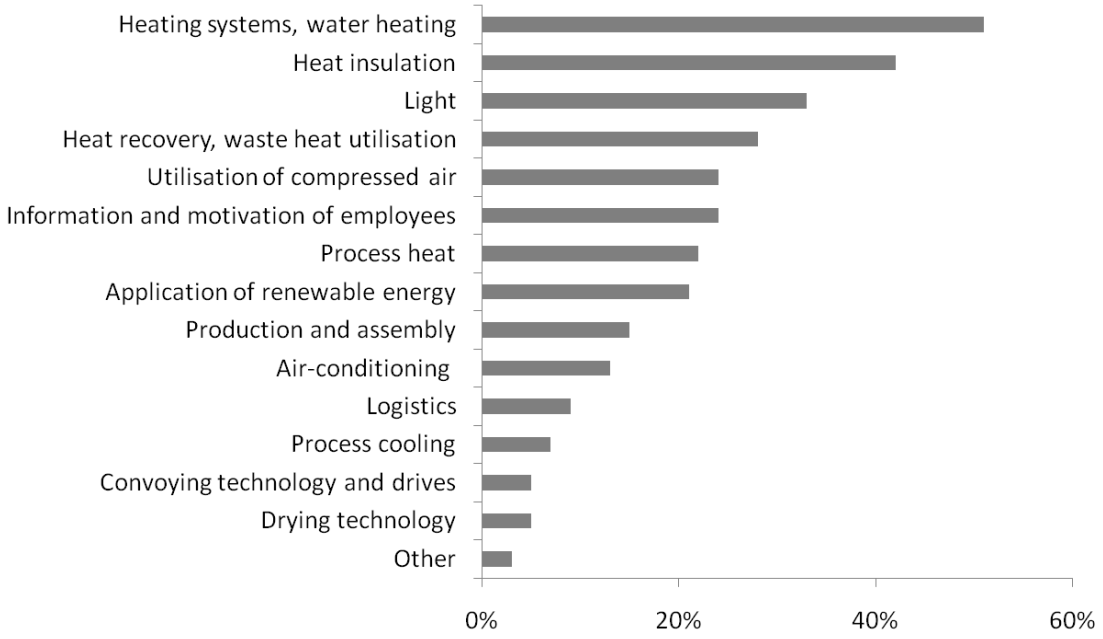


Figure 3-9: Realized implementation of energy saving measures, ordered by sectors

35 Thamling, N.; Seefeldt, F.; Glöckner, U.: Rolle und Bedeutung von Energieeffizienz und Energiedienstleistungen in KMU. Report of Prognos AG on behalf of the KfW Bankengruppe, Berlin, 05/02/2010.

36 Thamling, N.; Seefeldt, F.; Glöckner, U.: Rolle und Bedeutung von Energieeffizienz und Energiedienstleistungen in KMU. Report of Prognos AG on behalf of the KfW Bankengruppe, Berlin, 05/02/2010.

3.2.1 Metal working machine tools

- **Energy efficiency**

The survey of this study supports the statements of Thamling et al. It reveals that for 87.5 % of manufacturers the energy consumption of designed metal working machine tools is relevant and for 62.5 % the energy consumption of machine tool production. The results show further that 83.3 % intend to plan measures to diminish energy consumption of designed machine tools and 71.4 % of the machine tool production. 85.7 % of machine tool manufacturers claim to already offer energy saving modes and modules such as sleep and stand-by modes or the use of synchronous motors (see Task 4 “Best Available Technology”). However, only 7.2 % of customers actually demand energy saving modes or modules.

Table 3-3: Energy consumption of machine tools

	Yes	No
Is the energy consumption of designed machine tools relevant?	87,5 %	12,5 %
Is the energy consumption of the machine tool production relevant?	62,5 %	37,5 %
Does your company plan measures to diminish energy consumption of designed machine tools?	83,3 %	16,6 %
Does your company plan measures to diminish energy consumption of the machine tool production?	71,4 %	28,6 %
Does your company offer energy saving modes or modules of designed machine tools?	85,7 %	14,3 %

The difference between the offered energy saving modules and the demand is founded in the structure of the relevant customer branch. Over 55 % of the costumers of the metal working machine tools are automobile manufacturers or suppliers[37]. Additionally, more than 90 % of the companies of that branch are SME[38]. Here, the actual energy saving of machine tools is not relevant (see table 3-9).

37 VDW: “Die deutsche Werkzeugmaschinenindustrie im Jahr 2009.“ Annual Report of the German Machine Tool Builder Association (VDW), 2010

38 Personal Information of Mr. A. v. Gersdorff, Press Office of the German Association of the Automotive Industry (VDA), 15/12/2010

Complementary to these numbers, the energy saving potential of German machinery and plant products is presented in a survey conducted by Roland Berger Strategy Consultants. According to manufacturers, 56 % of efficiency improvement will be realized through existing technologies and 44 % through new technologies. Similar numbers can be found in the machine tool sector[39], where 54 % of energy saving will be realized through already available technologies and 46 % through new ones. The use of energy efficient technologies for machinery and plants will increase by 27 % from 40 % to 67 % in the next ten years. Taking centre stage in this process will be the further development and improvement of existing technologies and their implementation. Therefore, the average possible energy efficiency improvement in the production industry will slightly increase[40].

When looking at the use phase of machine tools energy consumption has to be seen in close relation to productivity, availability and/or accuracy. The following example explains this matter in more detail: The comparison of a conventional turning lathe from 30 years ago to a today's numerical controlled turning centre shows that the weight of both machines is practically the same but the energy consumption of the modern machine is about 10 times higher. It should be clearly recognized that modern machine's productivity is 20 times higher in comparison to older models. Further, it has to be considered that a much higher productivity reduces also the energy consumption of the production facility for heating, air conditioning and lighting per produced unit. Even though most manufacturers apply energy saving measures, it can be stated that in the course of time the energy consumption of a single machine tool is continuously increasing. Nevertheless, the energy consumption *per produced unit* is significantly reduced.[41]

- **Materials and resource efficiency**

Additionally to energy consumption, the consumption of resources is important. Thus, every manufacturer stated within the survey of this study that resource consumption of machine tools (e.g. lubrication) is relevant and 87.5 % declare the relevance of resource consumption of the machine tool production (e.g. waste material).

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[39] Henzelmann, T. et al. presumably refer to the metal working machine tools sector with this statement

[40] Henzelmann, T., Büchele, R.: Der Beitrag des Maschinen- und Anlagenbaus zur Energieeffizienz. Report of Roland Berger Strategy Consultants on behalf of VDMA, 2009

[41] Expert opinion of a machine tools manufacturing stakeholder

- **Real life use patterns**

There are various reasons why machine tools are frequently not shut off at the end of a shift: One reason is to ensure thermal steady-state conditions with a specific thermal strain, which is very important for high accuracy of metal working machine tools, complex products and work pieces. Overnight shut off or other periods of non-operation of machine tools could result in processing temperatures to fall below desirable levels, and thus having an adverse impact on the process and manufacturing precision. Thus many users do not turn the machines off, keeping them in operational mode overnight to hold the thermal strain “constant” and to avoid lengthy start up times in the morning to bring the machines back to stable process conditions. In this example both aims, energy efficiency and accuracy, are contradictory to each other. On the other hand, this example also shows the playing field for eco-design. Fast reactivation technologies could lead to low power standby for machines. By that considerable energy savings could be realized as other industries (e.g. printing) as shown in past few years.

We have already touched the issue of measurement and comparison of energy consumption. A calculation of energy used as a function of material removal rate for a 3-axis milling machine is given in Figure 3-10.[42] So the amount of electrical energy consumed without manufacturing remains constant, which is at least one third of the total used energy during maximum machining load.

42 Kordonowy, D.N.: A Power Assessment of Machining Tools, Massachusetts Institute of Technology, B.S. Thesis, Department of Mechanical Engineering, Cambridge, MA, USA.

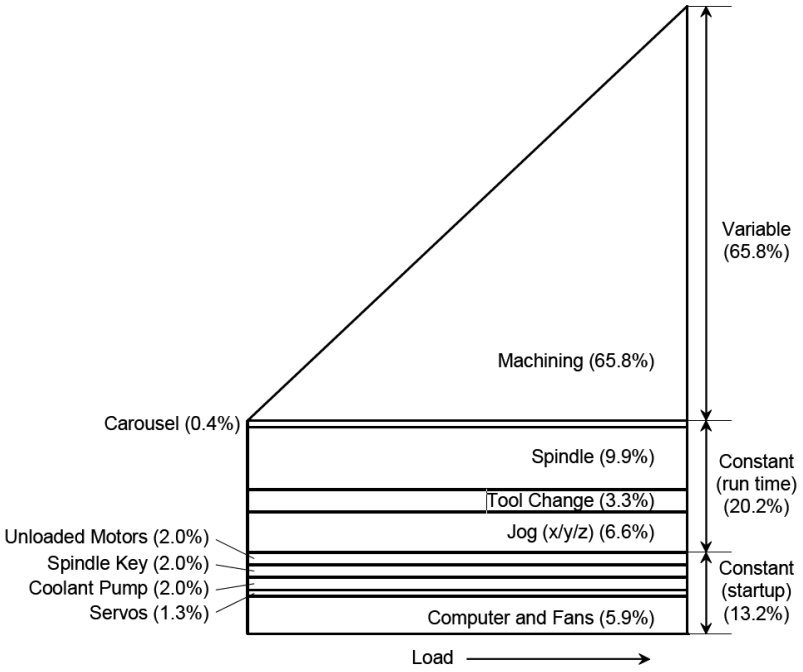


Figure 3-10: Energy used as a function of production rate for a 3-axis CNC milling machine[9]

The evaluation of "typical" use patterns are challenging due to the very different machining cycles in manufacturing processes. In automotive industry machine tools are deployed for 24 hours a day, whereas in workshops operational times of 8 hours a day with intermitting operation cycles are typical. Thus, the broad spectrum of use patterns includes one or more shifts operation and permanent or occasional usage.

Very expensive machine tools are likely to be operated close to maximum capacity to allow for a timely Return-on-Investment (ROI), unless the machine tool is intended to be used for very specific tasks, which mean a high added value for the work piece. In this case even for a very costly machine tool occasional use might be the case.

Machine tools for mass production or for very large and/or for complex work pieces are working in five-shift-operation (24 hours at seven days a week). An opposing example is simple vertical drilling machines. These machines are operated often only for a few minutes a day.

The UK Manufacturing Technologies Association (MTA) estimated the typical annual operating hours for metal working machine tools, making a distinction between "small",

"medium" and "large" machine tools[43] as stated in Table 3-4. "Large" machine tools are, for example, machining centres. Annual operating hours of 4.416 roughly correspond with a two-shift pattern of operation. Smaller machine tools, which also cover the non-CNC range, are stated as having 1,820 annual operating hours, which is a little more than a 1-shift operation.

Table 3-4: Metal working machine tool annual operating hours (source: MTA)

Size	Hours per annum.
Small	**1,820**
Medium	**2,897**
Large	**4,416**

Another important aspect for determining use patterns for metal working machine tools are the type of batch production: large-batches typically mean a high share of productive time, whereas the share of set-up times and tool change times increases with smaller batch sizes. Kuhrke[44] states some typical profiles for usage of machine tools, meant to be used for calculating usage scenarios (see Table 3-5).

Table 3-5: Production type related time-split of metal working machine tools usage

	Lot size	operational	idle	standby	set-up time, tool change
single-part production	1 … 10	40 %	5 %	20 %	35 %
small-batch production	10 … 100	55 %	10 %	15 %	20 %
Medium-sized batch production	100 … 1,000	63 %	3 %	27 %	7 %
large-batch production	1,000 … 10,000	70 %	3 %	23 %	4 %

This range of use patterns has to be considered in the definition of base cases for the environmental assessments in task 4 of this study. Moreover, it has to be considered, that under real life conditions for the sake of thermal stability metal working machine tools might run in operational mode during free shifts without processing any work piece. Here, thermal compensation via CNC might be needed to reduce energetic effort.

43 SKM Enviros: Estimating the Energy Saving Potential from Small Motors and Machine Tools, Report on Machine Tools Research & Modelling, 11 July 2011, p.19

44 Kuhrke, B.: Ansätze zur Optimierung und Bewertung des Energieverbrauchs von Werkzeugmaschinen, Proceedings of Symposium „Die energieeffiziente Werkzeugmaschine" METAV Fair 2010, 24 February

Table 3-5 displays typical assumed use patterns for selected machine tools categories. 50 % of the most relevant machine tools are used without switching-off during idle time and so energy is wasted with basic load.

Table 3-6: Use patterns for selected types of metal working machine tools

PRODCOM Code	Label	Workshop	Industrial plant	1 or 2 shifts	3 & more shifts	Switch-off
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	y	n	y	n	y
28413470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal	y	y	y	y	n
28412470	Sawing or cutting-off machines for working metal	y	n	y	n	y
28411220	Horizontal machining centres for working metal	y	y	y	y	n
28412223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	y	y	y	y	n
28412395	Machines for deburring or polishing metal (excluding gear finishing machines)	y	y	y	y	y
28412375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal	y	n	y	n	y
28412490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.	y	y	y	y	n
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	y	n	y	n	y

- **Maintenance and repair**

Maintenance and repair practice depend on failure modes. Typical failures of metal working machine tools are as follows[45]:

- Drive axes (38 %)
- Spindle and tool changer (26 %)
- Electronics (23 %)
- Fluidics (13 %)

45 Fleischer, J., Schopp, M., Broos, A., Wieser, J., 2007, Datenbasis für lastabhängige Prozesseingriffe – Modularisierung und Analyse von Ausfallursachen zur Erhöhung der Verfügbarkeit von Werkzeugmaschinen. wt Werkstattstechnik online,Jahrgang, 97/H.7/8: 491–497.

The resulting repair cycles and expenses need to be investigated. In some cases failures might not even lead to repair, but disposal of equipment. For example, 20-year old machines run with 20-years old electronics assemblies, which might not be available on the market anymore. Meaning, instead of repairing the whole machine tool or major parts the machine would be scrapped.

3.2.2 Wood working machine tools

Table 3-7 displays typical assumed use patterns for selected wood working machine tools categories.

Table 3-7: Use patterns for selected types of wood working machine tools

PRODCOM Code	Label	Workshop	Industrial plant	1 or 2 shifts	3 & more shifts	Switch-off
28491233	Band saws for working wood, cork, bone and hard rubber, hard plastics or similar hard materials	y	y	y	n	y
28491263	Grinding, sanding or polishing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	y	y	y	n	y
28491279	Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials, etc.	y	y	y	n	n
28491237	Sawing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials (excluding band saws, circular saws)	y	n	y	n	y
28491235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	y	y	y	n	y
28491250	Planning, milling or moulding (by cutting) machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	y	y	y	y	n
28491287	Presses for the manufacture of particle board or fibre building board of wood or other ligneous materials, and other machines with individual functions for treating wood or cork	y	y	y	y	y

3.2.3 Welding, soldering and brazing equipment

Welding, soldering and brazing equipment is rather used as auxiliary equipment. Hence the actual usage times are typically much lower than working shifts. According to an expert's estimate[46] hours in productive operation per working day are roughly as stated in Table 3-8 (allocation to PRODCOM categories).

46 P. Couderc, Air Liquide

Table 3-8: Use patterns and characteristics of welding, soldering and brazing equipment

PRODCOM Code	Label	CNC controlled yes/no	average use scenario: hours in productive operation per working day
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	Yes	8h
27903145	Electric machines and apparatus for resistance welding of metal	No	8h
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	No	2h
27903163	Other for manual welding with coated electrodes	No	1h
27903172	Other shielded arc welding	No	1h
27903181	Machines and apparatus for welding or spraying of metals, etc.	Yes	5h
27903190	Machines and apparatus for resistance welding of plastics	Yes	5h
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	Yes	5h
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	Yes	5h

In the specific segment of soldering equipment for printed circuit board assembly[47] similar observations are made as for metal working machine tools: Although manufacturers offer energy saving modules and features, such as power management, this is rarely asked for when purchasing decisions are made[48]. On the other hand, there are (few) assemblers considering in particular following aspects when specifying and purchasing equipment[49]:

Generic requirements:

- Energy efficient machinery controls such as

[47] this industry typically uses soldering ovens (reflow, wave, induction ovens) , which are considered to be covered under the Product Group Study Lot 4 - Industrial and Laboratory Furnaces and Ovens, www.eco-furnace.org

[48] Friedrich, J. at Expertenforum SMT Hybrid Packaging 2010, Nissen, N.F.; Friedrich, J.; Husemann, J.: Energieeffizienz in der Baugruppenfertigung – June 10, 2010

[49] Husemann, J. at Expertenforum SMT Hybrid Packaging 2010, Nissen, N.F.; Friedrich, J.; Husemann, J.: Energieeffizienz in der Baugruppenfertigung – June 10, 2010

- Static power management
- Dynamic / smart power management

Requirements specific to SMD (surface mount devices) assembly:

- Housing of machinery (reducing heat losses)
- Optimized heat transfer
- Specifying machine design according to contact pad geometries
- Selection of optimal technology for a given soldering task / adaptation to the products to be soldered

This list of requirements indicates, that for the printed circuit board assembly industry among the specific requirements oven related aspects dominate.

3.2.4 Other machine tools

The ceramics industry, where cutting tools are used, is characterized by a rather large share of energy costs (see Figure 3-7, p. 22). This is due to the thermal oven processes applied in this industry, and not related to the machine tools used in this sector.

Table 3-9 displays typical assumed use patterns for selected machine tools categories.

Table 3-9: Use patterns for selected types of other machine tools

PRODCOM Code	Label	Workshop	Industrial plant	1 or 2 shifts	3 & more shifts	Switch-off
28951140	Other cutting machines for paper or paperboard	y	y	y	y	n
28491170	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)	y	y	y	n	n
28491130	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	y	y	y	n	n

3.3 End-of-Life behaviour

Due to the B2B characteristics of this product group it can be assumed, that disposal of end-of-life machine tools largely happens under well controlled and state-of-the art

conditions. Furthermore, most of the machine parts represent a remarkable intrinsic value due to the scrap metal values, so high down-stream recycling quotas can be anticipated. However, this has to be verified. Under certain circumstances recycling might be hindered by contaminations (for illustration: semiconductor manufacturing equipment sometimes has to be treated as hazardous waste due to inflammable gases diffusing into metal parts and being released over time, but in explosive concentrations).

- **Retrofitting cycles and end-of-life**

A survey of the German Machine Tool Builders' Association (VDW)[50] unveils the conditions of retrofitting[51] and refurbishment[52] measures of the most top-selling machine tool companies. According to Figure 3-11 this survey covers mainly machine tools for cutting purposes with medium or large dimensions. It has to be considered that refurbishing and retrofitting costs of machine tools with small dimensions compared to the investment costs are in percent higher. So, the overhaul of that category of machines is energetically and economically of less interest compared to machine tools with medium and high dimensions.

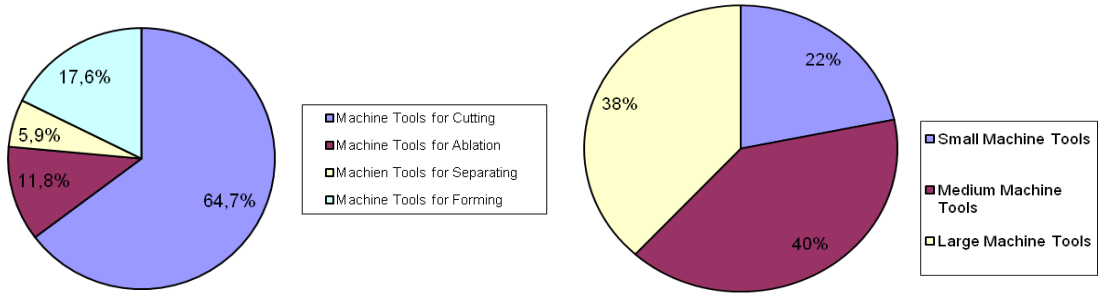


Figure 3-11: Survey among machine tools users: Machine tool purpose (left), Machine tool size (right)

50 Personal Information of Mr. Detlef Hagemann, Systems Engineering and Automation of the VDW, 09/03/2010.

51 Modifying existing equipment or structures with additional or new components or members [http://www.businessdictionary.com/definition/retrofitting.html]

52 Servicing and/or renovation of older or damaged equipment to bring it to a workable or better looking condition. Refurbished goods are of older model and usually in worse condition than reconditioned goods. [http://www.businessdictionary.com/definition/refurbishing.html]

The machine tools' age at first retrofitting/refurbishment measures is mainly between 5 and ten years. 80 % of the machine tools are retrofitted and refurbished between 5 years and 15 years as to be seen in Figure 3-12.

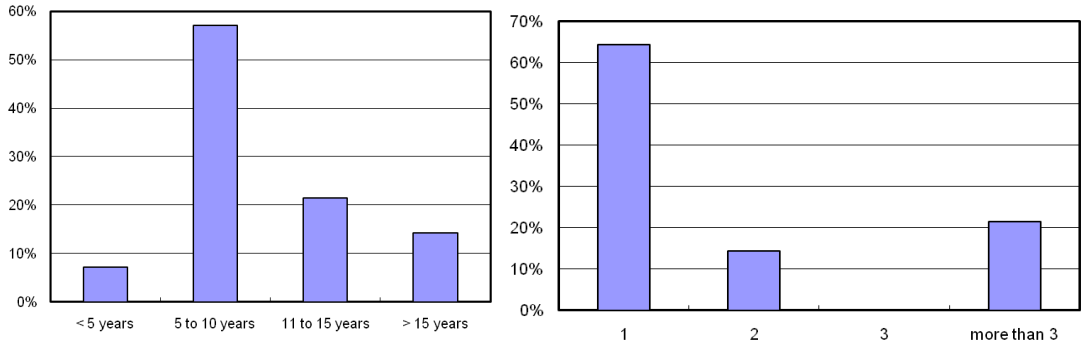


Figure 3-12: Survey among machine tools users on retrofitting/refurbishment: Age of first measures (left), Number of cycles (right)

End of life of a machine tool is reached after at least ten years (Figure 3-13):

- 55 % of the machine tools have a maximum life span of 25 years.
- 45 % of the machine tools have a life span of more than 25 years,

Average amortization time is eight years with a range of five to ten years of amortisation period for survey related CNC controlled machines tools[53].

As measures for retrofitting/refurbishment the mechanical and electrical maintenance is dominating. Renewal and extension are of secondary importance.

53 http://www.urbs.de/afa/change.htm?afa101.htm. Access on 07/05/2010.

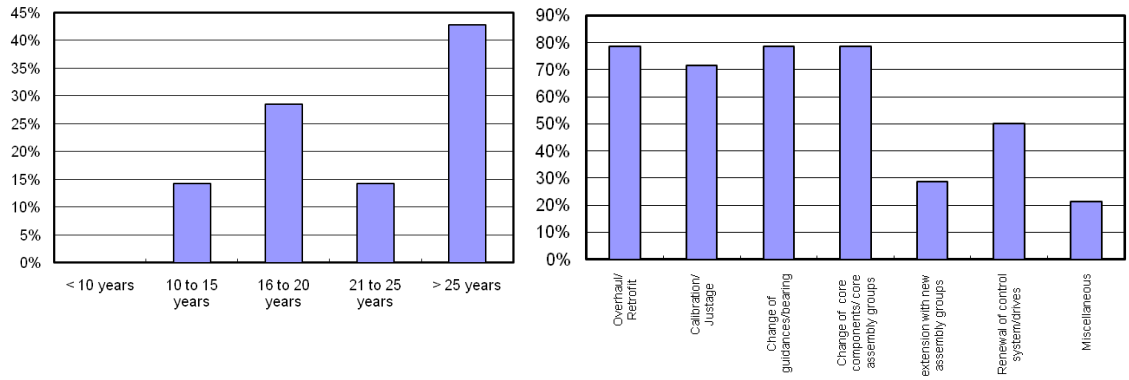


Figure 3-13: Survey among machine tools users: Age of machine tool run-out (left), Retrofitting/refurbishment measures in detail (right)

62.5 % of the companies of the study provide ecological information which mainly concerns the recycling of machine components. To realize the recycling of machine components, machine tool manufacturers mainly apply recyclable materials.[54]

- **Third country exports**

In 2003 a study for the German Council for Sustainable Development stated[55]: "The transfer of second-hand machinery and equipment has now evolved to become an important business sector - almost unnoticed. Enterprises in developing countries and emerging markets have recognized that second-hand machinery and equipment from industrialized countries represent a low-cost and fast solution to the problem of replacing outdated machinery and/or building up new capacities. At the same time machinery dealers from industrialized countries have discovered the market gap and are now extremely active in this field. The import of second-hand goods in the machinery and equipment sector has therefore become a daily reality in developing countries and emerging markets. At the time the study was published, the proportion accounted for by second-hand machinery in the total sales of machinery in Germany was estimated by experts to be 3 to 5 %. For wood working machines, machine tools or machinery for plastics 15 % and more are stated, including domestic sales and abroad. Although

54 Questionnaire result

55 Janischweski, J.; Henzler, M. P.; Kahlenborn, W.: The Export of Second-Hand Goods and the Transfer of Technology – An Obstacle to Sustainable Development in Developing Countries and Emerging Markets? May 2003

second-hand machinery in many regions might be the only affordable solution to ramp up production, the implications are as follows:

- Life time of machinery of low efficiency is extended, resulting in proportionally higher power consumption in the destination countries
- Once the machine tools reach their end-of-life controlled disposal of the very minor amount of potentially critical components is questionable.

Fraunhofer

Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 4 Report – Assessment of Base Case

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary – Task 4

According to Task 1 the scope of the study selected nine base cases reflecting the following aspects:

- type of manufacturing,
- level of automation,
- type of machine tool according to DIN EN ISO 23125,
- metal forming machinery and machine tool according to EUROSTAT, NACE Rev. 2,
- PRODCOM,
- EPTA study,
- woodworking machine tools according to ISO 7984 and
- machine tool's definition according to CECIMO, VDW and other stakeholders.

The base cases have been extracted from these criteria in chapter 4.2. According to Task 2, Table 2-3 the overall stock of metal working machine tools presented a volume of €14.1 billion in 2009. Woodworking machine tools had a market volume of €2.5 billion in 2009, welding, soldering and brazing equipment a market volume of €2.0 billion. The future market share of these five categories is estimated to be roughly the same as in the past and present with a slight increase of numerically controlled machine tools accounting non-numerically controlled machine tools. Based on findings for the machine tools market the **Base Case (BC) assessments**, meant to be conscious abstractions of reality, cover one typical machinery of each of the following segments:

- **BC 1: numerically controlled machining centre,**
- **BC 2: numerically controlled deep drawing or bending machine tool,**
- **BC 3: laser cutting machine tool,**
- **BC 4: non-numerically controlled metal working drilling machine,**
- **BC 5: machine tool for woodworking: light stationary table saw,**
- **BC 6: machine tool for woodworking: horizontal panel saw,**

- **BC 7: machine tool for woodworking: throughfeed edge banding machine,**
- **BC 8: machine tool for woodworking: CNC machining centre, and**
- **BC 9: transportable welding equipment.**

This choice is based on the rationale, that the various levels of machine complexity should be addressed, different processes applied and the variety of materials processed.

The assessments confirm the relevancy of use phase energy consumption, but for some impact categories also the production of the machine tools matters.

The total energy consumption (primary energy) of **CNC metal working machining centres** (Base Case 1) is in the range of **410 PJ per year**, which is much more than for any of the other calculated Base Cases. Further relevant machine tools segments are welding equipment (46 PJ per year), industrial wood working machine tools (represented by horizontal panel saws, throughfeed edge banding machines, and CNC machining centres; 36 PJ per year) and CNC laser cutting machine tools (32 PJ per year). The **total energy consumption of all Base Cases is 645 PJ per year**, of which **60 kWh comprises electricity**, and the total aggregated **Greenhouse Gas emissions** amount to **28 million tonnes CO_2-equivalents**. The Base Cases cover the most relevant market segments of machine tools covered by this study, but not all such segments. Therefore, there is an underestimation of total impacts; however the order of magnitude is plausible.

4 Task 4 – Assessment of Base Case

For the environmental and economic assessment relevant machines constitute so-called Base Cases. On these Base Cases most of the environmental and Life Cycle Cost analyses will be built throughout the rest of the study. The Base Case is furthermore the point of reference for tasks 6 (improvement potential) and 7.2 (impact analysis). The Base Case is a conscious abstraction of reality. Having said that, the question if this abstraction leads to inadmissible conclusions for certain market segments will be addressed in the sensitivity and impact analysis.

The assessment methodology used for this analysis is the Excel MEEuP report, developed in 2005 by VHK to provide a standardised frameset for all product assessments in the Preparatory Studies / Product Group Analyses under the Ecodesign Framework Directive. The spreadsheets can be downloaded at http://www.ecomachinetools.eu/typo/reports.html.

4.1 Product-specific inputs

Product specific inputs vary broadly, depending on the type of machinery, actual application (i.e. workpieces to be processed) and use patterns. Hence, all data provided below can only represent exemplary settings, which to our best knowledge reflect typical conditions.

The product-specific inputs are structured in a way, which allows a direct correlation with Base Cases defined in 4.2. Consequently, product-specific inputs listed here reflect the classification systems of machine tools according to the product scope of this study and the previously drawn conclusion on product and market relevance of machine tools. The following classification systems are taken into account:

- Machine tools system
- Machine tools modules
- Application of machine tools
- Machine tools' complexity
- Manufacturing technology to be performed by machine tools
- CECIMO SRI approach of functional modules.

The machine tools system is sub-divided into workpiece system and tool system with clamping, handling and changing functions. The kinematic system realises all motions between workpiece and tool as well as all support motions. The energy system is regarded to transform the input energy in other energetic states for the manufacturing process. The information system serves the programming of all planned steps of manufacturing.

Related to this the module related approach of machine tools is defined as electrical system for control and mechanic purposes, control system, pneumatic system, hydraulic system, main and feed drives, handling system for tools and workpieces as well as consumables and waste materials.

The application related approach takes into account the application environment (e.g. workshop, industrial plant), number of shifts, embedding (e.g. single machine, automated production system), control system (e.g. mechanic, automated), energy system (e.g. switch-off, power data for sub-systems) and manufacturing method. The complexity related classification defines highly complex CNC, medium complex CNC and simple machine tools. The first are vertical, horizontal or combined horizontal and vertical machining centres. Moreover, lathes including turning centres, but excluding horizontal lathes, and numerically controlled bending, folding, straightening or flattening machines for working flat metal or other materials including presses are covered by this. The second group of machine tools are machine tools for working any material by removal of material, partly operated by laser or other light or photon beam processes as well as hydraulic presses for working metal and other formable material. Simple machine tools are non-numerically controlled machine tools and non-hydraulic and non-numerically controlled presses for working metal or other formable material.

The manufacturing technology related classification is dedicated to the machining purpose of the machine tool. Here, numerically controlled machining centre, numerically controlled deep drawing machine tool, welding equipment, machine tools for woodworking and non-numerically controlled drilling machine are to be found as representatives.

4.1.1 Production phase

The production phase covers the acquisition of the raw materials and the production and assembly processes to construct machine tools.

4.1.1.1 CNC milling and turning machine tools

4.1.1.1.1 Aggregated CECIMO data

CECIMO cordially provided on an aggregated, anonymised level the input data for the LCAs undertaken in preparation of the SRI proposal in 2009. Nine machine tools were taken into account for these assessments, representing a broad spectrum of metal working machine tools ranging from 5 tonnes to nearly 100 tonnes machinery weight. Table 4-1 displays for all nine machine tools the material distribution for each group of materials in kilograms.

Table 4-1: Itemized Bill-of-materials for CNC milling and turning machine tools - CECIMO assessments

Machine tool	1	2	3	4	5	6	7	8	9
Weight in kg									
Aluminium parts	50,5	56	1500	2500	160	210	43	45	0
Cast iron parts	4250	92770	400	400	6137	6588	3167	3271	2075
Copper parts	4	15	0	0	0	0	112	133	140
Electric control cabinet	400	2000	1500	3500	1050	1300	0	0	800
Motor 0-10 kW	540	540	1264	2716	400	360	0	720	648
Motor 101-200 kW	0	0	0	0	0	0	660	0	0
Motor 11-100kW	114	192	0	0	0	116	132	132	0
Polycarbonate parts	30	240	0	0	0	0	0	0	0
Polypropylene parts	0	0	0	0	100	110	3	3	0
Resin-beton parts	0	0	0	0	1500	1500	0	0	0
Rubber parts	0	0	0	0	0	0	21	21	0
Stainless steel parts	0	0	6461	43520	180	180	0	0	0
Steel cast part alloyed	880	3400	500	800	3665	4531	1267	1318	3310
Window glass	0	0	0	0	0	0	3	3	0
Totals	**6270**	**99215**	**11628**	**53440**	**13198**	**14901**	**5415**	**5654**	**6982**

In Table 4-2 the data provided by CECIMO is listed as averaged data in the format of the MEEuP EcoReport.

Table 4-2: Aggregated Bill-of-materials for CNC milling and turning machine tools – averaged data based on CECIMO assessments

Nr	Product name	Date	Author
	averaged CNC milling and turning machine tools (basis: 9 machine tools)		**KSchi, based on CECIMO**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Aluminium parts	507166,7	4-Non-ferro	**27-Al diecast**
2	Cast iron parts	13228666,7	3-Ferro	**23-Cast iron**
3	Copper parts	44888,9	4-Non-ferro	**30-Cu tube/sheet**
4	Electric control cabinet (total: 1.172.222,2 g)	172222,2	6-Electronics	**98-controller board**
5		400000,0	6-Electronics	**44-big caps & coils**
6		600000,0	3-Ferro	**25-Stainless 18/8 coil**
7	Motor 0-10 kW (total 798.666,7 g)	398666,7	4-Non-ferro	**28-Cu winding wire**
8		400000,0	3-Ferro	**23-Cast iron**
9	Motor 101-200 kW (total: 73.333,3 g)	35333,3	4-Non-ferro	**28-Cu winding wire**
10		38000,0	3-Ferro	**23-Cast iron**
11	Motor 11-100kW (total: 76.222,2 g)	36222,2	4-Non-ferro	**28-Cu winding wire**
12		40000,0	3-Ferro	**23-Cast iron**
13	Polycarbonate parts	30000,0	2-TecPlastics	**12-PC**
14	Polypropylene parts	24000,0	1-BlkPlastics	**4-PP**
15	Resin-beton parts	333333,3	7-Misc.	**58-Concrete**
16	Rubber parts	4666,7		
17	Stainless steel parts	5593444,4	3-Ferro	**25-Stainless 18/8 coil**
18	Steel cast part alloyed	2185766,7	3-Ferro	**23-Cast iron**
19	Window glass	666,7	7-Misc.	**54-Glass for lamps**

It is evident, that the material composition is dominated by cast iron parts, which represent 13.2 tonnes of the average machine tools weight, i.e. more than 50% of the total weight of nearly 25 tonnes. Stainless steel parts represent another 5.6 tonnes, alloyed steel cast parts 2.2 tonnes.

4.1.1.1.2 CNC 4-axis multifunctional milling centre

Complementary to the data provided by CECIMO a machine tools manufacturer provided separately and independently data for a CNC machining centre supposed to represent typical machine tools in the segment of very complex high-value metal working machinery.

The 4-axis multifunctional milling centre is equipped with multi-functionality for milling, turning and hobbing in all axes simultaneously. The working space is 700 x 90 x 800 mm^3. The machine tool is equipped with hydraulic system for clamping purposes and cooling equipment for the main spindle. Moreover, central component lubrication is part of the milling centre. Main drive and feed drives are provided with energy recovery system[1].

The most used material for the system is cast iron and steel with 24.3 t of an overall weight of 25.8 t excluding the iron based material of the electrical motors. Non-ferrous metal is taken into account with 0.87 t, mainly resulting from copper parts of the power electronics and the electrical motors. Plastic and rubber materials result in a weight of 70 kg. The Bill-of-materials in Table 4-3 is nearly the same as the average BOM according to the CECIMO assessments as documented in chapter 4.1.1.1.1. 15% of sheet metal is estimated as scrap during manufacturing.

Table 4-3: Bill-of-materials for the CNC 4-axis multifunctional milling centre

Nr	Product name	Date	Author
	Hor. M/C - 500x500 pallet, 4 Axis, ATC 150, Multifunctional		

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Aluminium parts	40000,0	4-Non-ferro	**27-Al diecast**
2	Cast iron parts	16000000,0		**23-Cast iron**
3	Steel parts	5500000,0	3-Ferro	**22-St tube/profile**
4		2800000,0	3-Ferro	**21-St sheet galv.**
5	Copper parts	80000,0	4-Non-ferro	**31-CuZn38 cast**
6	Electrical Cabinet	158000,0	4-Non-ferro	**28-Cu winding wire**
7		80000,0	4-Non-ferro	**31-CuZn38 cast**
8		138000,0	4-Non-ferro	**28-Cu winding wire**
9	Motor 0-10 kW	138000,0	4-Non-ferro	**28-Cu winding wire**
10		260000,0	3-Ferro	**24-Ferrite**
11		125000,0	4-Non-ferro	**27-Al diecast**
12	Motor 11-100 kW	110000,0	4-Non-ferro	**28-Cu winding wire**
13		120000,0	3-Ferro	**22-St tube/profile**
14		90000,0	3-Ferro	**24-Ferrite**

[1] Note, that for the later Base Case assessment this sophisticated option of energy recovery is not taken into account for the majority of the installed stock of CNC machining centres

15	Polycarbonate parts	12000,0	2-TecPlastics	**12-PC**
16	Polypropylen parts	30000,0	1-BlkPlastics	**4-PP**
17	Rubber parts	28000,0		
18	Stainless steel parts	50000,0	3-Ferro	**25-Stainless 18/8 coil**
19	Window glass	16000,0	7-Misc.	**54-Glass for lamps**

The main production processes to produce CNC machine tools are typical metal working processes (drilling, cutting, bending etc.) performed on other metal working machine tools and the following assembly processes. Plastic parts are typically manufactured with injection moulding machines, electronics are assembled with standard technologies, surfaces of the machine housing are typically colour coated (powder coating or similar). Although the production process of machine tools is very complex, actually standard manufacturing processes are used in their majority, hence the standard production processes implemented in the MEEuP EcoReport template are likely to reflect properly the real production processes to manufacture a machine tool. Furthermore, as the production processes of machine tools are largely performed by metal working machine tools, this Product Group Study directly tackles the production processes of machine tools and related machinery themselves.

4.1.1.2 CNC laser cutting machine

Compact CNC CO_2-laser cutting machines for working metal sheets of up to 15 mm mild steel or 6 mm aluminium come with a machinery weight of roughly 10 tonnes. Laser power of such machines is in the range of 2 kW. More universal laser cutting machines for up to 20 mm mild steel and 8 mm Aluminium (for a working range of 3000 mm in the X axis and 1500 mm in the Y axis, maximum laser power 3 – 5 kW typically) weigh in the range of 12 tonnes, whereas laser cutting machines for oversize formats could exceed 15 t of total machinery weight.

Production of these laser cutting machines and material composition is very similar to other types of CNC metal working machine tools. Specific components used in laser cutting machines are

- HF generator / laser source
- chiller system
- extraction system

However, these components do not change much of the overall material composition. Hence, as a typical material composition the CECIMO data for 9 metal working machine tools as stated above can be scaled for a total machinery weight of 12 tonnes[2].

Table 4-4: Aggregated Bill-of-materials for a (generic) CNC Laser cutting machine tool

Nr	Product name	Date	Author
	Generic CNC Laser cutting machine tool		**KSchi**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Aluminium parts	250000,0	4-Non-ferro	**27-Al diecast**
2	Cast iron parts	6600000,0	3-Ferro	**23-Cast iron**
3	Copper parts	22000,0	4-Non-ferro	**30-Cu tube/sheet**
4	Electric control cabinet	170000,0	6-Electronics	**98-controller board**
5		200000,0	6-Electronics	**44-big caps & coils**
6		300000,0	3-Ferro	**25-Stainless 18/8 coil**
7	Motor 0-10 kW	190000,0	4-Non-ferro	**28-Cu winding wire**
8		200000,0	3-Ferro	**23-Cast iron**
9	Motor 101-200 kW		4-Non-ferro	**28-Cu winding wire**
10			3-Ferro	**23-Cast iron**
11	Motor 11-100kW		4-Non-ferro	**28-Cu winding wire**
12			3-Ferro	**23-Cast iron**
13	Polycarbonate parts	15000,0	2-TecPlastics	**12-PC**
14	Polypropylen parts	12000,0	1-BlkPlastics	**4-PP**
15	Resin-beton parts	160000,0	7-Misc.	**58-Concrete**
16	Rubber parts	2000,0		
17	Stainless steel parts	2790000,0	3-Ferro	**25-Stainless 18/8 coil**
18	Steel cast part alloyed	1090000,0	3-Ferro	**23-Cast iron**
19	Window glass	300,0	7-Misc.	**54-Glass for lamps**

[2] Following adaptations applied: no motors > 10 kW, controller boards weight remains unchanged, rounded figures

4.1.1.3 Hydraulic Press Brake

A press brake is a machine tool for bending sheet metal or plate material. A typical bill-of-materials for a hydraulic press brake is as listed in Table 4-5. The BOM and allocation to modules and material categories has been cordially provided by Marta Lopes de Oliveira and Ana Reis, Universidade do Porto.

The allocation per module follows the assembly structure of the press brake manufacturer and hence slightly deviates from the modular structure as defined in Task 1. The main structural modules are:

- Structural components
- Laser safety assembly
- Common components (in between different machine models)
- Table assembly
- Bumping system assembly
- Hydraulic system assembly
- Lateral guards assembly

The specification of the press brake under study is as follows:

- Commercially available hydraulic press-brake, standard construction as of 2006
- Maximum bending capacity: 110 t
- Maximum bending length: 3 m
- Main motor rated at 7.5 kW

Table 4-5: Aggregated Bill-of-materials for a Hydraulic Press Brake

Nr	Product name	Date	Author
	CNC Bending machine tool	**Dec, 2011**	**KSchi**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	STRUCTURAL COMPONENTS			
2	Steel	6224490,0	3-Ferro	**22-St tube/profile**
3	LASER SAFETY ASSEMBLY			
4	Steel	10360,0	3-Ferro	**22-St tube/profile**
5	Stainless steel	1020,0	3-Ferro	**25-Stainless 18/8 coil**
6	Aluminium	6920,0	4-Non-ferro	**26-Al sheet/extrusion**
7	COMMON COMPONENTS			
8	Steel	569210,0	3-Ferro	**22-St tube/profile**
9	Stainless steel	1620,0	3-Ferro	**25-Stainless 18/8 coil**
10	TABLE ASSEMBLY			
11	Steel	285770,0	3-Ferro	**22-St tube/profile**
12	BUMPING SYSTEM ASSEMBLY			
13	Steel	431330,0	3-Ferro	**22-St tube/profile**
14	Galvanized steel	1920,0	3-Ferro	**21-St sheet galv.**
15	Stainless steel	15040,0	3-Ferro	**25-Stainless 18/8 coil**
16	Aluminium	13390,0	4-Non-ferro	**26-Al sheet/extrusion**
17	Plastics	280,0	2-TecPlastics	**11-PA 6**
18	HYDRAULIC SYSTEM ASSEMBLY			
19	Steel	92920,0	3-Ferro	**22-St tube/profile**
20	Cast iron	97700,0	3-Ferro	**23-Cast iron**
21	Aluminium	520,0	4-Non-ferro	**26-Al sheet/extrusion**
22	LATERAL GUARDS ASSEMBLY			
23	Steel	110070,0	3-Ferro	**22-St tube/profile**
24	Composites	9410,0	2-TecPlastics	**18-E-glass fibre**

The main production processes to produce press brakes are typical metal working processes (drilling, cutting, bending etc.) performed on other metal working machine tools and the following assembly processes.

4.1.1.4 Non-numerical controlled metal working machine tools

Main parts of non-numerical controlled machine tools are also metal parts, typically steel, for machinery frame, guides and bearings. Motors and potentially power electronics represent an important but minor weight share.

Engine and feed shaft lathes are the most used machines in the metal working industry. Typical components:

- Headstock,
- main spindle (drive),
- machine base / frame,
- tool slide,
- tailstock,
- cabinet

Total weight of a typical manually controlled machine tool: 1.000 kg.

Table 4-6: Aggregated Bill-of-materials for a manually controlled engine and feed shaft lathe

Nr	Product name	Date	Author
	manually controlled lathe		**DuB**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Aluminium parts	0,0		
2	Cast iron parts	741021,0		**23-Cast iron**
3	Steel parts	110000,0	3-Ferro	**22-St tube/profile**
4		110000,0	3-Ferro	**21-St sheet galv.**
5	Copper parts	3100,0	4-Non-ferro	**31-CuZn38 cast**
6	Electrical Cabinet	6130,0	4-Non-ferro	**28-Cu winding wire**
7		3104,0	4-Non-ferro	**31-CuZn38 cast**
8		5355,0	4-Non-ferro	**28-Cu winding wire**
9	Motor 0-10 kW	5355,0	4-Non-ferro	**28-Cu winding wire**
10		10090,0	3-Ferro	**24-Ferrite**
11		4850,0	4-Non-ferro	**27-Al diecast**
12	Motor 11-100 kW	0,0		

13		0,0		
14		0,0		
15	Polycarbonate parts	0,0		
16	Polypropylen parts	500,0	1-BlkPlastics	**4-PP**
17	Rubber parts	500,0		
18	Stainless steel parts	0,0		
19	Window glass	0,0		**54-Glass for lamps**

Just as with CNC-machine tools the main production processes to produce non-NC machine tools are on the one hand typical metal working processes (drilling, cutting, bending etc.) performed on other metal working machine tools and on the other hand the assembly processes.

4.1.1.5 Wood working machine tools: Light stationary table saw

Light stationary tools for wood working are typically in the range of 10 – 50 kg. Main parts are the chassis or base part (typically made of cast iron parts or steel sheets), manually operated adjustment parts, the saw table, which might be made of CNC machined aluminium or steel, and motor, gear, drive axis with protective covers.

An exemplary Bill-of-materials is displayed in Table 4-8. This bill of materials is compiled based on spare parts lists and explosion drawings of a table saw; the weight per component has been estimated. The total weight of the table saw is approximately 27 kg. The specification is as listed in Table 4-7.

Table 4-7: Parameters - Exemplary Table Saw

Parameter	
Dimensions: Depth x length x height	**73 x 78 x 34 cm**
Table size	**641 x 737 mm**
No-load speed	**3.650 rpm**
Motor rating	**1.800 W**
Price	**Approx. 1.000 Euro**

With these characteristics, this exemplary table saw is above average in terms of power rating and price of light stationary woodworking tools.

Table 4-8: Aggregated Bill-of-materials for a Table Saw

Nr	Product name	Date	Author
	Light Stationary Wood Working Equipment / Table Saw		**Kschi**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	MOTOR and GEAR DRIVE			
2	Motor Housing	1000,0	3-Ferro	**23-Cast iron**
3	Field	500,0	3-Ferro	**21-St sheet galv.**
4		500,0	4-Non-ferro	**28-Cu winding wire**
5	Armature	200,0	3-Ferro	**22-St tube/profile**
6		300,0	4-Non-ferro	**28-Cu winding wire**
7	Cover	200,0	3-Ferro	**23-Cast iron**
8	Gear Housing	400,0	3-Ferro	**23-Cast iron**
9	Screws, springs, nuts etc.	20,0	4-Non-ferro	**31-CuZn38 cast**
10	Gear Cover	60,0	3-Ferro	**23-Cast iron**
11	Rubber ring	5,0	7-Misc.	
12	Ball bearings	20,0	3-Ferro	**22-St tube/profile**
13	Threaded Rod	30,0	3-Ferro	**22-St tube/profile**
14	Protective Cover	20,0	3-Ferro	**25-Stainless 18/8 coil**
15				
16				
17	CHASSIS / BASE			
18	Housing	10000,0	3-Ferro	**23-Cast iron**
19	Container	500,0	3-Ferro	**21-St sheet galv.**
20	Guard plates	300,0	3-Ferro	**21-St sheet galv.**
21	Front Panel	200,0	3-Ferro	**21-St sheet galv.**
22	Power supply cord	400,0	1-BlkPlastics	**8-PVC**
23		400,0	4-Non-ferro	**29-Cu wire**
24	Switch Housing	50,0	1-BlkPlastics	**10-ABS**
25	Hand wheel assembly	300,0	3-Ferro	**23-Cast iron**
26	Slide	50,0	3-Ferro	**23-Cast iron**
27	On-off switch	20,0	1-BlkPlastics	**10-ABS**
28		10,0	4-Non-ferro	**29-Cu wire**
29		10,0	3-Ferro	**21-St sheet galv.**
30	Coil	10,0	4-Non-ferro	**29-Cu wire**
31	Screws, springs, nuts etc.	40,0	4-Non-ferro	**31-CuZn38 cast**
32	Threaded bushing	20,0	3-Ferro	**22-St tube/profile**
33				
34	STRUCTURAL COMPONENTS			
35	Holding Plate	400,0	3-Ferro	**21-St sheet galv.**
36	Flap Guards	100,0	2-TecPlastics	**13-PMMA**

37	Cover Plates	50,0	3-Ferro	**21-St sheet galv.**
38	Screws, springs, nuts etc.	30,0	4-Non-ferro	**31-CuZn38 cast**
39	Riving Knife	10,0	3-Ferro	**25-Stainless 18/8 coil**
40	Guard Holder	10,0	3-Ferro	**23-Cast iron**
41	Shaft and Guiding Bolts	20,0	3-Ferro	**22-St tube/profile**
42				
43	TABLE			
44	Table Plates	9000	4-Non-ferro	**27-Al diecast**
45	Profile Rails	1000	4-Non-ferro	**26-Al sheet/extrusion**
46	End stop	200	4-Non-ferro	**26-Al sheet/extrusion**
47	Housing	20	1-BlkPlastics	**10-ABS**
48	Clamping Plates	10	3-Ferro	**21-St sheet galv.**
49	Mounting Rails	20	3-Ferro	**25-Stainless 18/8 coil**
50	Clamp Handle	50	3-Ferro	**23-Cast iron**
51	Screws, rings etc.	20	4-Non-ferro	**31-CuZn38 cast**
52	End stop	200	3-Ferro	**23-Cast iron**
53	Clamp handle end stop	50	3-Ferro	**23-Cast iron**
54	Insert	200	3-Ferro	**21-St sheet galv.**
55	Rod	15	3-Ferro	**22-St tube/profile**
56	Guide bar	30	3-Ferro	**22-St tube/profile**

For smaller wood working machine tools also motors with a smaller power rating are used than for large machinery. An evaluation of product catalogues for wood working machinery (not only table saws but also mid-range machinery up to 1 ton in machinery weight) unveils the motor sizes typically used in such machines (Figure 4-1).

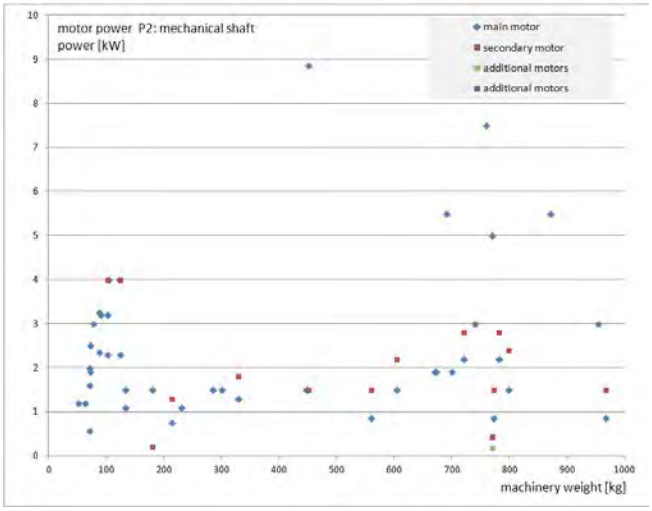


Figure 4-1: Output motor power (mechanical shaft power) of main and auxiliary motors in small and mid-range wood working machine tools

It is evident that even among smaller machines there are only very few motors used with a mechanical shaft power of less than 1 kW, meaning an even higher rated input power.

4.1.1.6 Wood working machine tools: Horizontal panel saw

An averaged bill-of-materials for a horizontal panel saw is as listed in Table 4-9. This bill-of-materials is derived from general insights in construction and modules of horizontal panel saws, checked against plausibility on the basis of typical machinery weights and composition of other large industrial equipment. Consequently the data does not represent any real machinery and has to be understood as an approximation. Data on the control computer is derived from the EuP Lot 3 study on computers, laptops and monitors, as standard PCs are typically use for this kind of machinery.

Table 4-9: Aggregated Bill-of-materials for a Horizontal panel saw

Nr	Product name	Date	Author
	Horizontal panel saw		**Pwi**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Machine table			
2	epoxy panels	100000,0	2-TecPlastics	**14-Epoxy**
3	steel sheets	1100000,0	3-Ferro	**22-St tube/profile**
4				
5	Feed table			
6	steel sheets	1200000,0	3-Ferro	**22-St tube/profile**
7				
8	Horizontal Beam			
9	steel sheets	150000,0	3-Ferro	**22-St tube/profile**
10				
11	Saw Carriage			
12	steel sheets	150000,0	3-Ferro	**22-St tube/profile**
13				
14	Motor 0-10 kW			
15		56500,0	4-Non-ferro	**28-Cu winding wire**
16		106400,0	3-Ferro	**24-Ferrite**
17		37100,0	4-Non-ferro	**27-Al diecast**
18				
19	Pneumatic system			
20		40000,0	3-Ferro	**23-Cast iron**

21		10000,0	3-Ferro	**22-St tube/profile**
22				
23	PC			
24	LDPE	246,0	1-BlkPlastics	**1-LDPE**
25	ABS	381,0	1-BlkPlastics	**10-ABS**
26	PA 6	138,0	2-TecPlastics	**11-PA 6**
27	PC	264,0	2-TecPlastics	**12-PC**
28	Epoxy	98,0	2-TecPlastics	**14-Epoxy**
29	Flex PUR	2,0	2-TecPlastics	**16-Flex PUR**
30	Steel sheets galv.	6312,0	3-Ferro	**21-St sheet galv.**
31	Steel tube/profile	107,0	3-Ferro	**22-St tube/profile**
32	Cast iron	483,0	3-Ferro	**23-Cast iron**
33	Stainless 18/8 coil	10,0	3-Ferro	**25-Stainless 18/8 coil**
34	Al sheets	315,0	4-Non-ferro	**26-Al sheet/extrusion**
35	Al diecast	15,0	4-Non-ferro	**27-Al diecast**
36	Cu winding wire	257,0	4-Non-ferro	**28-Cu winding wire**
37	Cu wire	334,0	4-Non-ferro	**29-Cu wire**
38	Cu tube/sheet	67,0	4-Non-ferro	**30-Cu tube/sheet**
39	Powder coating	2,0	5-Coating	**39-powder coating**
40	Big caps & coil	483,0	6-Electronics	**44-big caps & coils**
41	Slots / ext. Ports	310,0	6-Electronics	**45-slots / ext. ports**
42	Integrate Circuits, 5% Si, 1% Au	69,0	6-Electronics	**46-IC's avg., 5% Si, Au**
43	Integrate Circuits, 1% Si	96,0	6-Electronics	**47-IC's avg., 1% Si**
44	SMD & LEDs avg	194,0	6-Electronics	**48-SMD/ LED's avg.**
45	PWB 1/2 lay 3,75kg/m2	78,0	6-Electronics	**49-PWB 1/2 lay 3.75kg/m2**
46	PWB 6 lay 4,5kg/m2	163,0	6-Electronics	**50-PWB 6 lay 4.5 kg/m2**
47	Solder SbAg4Cu0,5	48,0	6-Electronics	**52-Solder SnAg4Cu0.5**
48	Cardboard	2287,0	7-Misc.	**56-Cardboard**
49				
50	LCD			
51	LDPE	164	1-BlkPlastics	**1-LDPE**
52	EPS	279	1-BlkPlastics	**6-EPS**
53	PVC	43	1-BlkPlastics	**8-PVC**
54	ABS	679	1-BlkPlastics	**8-PVC**
55	PA 6	422	2-TecPlastics	**11-PA 6**
56	PC	385	2-TecPlastics	**12-PC**
57	PMMA	153	2-TecPlastics	**13-PMMA**
58	E-glass fibre	120	2-TecPlastics	**18-E-glass fibre**
59	Aramid fibre	6,5	2-TecPlastics	**19-Aramid fibre**
60	Steel sheet galvanized	1854	3-Ferro	**21-St sheet galv.**
61	Al sheet/extrusion	39	4-Non-ferro	**26-Al sheet/extrusion**
62	Cu wire	190	4-Non-ferro	**29-Cu wire**
63	Powder coating	1	5-Coating	**39-powder coating**
64	LCD Screen m2 (viewable screen size)	91	6-Electronics	**42-LCD per m2 scrn**

65	Big caps & coils	41	6-Electronics	**44-big caps & coils**
66	Slots /ext. Ports	37	6-Electronics	**45-slots / ext. ports**
67	Integrate Circuits, 5% Si, 1% Au	13	6-Electronics	**46-IC's avg., 5% Si, Au**
68	Integrate Circuits, 1% Si	20	6-Electronics	**47-IC's avg., 1% Si**
69	Solder SbAg4Cu0,5	11	6-Electronics	**52-Solder SnAg4Cu0.5**
70	SMD & LEDs avg	11	6-Electronics	**48-SMD/ LED's avg.**
71	PWB 1/2 lay 3,75kg/m2	30	6-Electronics	**49-PWB 1/2 lay 3.75kg/m2**
72	PWB 6 lay 4,5kg/m2	20	6-Electronics	**50-PWB 6 lay 4.5 kg/m2**
73	Glass for Lamps	26	7-Misc.	**54-Glass for lamps**
74	Cardboard	650	7-Misc.	**56-Cardboard**
75	Office paper	55	7-Misc.	**57-Office paper**
76	Misc glass	308	7-Misc.	
77	Cast iron	1165	3-Ferro	**23-Cast iron**
78				
79	Housing	30427,5	3-Ferro	**21-St sheet galv.**
80				
81	Chassis	1000000	3-Ferro	**21-St sheet galv.**
82		1000000	3-Ferro	**21-St sheet galv.**

4.1.1.7 Wood working machine tools: Throughfeed edge banding machine

An averaged bill-of-materials for a throughfeed edge banding machine is as listed in Table 4-10.

This bill-of-materials is derived from general insights in construction and modules of throughfeed edge banding machines, checked against plausibility on the basis of typical machinery weights and composition of other large industrial equipment. Consequently the data does not represent any real machinery and has to be understood as an approximation. Data on the control computer is derived from the EuP Lot 3 study on computers, laptops and monitors, as standard PCs are typically use for this kind of machinery.

Table 4-10: Aggregated Bill-of-materials for a Throughfeed edge banding machine

Nr	Product name	Date	Author
	Throughfeed edge banding machine		**Pwi**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Motors 0-10 kW			
2		79800,0	3-Ferro	**24-Ferrite**
3		42300,0	4-Non-ferro	**28-Cu winding wire**
4		27900,0	4-Non-ferro	**27-Al diecast**
5				
6	Cables	10000,0	4-Non-ferro	**29-Cu wire**
7				
8	Pipes	10000,0	3-Ferro	**22-St tube/profile**
9				
10	Cast steel parts	630000,0	3-Ferro	**23-Cast iron**
11				
12	PC			
13	LDPE	246,0	1-BlkPlastics	**1-LDPE**
14	ABS	381,0	1-BlkPlastics	**10-ABS**
15	PA 6	138,0	2-TecPlastics	**11-PA 6**
16	PC	264,0	2-TecPlastics	**12-PC**
17	Epoxy	98,0	2-TecPlastics	**14-Epoxy**
18	Flex PUR	2,0	2-TecPlastics	**16-Flex PUR**
19	Steel sheets galvanized	6312,0	3-Ferro	**21-St sheet galv.**
20	Steel tube/profile	107,0	3-Ferro	**22-St tube/profile**
21	Cast iron	483,0	3-Ferro	**23-Cast iron**
22	Stainless 18/8 coil	10,0	3-Ferro	**25-Stainless 18/8 coil**
23	Al sheet/extrussion	315,0	4-Non-ferro	**26-Al sheet/extrusion**
24	Al diecast	15,0	4-Non-ferro	**27-Al diecast**
25	Cu winding wire	257,0	4-Non-ferro	**28-Cu winding wire**
26	Cu wire	334,0	4-Non-ferro	**29-Cu wire**
27	Cu tube/sheet	67,0	4-Non-ferro	**30-Cu tube/sheet**
28	Powder coating	2,0	5-Coating	**39-powder coating**
29	Big caps & coils	483,0	6-Electronics	**44-big caps & coils**
30	Slots/ext. Port	310,0	6-Electronics	**45-slots / ext. ports**
31	Integrated Circuits, 5% Silicon, Au	69,0	6-Electronics	**46-IC's avg., 5% Si, Au**
32	Integrated Circuits, 1% Silicon	96,0	6-Electronics	**47-IC's avg., 1% Si**
33	SMD & LEDs avg	194,0	6-Electronics	**48-SMD/ LED's avg.**

34	PWB 1/2 lay 3,75kg/m2	78,0	6-Electronics	**49-PWB 1/2 lay 3.75kg/m2**
35	PWB 6 lay 4,5kg/m2	163,0	6-Electronics	**50-PWB 6 lay 4.5 kg/m2**
36	Solder SbAg4Cu0,5	48,0	6-Electronics	**52-Solder SnAg4Cu0.5**
37	Cardboard	2287,0	7-Misc.	**56-Cardboard**
38				
42	LCD			
43	LDPE	164	1-BlkPlastics	**1-LDPE**
44	EPS	279	1-BlkPlastics	**6-EPS**
45	PVC	43	1-BlkPlastics	**8-PVC**
46	ABS	679	1-BlkPlastics	**8-PVC**
47	PA 6	422	2-TecPlastics	**11-PA 6**
48	PC	385	2-TecPlastics	**12-PC**
49	PMMA	153	2-TecPlastics	**13-PMMA**
50	E-glass fibre	120	2-TecPlastics	**18-E-glass fibre**
51	Aramid fibre	6,5	2-TecPlastics	**19-Aramid fibre**
52	Steel sheet galvanized	1854	3-Ferro	**21-St sheet galv.**
53	Al sheet/extrusion	39	4-Non-ferro	**26-Al sheet/extrusion**
54	Cu wire	190	4-Non-ferro	**29-Cu wire**
55	Powder coating	1	5-Coating	**39-powder coating**
56	LCD Screen m2 (viewable screen size)	91	6-Electronics	**42-LCD per m2 scrn**
57	Big caps & coils	41	6-Electronics	**44-big caps & coils**
58	Slots /ext. Ports	37	6-Electronics	**45-slots / ext. ports**
59	Integrate Circuits, 5% Si, 1% Au	13	6-Electronics	**46-IC's avg., 5% Si, Au**
60	Integrate Circuits, 1% Si	20	6-Electronics	**47-IC's avg., 1% Si**
61	Solder SbAg4Cu0,5	11	6-Electronics	**52-Solder SnAg4Cu0.5**
62	SMD & LEDs avg	11	6-Electronics	**48-SMD/ LED's avg.**
63	PWB 1/2 lay 3,75kg/m2	30	6-Electronics	**49-PWB 1/2 lay 3.75kg/m2**
64	PWB 6 lay 4,5kg/m2	20	6-Electronics	**50-PWB 6 lay 4.5 kg/m2**
65	Glass for Lamps	26	7-Misc.	**54-Glass for lamps**
66	Cardboard	650	7-Misc.	**56-Cardboard**
67	Office paper	55	7-Misc.	**57-Office paper**
68	Misc glass	308	7-Misc.	
69	Cast iron	1165	3-Ferro	**23-Cast iron**
70				
71	Housing	30427,5	3-Ferro	**21-St sheet galv.**
72				
73	Chassis			
74	steel sheet	700000	3-Ferro	**21-St sheet galv.**
75	steel sheet	700000	3-Ferro	**21-St sheet galv.**
76	PMMA	20000	2-TecPlastics	**13-PMMA**
77	Al	150000	4-Non-ferro	**26-Al sheet/extrusion**

78	Cables	20000	4-Non-ferro	**29-Cu wire**
79	tubes	10000	3-Ferro	**22-St tube/profile**
80	Motors 0-10 kW			
81		26600	3-Ferro	**24-Ferrite**
82		14100	4-Non-ferro	**28-Cu winding wire**
83		9300	4-Non-ferro	**27-Al diecast**

4.1.1.8 Wood working machine tools: CNC machining centre

An averaged bill-of-materials for a CNC machining centre is as listed in **Table 4-11**.

Wood working machinery labelled as CNC machining centres starts from lower weights than metal working “machining centres”, i.e. in the range of few tonnes. Typical groove machines for workshop use are in the weight range of 2-3 tonnes. Industrial sawing machines span a wide range from few hundred kilograms to several tonnes.

For structural parts of wood working machinery steel parts are common, which dominate the overall machinery weight. Electronics, window glass, motors and plastic and rubber parts are of secondary importance. Integrated chip and dust extracting systems require fans, and vacuum systems.

Table 4-11: Aggregated Bill-of-materials for a CNC machining centre

Nr	Product name	Date	Author
	CNC machining center		**Pwi**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Aluminium parts	167489,2	4-Non-ferro	**27-Al diecast**
2	Cast iron parts	4368699,6	3-Ferro	**23-Cast iron**
3	Copper parts	14824,3	4-Non-ferro	**30-Cu tube/sheet**
4	Electric control cabinet (total: 1.172.222,2 g)	56875,5	6-Electronics	**98-controller board**
5		132098,0	6-Electronics	**44-big caps & coils**
6		198146,9	3-Ferro	**25-Stainless 18/8 coil**
7	Motor 0-10 kW (total 798.666,7 g)	131657,6	4-Non-ferro	**28-Cu winding wire**
8		132098,0	3-Ferro	**23-Cast iron**
9	Motor 101-200 kW (total: 73.333,3 g)	11668,7	4-Non-ferro	**28-Cu winding wire**
10		12549,3	3-Ferro	**23-Cast iron**
11	Motor 11-100kW (total: 76.222,2	11962,2	4-Non-ferro	**28-Cu winding wire**
12		13209,8	3-Ferro	**23-Cast iron**
13	Polycarbonate parts	9907,3	2-TecPlastics	**12-PC**

14	Polypropylen parts	7925,9	1-BlkPlastics	**4-PP**
15	Resin-beton parts	110081,6	7-Misc.	**58-Concrete**
16	Rubber parts	1541,1		
17	Stainless steel parts	1847206,5	3-Ferro	**25-Stainless 18/8 coil**
18	Steel cast part alloyed	721838,3	3-Ferro	**23-Cast iron**
19	Window glass	220,2	7-Misc.	**54-Glass for lamps**
20				
21	PC			
22	LDPE	246,0	1-BlkPlastics	**1-LDPE**
23	ABS	381,0	1-BlkPlastics	**10-ABS**
24	PA 6	138,0	2-TecPlastics	**11-PA 6**
25	PC	264,0	2-TecPlastics	**12-PC**
26	Epoxy	98,0	2-TecPlastics	**14-Epoxy**
27	Flex PUR	2,0	2-TecPlastics	**16-Flex PUR**
28	Steel sheets galv.	6312,0	3-Ferro	**21-St sheet galv.**
29	Steel tube/profile	107,0	3-Ferro	**22-St tube/profile**
30	Cast iron	483,0	3-Ferro	**23-Cast iron**
31	Stainless 18/8 coil	10,0	3-Ferro	**25-Stainless 18/8 coil**
32	Al sheets	315,0	4-Non-ferro	**26-Al sheet/extrusion**
33	Al diecast	15,0	4-Non-ferro	**27-Al diecast**
34	Cu winding wire	257,0	4-Non-ferro	**28-Cu winding wire**
35	Cu wire	334,0	4-Non-ferro	**29-Cu wire**
36	Cu tube/sheet	67,0	4-Non-ferro	**30-Cu tube/sheet**
37	Powder coating	2,0	5-Coating	**39-powder coating**
38	Big caps & coil	483,0	6-Electronics	**44-big caps & coils**
39	Slots / ext. Ports	310,0	6-Electronics	**45-slots / ext. ports**
40	Integrated Circuits, 5% Si, 1% Au	69,0	6-Electronics	**46-IC's avg., 5% Si, Au**
41	Integrated Circuits, 1% Si	96,0	6-Electronics	**47-IC's avg., 1% Si**
42	SMD & LEDs avg	194,0	6-Electronics	**48-SMD/ LED's avg.**
43	PWB 1/2 lay 3,75kg/m2	78,0	6-Electronics	**49-PWB 1/2 lay 3.75kg/m2**
44	PWB 6 lay 4,5kg/m2	163,0	6-Electronics	**50-PWB 6 lay 4.5 kg/m2**
45	Solder SbAg4Cu0,5	48,0	6-Electronics	**52-Solder SnAg4Cu0.5**
46	Cardboard	2287,0	7-Misc.	**56-Cardboard**
47				
48	LCD			
49	LDPE	164	1-BlkPlastics	**1-LDPE**
50	EPS	279	1-BlkPlastics	**6-EPS**
51	PVC	43	1-BlkPlastics	**8-PVC**
52	ABS	679	1-BlkPlastics	**8-PVC**
53	PA 6	422	2-TecPlastics	**11-PA 6**
54	PC	385	2-TecPlastics	**12-PC**
55	PMMA	153	2-TecPlastics	**13-PMMA**
56	E-glass fibre	120	2-TecPlastics	**18-E-glass fibre**
57	Aramid fibre	6,5	2-TecPlastics	**19-Aramid fibre**

58	Steel sheet galvanized	1854	3-Ferro	**21-St sheet galv.**
59	Al sheet/extrusion	39	4-Non-ferro	**26-Al sheet/extrusion**
60	Cu wire	190	4-Non-ferro	**29-Cu wire**
61	Powder coating	1	5-Coating	**39-powder coating**
62	LCD Screen m2 (viewable screen size)	91	6-Electronics	**42-LCD per m2 scrn**
63	Big caps & coils	41	6-Electronics	**44-big caps & coils**
64	Slots /ext. Ports	37	6-Electronics	**45-slots / ext. ports**
65	Integrate Circuits, 5% Si, 1% Au	13	6-Electronics	**46-IC's avg., 5% Si, Au**
66	Integrate Circuits, 1% Si	20	6-Electronics	**47-IC's avg., 1% Si**
67	Solder SbAg4Cu0,5	11	6-Electronics	**52-Solder SnAg4Cu0.5**
68	SMD & LEDs avg	11,0	6-Electronics	**48-SMD/ LED's avg.**
69	PWB 1/2 lay 3,75kg/m2	30,0	6-Electronics	**49-PWB 1/2 lay 3.75kg/m2**
70	PWB 6 lay 4,5kg/m2	20,0	6-Electronics	**50-PWB 6 lay 4.5 kg/m2**
71	Glass for Lamps	26	7-Misc.	**54-Glass for lamps**
72	Cardboard	650	7-Misc.	**56-Cardboard**
73	Office paper	55	7-Misc.	**57-Office paper**
74	Misc glass	308	7-Misc.	
75	Cast iron	1165	3-Ferro	**23-Cast iron**
76				
77	Housing	30427,5	3-Ferro	**21-St sheet galv.**

The main production processes to produce wood working machine tools are typical metal working processes (drilling, cutting, bending etc.) and the following assembly processes. The minor share of plastic parts are typically manufactured with injection moulding machines, electronics are assembled with standard technologies, surfaces of the machine housing are typically colour coated (powder coating or similar). Standard manufacturing processes are used in the majority of cases, hence the standard production processes implemented in the MEEuP EcoReport template are likely to reflect properly the real production processes to manufacture wood working machinery. Furthermore, as the production processes of wood working machinery are largely performed by metal working machine tools, this Product Group Study directly tackles the relevant production processes.

4.1.1.9 Welding equipment

A major part of typical transportable welding equipment is the power source, i.e. related transformer or power electronics / inverter and housing parts of the power source. Every piece of equipment comes with a control panel of its own. Torch, gas supply and welding wire feed are further essential components.

Smaller units start from roughly 7 kg in weight. Typical transportable arc welding power sources are in the range of 40 – 150 kg roughly. Transportable plasma cutting equip-

ment including power source, burner and cables are in the range of 10 – 30 kg per unit. Stated weights refer to current product models, former generations with power sources based on larger, less efficient transformers were heavier and larger regarding the electrical part, and thus also the housing.

Table 4-12: Parameters - Exemplary MIG/MAG Welding Equipment

Parameters		
Mains voltage	**3 x 230 V / 400 V**	
Welding current range	**10 – 340 A**	
Welding current at: 10 min/40° C	**35 % d.c.**	**340 A**
	60 % d.c.	**260 A**
	100 % d.c.	**200 A**
Open-circuit voltage	**45 V**	
Operating voltage	**14.5 – 31.0 V**	
N° of switching steps	**2 x 7**	
Protection level	**IP 23**	
Primary continuous power (100 % d.c.):	**6.2 kVA**	
efficiency	**76,8 % @ 200 A**	
price	**approx. 2.700,- Euro**[3]	

Table 4-13: Aggregated Bill-of-materials for a MIG/MAG Welding Equipment

Nr	Product name	Date	Author
	MIG/MAG-Welding Equipment		**KSchi**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	**Cover**			
2	handle tube Vario Synergic	2300,0	3-Ferro	**21-St sheet galv.**
3	Grip accom. left red	141,0	3-Ferro	**21-St sheet galv.**
4	Grip accom. right red	141,0	3-Ferro	**21-St sheet galv.**
5	BOTTLE CHAIN	110,0	3-Ferro	**21-St sheet galv.**
6	CHAIN ASSEMBLY	14,0	3-Ferro	**21-St sheet galv.**
7	Side panel right	5600,0	3-Ferro	**21-St sheet galv.**

[3] compared to PRODCOM unit value of 1.188 Euro for NACE Code 27903154, which covers an estimated stock of 1,27 million units

8	Sidepanel left top	12000,0	3-Ferro	**21-St sheet galv.**
9	Cover red	4500,0	3-Ferro	**21-St sheet galv.**
10	Sidepanel left red	4500,0	3-Ferro	**21-St sheet galv.**
11		30,0	5-Coating	**39-powder coating**
12				
13	**Chassis**			
14	PICK-UP WHEEL BLACK	1000,0	3-Ferro	**22-St tube/profile**
15	Bottom black	15000,0	3-Ferro	**21-St sheet galv.**
16	Rear panel bl	12000,0	3-Ferro	**21-St sheet galv.**
17	Bottle holder SW	600,0	3-Ferro	**21-St sheet galv.**
18	WHEEL STEEL 180 GL 45 20 (2 Stk)	2080,0	3-Ferro	**22-St tube/profile**
19	Motor plate 42V	1000,0	3-Ferro	**21-St sheet galv.**
20	front panel print	12000,0	3-Ferro	**21-St sheet galv.**
21	TUMBLER GEAR D=16O (2 Stk)	2000,0	3-Ferro	**22-St tube/profile**
22	STAR LOCK D= 2O (2 Stk)	20,0	3-Ferro	**22-St tube/profile**
23	CURRENT SOCKET/5O-7O MM2/6OOA (3 Stk)	255,0	1-BlkPlastics	**8-PVC**
24		300,0	4-Non-ferro	**29-Cu wire**
25	SOCKET-CONTACT	3,0	3-Ferro	**22-St tube/profile**
26	MAINS-CABLE	740,0	4-Non-ferro	**29-Cu wire**
27		740,0	1-BlkPlastics	**8-PVC**
28	ROCKER SWITCH	9,0	4-Non-ferro	**29-Cu wire**
29		9,0	1-BlkPlastics	**6-EPS**
30	TERMINAL STRIP 9pin	3,5	1-BlkPlastics	**8-PVC**
31		3,5	4-Non-ferro	**26-Al sheet/extrusion**
32	TURNING KNOB D=23 RED/BLA./RED	8,0	1-BlkPlastics	**10-ABS**
33		5,0	3-Ferro	**22-St tube/profile**
34	Decel.device kit D=300	390,0	3-Ferro	**23-Cast iron**
35	Nut for brake	28,0	4-Non-ferro	**31-CuZn38 cast**
36	MOUNTING SPRING FOR PLUG	3,0	3-Ferro	**25-Stainless 18/8 coil**
37	INSULATION F.BUSHING STRIP	5,0	1-BlkPlastics	**6-EPS**
38	AXLE	800,0	3-Ferro	**22-St tube/profile**
42	TRACTION RELEASE	18,0	1-BlkPlastics	**8-PVC**
43	RESISTOR	27,0	6-Electronics	**44-big caps & coils**
44	Frame device Industry red	12000	3-Ferro	**21-St sheet galv.**
45	Remote control cable 10-pin/20m	1750	4-Non-ferro	**29-Cu wire**
46		1750	1-BlkPlastics	**8-PVC**
47	Adaptor wire coil	630	3-Ferro	**23-Cast iron**
48	Isolation wire coil	410	3-Ferro	**23-Cast iron**
49				
50	Electronics			

51	Divider printed	12000	3-Ferro	**21-St sheet galv.**
52	CONTROL TRANSF. 440/460/500V	3200	6-Electronics	**44-big caps & coils**
53	PC-BOARD	29	6-Electronics	**98-controller board**
54	PC-Board	400	6-Electronics	**98-controller board**
55	PC-Board	450	6-Electronics	**98-controller board**
56	PC-Board	50	6-Electronics	**98-controller board**
57	FUSE HOLDER 6.3/5X20	50	3-Ferro	**23-Cast iron**
58	FUSE-CAP	1	3-Ferro	**23-Cast iron**
59	FUSE HOLDER	4	3-Ferro	**23-Cast iron**
60	FUSE	3	3-Ferro	**23-Cast iron**
61	FILTER-GLASS GREEN (2 Stk)	12	7-Misc.	**54-Glass for lamps**
62	ROT.SWITCH W.LINCHPIN (6 Stk)	3	4-Non-ferro	**29-Cu wire**
63		3	1-BlkPlastics	**8-PVC**
64	DISTANCE 9,5	1	3-Ferro	**23-Cast iron**
65	PROTECTION CIRCUIT EMV 500V	800	4-Non-ferro	**29-Cu wire**
66		800	1-BlkPlastics	**6-EPS**
67	CONTACTOR	800	4-Non-ferro	**29-Cu wire**
68	Current bolt 90mm²	250	4-Non-ferro	**31-CuZn38 cast**
69	TURNING KNOB D=23 RED/BLA./RED (2 Stk)	26	1-BlkPlastics	**6-EPS**
70	FUSE 1A/25O V	3	3-Ferro	**23-Cast iron**
71	GAS SOLENOiD VALVE	131	3-Ferro	**22-St tube/profile**
72				
73	Transformer assembly			
74	SWITCH KNOB BLACK (2 Stk)	25	1-BlkPlastics	**6-EPS**
75	RECTIFIER	1500	4-Non-ferro	**28-Cu winding wire**
76	Transformer 230/400V50Hz	15000	6-Electronics	**44-big caps & coils**
77	Output choke	7000	6-Electronics	**44-big caps & coils**
78	CAM-SWITCH	400	4-Non-ferro	**26-Al sheet/extrusion**
79		100	1-BlkPlastics	**8-PVC**
80	Contact cam	500	4-Non-ferro	**26-Al sheet/extrusion**
81	THERMAL CIRCUIT BREAKER	1	4-Non-ferro	**29-Cu wire**
82		1	1-BlkPlastics	**8-PVC**
83		1	4-Non-ferro	**26-Al sheet/extrusion**
84	THERMAL CIRCUIT BREAKER	4	1-BlkPlastics	**8-PVC**
85		4	4-Non-ferro	**29-Cu wire**
86	THERMAL CIRCUIT BREAKER	5	1-BlkPlastics	**8-PVC**
87		5	4-Non-ferro	**29-Cu wire**
88	FAN W.BLADE	1430	1-BlkPlastics	**7-HI-PS**
89	SHUNT VST	27	3-Ferro	**21-St sheet galv.**
90	PC-BOARD (2 Stk)	58	6-Electronics	**98-controller board**

4.1.1.10 Other machine tools and related machinery

Other machine tools and related machinery covers such a huge spectrum, that a statement regarding the production and material composition has to remain on a very general level:

- Total weight is from few kilograms to several tonnes
- Frames and housing parts, and thus the total machinery weight, are dominated by steel and other iron based materials
- Electrical and electronics parts are relevant (although not in terms of total weight) for all electricity powered and in particular automated machinery
- Motors are used in all kind of machinery, i.e. the typical composition of motors across all power ranges constitutes a share of the total machinery composition

Metal working machine tools are broadly used for machinery building and the related manufacturing processes of machinery parts and components.

4.1.2 Distribution phase

Industrial machinery is typically directly shipped from the manufacturer to the customer, either in parts to be assembled at the final destination or as a whole. Within Europe (and as the majority of machine tools operating in Europe actually comes from European manufacturers) ground transport by truck is the typical way of delivering machinery to the customer.

The MEEuP standard settings are based on final assembly, delivery distribution centre(s) and warehouses by intra-EU trucking / rail and for an import share of 10% sea-freight and EU trucking/rail. Set distances are 1,000 km intra-EU trucking/rail and for the imported share an additional 12,000 km sea-freight. In addition, final delivery to whole-seller or central retail warehouse in medium-sized truck, transport distance 500 km, is the standard entry. The latter and the impacts of distribution centres and warehouses as such are not relevant for typical machine tools, and therefore – taking 1,000 km intra-EU transport as a realistic figure for machinery – MEEuP is likely to overestimate the distribution impacts calculated.

4.1.2.1 CNC milling and turning machine tools

The 4-axis multifunctional milling centre in section 0 specified needs for packaging and distribution, mainly plastics, wood and sheet metal. The material has a minor level of

re-use. The most of it is further used in countries with waste treatment systems. The packaged volume of a unit is 72 m^3. Table 4-14 shows the entries to be made in the MEEuP EcoReport. Same entries regarding weight class and installation are to be made for the following types of machine tools.

Table 4-14: Distribution attributes of the CNC 4-axis multifunctional milling centre

Pos nr	DISTRIBUTION (incl. Final Assembly) Description		Answer	Category index (fixed)	
208	Is it an ICT or Consumer Electronics product <15 kg ?		NO	59	0
209	Is it an installed appliance (e.g. boiler)?		YES	60	1
				62	0
210	Volume of packaged final product in m^3	in m3	72	63	1

4.1.2.2 CNC laser cutting machine

The packaged final volume for a typical generic laser cutting machine tool, as outlined in 4.1.1.2, is 80 m^3.

4.1.2.3 Hydraulic Press Brake

The packaged final volume for the hydraulic press brake specified in 4.1.1.2 is 19.66 m^3.

4.1.2.4 Non-numerical controlled metal working machine tools

The packaged final volume for typical non-numerical controlled metal working machine tools is assumed to be in the range from 1-2 m^3 for smaller units up to maximum 20 m^3. Larger machinery is unlikely to be non-numerical controlled.

4.1.2.5 Wood working machine tools: Table saw

Light stationary wood working tools are assumed to start from roughly 0.2 m^3 packaged volume. Larger stationary, but less complex units are in the range of 1-2 m^3.

4.1.2.6 Wood working machine tools: Horizontal panel saw

Horizontal panel saws are shipped disassembled as they require larger tables for panel handling, and therefore feature a less compact design. Disassembled shipping allows an optimised use of any cargo capacity. For horizontal panel saws with a cutting length in the range of 3000 to 5000 mm the estimated shipped volume is in the range of 10 to 20 m³. 14 m³ can be considered a sound approximation.

4.1.2.7 Wood working machine tools: Throughfeed edge banding machine

Throughfeed edge bending machines are typically of a nearly cuboid shape, plus smaller feeding and auxiliary units and components. Typical machinery dimensions can be considered a sound approximation to calculate the shipping volume. Depending on the functionality and number of modules integrated in a throughfeed edge banding machine the shipping volume varies, but for a machinery length of roughly 6000 mm a sound approximation of packaged volume is 18 m³.

4.1.2.8 Wood working machine tools: CNC machining centre

Wood working CNC machining centres are of a packaged size of several tens of cubic meters.

4.1.2.9 Welding equipment

Smaller transportable units start from 0.02 m³ packaged volume. The typical wheeled arc welding equipment comes at roughly 0.3 m³ packaged volume.

4.1.2.10 Other machine tools and related machinery

The broad variety of machinery comes with a broad spectrum of “packaged volume”, in particular if whole production lines are addressed, such as in the paper and printing industry. Typical values cannot be stated besides the fact that small handheld units are excluded from the scope and stationary units are likely to start at 0.02 m³ packaged volume.

4.1.3 Use phase

The **tools** used for machining can be considered as a “consumable”. Tools are a very important component of the machine tool and the environmental impact related to tool

production itself could be relevant: Rajemi et al.[4] investigated optimum turning conditions based on minimum energy considerations, taking into account also the embodied energy of the tools. As tool wear and thus tool lifetime depends on machining velocity, high throughput means a shorter tool lifetime in terms of processing cycles per tool. Rajemi et al. found out, that in terms of total energy consumption a reduced processing velocity despite the longer processing times might result in a lower total energy consumption[5]. This aspect is a question of how setting process parameters right, not of the machine design as such. Tools are made of particularly durable materials, such as specific steel alloys, frequently underwent specific hardening processes or are surface coated. The assessment of tool production will be taken into account in the later analysis where relevant.

Hydraulic oil is an essential auxiliary material for most machine tools. Hydraulic oil is not a consumable in the closer sense compared to others (e. g. lube oil) because it is used in a closed system for power transmission. However, it has to be replaced regularly and thus will be listed under "consumables" in the MEEuP assessments. As the MEEuP EcoReport does not provide a dataset for hydraulic oil, the MEEuP assessment has to be complemented by literature data. McManus et al.[6] published Life Cycle Assessment data for hydraulic oil, but for mobile systems, such as agriculture vehicles. As an approximation this data will be used in this study. The calculated impacts per 1 kg mineral oil are listed in the table below. As the impact categories used deviate from the impact categories of MEEuP the right coulmn lists the corresponding categories. There is a considerable overlap of the categories, but not a full match.

Table 4-15: Production related life cycle impacts of mineral oil production

Impact of 1 kg mineral oil production for hydraulics			MEEuP equivalents
Greenhouse gases	Kilograms CO2 equivalent	3.56	Global Warming Potential (GWP)
Ozone-depleting gases	Kilograms CFC-11 equivalent	$8.90 * 10^{-12}$	None, category considered irrelevant for EuPs

4 Rajemi, M.F.; Mativenga, P.T.; Aramcharoen, A.: Sustainable machining: selection of optimum turning conditions based on minimum energy considerations, Journal of Cleaner Production 18 (2010), p. 1059-1065

5 CECIMO stated disagreement with this finding by Rajemi et al. and provided comprehensive data to verify this aspect. Data provided by CECIMO is cited in Task 5 (discussion on productivity) extensively.

6 McManus, M. C.; Hammond, G.P.; Burrows, C.R.: Life-Cycle Assessment of Mineral and Rapeseed Oil in Mobile Hydraulic Systems, Journal of Industrial Ecology, Volume 7, Issue 3-4, Article first published online: 8 Feb 2008

Impact of 1 kg mineral oil production for hydraulics			MEEuP equivalents
Acidification	Kilograms SO equivalent	0.00383	Acidification (AD)
Eutrophication	Kilograms PO equivalent	0.000378	Eutrophication (EUP)
Heavy metals	Kilograms Pb equivalent	$5.02 * 10^{-7}$	Not transferrable to Ni and Hg equivalents
Carcinogens	Kilograms B(a)P equivalent	$1.62 * 10^{-12}$	none
Winter smog	Kilograms SPM equivalent	0.0018	none
Summer smog	Kilograms C2H4 equivalent	$1.61 * 10^{-8}$	Approximation: Volatile Organic Compounds (VOC)
Energy	Megajoules LHV equivalent	5.94	Approximation: Total Energy
Solid waste	Kilograms	0.00519	Approximation: Waste, non-hazardous, landfill

Although leakages of hydraulic oil might happen, there is no evidence, that such leakages pose a major environmental problem for machine tools.

Cooling lubricants are an important auxiliary for metal working machine tools and serve several purposes, lubricating tool and workpiece, cooling both and enhancing the removal of chips from the processing area. Under certain conditions harzardous substances might be released. Reducing the exposition requires thorough controlling and maintenance of emulsions / solutions and system components. On site measures by industrial safety authorities indicate as of 2006 that the abatement systems frequently are not effective enough and substantial emissions are released back to the working environment[7].

Cooling lubricants despite being recovered and cycled typically within a manufacturing plant constitute – besides cut-offs of any kind - the most relevant waste generated at metal working processes. Those cooling lubricants stated as consumption in the use phase per Base Case below are understood to be net consumption (i.e. already internally recycled several times), and leave the process finally either as an emission, filtered in the abatement unit or as industrial waste (either separated as waste emulsions / solutions or attached as residue on metal chips, which are then processed in metals recycling).

[7] Pfeiffer, W.: Absaugen und Abscheiden von Kühlschmierstoffemissionen an geschlossenen Werkzeugmaschinen – Einführung, BGIA-Report 9/2006, Absaugen und Abscheiden von Kühlschmierstoffemissionen, Zusammenfassung der Vorträge anlässlich einer Fachveranstaltung am 11. Mai 2006 in Bonn

The assessments in this Task 4 cover the actual consumption of cooling lubricants (as well as of lubrication oil and hydraulic oil where relevant), but do not cover work place exposition and waste generation and disposal.

Further consumables of machine tools are **grease** for bearings and gears, and **air** for the pneumatic system. Pressurized air is assessed under the aspect energy consumption.

Furthermore, typical consumables depend on the type of machinery and are stated below.

The UK Manufacturing Technologies Association (MTA) stated metal working machine tool power ratings for major machine tool categories[8], see Table 4-16.

Table 4-16: Machine tool power ratings (source: MTA)

Machine Tool Category	Power (kW)		
	Minimum	Typical	Maximum
By laser, ultrasonic and the like	0.1	1.5	4
Machining centres	2	23	45
Lathes	1	11	75
Drilling, boring or milling; threading or tapping	0.25	23	30
Deburring, sharpening, grinding (finishing metal)	0.25	15	50
Planing, sawing, cutting-off (cutting metal)	0.25	2.2	50
Bending, folding and straightening	1.5	5	50
Shearing, punching and notching	1.5	5	30
Forging or die-stamping machines and hammers; hydraulic presses and presses	5	20	180
Sintered metal carbides or cermets, without removing material	1.5	5	50

The huge min-max range for all machine tools categories (factor 20 to 200) again shows the fact, that machine tools span a huge range of machinery sizes and technical performance. Any assumption about average power consumption therefore is a critical factor in the overall assessments.

4.1.3.1 CNC 4-axis multifunctional milling centre

Consumables for metal working machine tools are

[8] SKM Enviros: Estimating the Energy Saving Potential from Small Motors and Machine Tools, Report on Machine Tools Research & Modelling, 11 July 2011, p.20

- Hydraulic oil
- Lubricant oil
- Cooling lubricants

Water is a consumable either for water-miscible cooling lubricants, or (very occassionally) for cooling of machinery parts.

The product life cycle of the milling centre specified in 4.1.1.1.2 is set with 12 years, according to the analysis for machining centres provided in Task 2. The input power for the "real machine tool", which served as the background for this base case, is 25 kW during full operation. Being equipped with sophisticated energy recovery[9], an abstraction is required for a theoretical machine tool without this feature, which means higher power consumption in the range of approximately 30 kW during full operation[10]. In standby-mode power of 1.5 kW is consumed for latch mode of CNC control and power electronics (thyristor). Automated standby-mode switch-on is time scalable by the customer from five minutes to several hours. Usually, the time span for automated sleep is half an hour up to two hours. No electrical power is consumed during off-mode. The mode distribution is estimated for shifts of six days a week with 16.5 hours each including set-up, maintenance and repair. The operational availability is estimated for 4,400 hours/year as pure machining time with additional 750 hours/year for set-up works such as tool and work-piece change, cleaning, change of auxiliary materials as well as other maintenance and repair operations. The total switch-off is estimated with 3,600 hours/year. The operational time of 4,400 hours per year is confirmed by data provided by the UK Manufacturing Technologies Association (MTA)[11].

Water consumption for process lubrication emulsion totals in 18 m^3. A ratio of 6% to 7% lubrication oil in the range of 0.11 m^3 to 0.13 m^3 is mixed with it. The life cycle of the emulsion is strongly user-dependent and is estimated for a maximum of two years. Lube oil ("Auxiliary Material 2") with an amount of 0.1 m^3/year and hydraulic oil ("Auxil-

9 Main drive and feed drives are equipped with energy recovery modules for transforming kinetic energy in electrical energy during drive braking. The technology to be used for this is a controlled VAC drive. Moreover, using thermo sensors the transient heat fields are estimated for compensating thermally induced dislocations of the drives.

10 For comparison, MTA stated a minimum of 2 kW, a maximum of 45 kW and a typical value of 23 kW power rating for "machining centres"

11 SKM Enviros: Estimating the Energy Saving Potential from Small Motors and Machine Tools, Report on Machine Tools Research & Modelling, 11 July 2011, p.20

iary Material 3") with an amount of 0.025 m^3/year[12], both approximated with densities of 0.9 g/cm³, and cooling fluid with an amount of 0.11 m^3/year are also to be used ("Auxiliary Material 1", approximated with a density of 1 g/cm³)[13].

Throughout the use phase of metal working machine tools cooling lubricants waste has to be disposed off and can be recycled:

- Cooling lubricant oils: Secondary oil refinary for drilling, cutting, and grinding oil, or incineration
- Cooling lubricant emulsions: Emulsion cracking, recycling of the oil phase in a secondary oil refinary or thermal recycling
- Cooling lubricant solutions: Separation hindered, recycling critical
- Waste of sythetic cooling lubricants should not be mixed with mineral oil based ones as it hinders recycling

Hydraulic oil, being used in closed systems, can be recovered even much better, once it has to be replaced.

However, controlled disposal of cooling lubricants waste and other oil wastes in an industrial environment can be assumed as common practice.

Throughout the use phase cooling lubricant mist is generated and might pollute the working environment, but occupational safety regulations apply, which limit the impact on workers. There are large scale emissions of cooling lubricants and oils during nor-

12 information provided by one machine tools manufacturer in the course of base case compilation indicated a consumption of 100 l hydraulic oil per year, whereas VDMA Fluid Power / Power Transmission submitted a stakeholder comment, estimating a consumption of less than 25 liters/year and CECIMO similarly calculated with a consumption of 400 l hydraulic oil in 20 years (assumption)

13 VDMA Fluid Power / Power Transmission submitted a stakeholder comment, estimating a consumption of less than 10 liters/year cooling fluid and less than 25 liters/year hydraulic oil. The total consumption of cooling lubricants in the EU-27 is roughly 100.000 t (see 2.4.3.1), of which the majority is used in metal working. Assuming a consumption of 110 kg per year extrapolated to the total stock of CNC machine tools of 850.000 units in the EU-27 (which overestimates the consumption, as these 850.000 units do not include only machining centres but also less complex CNC machine tools) results in a total annual consumption of 93.500 t, which is pretty close to the EU-27 totals and thus seems to be plausible. CECIMO estimated in their LCA study a con-sumption of 4.000 kg coolant lubricant in 20 years for CNC machine tools, which equals 200 kg per year, which is even more than our estimate based on the information provided by one machine tools manufacturer in the course of base case compilation

mal operation of machine tools and regulation applies to minimize the impact of hazardous incidents.

Consequently the environmental impacts of cooling lubricants and oils throughout the use phase of a machine tool can be considered minor as long as state-of-the-art waste management practice is followed.

The efforts for maintenance, repair and service regard service travel of 500 kilometres per year for CNC machine tools. The service centres are situated in a maximum range of 200 kilometres to the customers. The spare part weight of 1% of the product weight is 260 kilograms. The percentage is fixed by the MEEuP template. The re-use of product parts and assemblies is to be taken into account for the estimation of spare part weight.

Table 4-17: Use phase entries for a CNC 4-axis multifunctional milling centre

Pos nr	USE PHASE Description		unit	Subtotals
211	**Product Life in years**	**12**	years	
	Electricity			
212	**On-mode: Consumption per hour, cycle, setting, etc.**	30	kWh	131610
213	**On-mode: No. Of hours, cycles, settings, etc. / year**	4387	#	
214	**Standby-mode: Consumption per hour**	1,5	kWh	1131
215	**Standby-mode: No. Of hours / year**	754	#	
216	**Off-mode: Consumption per hour**	0	kWh	0
217	**Off-mode: No. Of hours / year**	3619	#	
	TOTAL over Product Life	**1592,89**	**MWh (=000 kWh)**	65
	Consumables (excl, spare parts)			**material**
221	**Water**	18	m^3/year	**83-Water per m3**
222	**Auxilliary material 1 (Click & select)**	110	kg/ year	**85-None**
223	**Auxilliary material 2 (Click & select)**	90	kg/ year	**85-None**
224	**Auxilliary material 3 (Click & select)**	22,5	kg/ year	**85-None**
	Maintenance, Repairs, Service			
225	**No. of km over Product-Life**	6000	km / Product Life	86
226	**Spare parts** (fixed, 1% of product materials & manuf.)	257750	g	

4.1.3.2 CNC laser cutting machine

Consumables for laser cutting machines are

- Water (for cooling mainly the laser unit, de-ionised; to be replaced regularly also in integrated, closed chiller systems)
- Cutting gases, such as air, oxygen, nitrogen, or argon, typically few m^3/h[14]
- Laser gas (where applicable): CO_2, Nitrogen, ArF, KrF, XeCl, XeF, Ar, or Kr, consumption of typically few litres per hour[15] (high purity required)
- Lubrication oil for bearings
- Hydraulic oil

Oliveira et al.[16] investigated the power consumption of various laser-based technologies for metal cutting. It has to be noted, that CO_2 lasers are the most common ones, but fibre-lasers are gaining market shares and under many conditions those fibre-lasers are less energy consuming. However, both technologies present advantages for specific production conditions with respect to metal type and sheet thickness: CO_2 lasers are more efficient for thick sheets, and are said to result also in a better cut quality, whereas fibre lasers can process a broader range of metals beyond iron-based metals and aluminium, namely copper and copper alloys in particular. As the laser requires cooling, the machine tool might come with an integrated cooling system, or alternatively it has to be connected to a central chiller system. Consequently power consumption of laser cutting machine tools includes

- Electricity
- Cooling load

Main power consuming units of a laser cutting machine are:

- Laser source
- Chiller

14 Duflou, J.R.; Kellens, K.; Dewulf, W.: Unit process impact assessment for discrete part manufacturing: A state of the art, CIRP Journal of Manufacturing Science and Technology 4 (2011) 129-135; analysed scenario: 13,6 m^3/h N_2

15 Linde: LASERLINE®. Die perfekte Lösung für eine perfekte Gasversorgung, http://www.linde-gase.de/produkte/down/katalog_laserline.pdf

16 Oliveira, M.; Santos, J.P.; Almeida, F.G., Reis, A.; Pereira, J.P.; Rocha, A.B.: Impact of Laser-based Technologies in the Energy-Consumption of Metal Cutters: Comparison between commercially available Systems, Key Engineering Materials (Volume 473), Volume Sheet Metal 2011

- Control unit (feeding positioning motors and drives, remaining electronic controls)
- Exhaustion system

Key characteristics of laser cutting systems investigated by Oliveira et al are listed in Table 4-18. It is evident, that a major share of the energy consumption is attributed to the laser unit, which is adjusted with respect to power output and thus consumption to material and sheet thickness. Particularly for the 4.5 kW CO_2 laser there is a broad range from 18.5 kW for thin sheets to 70 kW for thicker ones.

Table 4-18: Key characteristics of exemplary CNC laser cutting machines

Laser type	CO2 laser	CO2 laser	Fibre laser
Laser power [kW]	2,5	4,5	2,0
Chiller cooling capacity [kW]	43,1	86,2	9,29
Laser unit stand-by power consumption [kW]	4,8	5,8	
Laser unit off mode power consumption [kW]	Considered negligible		
Laser unit working mode power consumption [kW] for various sheet thicknesses	18,5 / 34,0 / 40,0	18,5 / 70,0	max. 8,5
control unit stand-by power consumption [kW]	1,0	1,0	1,0 (assumption)
control unit working mode power consumption [kW]	5,8	5,8	5,8 (assumption)
chiller unit stand-by power consumption [kW]	6,8 (average)	30,0 (average)	6
chiller unit working mode power consumption [kW]	15,5	30,0 – 35,0	6
exhaustion system working mode power consumption [kW]	4 – 5,5	4 – 5,5	4 – 5,5
exhaustion system stand-by mode power consumption [kW]	Close to 0	Close to 0	Close to 0

Those facilities analysed by Oliveira et al. featured time shares in the various modes as follows:

- Working mode: 45-55%
- Standby mode: 35-50%
- Off mode: 5-10%

Given these ranges a realistic, but simplified use phase scenario for a CO_2 laser machine tool is as outlined in the following table. These values are much higher, than those stated by the UK Manufacturing Technologies Association (MTA) for "laser, ultrasonic and the like" (0,1 kW minimum, 1,5 kW typical, 4 kW maximum)[17], but values below have been confirmed by industry sources and literature. This discrepancy obviously stems from a different understanding of this market segment: Whereas MTA might have referred e.g. to smaller work shop laser engraving units, our focus is on large-scale industrial 2D laser cutting machine tools[18].

Table 4-19: Use phase scenario for a CNC laser cutting machine

Laser type	Off mode	Standby mode	Working mode
Time share	5%	40%	55%
Duration per working day, 2 shifts	0,8 h/d	6,4 h/d	8,8 h/d
Average power consumption	0 kW	26 kW	70 kW
laser unit	*0 kW*	*5 kW*	*35 kW*
control unit	*0 kW*	*1 kW*	*6 kW*
chiller unit	*0 kW*	*20 kW*	*24 kW*
exhaustion system	*0 kW*	*0 kW*	*5 kW*

However, it should be noted, that the power consumption profile is far from featuring constant power consumption in the various modes. For illustration see below measurements by Duflou[19] and Devoldere[20] for a 5 kW CO2 laser machine, processing 1 mm steel plates with three different laser output settings (see Figure 4-2).

17 SKM Enviros: Estimating the Energy Saving Potential from Small Motors and Machine Tools, Report on Machine Tools Research & Modelling, 11 July 2011, p.20

18 Consequently our results will be applied only to a smaller market share of laser machine tools, see chapter 4.5.2

19 Duflou, J.R.; Kellens, K.; Devoldere, T.; Deprez, W.; Dewulf, W.: Energy related environmental impact reduction opportunities in machine design: case study of a laser cutting machine. International Journal of Sustainable Manufacturing, 2010, 2(1), 80–98.

20 Devoldere, T.; Dewulf, W.; Deprez, W.; Duflou, J.R.: Energy Related Life Cycle Impact and Cost Reduction Opportunities in Machine Design: The Laser Cutting Case, Proc. 15th CIRP International Conference on Life Cycle Engineering, Sydney, Australia, ISBN 1-877040-67-3. pp. 412-419.

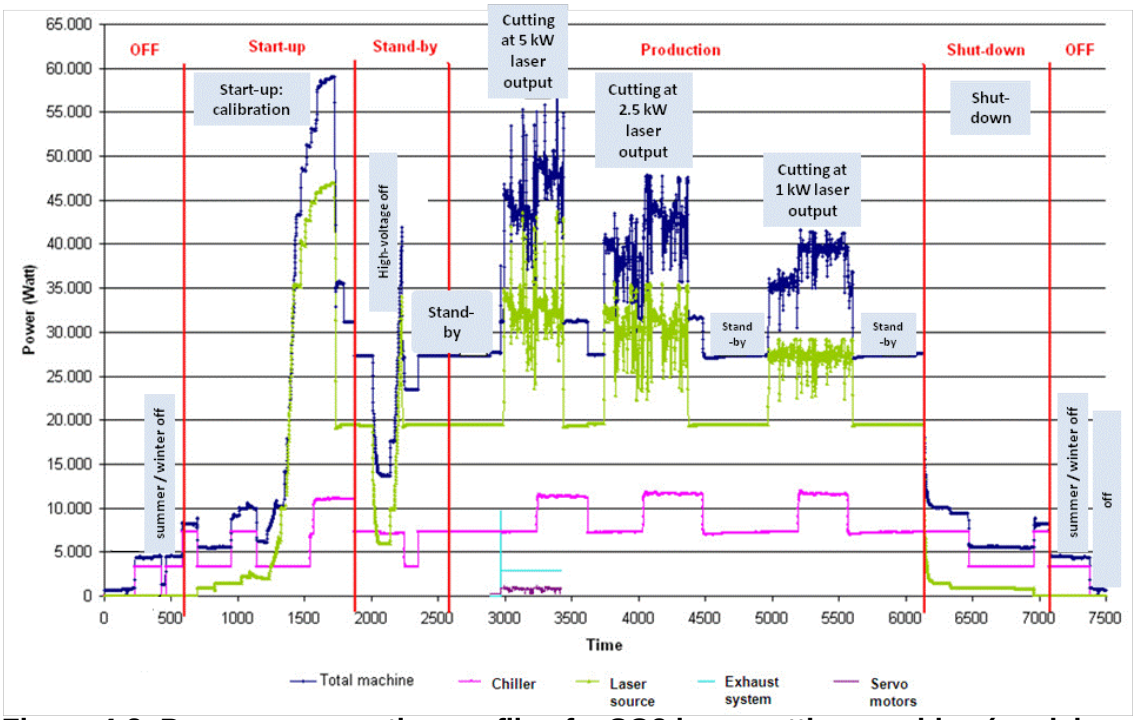


Figure 4-2: Power consumption profile of a CO2 laser cutting machine (model LVD Axel 3015 S, adapted from Deflou et al.)

The various modules are monitored throughout the start-up, stand-by, production, and shut-down phase, demonstrating the huge relevancy of the laser system as such, followed by the chiller, which switches on one or two compressors depending on cooling needs. Stand-by power is also dominated by the laser at a stable level of 27 kW in this case. A lower power mode is “high voltage off”, which un-excites the laser source, but is followed by a power consumption peak when the laser sources is reactivated. Motors, contrary to CNC machining centers, play a minor role regarding energy consumption: Servomotors are employed to move the laser head in three axes, when cutting a sheet. In average Duflou et al. measured a power consumption of 0,86 kW for these, compared to 32,7 kW for the laser source (at 5 kW output) and 7,24 to 11 kW for the chiller unit.

Another power consumption profile is provided by Oliveira et al.[21] comparing a 2,5 kW CO2 laser and a 4.5 kW CO2 laser in regular production. Exemplary measurements

[21] Oliveira, M.; Santos, J.P.; Almeida, F.G.; Reis, A.; Pereira, J.P.; Rocha, A.B.: Impact of Laser-Based Technologies in the Energy-Consumption of Metal Cutters: Comparison between Commercially Available Systems, Journal Key Engineering Materials, Vol. 473, 2011, pp. 809-815

are depicted in Figure 4-3, differentiating power consumption for the laser source, chiller, and control unit, which covers power supply of motors and drives and remaining electronics controls. Again, laser and chiller are dominating. Laser power consumption is characterised is subject to a large fluctuation when cutting is performed. Depending on sheet thickness, power consumption of the laser is adapted (visible in the right example). The chiller unit features two different profiles for the two machines measured, a rectangular profile for the 2,5 kW laser with longer standby periods, whereas the chiller for the 4,5 kW unit is constantly on a high level with regular peaks.

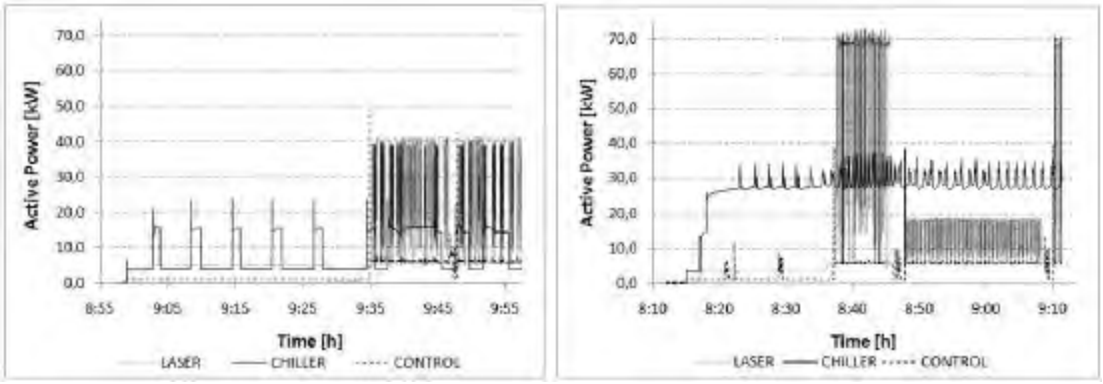


Figure 4-3: Exemplary Power consumption profiles of CO2 laser cutting machine (left: 2.5 kW, right: 4.5 kW, Oliveira et al.)

Regarding consumables, assumptions are as follows:

- (cooling) water: 2 m³/a
- ("Auxiliary material 1":) Laser gas CO_2 / N_2 / He: 20 l/h, i.e. 0,01 kg/h[22] (equals 80 m³/a, 40 kg/a at 16 h, 250 days)
- ("Auxiliary material 2":) Cutting gas N_2: 5 m³/h, i.e. 6,25 kg/h (equals 20,000 m³/a, 25 t/a)

The consumption of nitrogen represents the lower end of consumption data as stated by Linde[23] for cutting stainless steel (see Table 4-20),

[22] Assumption average density of gas mixture: 0,5 kg/m³

[23] Berkmanns, J.; Faerber, M.: Facts About Laser technology - Laser cutting, Linde AG, Cleveland, USA / Unterschleißheim, Germany

Table 4-20: Parameters for laser cutting of stainless steel with laser cutting nitrogen including pressure and volume requirements

material thickness (mm)	laser power (W)	nozzle diameter (mm)	nitrogen pressure (bar)	gas volume (m^3/h)	cutting speed (m/min)
1,0	1500	1,2–1,5	6,0	8,0	7,0
2,0	1500	1,2–1,5	9,0	12,0	4,0
4,0	3000	2,0–2,5	13,0	28,0	3,0
6,0	3000	2,5–3,0	14,0	52,0	1,5
9,0	4000	2,5–3,0	16,0	60,0	1,0
12,0	4000	2,5–3,0	18,0	68,0	0,5

Individual costs for laser gas depend on gas type and total consumption (rebates), but are roughly in the range of 20 €/m^3, and for cutting gas 1 €/m^3 [24].

Table 4-21: Use phase entries for a CNC laser cutting machine

Pos nr	USE PHASE Description		unit	Subtotals
211	**Product Life in years**	**12**	years	
	Electricity			
212	**On-mode: Consumption per hour, cycle, setting, etc.**	70	kWh	154000
213	**On-mode: No. Of hours, cycles, settings, etc. / year**	2200	#	
214	**Standby-mode: Consumption per hour**	26	kWh	41600
215	**Standby-mode: No. Of hours / year**	1600	#	
216	**Off-mode: Consumption per hour**	0	kWh	0
217	**Off-mode: No. Of hours / year**	4960	#	
	TOTAL over Product Life	**2347,20**	**MWh (=000 kWh)**	65
	Consumables (excl, spare parts)			**material**
221	**Water**	2	m^3/year	**83-Water per m3**
222	**Auxilliary material 1 (Click & select)**	40	kg/ year	**85-None**
223	**Auxilliary material 2 (Click & select)**	25000	kg/ year	**85-None**
224	**Auxilliary material 3 (Click & select)**	0	kg/ year	**85-None**
	Maintenance, Repairs, Service			
225	**No. of km over Product-Life**	6000	km / Product Life	86
226	**Spare parts** (fixed, 1% of product materials & manuf.)	120013	g	

[24] Scholz, J.: Laser in der Materialbearbeitung – Wirtschaftlichkeitsbetrachtungen, Linde AG, 2008, http://www.laserdeal.com/techInfoFiles/Facts%20about%20Wirtschaftlichkeit%20Laser%20in%20der%20Mat.pdf

The electricity consumption totals correspond also with a scenario analysed by Duflou et al.[25], who state an annual power consumption for a 5 kW CO_2 laser cutting machine in 2 shifts operation of nearly 200 MWh, which exactly matches the total lifetime (12 years) electricity consumption of 2.347 MWh calculated above, although the shares attributed to the various modes are slightly different.

The efforts for maintenance, repair and service regard service travel of 500 kilometres per year for CNC machine tools.

4.1.3.3 Hydraulic Press Brake

Power consumption of hydraulic press brakes has been investigated by Santos et al.[26] Figure 4-4 depicts the power consumption of a press brake during a working day (based on real measured data for machine tool with maximum bending capacity of 170 t) clearly showing the different power consumption levels working mode, stand-by and off-mode: For a single bending cycle (depicted schematically only) a distinction has to be made regarding the following phases: The tool approaching the work piece with a power consumption on the stand-by level, the actual bending process with elevated power consumption, followed by a return movement of the tool.

[25] Duflou, J.R.; Kellens, K.; Dewulf, W.: Unit process impact assessment for discrete part manufacturing: A state of the art, CIRP Journal of Manufacturing Science and Technology 4 (2011) 129-135

[26] Santos, J.P.; Oliveira, M.; Almeida, F.G., Pereira, J.P.; Reis, A.: Improving the environmental performance of machine-tools: influence of technology and throughput on the electrical energy consumption of a press-brake, Journal of Cleaner Production (2010), article in press, October 28, 2010

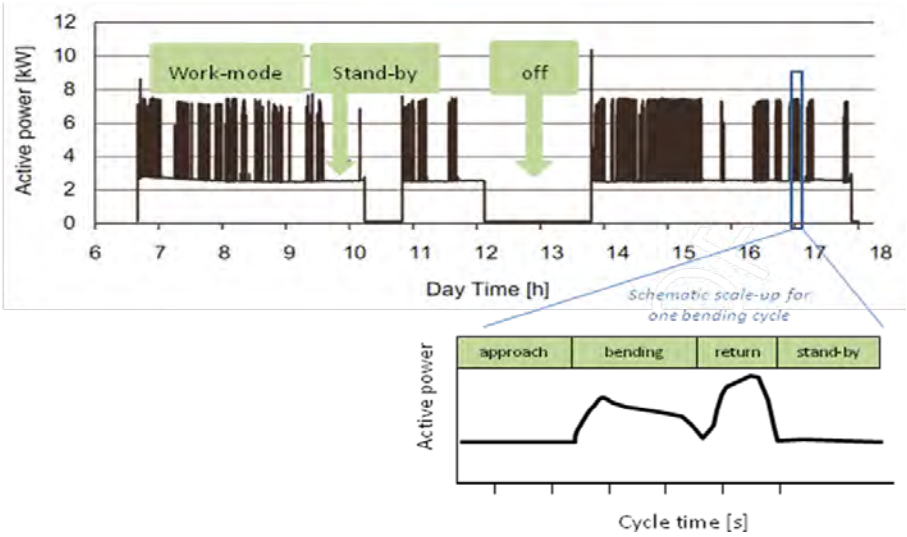


Figure 4-4: Power consumption cycles of press-brakes (adapted from Santos et al.)

For three hydraulic press brakes of a bending capacity of 110 t Santos et al. state work mode (approach / bending / return cycle) power consumption of 2-6 kW[27], stand-by (e.g. during workpiece change and fixing) power consumption of 1.5-3 kW, and off-mode values of maximum 0.5 kW. The actual use power consumption depends on throughput, i.e. cycle times and thus relation between work mode and stand-by times, the latter including load/unload times. Hydraulic oil consumption ("auxiliary material 2") is assumed to be 120 l, i.e. 108 kg/a.

For an exemplary use scenario of a hydraulic press-break the settings are listed in the table below. Product life time corresponds to the results of the analysis provided in task 2.

The efforts for maintenance, repair and service regard service travel of 500 kilometres per year for CNC machine tools.

[27] this range corresponds with power ratings stated by MTA for "bending, folding and straightening": min-max 1.5 – 50 kW, typical 5 kW power *rating*, but is much lower than that stated for "forging or die-stamping machines and hammers; hydraulic presses and presses: min-max 5 – 180 kW, typical 20 kW power rating

Table 4-22: Use phase entries for a hydraulic press brake

Pos nr	USE PHASE Description		unit	Subtotals
211	Product Life in years	17	years	
	Electricity			
212	On-mode: Consumption per hour, cycle, setting, etc.	0,0165	kWh	1856,25
213	On-mode: No. Of hours, cycles, settings, etc. / year	112500	#	
214	Standby-mode: Consumption per hour	0,9481	kWh	1659,175
215	Standby-mode: No. Of hours / year	1750	#	
216	Off-mode: Consumption per hour	0	kWh	0
217	Off-mode: No. Of hours / year	0	#	
	TOTAL over Product Life	59,76	MWh (=000 kWh)	65
	Consumables (excl, spare parts)			material
221	Water	0	m^3/year	83-Water per m3
222	Auxilliary material 1 (Click & select)	0	kg/ year	85-None
223	Auxilliary material 2 (Click & select)	108	kg/ year	85-None
224	Auxilliary material 3 (Click & select)	0	kg/ year	85-None
	Maintenance, Repairs, Service			
225	No. of km over Product-Life	8500	km / Product Life	86
226	Spare parts (fixed, 1% of product materials & man-uf.)	78720	g	

The on-mode values are based on a distinct theoretical analysis of the hydraulic system functioning sequence, provided by de Oliviera et al.[28] as listed in the following table.

Table 4-23: Bending cycle and related power consumption

Bending cycle	Duration [s]	active power [kW]	active energy [kWh]
Fast descending	1.5	1.79	0.0007
Slow descending without load	0.5	1.79	0.0002
Slow descending with load	2	12.13	0.0067
Stopping	2	12.13	0.0067
Ascending	2	3.66	0.0020
Totals per cycle	**8**	**-**	**0.0165**

[28] e-mail February 23, 2011; the power consumption profile presented in Figure 4-4 does not fully correspond with these stated values, see the peak for “return” compared to the rather low value stated here

Unit for the entry in row 213 (i.e. on-mode time) is the number of bending cycles per year, calculated as follows:

- Time in on-mode: 8 hrs/day;
- Time in working-mode (daily production of 8 h): 12.5%;
- Bending cycle time: 8 s/cycle.

Under these assumptions a theoretical value of 450 cycles/day is gained, resulting in 112,500 bending cycles per year, based on 250 working days per year.

The stated time in standby is the remaining time during productive hours, i.e. 87.5% of the 8-hours shift, equalling 7 hours in standby per day, but it should be noted for later quantification of improvement potential, that this is rather understood to be idle time covering times of work piece change etc. and not lengthy production breaks.

Off-mode considers a complete switch-off at night and at weekends.

For a two-shift operation, number of bending cycles and times in standby/idle would be twice as high.

4.1.3.4 Non-numerical controlled metal working machine tools

Non-numerical controlled metal working machine tools are used in one-shift operation mostly. Therefore the machine is in “on-mode” 1500 hours per year. Most of the time, 6760 hours, it is in “Off-mode”. Stand-by (500 hours) is the time to change workpieces or tools by hand or breaks. Off-mode considers a complete switch-off at night and at weekends.

Consumables for non-numerical controlled metal working machine tools are

- Hydraulic oil
- Cooling lubricants

Consumption of both is assumed to be 2 kg per year (“auxiliary material 1 and 2”). Water is a consumable for water-miscible cooling lubricants.

Power consumption was measured by Fraunhofer IPK for an exemplary machine tool. The power consumption profile is depicted in Figure 4-5.

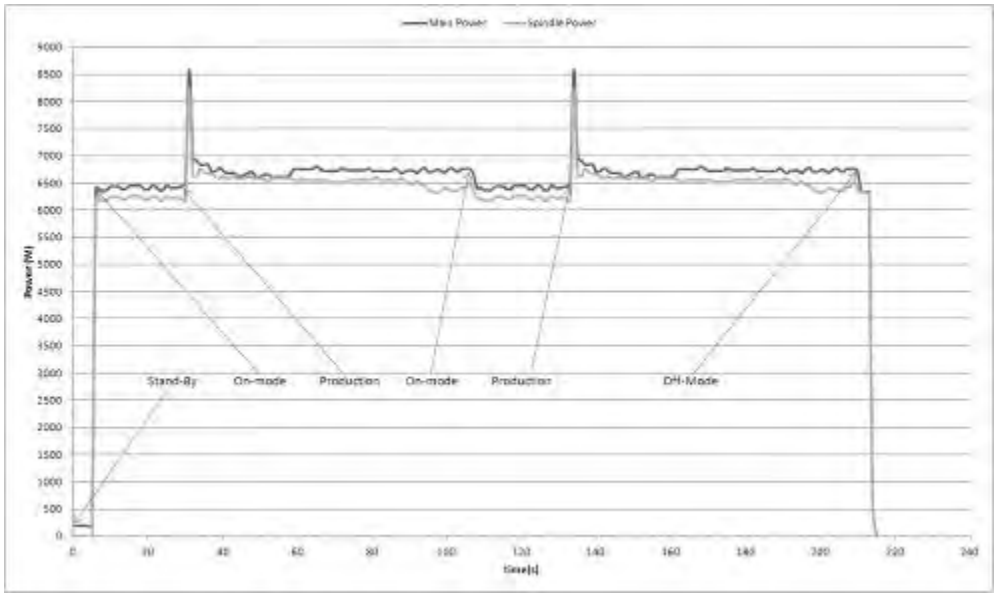


Figure 4-5: Power consumption non-numerical controlled metal working machine tools (own measures)

The parameter for these tests are:

- Cutting force v_C = 248 m/min
- Depth of cut a_p = 0,5 mm
- Feed rate = 0,8 m/min
- Workpiece diameter d = 77 mm
- Spindle speed = 180 min^{-1}
- Material: C45, round steel, hot rolled

The most relevant electric consumer is the main spindle (about 97 % of the machine energy). Cooling lubricant is often applied “by hand”.

The efforts for maintenance, repair and service regard service travel of a default value of 100 kilometres per year for non-CNC machine tools.

Table 4-24: Use phase entries for a non-numerical controlled metal working machine tools

Pos nr	USE PHASE Description		unit	Subtotals
211	**Product Life in years**	**18**	years	
	Electricity			
212	**On-mode: Consumption per hour, cycle, setting, etc.**	6,8	kWh	10200
213	**On-mode: No. Of hours, cycles, settings, etc. / year**	1500	#	
214	**Standby-mode: Consumption per hour**	0,2	kWh	100
215	**Standby-mode: No. Of hours / year**	500	#	
216	**Off-mode: Consumption per hour**	0	kWh	0
217	**Off-mode: No. Of hours / year**	6760	#	
	TOTAL over Product Life	**185,40**	**MWh (=000 kWh)**	65
	Consumables (excl, spare parts)			**material**
221	**Water**	0,5	m^3/year	**83-Water per m3**
222	**Auxilliary material 1 (Click & select)**	2	kg/ year	**85-None**
223	**Auxilliary material 2 (Click & select)**	2	kg/ year	**85-None**
224	**Auxilliary material 3 (Click & select)**	0	kg/ year	**85-None**
	Maintenance, Repairs, Service			
225	**No. of km over Product-Life**	1800	km / Product Life	86
226	**Spare parts** (fixed, 1% of product materials & manuf.)	10000	g	

4.1.3.5 Wood working machine tools: Table saw

For table saws manufacturers recommend lubrication according to maintenance manuals. Lubricants to be used for gear and tilt / elevating mechanism are e.g. dry silicone, teflon lubricants, or non-hardening lithium-based grease. Recommended frequency is once per month or more often, if required. For housed elevating mechanisms (which are more common for larger professional equipment), which are supplied through dedicated lubrication nipples, thorough maintenance might require a re-lubrication only once per year, or every 100 m aggregated travel distance. Assuming an application of 10 g lubricant per month as an approximation, total annual consumption is in the range of 120 g lubricant / grease per year per table saw.

Some manufacturers recommend applying a coat of paste wax or white talcum powder regularly to keep the table surface clean and free of rust. When such a saw is used for other material than wood, such as aluminium or plastics, usage of a spray cooling unit

might be advisable, i.e. also cooling lubricants might be used occasionally for table saws.

Plausible use phase values for light-stationary woodworking tools, in particular table and radial arm saws, band saws and planer thicknessers have been cordially provided by EPTA as listed in Table 4-25 (for stationary, corded, with induction motor).

Table 4-25: Use scenarios for light-stationary woodworking tools

	Average Motor Efficiency	Average Design Life	Average Design Life	Average Input Power	Average Lifetime Energy	Average Annual Energy
					Use phase	Use phase
	%	Hours	Years	KW	KWh	KWh
Scenario 1	**70**	**2500**	**10**	**1,0**	**2500**	**250**
Scenario 2	**70**	**3750**	**15**	**1,0**	**3750**	**250**

Basically light stationary tools feature only the two modes on and off, realised through a hard-switch.

Motors used in light stationary woodworking tools are typically single or three-phase induction motors with 2 or 4 poles. Three-phase induction motors are covered by Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors (see Task 1, 1.3.1; since June 2011 three-phase induction motors have to meet the IE2 level, which requires a motor efficiency of 77,4 to 85,5% for most frequently used motor ratings in light-stationary tools), whereas single phase motors are not[29]. Single-phase motors typically have got a lower efficiency than three phase motors, hence the scenario described above represents the multitude of single phase motor tools. However, single-phase motors are are also those intended for the DIY market, thus leaving a "grey area" with respect to the defined scope of this study, which is meant to cover only machine tools "intended for professional use" (see Task 1, 1.1.2.2).

Given the estimates provided by EPTA the power values translate into 250 hours (1 hour per working day) on-mode per year, 8510 hours switched off. The stated average design life of 10 and 15 years does not match with the initial estimate of a 20 years lifetime (see 2.2.1.2, task 2 report). For the sake of data coherence the following

29 These might be covered under the upcoming Preparatory Study "Lot 30 - Other electric motors (outside Regulation 640/2009)"

calculations are still based on assumed 20 years lifetime, but this is related to significant uncertainties.

Spare parts can be ordered directly at the manufacturer and retailer (operation manuals frequently feature an explosion drawing with parts list to allow individual replacement orders), and repair and maintenance typically is not done by external service personal. Therefore, use phase calculations take into account much less travel distances for maintenance, repairs, service than for large-scale industrial type equipment (10 km, which reflects the shipment of some replacement parts instead of a service personnel visit).

Table 4-26: Use phase entries for a table saw

Pos nr	USE PHASE Description		unit	Subtotals
211	**Product Life in years**	**20**	years	
	Electricity			
212	**On-mode: Consumption per hour, cycle, setting, etc.**	1	kWh	250
213	**On-mode: No. Of hours, cycles, settings, etc. / year**	250	#	
214	**Standby-mode: Consumption per hour**	0	kWh	0
215	**Standby-mode: No. Of hours / year**	0	#	
216	**Off-mode: Consumption per hour**	0	kWh	0
217	**Off-mode: No. Of hours / year**	0	#	
	TOTAL over Product Life	**5,00**	**MWh (=000 kWh)**	65
	Consumables (excl, spare parts)			**material**
221	**Water**	0	m^3/year	**83-Water per m3**
222	**Auxilliary material 1 (Click & select)**	0,12	kg/ year	**85-None**
223	**Auxilliary material 2 (Click & select)**	0	kg/ year	**85-None**
224	**Auxilliary material 3 (Click & select)**	0	kg/ year	**85-None**
	Maintenance, Repairs, Service			
225	**No. of km over Product-Life**	10	km / Product Life	86
226	**Spare parts** (fixed, 1% of product materials & man-uf.)	270	g	

4.1.3.6 Wood working machine tools: Horizontal panel saw

A typical horizontal panel saw is characterised as follows:

- Connection power: 15 kW
- Extraction air volume: 5000 m³/h (in any mode)

- Pressurized air consumption: 0,15 Nm³/h (in any mode)

Power consumption in absence of real measured values can be estimated as follow (which largely corresponds with estimates practiced by leading machinery manufacturers):

- Power consumption in operational mode: 12 kW (80% of connection power)
- Power consumption in idle mode: 7,5 kW (50% of connection power)
- Power consumption in standby: 750 W (5% of connection power)

These panel saws are used in the furniture industry, but in their majority in craft businesses, i.e. typically 1 shift operation. These assumptions result in the following mode scenario:

- 8 h/d, 250 days per year
- 6,25% in operational mode: 0.5 h per day
- 75% in idle mode: 6 h/d
- 18,75% in standby mode: 1.5 h per day

The efforts for maintenance, repair and service regard service travel of a default value of 100 kilometres per year for this kind of industrial wood working machine tools.

Use phase entries for the environmental and cost assessment are as listed in Table 4-27.

Table 4-27: Use phase entries for a horizontal panel saw

Pos nr	USE PHASE Description		unit	Subtotals
211	**Product Life in years**	**20**	years	
	Electricity			
212	**On-mode: Consumption per hour, cycle, setting, etc.**	12	kWh	1500
213	**On-mode: No. Of hours, cycles, settings, etc. / year**	125	#	
214	**Standby-mode: Consumption per hour**	7,5	kWh	11250
215	**Standby-mode: No. Of hours / year**	1500	#	
216	**Off-mode: Consumption per hour**	0,75	kWh	281,25
217	**Off-mode: No. Of hours / year**	375	#	
	TOTAL over Product Life	**260,63**	**MWh (=000 kWh)**	65
	Consumables (excl. spare parts)			material

221	**Water**	0	m^3/year	**83-Water per m3**
222	**Auxilliary material 1 (Click & select)**	0	kg/ year	**85-None**
223	**Auxilliary material 2 (Click & select)**	0	kg/ year	**85-None**
224	**Auxilliary material 3 (Click & select)**	0	kg/ year	**85-None**
	Maintenance, Repairs, Service			
225	**No. of km over Product-Life**	2000	km / Product Life	86
226	**Spare parts** (fixed, 1% of product materials & manuf.)	50000	g	

4.1.3.7 Wood working machine tools: Throughfeed edge banding machine

Characteristics of such edge banding machines, being in operation at large currently, not including latest energy savings measures:

- Connection power: 12 kW
- Extraction air volume: 1800 m³/h (in any mode)
- Pressurized air consumption: 0,05 Nm³/h (in any mode)

Power consumption in absence of real measured values can be estimated as follow (which largely corresponds with estimates practiced by leading machinery manufacturers):

- Power consumption in operational mode: 9,6 kW (80% of connection power)
- Power consumption in idle mode: 6 kW (50% of connection power)
- Power consumption in standby: 600 W (5% of connection power)

These throughfeed edge banding machine are used in the furniture industry, but in their majority in craft businesses, i.e. typically 1 shift operation. These assumptions result in the following mode scenario:

- 8 h/d, 250 days per year
- 6,25% in operational mode: 0.5 h per day
- 75% in idle mode: 6 h/d
- 18,75% in standby mode: 1.5 h per day

Use phase entries for the environmental and cost assessment are as listed in Table 4-28.

The efforts for maintenance, repair and service regard service travel of a default value of 100 kilometres per year for this kind of industrial wood working machine tools.

Table 4-28: Use phase entries for a throughfeed edge banding machine

Pos nr	USE PHASE Description		unit	Subtotals
211	Product Life in years	20	years	
	Electricity			
212	On-mode: Consumption per hour, cycle, setting, etc.	9,6	kWh	1200
213	On-mode: No. Of hours, cycles, settings, etc. / year	125	#	
214	Standby-mode: Consumption per hour	6	kWh	9000
215	Standby-mode: No. Of hours / year	1500	#	
216	Off-mode: Consumption per hour	0,6	kWh	225
217	Off-mode: No. Of hours / year	375	#	
	TOTAL over Product Life	208,50	MWh (=000 kWh)	65
	Consumables (excl, spare parts)			material
221	Water	0	m^3/year	83-Water per m3
222	Auxilliary material 1 (Click & select)	0	kg/ year	85-None
223	Auxilliary material 2 (Click & select)	0	kg/ year	85-None
224	Auxilliary material 3 (Click & select)	0	kg/ year	85-None
	Maintenance, Repairs, Service			
225	No. of km over Product-Life	2000	km / Product Life	86
226	Spare parts (fixed, 1% of product materials & manuf.)	25000	g	

4.1.3.8 Wood working machine tools: CNC machining centre

Characteristics of such CNC centres, not including latest energy savings measures, are:

- Connection power: 25 kW
- Extraction air volume: 5000 m³/h (in any mode)
- Pressurized air consumption: *no data available*

Power consumption in absence of real measured values can be estimated as follow (which largely corresponds with estimates practiced by leading machinery manufacturers):

- Power consumption in operational mode: 20 kW (80% of connection power)
- Power consumption in idle mode: 12,5 kW (50% of connection power)
- Power consumption in standby: 1 kW (5% of connection power)

These machining centres are mainly used in furniture making industry, occasionally also in crafts business, but this is not the main market for this type of machines. Therefore typically a 2 shifts operation can be assumed, which leads to the following mode scenario:

- 16 h/d, 250 days per year
- 40% in operational mode: 6,4 h per day
- 40% in idle mode: 6,4 h/d
- 20% in standby mode: 3,2 h per day

Use phase entries for the environmental and cost assessment are as listed in Table 4-29.

The efforts for maintenance, repair and service regard service travel of 500 kilometres per year for CNC machine tools.

Table 4-29: Use phase entries for a wood working CNC machining centre

Pos nr	USE PHASE Description		unit	Subtotals
211	**Product Life in years**	**20**	years	
	Electricity			
212	**On-mode: Consumption per hour, cycle, setting, etc.**	20	kWh	32000
213	**On-mode: No. Of hours, cycles, settings, etc. / year**	1600	#	
214	**Standby-mode: Consumption per hour**	12,5	kWh	20000
215	**Standby-mode: No. Of hours / year**	1600	#	
216	**Off-mode: Consumption per hour**	1	kWh	800
217	**Off-mode: No. Of hours / year**	800	#	
	TOTAL over Product Life	**1056,00**	**MWh (=000 kWh)**	65
	Consumables (excl, spare parts)			material

221	**Water**	0	m^3/year	**83-Water per m3**
222	**Auxilliary material 1 (Click & select)**	0	kg/ year	**85-None**
223	**Auxilliary material 2 (Click & select)**	0	kg/ year	**85-None**
224	**Auxilliary material 3 (Click & select)**	0	kg/ year	**85-None**
	Maintenance, Repairs, Service			
225	**No. of km over Product-Life**	10000	km / Product Life	86
226	**Spare parts** (fixed, 1% of product materials & manuf.)	80000	g	

4.1.3.9 Welding equipment

Major consumables of welding and soldering processes are highly dependent on the technology, i.e. type of process applied.

The two major types of consumables are

- Welding wire or welding electrodes, or solder respectively
- Welding gases of various types

However, consumption is very specific for the intended purpose (type of weld, material).

Efficiency of arc welding power sources varies with the type of source and sees a steady shift towards more efficient units. Table 4-30 lists the mean efficiency of these technologies, related sales by EWA members 2009-2011 and the estimated installed stock in EU-27 according to data provided by EWA.

Table 4-30: Efficiency of arc welding units sales and stock (sales by EWA members)

Sales by EWA members	Mean Effiency	EWA Sales 2009	EWA Sales 2010	EWA Sales 2011	2012 EU-27 installed stock estimation
Inverter single-phase	78%	20%	24%	23%	20%↗
Inverter 3-phase	83%	39%	47%	51%	20%↗
Thyristor or Chopper 3-phase	73%	7%	6%	4%	16%↘
Transformer single-phase	68%	7%	1%	1%	10%↘
Transformer 3-phase	73%	27%	22%	21%	33%↘
Rotating type	45%	0%	0%	0%	1%↘
Total		100%	100%	100%	100%
Weighted efficiency average		77%	79%	79%	**75%**

The weighted efficiency average as of 2012 is estimated to be 75%.

A typical arc welding unit[30] has a primary continuous power consumption of 6.2 kVA (arc-on), equalling at 75% efficiency at 200 A an output power of 4.65 kW (23.25 V).

In their majority these units are used in 1-shift-operations. A realistic arc-on time (i.e. operating factor) is 25% (see also chapter 3.2.3). This operating factor might be much lower in smaller repair shops or in the construction sector, where the welding equipment is used only occassionally, and higher in industrial production, where a similar welding unit might be used at high load in a roboter based production line.

Given 25 % arc-on time, total arc-on time per year is 500 hours, idle time 1500 hours, based on one shift for 250 days a year.

Typical idle-mode power is 0.05 kVA, which used to be much higher for former transformer style welding power sources.

Repair and maintenance typically is not done by external service personal. Therefore, use phase calculations take into account much less travel distances for maintenance, repairs, service than for large-scale industrial type equipment (10 km, which reflects the shipment of some replacement parts instead of a service personnel visit).

Table 4-31: Use phase entries for an arc welding unit

Pos nr	USE PHASE Description		unit	Subtotals
211	**Product Life in years**	**7**	years	
	Electricity			
212	**On-mode: Consumption per hour, cycle, setting, etc.**	6,2	kWh	3100
213	**On-mode: No. Of hours, cycles, settings, etc. / year**	500	#	
214	**Standby-mode: Consumption per hour**	0,05	kWh	75
215	**Standby-mode: No. Of hours / year**	1500	#	
216	**Off-mode: Consumption per hour**	0	kWh	0
217	**Off-mode: No. Of hours / year**	0	#	
	TOTAL over Product Life	**22,23**	**MWh (=000 kWh)**	65
	Consumables (excl, spare parts)			**material**
221	**Water**	0	m^3/year	**83-Water per m3**
222	**Auxilliary material 1 (Click & select)**	500	kg/ year	**85-None**
223	**Auxilliary material 2 (Click & select)**	0	kg/ year	**85-None**
224	**Auxilliary material 3 (Click & select)**	0	kg/ year	**85-None**

[30] See Bill-of-materials above

	Maintenance, Repairs, Service			
225	**No. of km over Product-Life**	10	km / Product Life	86
226	**Spare parts** (fixed, 1% of product materials & manuf.)	1400	g	

Based on these assumptions power consumption in on-mode, which is understood to be arc-on time is 3,100 kWh/a and in idle time 75 kWh/a.

For most gas metal arc welding applications as a rule of thumb a flow of shielding gas of 0,1 l/min per 1 mm welding wire diameter is recommended, resulting in 0,6 Nm^3/h as an approximation for typical welding tasks, equalling roughly 1 kg/h Argon gas during arc-on time (listed as “auxiliary 1” in the table). Argon is taken here as a proxy for the multitude of welding gas mixtures, most of them being dominated by a high Argon content.

4.1.3.10 Other machine tools and related machinery

Consumables used in other machine tools and related machinery than those described above are manifold and frequently include hydraulic oil, occasionally also cooling lubricants (e.g. for stone working applications).

4.1.4 End-of-life phase

Disposal of machine tools and related machinery in the EU (but also worldwide) is characterised by metal recovery as the metal components represent a significant value. Although a minor share of composite or mixed materials might be disposed of in landfills this is considered negligible compared to the bulk metal parts. Hence, the ratio of material to landfill is set to 0% unless certain fractions are identified, which are likely to be disposed of in a landfill. For plastics end-of-life the default settings of MEEuP are 1% re-use, closed loop recycling, 9% materials recycling, and 90% thermal recycling for the larger share of mixed plastics. Given the fact, that the amount of homogenous bulk plastics parts is significant, a larger plastics fraction can be separated for materials recycling. Accordingly the standard settings are adjusted as follows to reflect this fact: 1% re-use, closed loop recycling, 19% materials recycling, and 80% thermal recycling. Printed Circuit Boards are considered easy to disassemble as these are typically used similar to PCs.

Table 4-32: End of life settings for B2B machine tools and related machinery

Pos nr	DISPOSAL & RECYCLING Description		unit
	Substances released during Product Life and Landfill		
227	Refrigerant in the product (Click & select)	0	g
228	Percentage of fugitive & dumped refrigerant	0%	
229	Mercury (Hg) in the product	0	g Hg
230	Percentage of fugitive & dumped mercury	0%	
	Disposal: Environmental Costs per kg final product		
231	Landfill (fraction products not recovered) in g en %	0	0%
232	Incineration (plastics & PWB not re-used/recycled)	[calculated]	g
233	Plastics: Re-use & Recycling ("cost"-side)	[calculated]	g
	Re-use, Recycling Benefit	in g	% of plastics fraction
234	Plastics: Re-use, Closed Loop Recycling (please edit %)	[calculated]	1%
235	Plastics: Materials Recycling (please edit% only)	[calculated]	19%
236	Plastics: Thermal Recycling (please edit% only)	[calculated]	80%
237	Electronics: PWB Easy to Disassemble? (Click&select)	[calculated]	YES
238	Metals & TV Glass & Misc. (95% Recycling)	[calculated]	

This scenario refers to the “final” end-of-life, but it should be acknowledged, that throughout the lifetime of a machine tool remanufacturing is very common, just as stated by SKM Enviros in their study for UK DEFRA[31]: “The machine tools market is a business to business market and operates differently to markets for consumer products. Given their relatively high value and the fact that the chassis design has changed little over the years a significant proportion of machine tools are ‘recycled’, where they are either refurbished or remanufactured and updated to new standards. This ranges from fairly modest improvements through full rebuilds incorporating full automation and control systems. Where a machine tool has been remanufactured it is quite possible for more energy efficient components or controls to be added thus leading to a reduction in the energy consumption of the whole machine.” Neither aspect, neither the remanufacturing as such nor the potential efficiency improvements implemented at some point, are reflected in our analysis. However, what can be stated (also in line with reuse market data in Task 2 and the assessment in Task 3) is the fact, that remanufacturing and lifetime extension of machine tools actually happens frequently and is not a field of ma-

31 SKM Enviros: Estimating the Energy Saving Potential from Small Motors and Machine Tools, Report on Machine Tools Research & Modelling, 11 July 2011, p.26

jor additional improvement potential besides setting possibly incentives to equip machines with energy efficient components and control instruments when being refurbished or upgraded.

4.1.4.1 CNC 4-axis multifunctional milling centre

The amount of refrigerant remaining in the product at end of life is estimated to be 3 kilogram of remaining cooling lubricant liquid. Other cooling liquids for rarely applied closed cooling cycles are typically water based, potentially with additives to avoid fouling and corrosion, but amount is considered minor. Mercury is part of lightening and trace element of constructed metals. According to survey results and general experience both these materials are not released during product life or at landfill. A closer examination of leakage or similar possibilities of material release is not carried out, because refrigerants make up a very small share of the overall mass of the CNC 4-axis milling centre.

51 kilogrammes, or 0.2% of the final product weight, are to be dumped at landfill. 42.4 kilogrammes of plastics are to be recycled or re-used. 33.6 kilogram or 80% of plastics and printed wiring board (PWB) are fed to incineration. PWB are easy to disassemble with no further impact on disposal and recycling. Re-used and recycled plastics comprise a weight of 8.8 kilogram.

The outstanding part of materials with a weight of 24.4 tonnes or 95% of the final product weight is subject to re-use and recycling.

Table 4-33: End of life settings for the CNC 4-axis multifunctional milling centre

Pos nr	DISPOSAL & RECYCLING Description		unit
	Substances released during Product Life and Landfill		
227	Refrigerant in the product (Click & select)	3000	g
228	Percentage of fugitive & dumped refrigerant	0%	
229	Mercury (Hg) in the product	0,5	g Hg
230	Percentage of fugitive & dumped mercury	0%	
	Disposal: Environmental Costs perkg final product		
231	Landfill (fraction products not recovered) in g en %	51550	0%
232	Incineration (plastics & PWB not re-used/recycled)	33600	g
233	Plastics: Re-use & Recycling ("cost"-side)	8820	g

	Re-use, Recycling Benefit	in g	% of plastics fraction
234	Plastics: Re-use, Closed Loop Recycling (please edit%)	420	1%
235	Plastics: Materials Recycling (please edit% only)	8400	20%
236	Plastics: Thermal Recycling (please edit% only)	33600	80%
237	Electronics: PWB Easy to Disassemble ? (Click&select)	0	YES
238	Metals & TV Glass & Misc. (95% Recycling)	24446350	

4.1.4.2 CNC laser cutting machine

For CNC laser cutting machines the standard settings as listed in Table 4-32 are applied.

4.1.4.3 Hydraulic Press Brake

For hydraulic press brakes the standard settings as listed in Table 4-32 are applied.

4.1.4.4 Non-numerical controlled metal working machine tools

For non-numerical controlled metal working machine tools the standard settings as listed in Table 4-32 are applied.

4.1.4.5 Wood working machine tools: Table saw

For wood working machine tools the standard settings as listed in Table 4-32 are applied.

4.1.4.6 Wood working machine tools: Horizontal panel saw

For wood working machine tools the standard settings as listed in Table 4-32 are applied.

4.1.4.7 Wood working machine tools: Throughfeed edge banding machine

For wood working machine tools the standard settings as listed in Table 4-32 are applied.

4.1.4.8 Wood working machine tools: CNC machining centre

For wood working machine tools the standard settings as listed in Table 4-32 are applied.

4.1.4.9 Welding equipment

Smaller units of welding equipment fall under the WEEE directive and hence the manufacturers are responsible to agree on disposal conditions with their B2B customers, hence a proper disposal and recycling can be assumed for the whole welding equipment product range.

4.1.4.10 Other machine tools and related machinery

End-of-life of other machine tools and related machinery are likely to be similar to the standard settings listed in Table 4-32 as defined in in most cases. Exemptions are for example contaminated machine tools from the semiconductor industry, which might be disposed of as hazardous waste as certain explosive or toxic gases diffused into the material.

4.2 Definition of Base Cases

The definition of the Base Cases should allow for a broad coverage of the machine tools market. Market relevancy and coverage by Base Cases is an important criterion to select suitable machinery archetypes. Various characteristics have to be taken into account to realise such a coverage. First of all, the broad variety of application scenarios has to be considered:

- Application area (workshop, industrial plant),
- Number of shifts (1 or 2, 3 and more),
- Embedding (Single machine, automated production system),
- Control system (Mechanic, Automatic),
- Energy system (Switch-off, power data for sub-systems),
- Manufacturing method, and
- Sold number of machine tools.

The second classification order is the complexity and level of automation of the machine tool. Three categories were identified to summarise possible application scenarios:

- Complex CNC machine tools (high complexity)

Vertical or combined horizontal and vertical machining centres for working metal

Horizontal machining centres for working metal

Lathes, including turning centres, for removing metal

- Complex CNC machine tools (moderate complexity)

  Machine tools for working any material by removal of material, operated by laser or other light or photon beam processes

  Hydraulic presses for working metal

- Simple machine tools

  Non-numerically controlled horizontal lathes, for removing metal

  Non-numerically controlled presses for working metal

Highly complex CNC controlled machine tools are used for realising processes with highest productivity and accuracy. Dedicated for metalworking they provide an exceptional functionality. These machine tools are to be designated for the integration in energy management systems via interfaces.

CNC machines of moderate complexity are used for machining various materials. Beside metals wood, ceramics, glass etc. are machined. More simple mechanic machining such as cutting and forming is carried out. Moreover, non-mechanic processes are to be realised with this category of machine tools. The integration in energy management systems is possible, too.

The simple machine tools have no CNC control. The are to be controlled mechanically or via path control. This category of machine tools is dedicated for cutting or forming metal with lower requirements on accuracy and productivity of the machining. An energy monitoring is not intended. The use occurs in low frequency and often without pre-planning.

Furthermore, an appropriate coverage of the various functional modules defined in task 1 is required to allow for an assessment of these modules in a given application. These are:

- Electrical system for control and for mechanic purposes,
- Pneumatic system,

- Hydraulic system,
- Main drives,
- Feed drives,
- Handling system for tools and workpieces,
- Handling of support and waste materials, and
- Control system.

Furthermore, specifics of highly relevant technologies should be reflected by complementary Base Cases.

Derived from all these assumptions the following Base Cases are defined:

- Numerically controlled machining centre,
- Numerically controlled deep drawing or bending machine tool,
- Laser cutting machine tools,
- Non-numerically controlled metal working drilling machine,
- Machine tool for woodworking
    - Table saw,
    - Horizontal panel saw,
    - Throughfeed edge banding machine,
    - CNC machine centre, and
- Transportable welding equipment.

Justification for the chosen Base Cases is summarised in **Table 4-34**. This segmentation is the best possible compromise to accommodate the above criteria with a limited number of Base Cases.

Table 4-34: Base Case characteristics

		Metal working	Wood working	High market relevancy (according to task 2 analysis)	CNC	Further specifics
(1)	CNC machining centres (and similar)	x		x	x	Typical representative of CNC machine tools
(2)	CNC Laser cutting machine tools	x			x	Very specific technology, which is not properly covered by any other Base Case, complementary to Base Case 1
(3)	CNC Bending machine tools (and similar)	x			x	Highly relevant process, which is not properly covered by machining centre, complementary to Base Case 1
(4)	Non-NC metal working machine tools (and similar)	x		x		Typical representative of non-NC machine tools
(5)	Table saw (and similar)		x	x		Represents all light stationary wood working machine tools
(6)	Horizontal panel saw (and similar)		x		x	Represents typical industrial wood working machine tools
(7)	Throughfeed edge banding machine (and similar)		x		x	Widespread industrial use, but technically very different from horizontal panel saws, complementary to Base Case 6
(8)	CNC machining centre (and similar)		x		x	Represents upper market segment in terms of machinery complexity
(9)	Welding equipment	x		x		Very specific technology, which is not properly covered by any other Base Case

Every Base Case is meant not only to represent the machine tools archetype, which is analysed in detail, but also market segments, which are similar in terms of complexity, use patterns, and process technology.

4.2.1 Base Case 1: CNC 4-axis multifunctional milling centre

According to product-specific inputs in chapter 4.1 the CNC 4-axis multifunctional milling centre is a highly complex machining centre applying all functions needed for highly flexible work-piece machining. It enables besides milling operations, turning and hobbing machining steps. It is built-up by modules representing the state-of-the-art system for productivity oriented manufacturing. The machine tool is applied in mass as well as workshop production with various shift types. The control system allows to implement the milling centre in energy monitoring systems with the options of operation, sleep

mode and switch-off. The overall stock of the machine tool in Europe is 280 items with an annual sale of 30 units.

4.2.2 Base Case 2: Laser cutting machine tool

Laser cutting machine tools have been chosen as a complementary base case to cover the specifics of this technology and as laser technology gains steadily increasing market shares in metal processing (but also other materials). The base case reflects the currently dominating technology of CO_2 lasers. Assumptions are outlined in 4.1 and are based on technology insights, but the base case data does not come from any specific real laser cutting machine and constitutes an abstraction of reality.

4.2.3 Base Case 3: CNC Metal working bending machine tools

This base case is based on five press-brakes and their assessment as provided by Santos et al. [32]. Specification of these five press-brakes is as listed in Table 4-35.

Table 4-35: Technical characteristics of the press-brakes

	A	B	C	D	E
Technology	hydraulic	hydraulic robot-assisted	hydraulic	hydraulic	electric
Max. bending capacity [t]	170	110	110	110	100
Motor rated power [kW]	15	11	11	7.5	11
Max. bending length				3 m	
Year of construction				2006	
Base Case data origin and assumptions					
BOM				x	
Hydraulic oil consumption				120 l/a[33]	
Electricity consumption	x	x	x	x	x
Lifetime	**17 years** as stated in Task 2 for hydraulic metal working presses (whereas the assessment by Santos et al. is based on 15 years assumed lifetime)				

[32] Santos, J.P. et al.: Improving the environmental performance of machine-tools: influence of technology and throughput on the electrical energy consumption of a press-brake, Journal of Cleaner Production (2010)

[33] According to the preventive maintenance plan

It has to be acknowledged, that these press brakes rather cover a level of lower bending capacity and are not representative for larger presses and bending machine tools as used in e.g. the automotive sector for processing larger chassis parts. The range of 100-170 t bending capacity according to VDMA Fachverband Fluidtechnik is a market segment, where electromechanical presses are common. Hydraulic press brakes are typically applied where bending capacities of up to several thousand tonnes are required[34], where electromechanical solutions are not an option, but there is also a market segment, where high bending capacities are required and both hydraulic presses and electromechanical presses are offered.

4.2.4 Base Case 4: Non-numerical controlled metal working machine tools

Engine and feed shaft lathes may be equipped with the following features:

- mechanical facilities for mechanical feed or thread cutting,
- electronic facilities for constant surface speed (CSS),
- copying attachments (cam, template, etc.),
- but shall have no limited or full numeric control system (NC).

All movements are initiated and controlled by the operator, one at a time. These machine tool allows all turning process on one machine. The feed is usable manual or by machine. Hand wheels are available for these operations. Engine and feed shaft lathes are used for one-off and small batch production because of the low planning expenditure as well as the low price.

Connected power: 5 kW to 11 kW.

4.2.5 Base Case 5: Wood working machine tools: Table saw

Typical table saws feature characteristics as outlined in Table 4-36. The saw is manually switched on and off. The operator feeds the workpiece manually, and all settings are made manually. There is only one motor and no auxiliary units.

[34] Statement provided by VDMA Fachverband Fluidtechnik, J. Dürer, December 6, 2010

Table 4-36: Technical characteristics of an exemplary table saw

Parameter	
Table size	641 x 737 mm
Depth x length x height	730 x 780 x 340 mm
No-load speed	3.650 rpm
Saw blade diameter	254 mm
Saw blade bore	30 mm
Powerful motor rating	1800 W
Max. cutting heights	79 mm

4.2.6 Base Case 6: Wood working machine tools: Horizontal panel saw

Typical horizontal panel saws, for illustration only, are Holz-her CUT 6120, SCM SIGMA 105 Impact, HOLZMA HPP 250.

Technical characteristics of such panel saws are: manual panel feed, cutting length in the range of 4000 mm, max. saw carriage speed 100 m/min; main saw (7 – 10 kW) and scoring saw (in the range of 1 kW), air table, horizontal beam with integrated extraction system.

A typical price for such a machine is in the range of 60.000 Euro.

4.2.7 Base Case 7: Wood working machine tools: Throughfeed edge banding machine

Throughfeed edge banding machine tools are multi-purpose machines with automatic transfer of the workpieces, planning, milling or moulding (by cutting) machines

Typical machine models, for illustration only, are: BRANDT KDF 650, Holz-her SPRINT 1312 / ARCUS 1334, WINTER KANTOMAX speed.

Technical characteristics: processed edge thickness 0,4 - 12 mm, workpiece thickness 8 - 60 mm, max. feed speed 15 m/min.

Main modules are the aggregates (1) magazine and pre-melter/ radiant heater/ pressure zone, (2) end-trimming unit, (3) trimming unit, (4) corner rounding unit, (5) profile scraping unit, (6) buffing unit, PC, chassis.

Such a throughfeed edge banding machine tool comprises a rather larger number of auxiliary motors: 6 or more smaller motors in the range of 0,25 – 0,4 kW connection power, 2 motors at roughly 2 kW connection power, and 2 small motors for the buffing unit in the range of 0,1 kW connection power.

A typical price for such a machine is in the range of 60.000 Euro.

4.2.8 Base Case 8: Wood working machine tools: CNC machining centre

The base case on wood working CNC machining centres represents those for drilling and multipurpose (drilling, milling, sawing). Typical machine models, for illustration only, in this category comprise: SCM Accord 40 Prisma, WEEKE Venture 440/450, MORBIDELLI Author X 5.

Technical characteristics (exemplarily) comprise: vacuum clamping system, 5 axis milling spindle (main milling spindle with liquid cooling, auxiliary milling spindle), drilling head with multiple vertical and horizontal spindles, grooving saw, multiple tool changer, working range X, Y, Z = 4.500 x 2.000 x 300 mm, central greasing system.

Main modules are spindles / tool changers / tool magazine / saw with related drives, movable, grooving table, vacuum clamping system, machine frame, PC, chassis.

A typical price for such a CNC machining centre is in the range of 300.000 Euro.

4.2.9 Base Case 9: Welding equipment

Fully or partly automatic electric machines for arc welding of metals are among those with the highest calculated stock figures among welding equipment (see task 2). A typical unit for this segment is a MIG/MAG welding unit with 200 – 400 A maximum welding current. Such units could be air or liquid cooled. A liquid cooling unit typically is supplied separately and not as part of the equipment as such.

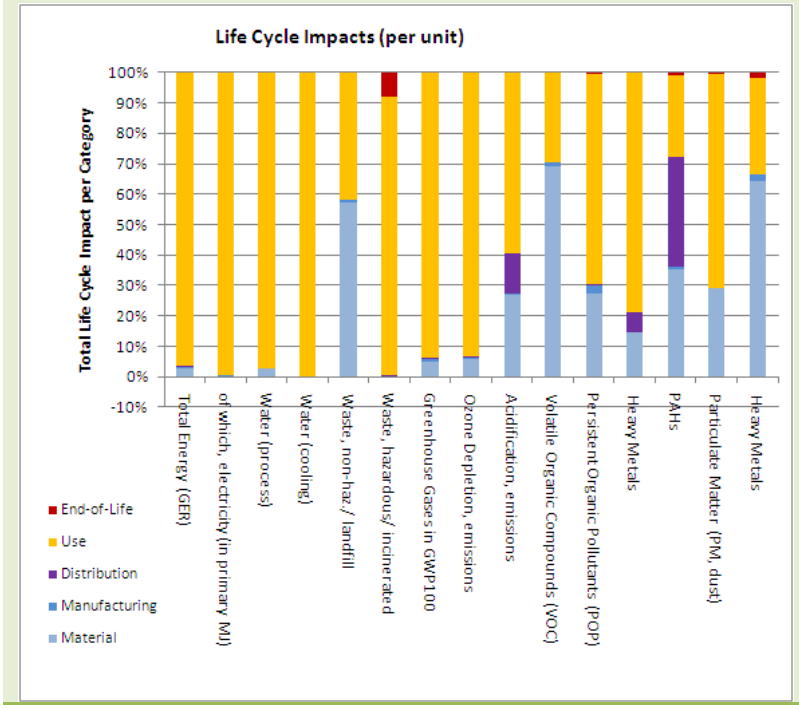
The bill-of-materials listed in 4.1.1.9 is a typical unit for this product category. As it represents rather the slightly more powerful range of equipment (with 340 A maximum output current, 140 kg weight and an above-average price), such a base case might lead to a slight overestimation of impacts of this distinct product group “fully or partly automatic electric machines for arc welding of metals”.

4.3 Base Cases Environmental Impact Assessment

As there is no power consumption standard for machine tools yet, which reflects different modes and use patterns the base case calculations do not need to be split in a "standard Base case" and "a real-life-base case", there will be only **a "real life" scenario**, reflecting typical use patterns identified in task 3.

4.3.1 Base Case 1: Horizontal CNC 4-axis multifunctional machining centre

The figure below displays the environmental impact according to the MEEuP EcoReport for one unit. The highest impact is related to the use phase. The second most important impact is related to the materials to be used for the machine tool construction. It contributes with ratios of 55% to 70% to waste (non-hazardous materials to landfill), volatile organic compounds and heavy metals (emissions to water). PAHs as well as acidification show also a relatively high impact from material and distribution.



Lifetime assumed:

12 years

Shift pattern assumed:

2 shifts / day

6 days/week

Operational time per year assumed:

4.400 h/a

Figure 4-6: Environmental Assessment – Base Case 1: CNC 4-axis horizontal machining centre

Totals for this Base Case for each life cycle phase and each unit indicator are presented in the table below.

Total life cycle impacts of one such machining centre are e.g. 17,4 TJ total energy (i.e. primary energy) consumption, and a Global Warming Potential of 782 t CO_2-eq.

Table 4-37: Environmental Assessment – Base Case 1: CNC 4-axis horizontal machining centre

NR	Life cycle Impact per product:								Date	Author	
0	Non-NC controlled metal working lathe								0		
	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	unit									
1	Bulk Plastics	g			500			450	50	500	0
2	TecPlastics	g			0			0	0	0	0
3	Ferro	g			230090			11505	218586	230090	0
4	Non-ferro	g			27894			1395	26499	27894	0
5	Coating	g			0			0	0	0	0
6	Electronics	g			0			0	0	0	0
7	Misc	g			0			0	0	0	0
	Total weight	g			258484			13349	245135	258484	0
	Other Resources & Waste							debet	see note! credit		
8	Total Energy (GER)	MJ	16476	3725	20202	6715	1951235	3447	-21	3468	1981619
9	of which, electricity (in primary MJ)	MJ	892	2201	3093	17	1946731	0	0	0	1949841
10	Water (process)	ltr	1363	32	1394	0	138794	0	0	0	140188
11	Water (cooling)	ltr	2736	387	3123	0	5191237	0	1	-1	5194365
12	Waste, non-haz./ landfill	g	897187	14242	911430	2774	2266203	61297	1	61297	3241703
13	Waste, hazardous/ incinerated	g	18	1	20	55	44858	450	0	450	45382
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kgCO2eq	1442	209	1651	396	85304	257	-2	259	87610
15	Ozone Depletion, emissions	mg R-11 eq	negligible								
16	Acidification, emissions	g SO2 eq.	9137	904	10041	1212	501710	505	-2	507	513470
17	Volatile Organic Compounds (VOC)	g	118	2	120	124	804	14	0	14	1063
18	Persistent Organic Pollutants (POP)	ng i-Teq	9407	194	9601	16	12856	422	0	422	22894
19	Heavy Metals	mg Ni eq.	3817	454	4271	141	34377	1008	0	1008	39796
	PAHs	mg Ni eq.	221	0	221	267	4773	0	0	0	5261
20	Particulate Matter (PM, dust)	g	10902	139	11041	20509	26693	4487	0	4487	62730
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	1456	0	1456	4	12566	286	0	286	14313
22	Eutrophication	g PO4	34	2	36	0	60	16	0	16	113
23	Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

Not included in these assessments are the production related impacts of lubrication oil, hydraulic oil and cooling lubricants. For simplification all oil based auxiliaries are assessed with the background data documented in Table 4-15, p. 36. Total impacts for the production of 2,67 t oil (lubricant oil, hydraulic oil, cooling lubricants over 12 years lifetime of the machining centre base case) is listed in Table 4-38.

Table 4-38: Environmental Assessment – Base Case 1: CNC 4-axis horizontal machining centre – lubrication oil / hydraulic oil / cooling lubricants

Impact 1 kg mineral oil production for hydraulics			MEEuP equivalents	total oil production related impact of 2670 kg oil consumption (aggregate of lubrication oil, hydraulic oil, cooling lubricants over 12 years; emission during use and end of life not included)
Greenhouse gases	Kilograms CO2 equivalent	3,56	Global Warming Potential (GWP)	9505,2
Ozone-depleting gases	Kilograms CFC-11 equivalent	$8.90 * 10^{-12}$	None, category considered irrelevant for EuPs	Not applicable
Acidification	Kilograms SO equivalent	0,00383	Acidification (AD)	10,2261
Eutrophication	Kilograms PO equivalent	0,000378	Eutrophication (EUP)	1,00926
Heavy metals	Kilograms Pb equivalent	$5.02 * 10^{-7}$	Not transferrable to Ni and Hg equivalents	Not applicable
Carcinogens	Kilograms B(a)P equivalent	$1.62 * 10^{-12}$	none	Not applicable
Winter smog	Kilograms SPM equivalent	0,0018	none	4,806
Summer smog	Kilograms C2H4 equivalent	1,61E-08	Approximation: Volatile Organic Compounds (VOC)	4,2987E-05
Energy	Megajoules LHV equivalent	5,94	Approximation: Total Energy	15859,8
Solid waste	Kilograms	0,00519	Approximation: Waste, non-hazardous, landfill	13,8573

For those impact categories, for which impact indicators corresponding to MEEuP are available, the correlation between oil (production) related impacts and all other life cycle phases of the machining centre is available is depicted in Figure 4-7. There is only one impact category, which is eutrophication, where the mineral oil production in com-

parison to all other life cycle phases has an important impact of nearly 38%[35]. The contribution to the total lifecycle Global Warming Potential is 1,2%, to acidification 0,22% and to all other available categories less than 0,1%.

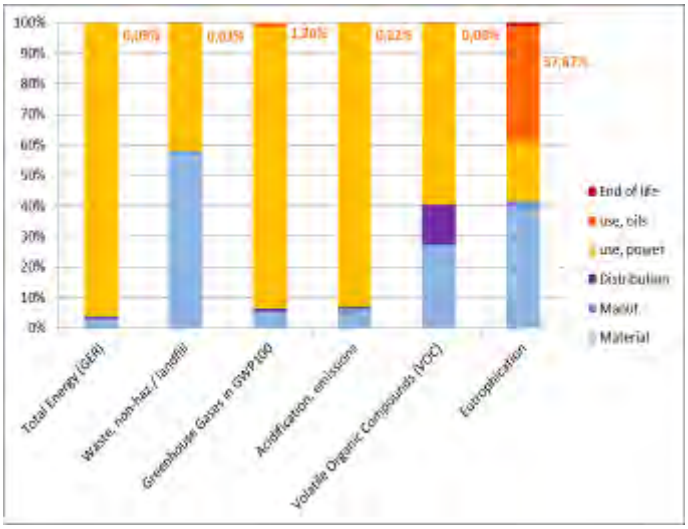


Figure 4-7: Environmental Assessment – Base Case 1: CNC 4-axis horizontal machining centre – lubrication oil / hydraulic oil / cooling lubricants included

For comparison, the averaged data based on the input provided by CECIMO and stemming from their LCA activities in preparation of the SRI result in an MEEuP assessment as shown in Figure 4-8: The overall trends are confirmed, but in some categories deviations are obvious.

35 The LCA study by CECIMO in preparation of the SRI did not result in a similar relevancy for oil towards the category eutrophication despite the fact, that similar assumptions where made as in our Base Case – which obviously means, the background dataset used by CECIMO / PE has a much lower impact on eutrophication than McManus et al.

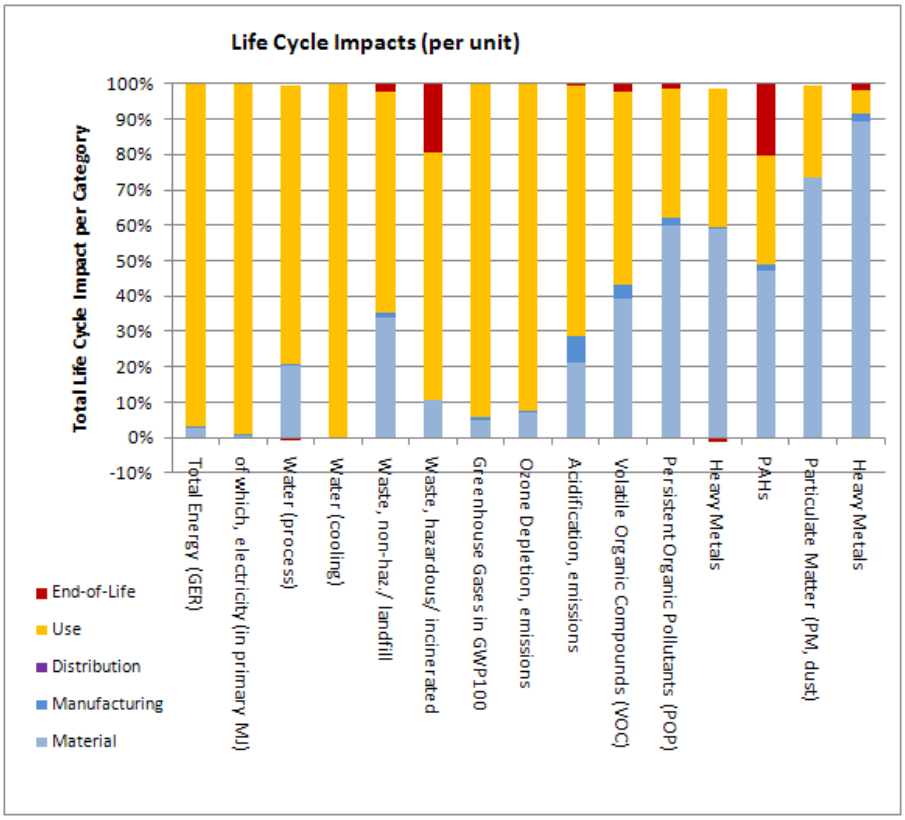


Figure 4-8: Comparative environmental assessment results based on CECIMO's base figures

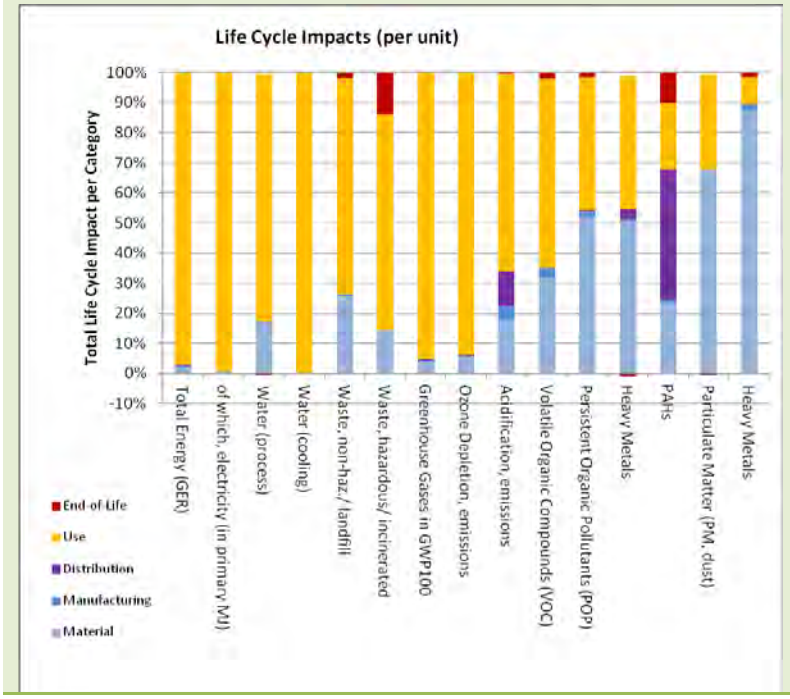
4.3.2 Base Case 2: CNC Laser cutting machine tools

The assessment findings for the Base Case "CNC laser cutting machine tools" are depicted in Figure 4-11. Not considered in this figure are the use phase impacts of laser and cutting gas consumption.

The categories total energy and Global Warming Potential are clearly dominated by use phase impacts (power consumption), whereas several other categories are dominated by the impacts of the material used to construct the laser cutting machine tool:

- Persistent Organic Pollutants
- Heavy metals emitted to air and water
- Particulate matter (dust)

Consequently, power consumption in the use phase is not the only relevant life cycle aspect for laser cutting machine tools, but the environmental impacts related to machinery material actually is related to the bulk of steel parts and components.



Lifetime assumed:

12 years

Shift pattern assumed:

2 shifts / day

6 days/week

Operational time per year assumed:

3.800 h/a

Figure 4-9: Base case CNC laser cutting machine tools

Not included in these assessments are the production related impacts of cutting gas nitrogen.

Impacts in absolute numbers for this Base Case are listed in the table below, referring to one unit i.e. machine. The total energy consumption over the life cycle is 25 TJ, and the Global Warming Potential is 1,130 t CO_2-eq. over the whole product life of 12 years.

Table 4-39: Environmental Assessment – Base Case 2: CNC laser cutting machine tools

Nr	Life cycle impact per product:	Date	Author
0	Generic CNC Laser cutting machine tool	0	KSchi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	unit									
1	Bulk Plastics	g			12000			10800	1200	12000	0
2	TecPlastics	g			15000			13500	1500	15000	0
3	Ferro	g			10980000			549000	10431000	10980000	0
4	Non-ferro	g			462000			23100	438900	462000	0
5	Coating	g			0			0	0	0	0
6	Electronics	g			370000			270000	100000	370000	0
7	Misc.	g			160300			8015	152285	160300	0
	Total weight	g			11999300			874415	11124885	11999300	0
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	524933	102152	627086	88902	24666313	49381	28139	21242	25403541
9	of which, electricity (in primary MJ)	MJ	129833	44879	174712	227	24647347	0	11600	-11600	24810686
10	Water (process)	ltr	340451	2965	343416	0	1670474	0	10474	-10474	2003416
11	Water (cooling)	ltr	99090	26217	112307	0	65722723	0	2169	-2169	65832860
12	Waste, non-haz./ landfill	g	######	371896	10530155	36350	28680476	735652	33633	702019	39949001
13	Waste, hazardous/ incinerated	g	115190	892	116082	722	569068	124300	13055	111245	797117
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	43090	6052	49142	5226	1077128	3685	1957	1728	1133224
15	Ozone Depletion, emissions	mg R-11 eq				negligible					
16	Acidification, emissions	g SO2 eq	364968	28652	393620	16012	6351294	7249	9912	-2663	6758263
17	Volatile Organic Compounds (VOC)	g	2498	693	3191	1651	9547	188	145	43	14432
18	Persistent Organic Pollutants (POP)	ng I-Teq	82018	8396	90414	205	162446	5065	127	4938	258003
19	Heavy Metals	mg Ni eq.	499667	19798	519465	1843	431140	14243	1470	12773	965222
	PAHs	mg Ni eq.	56981	523	57503	3522	52839	0	1208	-1208	112656
20	Particulate Matter (PM, dust)	g	147580	5885	153465	273446	190005	83991	489	83523	680439
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	349232	96	349327	58	162401	4113	6666	-2554	509232
22	Eutrophication	g PO4	8242	172	8415	1	842	235	94	141	9398
23	Persistent Organic Pollutants (POP)	ng I-Teq				negligible					

Taking into account also the nitrogen consumption (cutting gas) the assessment changes slightly. Taking the ELCD dataset[36] as cradle-to-gate inventory for 1 kg nitrogen inter alia yields in 1,8 MJ net caloric value of all energy carriers (comparable to Total Energy GER), and emissions of 0.083 kg CO2 as the dominating greenhouse gas. The machinery's consumption of 25 t nitrogen per year thus equals 45,000 MJ/a, and 540,000 MJ over the total life cycle – roughly 2% of the Total Energy consumption which can be attributed to nitrogen consumption. Similarly the nitrogen related CO2 emissions of slightly more than 2,000 kg per year and close to 25,000 kg over the total

36 European Life Cycle Data ELCD database 2.0: Nitrogen; via cryogenic air separation; production mix, at plant; gaseous

life cycle equal 2% of the total life cycle impacts of the laser cutting machine tool as such.

Total impacts for the production of 300 t N_2 (over 12 years lifetime of the laser cutting machine tools base case) is listed in Table 4-40. Background data is derived from Pro-Bas (dataset: Xtra-generischN2, gasförmig).

Table 4-40: Environmental Assessment – Base Case 2: CNC laser cutting machine tools – laser cutting gas nitrogen

Impact 1 kg nitrogen			**MEEuP equivalents**	**total nitrogen production related impact of 300 t consumption** (over 12 years)
Greenhouse gases	Kilograms CO2 eq.	0,0739	Global Warming Potential (GWP)	22170 kg
Acidification	Kilograms SO2 equivalent	0,0000965	Acidification (AD)	28,95 kg
Heavy metals	Kilograms Hg (water)	$272 * 10^{-18}$	Emissions to water (mg Hg/20) (other heavy metals – As, Cd, Cr, Pb – listed as well in ProBas, but no equivalent in MEEuP available)	0,00163 mg Hg/20
	Kilograms Ni (air)	$4,24 * 10^{-9}$	Emissions to air (mg Ni eq.) (other heavy metals – As, Cd, Hg, Pb – listed as well in ProBas, but no equivalent in MEEuP available)	1270 mg Ni.eq
Eutrophication	Kilograms PO equivalent	k.A.	Eutrophication (EUP)	0

For those impact categories, for which impact indicators corresponding to MEEuP are available, the correlation between nitrogen (production) related impacts and all other life cycle phases of the laser cutting machine tool is depicted in Figure 4-10, which basically confirms the data based on ELCD.

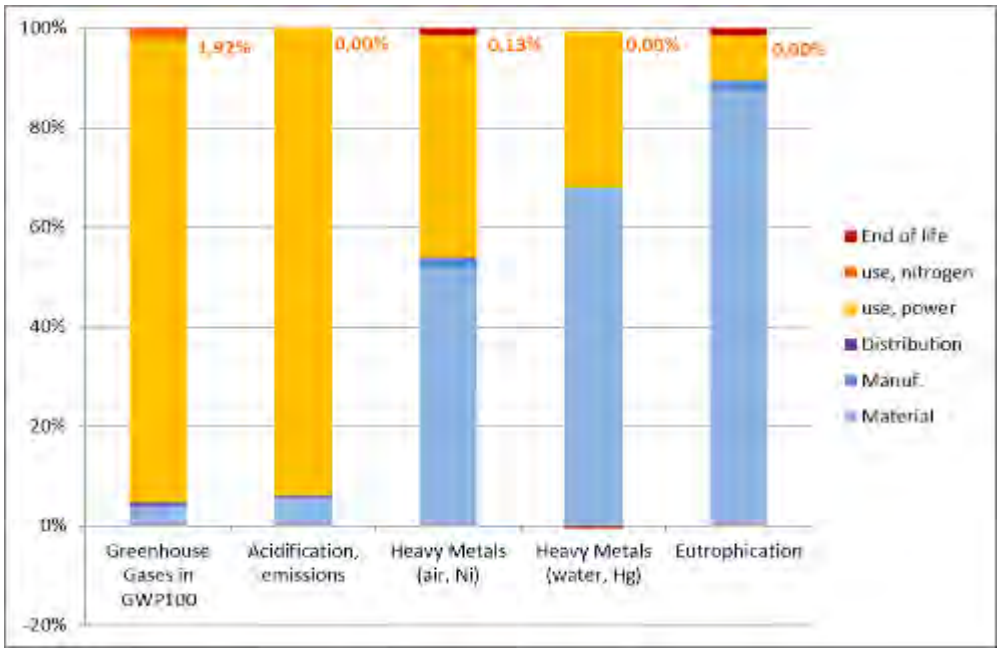


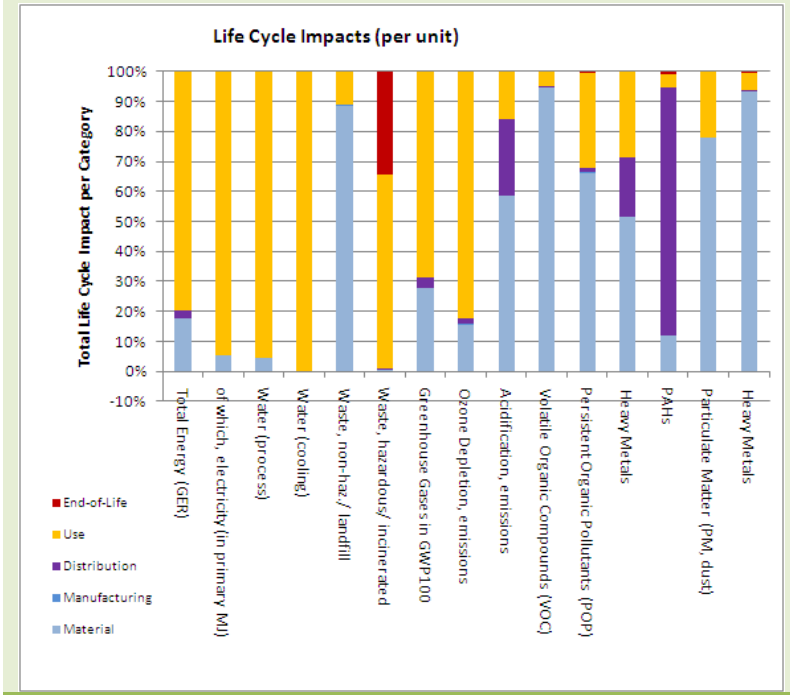
Figure 4-10: Environmental Assessment – Base Case 2: CNC laser cutting machine tools – nitrogen included

4.3.3 Base Case 3: CNC Metal working bending machine tools

The assessment findings for the Base Case “Metal working bending machine tools” is depicted in Figure 4-11. The categories total energy and Global Warming Potential are clearly dominated by use phase impacts (power consumption), whereas several other categories are dominated by the impacts of the material used to construct the bending machine tool:

- Non-hazardous waste to landfill
- Acidification
- Volatile Organic Compounds
- Persistent Organic Pollutants
- Heavy metals emitted to air and water
- Particulate matter (dust)

Consequently, power consumption in the use phase is not the only relevant life cycle aspect for bending machine tools.



Lifetime assumed:

17 years

Shift pattern assumed:

1 shift / day

5 days/week

Operational time per year assumed:

2.000 h/a

Figure 4-11: Base case CNC Bending machine tools

As a 1-shifts operation of this kind of bending machine is common, but the lower end of the actual use scenarios, the following figure depicts the assessment results, if a 2-shifts production model is calculated: Not surprisingly, the use phase sees a higher impact share in all impact categories, but even under these conditions several categories are still dominated by material related impacts: In 8 out of 15 categories the use phase impacts have a share of less than 50% of the total impacts.

INEGI provided a complementary assessment of the same base case with the Eco-Indicator approach, which allows a cross-check of the MEEuP results with other LCA approaches. INEGI's assessment results are depicted in Figure 4-12.

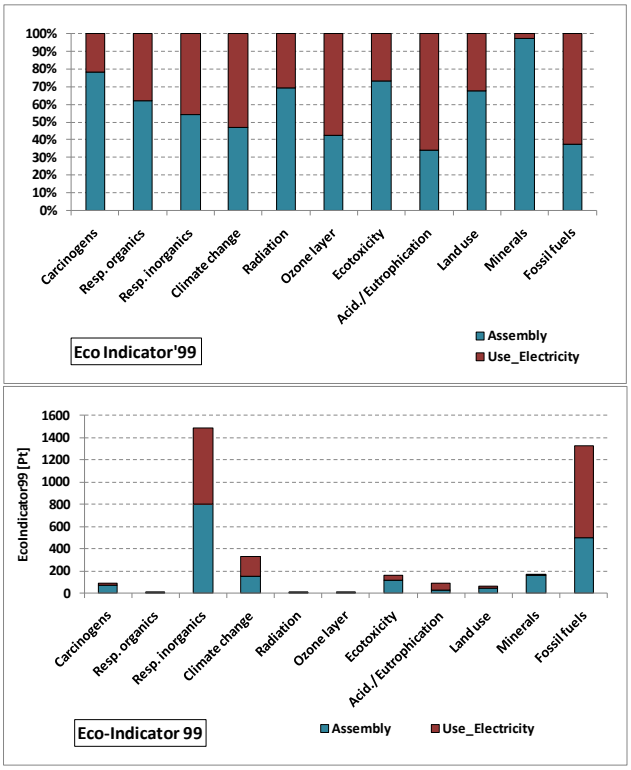
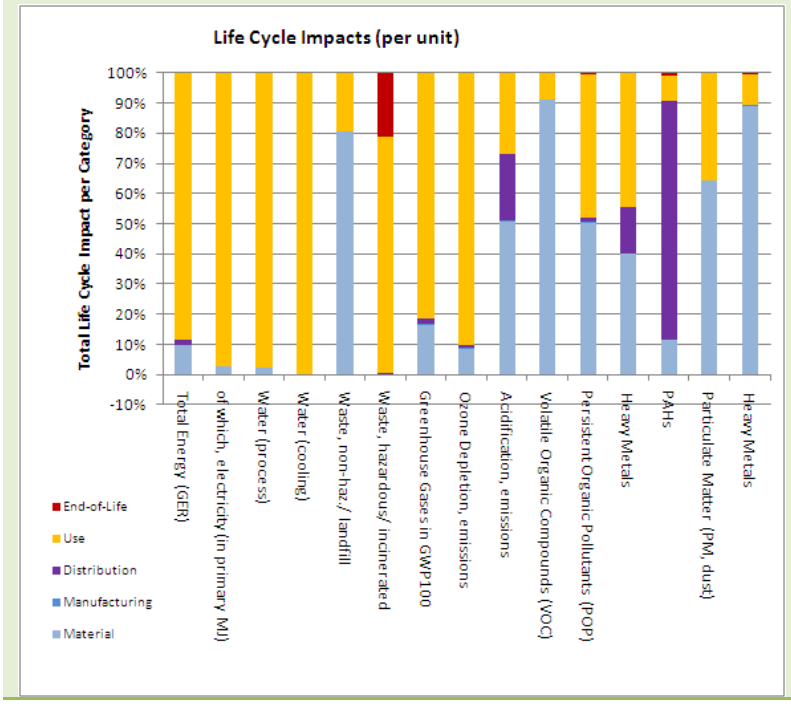


Figure 4-12: Eco-Indicator 99 assessment of Base case CNC Bending machine tools (1-shift)

INEGI's interpretation of these Eco-Indicator 99 results can be summarized as follows and is shared by Fraunhofer: The comparative analysis of the MEEuP and Eco-Indicator 99 charts makes evident that the relative contributions values seem to be valid for the analysis of the contribution of each life cycle stage to the overall environmental impact. In terms of relative contributions of the 2 life-cycle stages, the results obtained with both methodologies are indeed comparable, as, from both charts (a) and (b) one can retain that the 2 life-cycle stages analyzed (assembly and use of electricity in the use phase) indeed share more or less equally the full environmental impact. However, the analysis per impact categories is quite difficult to evaluate, even in cases where the correspondence is easier, such as Acidification and Eutrophication.

The analysis of absolute impact values (only possible with the normalized Eco-Indicator 99) unveils a high relevancy of emissions of respiratory inorganics, which have a similar degree of relevance as fossil fuels, and much more than Global Warming Potential. This leads to the insight that conclusions should not only be based on GWP or energy criteria.



Lifetime assumed:

17 years

Shift pattern assumed:

2 shifts / day

5 days/week

Operational time per year assumed:

4.000 h/a

Figure 4-13: Base case CNC Bending machine tools – variant: 2-shifts operation

Impacts in absolute numbers for this Base Case (relating to a 1-shifts production model) are listed in the table below, referring to one unit i.e. machine. The total energy consumption over the life cycle is 790 GJ, and the Global Warming Potential is 40 t CO2-eq. over the whole product life of 17 years.

Table 4-41: Environmental Assessment – Base Case 3: CNC bending machine tools

Nr	Life cycle Impact per product:	Date	Author
0	CNC Bending machine tool	Dec, 2011	KSchi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	unit									
1	Bulk Plastics	g			0			0	0	0	0
2	TecPlastics	g			9690			8721	969	9690	0
3	Ferro	g			7841450			0	7841450	######	0
4	Non-ferro	g			20830			0	20830	20830	0
5	Coating	g			0			0	0	0	0
6	Electronics	g			0			0	0	0	0
7	Misc.	g			0			0	0	0	0
	Total weight	g			7871970			8721	7863249	######	0
	Other Resources & Waste							debet	credit (see note!)		
8	Total Energy (GER)	MJ	138115	1343	139458	21886	649357	593	-886	1479	812180
9	of w hich, electricity (in primary MJ)	MJ	35710	785	36495	56	627868	0	4	-4	664416
10	Water (process)	ltr	1981	11	1993	0	41853	0	2	-2	43844
11	Water (cooling)	ltr	3121	347	3468	0	1673377	0	20	-20	1676825
12	Waste, non-haz./ landfill	g	######	5650	6326688	8972	790821	3	14	-11	7126470
13	Waste, hazardous/ incinerated	g	72	1	72	178	14460	8721	2	8719	23430
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq	11092	76	11168	1288	29077	44	-69	113	41646
15	Ozone Depletion, emissions	mg R-11 e				negligible					
16	Acidification, emissions	g SO2 eq	30763	329	31091	3944	163474	89	-85	174	198683
17	Volatile Organic Compounds (VOC)	g	922	1	923	406	576	1	-1	3	1907
18	Persistent Organic Pollutants (POP)	ng i-Teq	93566	109	93675	51	5050	0	0	0	98776
19	Heavy Metals	mg_Ni eq	22876	255	23130	455	15417	158	0	158	39161
	PAHs	mg_Ni eq	2265	0	2265	868	5682	0	0	0	8815
20	Particulate Matter (PM, dust)	g	9694	50	9744	67200	78519	768	-1	769	156231
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	14923	0	14923	14	4195	50	0	50	19182
22	Eutrophication	g PO4	370	1	371	0	23	3	0	3	397
23	Persistent Organic Pollutants (POP)	ng i-Teq				negligible					

This assessment does not include the consumption of hydraulic oil in absence of a related data set in the MEEuP methodology. For estimating the relevancy of hydraulic oil consumption we apply the background dataset introduced in 4.1.3 to the total hydraulic oil consumption of the machine tools lifetime of estimated 17 years: Total impacts for the production of 1,836 t oil is listed in Table 4-42.

Table 4-42: Environmental Assessment – Base Case 3: CNC bending machine tools – hydraulic oil

Impact 1 kg mineral oil production for hydraulics			MEEuP equivalents	total oil production related impact of 1836 kg oil consumption (hydraulic oil over 17 years; emission during use and end of life not included)
Greenhouse gases	Kilograms CO2 equivalent	3,56	Global Warming Potential (GWP)	6536,16
Ozone-depleting gases	Kilograms CFC-11 equivalent	$8.90 * 10^{-12}$	None, category considered irrelevant for EuPs	Not applicable
Acidification	Kilograms SO equivalent	0,00383	Acidification (AD)	7031,88
Eutrophication	Kilograms PO equivalent	0,000378	Eutrophication (EUP)	694,008
Heavy metals	Kilograms Pb equivalent	$5.02 * 10^{-7}$	Not transferrable to Ni and Hg equivalents	Not applicable
Carcinogens	Kilograms B(a)P equivalent	$1.62 * 10^{-12}$	none	Not applicable
Winter smog	Kilograms SPM equivalent	0,0018	none	3,3048
Summer smog	Kilograms C2H4 equivalent	1,61E-08	Approximation: Volatile Organic Compounds (VOC)	0,0295596
Energy	Megajoules LHV equivalent	5,94	Approximation: Total Energy	10905,84
Solid waste	Kilograms	0,00519	Approximation: Waste, non-hazardous, landfill	9528,84

For those impact categories, for which impact indicators corresponding to MEEuP are available, the correlation between oil (production) related impacts and all other life cycle phases of the CNC bending machine tool is available is depicted in Figure 4-14. There is one impact category, which is eutrophication, where the mineral oil production in comparison to all other life cycle phases has dominating impact of nearly 64%, and one category, which is Greenhouse Gas emissions, where there is a significant impact as well (13,6%).

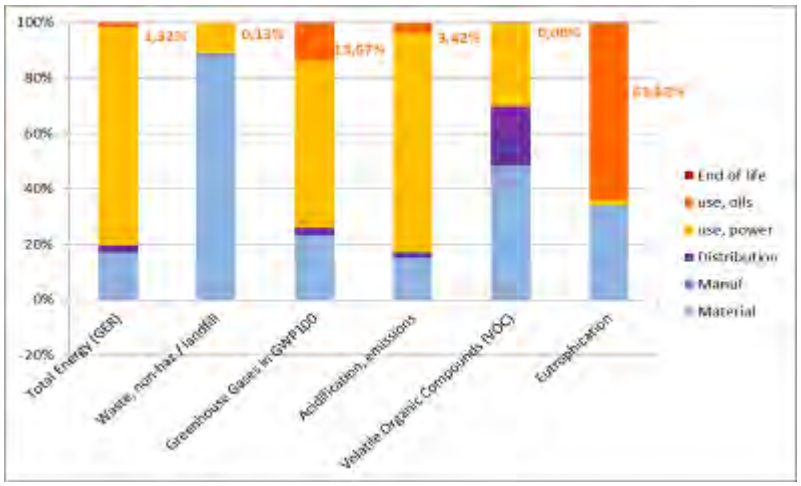


Figure 4-14: Environmental Assessment – Base Case 3: CNC bending machine tool – hydraulic oil included

INEGI provided a stakeholder comment to this study, which outlines the relevancy of hydraulic oil in their einvironmental assessments of press brakes:

The LCA analysis was followed with Simapro software and EcoInvent databases. ... The oil source considered was a standard crude oil, and incineration was the end-of-life scenario associated.

Based on this, it was expected that the use of no-renewable resources would determine the environmental impact profile related to the oil consumption. This is indeed confirmed from Figure 4-15*. The results show both (a) the relative contributions and (b) the absolute Eco-indicator99 values of the impact of the Assembly-phase and Use-phase (Electricity and Oil) to the different middle-point impact categories.*

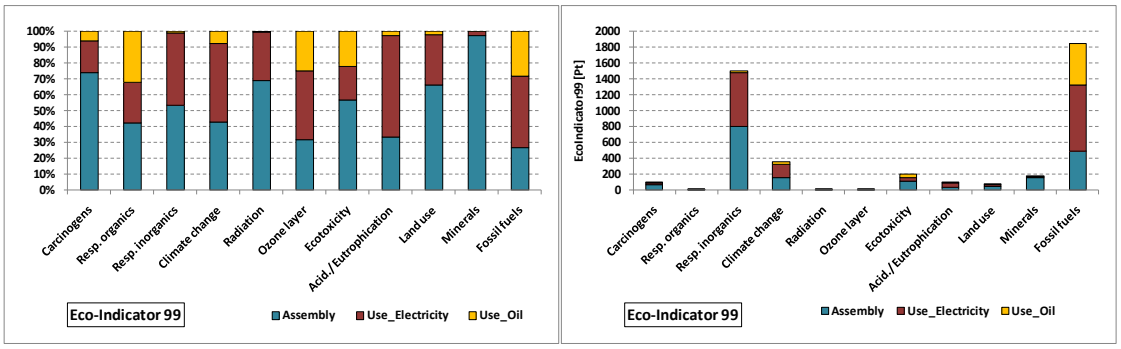


Figure 4-15: Results per impact category (middle-point) by analysing: (a) the relative contributions and (b) the absolute Eco-indicator99 values, of the Assembly-phase and Use-phase (Electricity and Oil) inputs

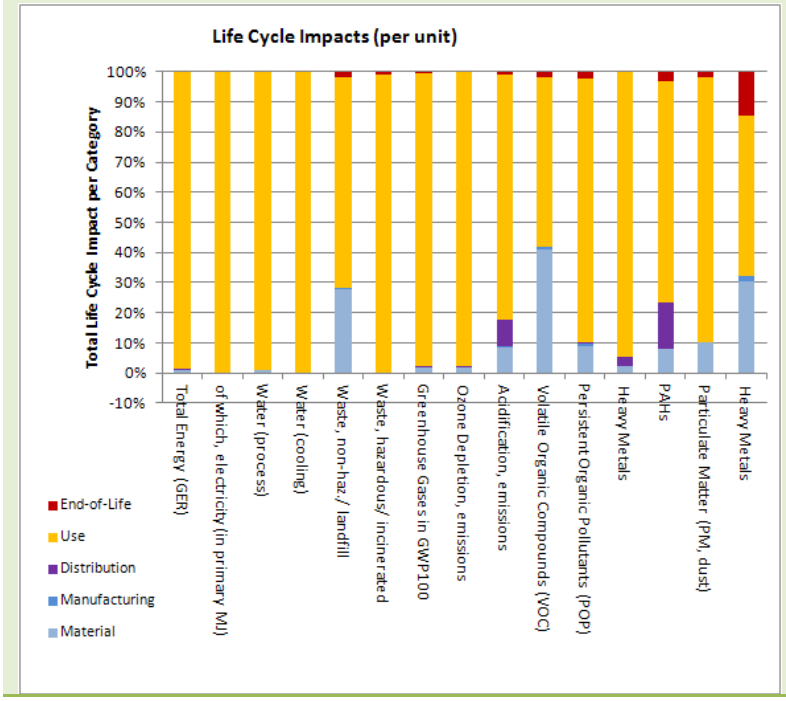
From these results, the following is to be highlighted:

- *The relative contribution of the oil consumption to the global environmental impact of the machine is higher than 20%, in 4 of the 11 impact categories analyzed;*
- *The main impact of the oil consumption, in absolute value of the indicator, is on the depletion of fossil fuels, and, in this category, the impact is similar to that of the assembly resources;*
- *The significant relative contributions of the oil consumption in other categories correspond only to minor impact values (such as in ecotoxicity or respiratory organics) or are even negligible (such as the effect on ozone layer).*

Compared to the Base Case 1 assessment the results for Base Case 3 show a higher relevancy of hydraulic oil consumption, which is of some relevance compared to other life cycle aspects.

4.3.4 Base Case 4: Non-numerical controlled metal working machine tools

The figure below displays the environmental impact according to the MEEuP EcoReport for one unit of the Base Case “Non-numerical controlled metal working machine tools”. The highest impact is related to the use phase. The second most important impact is related to the materials to be used for the machine tool construction similar to Base Case 1. The categories total energy and Global Warming Potential are clearly dominated by use phase impacts (power consumption throughout all impact categories.



Lifetime assumed:

18 years

Shift pattern assumed:

1 shift / day

5 days/week

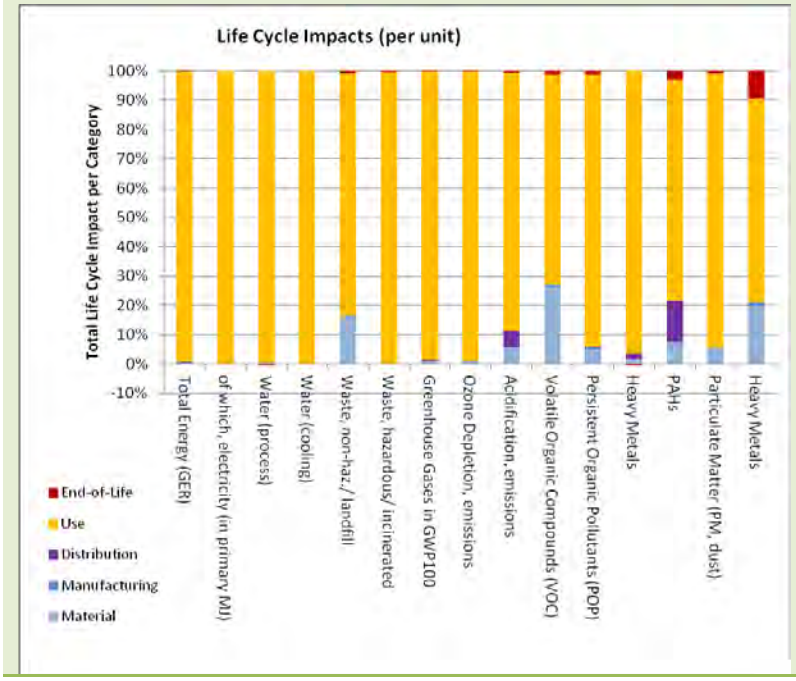
Operational time per year assumed:

2.000 h/a

Figure 4-16: Base case Non-numerical controlled metal working machine tools (1-shift-operation)

As a 1-shifts operation is common, but the lower end of the actual use scenarios, the following figure depicts the assessment results, if a 2-shifts production model is calculated: Not surprisingly, the use phase sees a higher impact share in all impact categories. This phase has a proportion of over 70 % in all categories.

The relevance of energy consumption rises if these machines are used in 2-shift-operation, as shown in Figure 4-17.



Lifetime assumed:

18 years

Shift pattern assumed:

2 shifts / day

5 days/week

Operational time per year assumed:

4.000 h/a

Figure 4-17: Base case Non-numerical controlled metal working machine tool (2-shift-operation)

Impacts in absolute numbers for this Base Case (relating to a 1-shifts production model) are listed in the table below, referring to one unit i.e. machine. The total energy consumption over the life cycle is 2000 GJ the Global Warming Potential is at 89 t CO2-eq over the whole product life of 18 years.

Table 4-43: Environmental Assessment – Base Case 4: Non-numerical controlled metal working machine tools

Nr	Life cycle Impact per product:	Date	Author
0	Non-NC controlled metal working lathe	0	

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	unit									
1	Bulk Plastics	g			500			450	50	500	0
2	TecPlastics	g			0			0	0	0	0
3	Ferro	g			230090			11505	218586	230090	0
4	Non-ferro	g			27894			1395	26499	27894	0
5	Coating	g			0			0	0	0	0
6	Electronics	g			0			0	0	0	0
7	Misc.	g			0			0	0	0	0
	Total weight	g			258484			13349	245135	258484	0
	Other Resources & Waste							debet	see note! credit		
8	Total Energy (GER)	MJ	16476	3725	20202	6715	1951235	3447	-21	3468	1981619
9	of w hich, electricity (in primary MJ)	MJ	892	2201	3093	17	1946731	0	0	0	1949841
10	Water (process)	ltr	1363	32	1394	0	138794	0	0	0	140188
11	Water (cooling)	ltr	2732	997	3729	0	5191237	0	1	-1	5194965
12	Waste, non-haz./ landfill	g	897187	14242	911430	2774	2266203	61297	1	61297	3241703
13	Waste, hazardous/ incinerated	g	18	1	20	55	44858	450	0	450	45382
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq	1442	209	1651	396	85304	257	-2	259	87610
15	Ozone Depletion, emissions	mg R-11 e				negligible					
16	Acidification, emissions	g SO2 eq	9137	904	10041	1212	501710	505	-2	507	513470
17	Volatile Organic Compounds (VOC)	g	118	2	120	124	804	14	0	14	1063
18	Persistent Organic Pollutants (POP)	ng i-Teq	9407	194	9601	16	12856	422	0	422	22894
19	Heavy Metals	mg Ni eq	3817	454	4271	141	34377	1008	0	1008	39796
	PAHs	mg Ni eq	221	0	221	267	4773	0	0	0	5261
20	Particulate Matter (PM, dust)	g	10902	139	11041	20509	26693	4487	0	4487	62730
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	1456	0	1456	4	12566	286	0	286	14313
22	Eutrophication	g PO4	34	2	36	0	60	16	0	16	113
23	Persistent Organic Pollutants (POP)	ng i-Teq				negligible					

This assessment does not include the consumption of hydraulic oil in absence of a related data set in the MEEuP methodology. For estimating the relevancy of hydraulic oil consumption we apply the background dataset introduced in 4.1.3 to the total hydraulic oil and cooling lubricant consumption of the machine tools lifetime of estimated 18 years: Total impacts for the production of 72 kg oil is listed in Table 4-44.

Table 4-44: Environmental Assessment – Base Case 4: Non-numerical controlled metal working machine tools – hydraulic oil / cooling lubricants

Impact 1 kg mineral oil production for hydraulics			MEEuP equivalents	total oil production related impact of 72 kg oil consumption (hydraulic oil and cooling lubricant over 18 years; emission during use and end of life not included)
Greenhouse gases	Kilograms CO2 equivalent	3,56	Global Warming Potential (GWP)	256,32
Ozone-depleting gases	Kilograms CFC-11 equivalent	$8.90 * 10^{-12}$	None, category considered irrelevant for EuPs	Not applicable
Acidification	Kilograms SO equivalent	0,00383	Acidification (AD)	275,76
Eutrophication	Kilograms PO equivalent	0,000378	Eutrophication (EUP)	27,216
Heavy metals	Kilograms Pb equivalent	$5.02 * 10^{-7}$	Not transferrable to Ni and Hg equivalents	Not applicable
Carcinogens	Kilograms B(a)P equivalent	$1.62 * 10^{-12}$	none	Not applicable
Winter smog	Kilograms SPM equivalent	0,0018	none	0,1296
Summer smog	Kilograms C2H4 equivalent	1,61E-08	Approximation: Volatile Organic Compounds (VOC)	0,0011592
Energy	Megajoules LHV equivalent	5,94	Approximation: Total Energy	427,68
Solid waste	Kilograms	0,00519	Approximation: Waste, non-hazardous, landfill	373,68

For those impact categories, for which impact indicators corresponding to MEEuP are available, the correlation between oil (production) related impacts and all other life cycle phases of the non-numerical controlled metal working machine tool is available is depicted in Figure 4-18. There is only one impact category, which is eutrophication, where the mineral oil production in comparison to all other life cycle phases has an important impact of nearly 20%. The contribution to the total lifecycle Global Warming Potential is 0,3%.

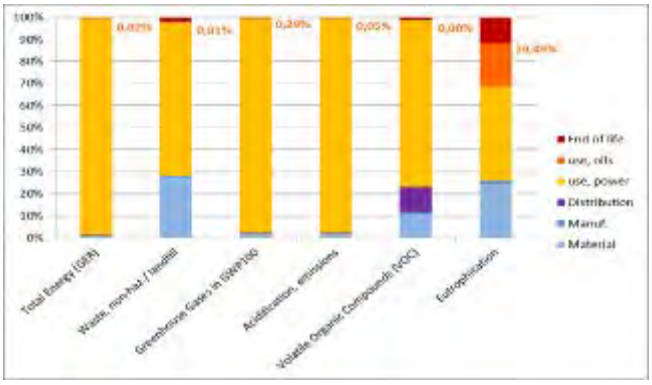


Figure 4-18: Environmental Assessment – Base Case 4: Non-numerical controlled metal working machine tools – hydraulic oil / cooling lubricant included

Given these findings it can be concluded, that auxiliaries for non-NC machine tools are of minor relevancy.

4.3.5 Base Case 5: Wood working machine tools: Table saw

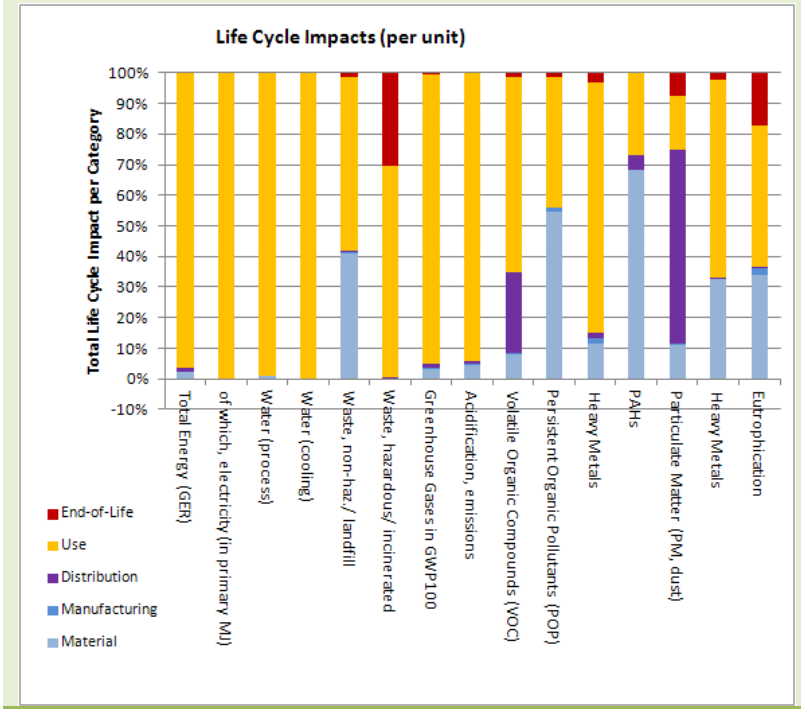
The assessment findings for the Base Case “Table saw” are depicted in Figure 4-21.

The categories total energy and Global Warming Potential are clearly dominated by use phase impacts (power consumption), whereas several other categories are dominated by the impacts of the material used to construct the table saw:

- Persistent Organic Pollutants
- Polyaromatic hydrocarbons’ emissions to air

Consequently, power consumption in the use phase is not the only relevant life cycle aspect for table saws, but the environmental impacts related to machinery material actually is related to die cast aluminium for the sawing table used by some manufacturers. Cast iron, which is used by others, according to the MEEuP base data, comes at much lower environmental impact than the aluminium.

Given the low use time per working day (1 hour) compared to 1- or 2-shifts-operation of industrial machine tools it might have been expected, that the use phase is less dominant, but this is outweighed by the also much less material intensive design of light-stationary woodworking tools, and the anticipated long lifetime of 20 years.



Lifetime assumed:

20 years

Shift pattern assumed:

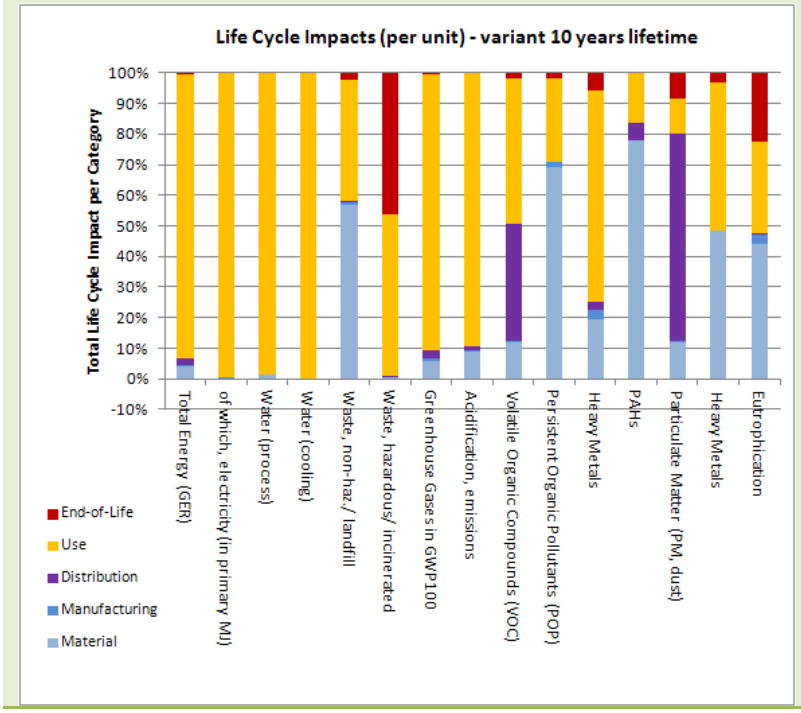
1 h of use / day

Operational time per year assumed:

250 h/a

Figure 4-19: Base case Table saw

To give an impression of the effect of shorter lifetime assumptions Figure 4-20 depicts the result for 10 years lifetime of the same table saw: Dominance of energy consumption in the use phase is still evident, but relevancy of material related up-stream impacts increases apparently.



Lifetime assumed:

10 years

Shift pattern assumed:

1 h of use / day

Operational time per year assumed:

250 h/a

Figure 4-20: Base case Table saw – variant 10 years lifetime

Impacts in absolute numbers for this Base Case (referring now again to the initial assumption of 20 years lifetime) are listed in the table below, referring to one unit i.e. machine. The total energy consumption over the life cycle is 55 GJ, the Global Warming Potential is 2,4 t CO_2-eq. over the whole product life.

Table 4-45: Environmental Assessment – Base Case 5: Table saw

Nr	Life cycle Impact per product:	Date	Author
0	Light Stationary Wood Working Equipment / Table Saw	0	Kschi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	**unit**									
1	Bulk Plastics	g			490			441	49	490	0
2	TecPlastics	g			100			90	10	100	0
3	Ferro	g			14875			744	14131	14875	0
4	Non-ferro	g			11530			577	10954	11530	0
5	Coating	g			0			0	0	0	0
6	Electronics	g			0			0	0	0	0
7	Misc.	g			5			0	5	5	0
	Total weight	g			27000			1852	25149	27000	0
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	1148	172	1315	594	52537	128	18	110	54556
9	of which, electricity (in primary MJ)	MJ	15	102	117	1	52501	0	0	0	52619
10	Water (process)	ltr	26	1	27	0	3500	0	0	0	3528
11	Water (cooling)	ltr	88	46	134	0	140001	0	1	-1	140134
12	Waste, non-haz./ landfill	g	44210	661	44871	313	61319	1655	1	1654	108158
13	Waste, hazardous/ incinerated	g	4	0	4	6	1210	531	0	531	1751
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	75	10	84	37	2294	10	1	8	2423
15	Ozone Depletion, emissions	mg R-11 eq.	negligible								
16	Acidification, emissions	g SO2 eq.	663	42	705	111	13528	19	2	17	14360
17	Volatile Organic Compounds (VOC)	g	3	0	3	8	20	0	0	0	32
18	Persistent Organic Pollutants (POP)	ng i-Teq	450	9	459	2	349	1	0	11	821
19	Heavy Metals	mg Ni eq.	127	22	148	16	907	37	0	37	1108
	PAHs	mg Ni eq.	282	0	282	20	111	0	0	0	414
20	Particulate Matter (PM, dust)	g	242	6	248	1368	379	167	0	167	2162
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	171	0	171	0	340	11	0	11	523
22	Eutrophication	g PO4	1	0	1	0	2	1	0	1	4
23	Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

4.3.6 Base Case 6: Wood working machine tools: Horizontal panel saw

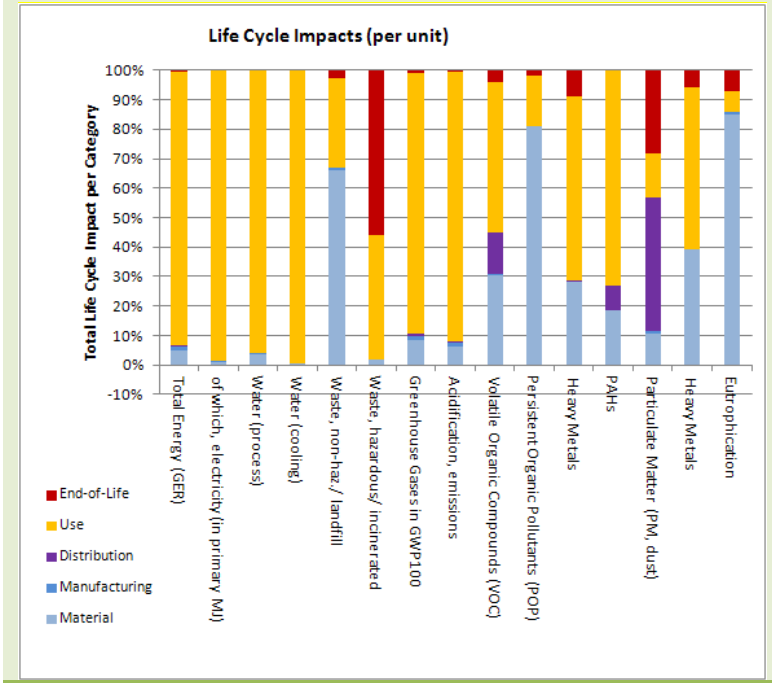
The assessment findings for the Base Case “Horizontal panel saw” are depicted in Figure 4-21. Not included is the energy consumption of a central extraction system.

The categories total energy and Global Warming Potential are clearly dominated by use phase impacts (power consumption), whereas several other categories are dominated by the impacts of the material used to construct the horizontal panel saw:

- Persistent Organic Pollutants
- Eutrophication

- Waste (non-hazardous)

Consequently, power consumption in the use phase is not the only relevant life cycle aspect for horizontal panel saws, but the environmental impacts related to machinery material actually is related to the bulk of steel parts and components.



Lifetime assumed:

20 years

Shift pattern assumed:

1 shift / day

5 days / week

Operational time per year assumed:

1.625 h/a (incl. idle)

Figure 4-21: Base case horizontal panel saw

Impacts in absolute numbers for this Base Case are listed in the table below, referring to one unit i.e. machine. The total energy consumption over the life cycle is 3 TJ, and the Global Warming Potential is 135 t CO_2-eq. over the whole product life of 20 years.

Table 4-46: Environmental Assessment – Base Case 6: Horizontal panel saw

Nr	Life cycle Impact per product:	Date	Author
0	Horizontal panel saw	0	Pwi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	**unit**									
1	Bulk Plastics	g			**1792**			1434	358	**1792**	**0**
2	TecPlastics	g			**101589**			81271	20318	**101589**	**0**
3	Ferro	g			**4796759**			239838	4556921	**4796759**	**0**
4	Non-ferro	g			**94817**			4741	90076	**94817**	**0**
5	Coating	g			**3**			0	3	**3**	**0**
6	Electronics	g			**1715**			961	754	**1715**	**0**
7	Misc.	g			**3326**			166	3160	**3326**	**0**
	Total weight	g			**5000000**			328411	4671589	**5000000**	**0**
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	146100	37209	**183309**	**15600**	**2743209**	22832	4507	**18325**	**2960444**
9	of which, electricity (in primary MJ)	MJ	20845	22289	**43134**	**40**	**2736994**	0	164	**-164**	**2780003**
10	Water (process)	ltr	7040	353	**7394**	**0**	**182511**	0	130	**-130**	**189775**
11	Water (cooling)	ltr	39220	10565	**49785**	**0**	**7297998**	0	440	**-440**	**7347343**
12	Waste, non-haz./ landfill	g	######	116146	**7224974**	**6404**	**3245139**	306552	551	**306001**	**10782517**
13	Waste, hazardous/ incinerated	g	2648	6	**2654**	**127**	**63085**	83460	145	**83314**	**149181**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	11194	2067	**13261**	**918**	**119927**	1703	279	**1424**	**135530**
15	Ozone Depletion, emissions	mg R-11 eq	negligible								
16	Acidification, emissions	g SO2 eq.	49299	8929	**58228**	**2812**	**705619**	3376	439	**2937**	**769596**
17	Volatile Organic Compounds (VOC	g	623	7	**630**	**289**	**1115**	85	5	**80**	**2114**
18	Persistent Organic Pollutants (POP	ng i-Teq	90208	0	**90208**	**36**	**18839**	2111	1	**2110**	**111194**
19	Heavy Metals	mg Ni eq.	21333	1	**21335**	**325**	**48202**	6532	11	**6521**	**76383**
	PAHs	mg Ni eq.	1376	5	**1381**	**619**	**6445**	0	13	**-13**	**8431**
20	Particulate Matter (PM, dust)	g	11048	1388	**12436**	**47853**	**32815**	29936	17	**29920**	**123024**
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	12718	1	**12719**	**10**	**17772**	1893	50	**1843**	**32344**
22	Eutrophication	g PO4	1226	17	**1243**	**0**	**97**	108	2	**106**	**1446**
23	Persistent Organic Pollutants (POP	ng i-Teq	negligible								

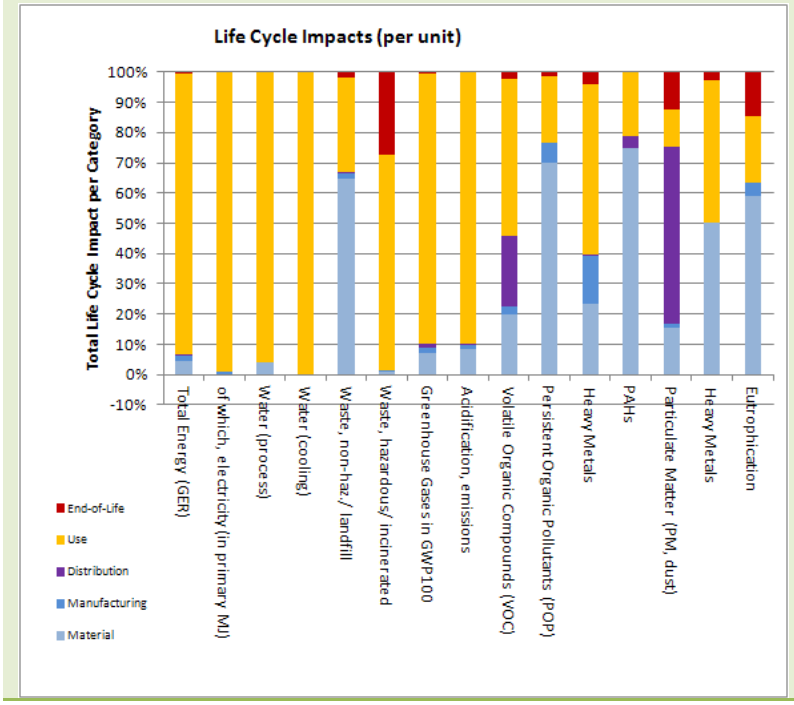
4.3.7 Base Case 7: Wood working machine tools: Throughfeed edge banding machine

The assessment findings for the Base Case “Throughfeed edge banding machine” are depicted in Figure 4-22. Not included is the consumption of glue and energy consumption of a central extraction system.

The categories total energy and Global Warming Potential are clearly dominated by use phase impacts (power consumption), whereas several other categories are dominated by the impacts of the material used to construct the throughfeed edge banding machine:

- Waste (non-hazardous)
- Persistent Organic Pollutants
- Polyaromatic Hydrocarbons
- Eutrophication

Consequently, power consumption in the use phase is not the only relevant life cycle aspect for throughfeed edge banding machines, but the environmental impacts related to machinery material actually is related to the bulk of steel parts and components.



Lifetime assumed:

20 years

Shift pattern assumed:

1 shift / day

5 days / week

Operational time per year assumed:

1.625 h/a (incl. idle)

Figure 4-22: Base case throughfeed edge banding machine

Including also the allocated energy consumption share of a centralised extraction system the energy consumption in the use phase increases by nearly 50%, and so does the impact of the use phase throughout all impact categories, see **Figure 4-23**. This calculation is based on an extraction volume of 1.600 m³/h and and an electrical power of 1,8 kW per 1000 m³/h extraction volume at 2.500 Pa[37].

[37] Following a calculation example stated by HOMAG in their ecoPlus brochure

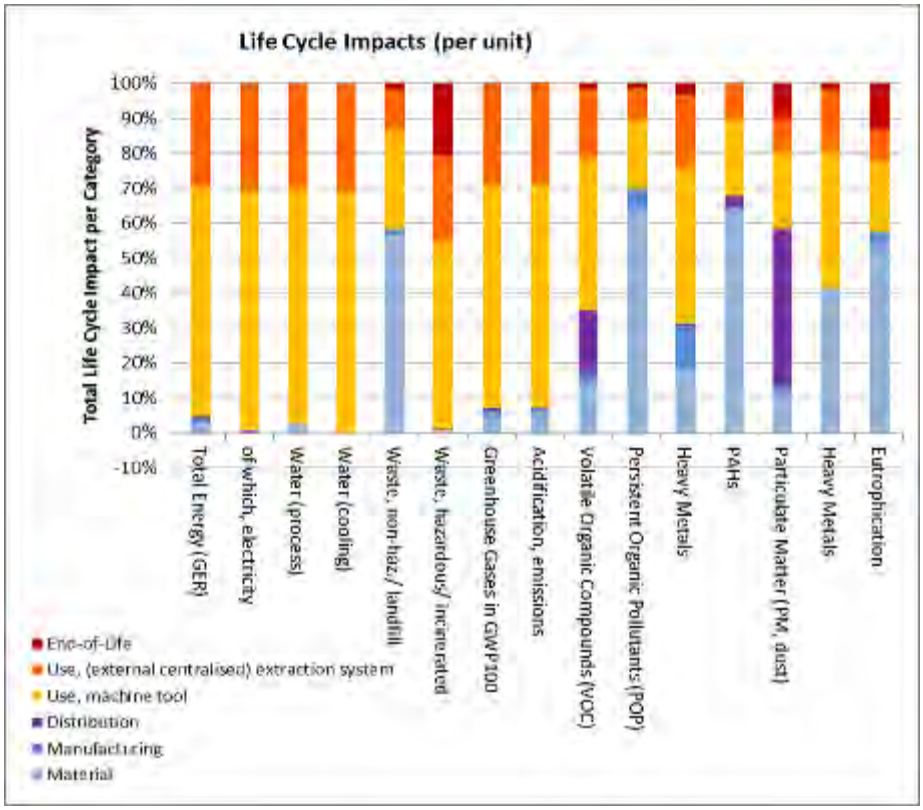


Figure 4-23: Environmental Assessment – Base Case 7: Throughfeed edge banding machine – extraction system power consumption included

Impacts in absolute numbers for this Base Case (extraction system not included) are listed in the table below, referring to one unit i.e. machine. The total energy consumption over the life cycle is 2,4 TJ, the Global Warming Potential is 107 t CO_2-eq. over the whole product life of 20 years.

Table 4-47: Environmental Assessment – Base Case 7: Throughfeed edge banding machine

Nr	Life cycle impact per product:								Date	Author
0	Throughfeed edge banding machine								0	Pwi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	**unit**									
1	Bulk Plastics	g			1792			1434	358	1792	0
2	TecPlastics	g			21589			17271	4318	21589	0
3	Ferro	g			2196759			109838	2086921	2196759	0
4	Non-ferro	g			274817			13741	261076	274817	0
5	Coating	g			3			0	3	3	0
6	Electronics	g			1715			961	754	1715	0
7	Misc.	g			3326			166	3160	3326	0
	Total weight	g			2500000			143411	2356589	2500000	0
	Other Resources & Waste							debet	see note! credit		
8	Total Energy (GER)	MJ	108084	33505	141589	20043	2195480	9880	1226	8654	2365765
9	of which, electricity (in primary MJ)	MJ	5520	19084	24605	51	2189496	0	105	-105	2214047
10	Water (process)	ltr	6103	274	6377	0	146014	0	90	-90	152300
11	Water (cooling)	ltr	3498	8072	11571	0	5338116	0	112	-112	5349575
12	Waste, non-haz./ landfill	g	######	164999	6501072	8219	2593322	153258	321	152937	8255549
13	Waste, hazardous/ incinerated	g	783	32	815	163	50455	19459	109	19350	70783
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	7758	1919	9677	1179	96007	737	78	659	107522
15	Ozone Depletion, emissions	mg R-11 eq				negligible					
16	Acidification, emissions	g SO2 eq.	52728	8349	61077	3612	564715	1454	161	1293	630697
17	Volatile Organic Compounds (VOC)	g	317	44	361	372	906	39	2	37	1675
18	Persistent Organic Pollutants (POP)	ng i-Teq	47932	4564	52496	46	14875	1055	1	1054	68471
19	Heavy Metals	mg Ni eq.	15869	10692	26561	417	38865	2857	11	2846	68689
	PAHs	mg Ni eq.	15889	8	15897	795	5512	0	10	-10	22193
20	Particulate Matter (PM, dust)	g	16309	1283	17592	61526	29857	12910	7	12903	121878
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	15191	6	15197	13	14268	820	50	770	30248
22	Eutrophication	g PO4	185	13	198	0	69	47	1	46	313
23	Persistent Organic Pollutants (POP)	ng i-Teq				negligible					

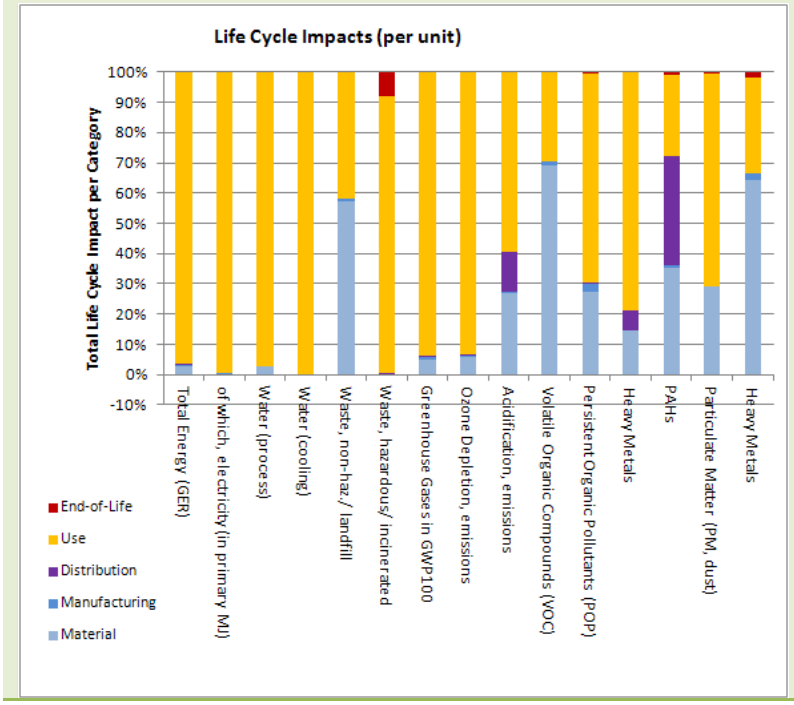
4.3.8 Base Case 8: Wood working machine tools: CNC machining centre

The assessment findings for the Base Case “Wood working CNC machining centre” is depicted in Figure 4-24. The energy consumption of a central extraction system is not included.

The categories total energy and Global Warming Potential are clearly dominated by use phase impacts (power consumption), whereas several other categories are dominated by the impacts of the material used to construct the horizontal panel saw:

- Waste (non-hazardous)
- Volatile Organic Compounds to air
- Heavy metals emissions to water

Consequently, power consumption in the use phase is not the only relevant life cycle aspect for horizontal panel saws, but the environmental impacts related to machinery material actually is related to the bulk of steel parts and components.



Lifetime assumed:

20 years

Shift pattern assumed:

2 shifts / day

5 days / week

Operational time per year assumed:

3.200 h/a (incl. idle)

Figure 4-24: Base case wood working CNC machining centre

Impacts in absolute numbers for this Base Case are listed in the table below, referring to one unit i.e. machine. The total energy consumption over the life cycle is 11,5 TJ, the Global Warming Potential is 515 t CO_2-eq. over the whole product life of 20 years.

Table 4-48: Environmental Assessment – Base Case 8: Wood working CNC machining centre

Nr	Life cycle impact per product:	Date	Author
0	CNC machining center	0	Pwi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	**unit**									
1	Bulk Plastics	g			9718			7774	1944	9718	0
2	TecPlastics	g			11496			9197	2299	11496	0
3	Ferro	g			7334107			366705	6967402	7334107	0
4	Non-ferro	g			338819			16941	321878	338819	0
5	Coating	g			3			0	3	3	0
6	Electronics	g			190688			123885	66803	190688	0
7	Misc.	g			113628			5681	107946	113628	0
	Total weight	g			7998459			530184	7468275	7998459	0
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	312229	62411	374640	0	11115816	32995	17941	15054	11505509
9	of which, electricity (in primary MJ)	MJ	55223	27666	82889	0	11088829	0	7758	-7758	11163960
10	Water (process)	ltr	197154	1984	199139	0	741191	0	7003	-7003	933327
11	Water (cooling)	ltr	51855	17625	69481	0	29568695	0	1498	-1498	29636677
12	Waste, non-haz./ landfill	g	######	156036	7477666	0	12930683	490390	22502	467887	20876237
13	Waste, hazardous/ incinerated	g	40658	564	41223	0	255912	83774	8727	75048	372183
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	26151	3649	29800	0	486033	2462	1237	1226	517058
15	Ozone Depletion, emissions	mg R-11 eq	negligible								
16	Acidification, emissions	g SO2 eq.	227841	17370	245211	0	2859472	4846	6537	-1691	3102993
17	Volatile Organic Compounds (VOC	g	1311	418	1729	0	4582	126	96	30	6342
18	Persistent Organic Pollutants (POP	ng i-Teq	55310	13	55323	0	73230	3376	85	3291	131844
19	Heavy Metals	mg Ni eq.	328750	117	328867	0	198717	9514	982	8532	536117
	PAHs	mg Ni eq.	34671	345	35016	0	27394	0	808	-808	61602
20	Particulate Matter (PM, dust)	g	97091	3678	100769	0	150192	42808	312	42495	293456
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	213460	57	213517	0	73627	2747	4453	-1707	285438
22	Eutrophication	g PO4	5212	115	5327	0	394	157	63	94	5815
23	Persistent Organic Pollutants (POP	ng i-Teq	negligible								

4.3.9 Base Case 9: Welding equipment

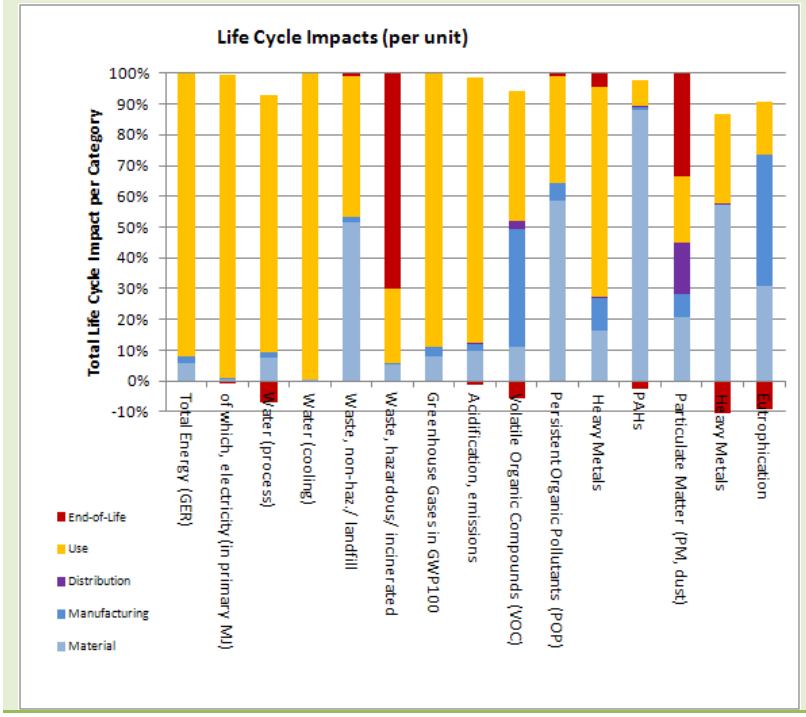
The assessment findings for the Base Case “Welding equipment” is depicted in Figure 4-24. Not included is the energy consumption of a central extraction system, nor the consumption of shielding gas or electrodes.

The categories total energy and Global Warming Potential are clearly dominated by use phase impacts (power consumption), whereas several other categories are dominated by the impacts of the material used to construct the welding equipment:

- Waste (non-hazardous)

- Volatile Organic Compounds to air
- Persistent Organic Pollutants to air
- Polyaromatic Hydrocarbons to air
- Heavy metals emissions to water

Consequently, power consumption in the use phase is not the only relevant life cycle aspect for welding equipment, but the environmental impacts related to machinery material actually is related to the bulk of steel sheets.



Lifetime assumed:

7 years

Shift pattern assumed:

1 shift / day

5 days / week

Operational time per year assumed:

2.000 h/a (incl. idle)

Figure 4-25: Base case Welding Equipment

Total impacts for the production of 3.5 t argon (proxy for used welding gases over 7 years lifetime of the equipment) is listed in Table 4-49. Background data is derived from ProBas (dataset: Xtra-generischArgon-DE-2005).

Table 4-49: Environmental Assessment – Base Case 9: Welding Equipment – argon

Impact 1 kg argon			**MEEuP equivalents**	**total argon production related impact of 3500 kg gas consumption** (aggregate over 7 years)
Greenhouse gases	Kilograms CO2	0,0689	Global Warming Potential (GWP)	241 kg
Acidification	Kilograms SO2 equivalent	0,0000862	Acidification (AD)	0,3017 kg
Heavy metals	Kilograms Hg (water)	$7.78 * 10^{-15}$	Emissions to water (mg Hg/20) (other heavy metals – As, Cd, Cr, Pb – listed as well in ProBas, but no equivalent in MEEuP available)	0,00054 mg Hg/20
	Kilograms Ni (air)	$6,94 * 10^{-9}$	Emissions to air (mg Ni eq.) (other heavy metals – As, Cd, Hg, Pb – listed as well in ProBas, but no equivalent in MEEuP available)	24,29 mg Ni.eq
Eutrophication	Kilograms PO equivalent	0	Eutrophication (EUP)	0

For those impact categories, for which impact indicators corresponding to MEEuP are available, the correlation between argon (production) related impacts and all other life cycle phases of the welding equipment is depicted in Figure 4-7. There is only one impact category, which is greenhouse gas, where the argon production in comparison to all other life cycle phases has at least a small impact of 2%. The contribution to the total lifecycle acidification is 0,44% and to heavy metals emissions to air 0,41%.

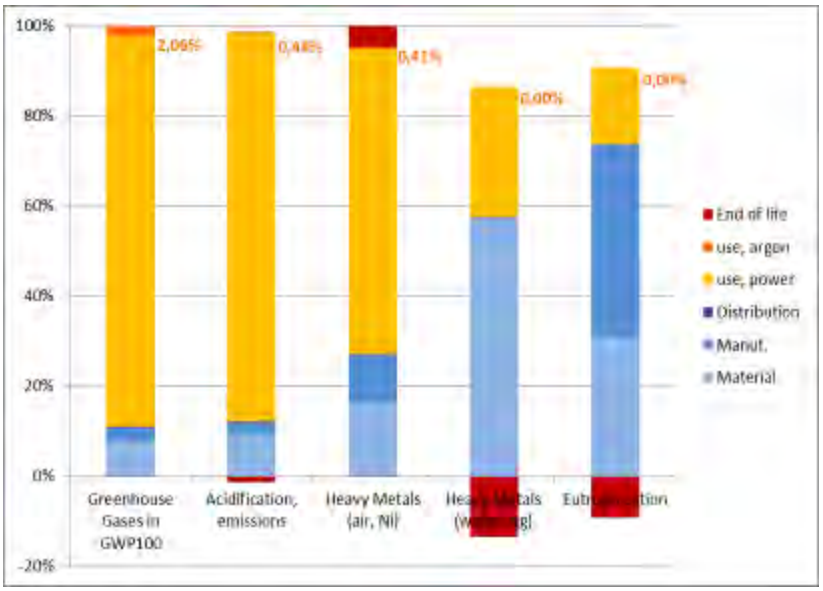


Figure 4-26: Environmental Assessment – Base Case 9: Welding equipment – argon consumption included

Impacts in absolute numbers for this Base Case are listed in the table below, referring to one unit. The total energy consumption over the life cycle is 250 GJ, the Global Warming Potential is 11,5 t CO_2-eq. over the whole product life. Consideration of shielding gas (for simplification: argon) results in additional upstream CO_2 emissions of 0,24 t over the whole product life of 7 years.

Table 4-50: Environmental Assessment – Base Case 9: Welding equipment

Nr	Life cycle Impact per product:	Date	Author
0	MIG/MAG-Welding Equipment	0	KSchi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	unit									
1	Bulk Plastics	g			5183			4664	518	5183	0
2	TecPlastics	g			0			0	0	0	0
3	Ferro	g			101467			5073	96394	101467	0
4	Non-ferro	g			7095			355	6740	7095	0
5	Coating	g			30			2	29	30	0
6	Electronics	g			26214			13601	12614	26214	0
7	Misc.	g			12			1	11	12	0
	Total weight	g			140000			23695	116305	140000	0
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	15044	5176	20220	459	233589	1644	2167	-523	253745
9	of which, electricity (in primary MJ)	MJ	857	1191	2048	1	233383	0	1464	-1464	233968
10	Water (process)	ltr	1438	312	1750	0	15575	0	1322	-1322	16004
11	Water (cooling)	ltr	2107	1371	3478	0	622335	0	277	-277	625535
12	Waste, non-haz./ landfill	g	306853	12137	318991	248	273760	8583	4245	4338	597337
13	Waste, hazardous/ incinerated	g	1158	108	1266	5	5390	17278	1647	15631	22291
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq	935	326	1260	29	10198	123	143	-21	11466
15	Ozone Depletion, emissions	mg R-11 e				negligible					
16	Acidification, emissions	g SO2 eq	6641	1716	8357	86	60176	244	1121	-877	67743
17	Volatile Organic Compounds (VOC)	g	23	80	104	6	89	4	17	-12	187
18	Persistent Organic Pollutants (POP)	ng i-Teq	2619	258	2876	1	1558	60	16	44	4480
19	Heavy Metals	mg Ni eq.	965	620	1585	13	4025	452	185	266	5888
	PAHs	mg Ni eq.	5489	65	5554	16	527	0	152	-152	5945
20	Particulate Matter (PM, dust)	g	1248	452	1700	1026	1389	2102	57	2045	6160
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	3013	11	3024	0	1535	138	841	-703	3856
22	Eutrophication	g PO4	14	19	32	0	7	8	12	-4	36
23	Persistent Organic Pollutants (POP)	ng i-Teq				negligible					

4.4 Base cases Life Cycle Costs

For the economic life cycle cost calculations the exemplary Base Case assessments have to be extrapolated to larger market segments to allow for estimates on the EU-27 level instead of a solely machine-centric view.

4.4.1 Base Case 1: CNC 4-axis multifunctional milling centre

The following table lists the Life Cycle Cost (LCC) entries for this Base Case: Product life is 12 years corresponding to the analysis in task 2. During life time a sum of 0.

1 Mio. € is spent for maintenance and repair. Cooling lubricants (concentrate) are listed as “auxiliary 1”, hydraulic oil as “auxiliary 2”.

Table 4-51: Base Case 1 - Entries for LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	**12**	years
B	Annual sales	**0,011085**	mln. units/year
C	EU Stock	**0,288845**	mln. Units
D	Product price	**480000**	Euro/unit
E	Installation/acquisition costs (if any)	**0**	Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	**0,11**	Euro/kWh
H	Water rate	**12**	Euro/m3
I	Aux. 1: None	**5**	Euro/kg
J	Aux. 2 :None	**2**	Euro/kg
K	Aux. 3: None	**2**	Euro/kg
L	Repair & maintenance costs	**100000**	Euro/ unit

4.4.2 Base Case 2: CNC Laser cutting machine tools

The following table lists the Life Cycle Cost (LCC) entries for this Base Case 2: Product life is 12 years corresponding to the analysis in task 2. During life time additional costs of 20% of the initial investment are related to maintenance and repair. Hydraulic oil is listed as “auxiliary 2”.

Table 4-52: Base Case 2 - Entries for LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	**12**	years
B	Annual sales	**0,0015**	mln. Units/year
C	EU Stock	**0,015**	mln. Units
D	Product price	**400000**	Euro/unit
E	Installation/acquisition costs (if any)		Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	**0,11**	Euro/kWh
H	Water rate		Euro/m3
I	Aux. 1: None	**10**	Euro/kg
J	Aux. 2 :None	**0,8**	Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	**40000**	Euro/ unit

4.4.3 Base Case 3: Metal working bending machine tools

The following table lists the Life Cycle Cost (LCC) entries for this Base Case: Product life is 17 years corresponding to the analysis in task 2. During life time additional costs of 20% of the initial investment are related to maintenance and repair. Hydraulic oil is listed as "auxiliary 2".

Table 4-53: Base Case 3 - Entries for LCC

Table . Inputs for EU-Totals & LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	**17**	years
B	Annual sales	**0,031676**	mln. Units/year
C	EU Stock	**0,201579**	mln. Units
D	Product price	**100000**	Euro/unit
E	Installation/acquisition costs (if any)		Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	**0,11**	Euro/kWh
H	Water rate		Euro/m3
I	Aux. 1: None		Euro/kg
J	Aux. 2 :None	**2**	Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	**20000**	Euro/ unit

4.4.4 Base Case 4: Non-numerical controlled metal working machine tools

The following table lists the Life Cycle Cost (LCC) entries for this Base Case: Product life is 18 years corresponding to the analysis in task 2. Cooling lubricants (concentrate) are listed as "auxiliary 1", hydraulic oil as "auxiliary 2".

Table 4-54: Base Case 4 - Entries for LCC

Table . Inputs for EU-Totals & LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	**18**	years
B	Annual sales	**0,038**	mln. Units/year
C	EU Stock	**0,69**	mln. Units
D	Product price	**5000**	Euro/unit

E	Installation/acquisition costs (if any)	0	Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	0,11	Euro/kWh
H	Water rate	12	Euro/m3
I	Aux. 1: None	5	Euro/kg
J	Aux. 2 :None	2	Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	2500	Euro/ unit

4.4.5 Base Case 5: Wood working machine tools: Table saw

The following table lists the Life Cycle Cost (LCC) entries for this Base Case: Product life is 20 years corresponding to the analysis in task 2. No data is available regarding maintenance and repair costs, but given the low investment costs theses can be assumed to be minor and are approximated with 5% of the initial purchase price. Lubricants are listed as “auxiliary 1”, with an estimated price of 4 Euro/kg, which could be significantly higher, if sold in small units for DIY or semi-professional users.

Table 4-55: Base Case 5 - Entries for LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	20	years
B	Annual sales	0,22	mln. Units/year
C	EU Stock	4,4	mln. Units
D	Product price	610	Euro/unit
E	Installation/acquisition costs (if any)		Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	0,14	Euro/kWh
H	Water rate		Euro/m3
I	Aux. 1: Lubricants	4	Euro/kg
J	Aux. 2 :None		Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	30,5	Euro/ unit

4.4.6 Base Case 6: Wood working machine tools: Horizontal panel saw

The following table lists the Life Cycle Cost (LCC) entries for this Base Case: Product life is 20 years corresponding to the analysis in task 2. For maintenance and repair costs 20% of the initial purchase price are assumed corresponding with data entries for other industrial equipment.

Table 4-56: Base Case 6 - Entries for LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	**20**	years
B	Annual sales	**0,0013**	mln. Units/year
C	EU Stock	**0,025**	mln. Units
D	Product price	**60000**	Euro/unit
E	Installation/acquisition costs (if any)		Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	**0,14**	Euro/kWh
H	Water rate		Euro/m3
I	Aux. 1: None		Euro/kg
J	Aux. 2 :None		Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	**12000**	Euro/ unit

4.4.7 Base Case 7: Wood working machine tools: Throughfeed edge banding machine

The following table lists the Life Cycle Cost (LCC) entries for this Base Case: Product life is 20 years corresponding to the analysis in task 2. For maintenance and repair costs 20% of the initial purchase price are assumed corresponding with data entries for other industrial equipment.

Table 4-57: Base Case 7 - Entries for LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	**20**	years
B	Annual sales	**0,0104**	mln. Units/year
C	EU Stock	**0,207**	mln. Units
D	Product price	**60000**	Euro/unit
E	Installation/acquisition costs (if any)		Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	**0,14**	Euro/kWh
H	Water rate		Euro/m3
I	Aux. 1: None		Euro/kg
J	Aux. 2 :None		Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	**12000**	Euro/ unit

4.4.8 Base Case 8: Wood working machine tools: CNC machining centre

The following table lists the Life Cycle Cost (LCC) entries for this Base Case: Product life is 20 years corresponding to the analysis in task 2. For maintenance and repair costs 20% of the initial purchase price are assumed corresponding with data entries for other industrial equipment.

Table 4-58: Base Case 8 - Entries for LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	**20**	years
B	Annual sales	**0,00067**	mln. Units/year
C	EU Stock	**13494**	mln. Units
D	Product price	**300000**	Euro/unit
E	Installation/acquisition costs (if any)		Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	**0,14**	Euro/kWh
H	Water rate		Euro/m3
I	Aux. 1: None		Euro/kg
J	Aux. 2 :None		Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	**60000**	Euro/ unit

4.4.9 Base Case 9: Welding equipment

The following table lists the Life Cycle Cost (LCC) entries for this Base Case: Product life is 7 years corresponding to the analysis in task 2. For maintenance and repair costs 5% of the initial purchase price are assumed given the shorter lifetime compared to other industrial equipment.

Table 4-59: Base Case 9 - Entries for LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	**7**	years
B	Annual sales	**0,18**	mln. Units/year
C	EU Stock	**1,27**	mln. Units
D	Product price	**1200**	Euro/unit
E	Installation/acquisition costs (if any)	**0**	Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	**0,11**	Euro/kWh
H	Water rate		Euro/m3
I	Aux. 1: None	**3**	Euro/kg

J	Aux. 2 :None		Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	60	Euro/ unit

4.5 EU-27 Total Impact

4.5.1 Base Case 1: CNC 4-axis multifunctional milling centre

This Base Case is meant to be a conscious abstraction, representing those product categories listed in Table 4-60.

Table 4-60: CNC machining centres - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28411220	Horizontal machining centres for working metal	35.032	33.965
28411240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	74.937	99.614
28411270	Multi-station transfer machines for working metal	24.746	22.828
28412123	Numerically controlled horizontal lathes, turning centres, for removing metal	32.253	34.214
28412127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	37.704	38.005
28412160	Lathes, including turning centres, for removing metal (excluding horizontal lathes)	57.653	58.210
	Totals	**264.320**	**288.845**

The following table lists the total extrapolated life cycle impacts for this Base Case on the EU-27 level for one year[38].

[38] Hydraulic oil and cooling lubricants not included with their life cycle impacts

Table 4-61: Base Case 1: CNC machining centres – Total EU-27 impacts per year[39]

Nr	EU Impact of Products in 2005 (produced, in use, discarded)***						Date	Author
	4 Axis, CNC machining center						0	

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	**Total**	BUTION		Disposal	Recycl.	**Total**	
	Materials	**unit**									
1	Bulk Plastics	kt			**0**			0	0	**0**	**0**
2	TecPlastics	kt			**0**			0	0	**0**	**0**
3	Ferro	kt			**98**			0	98	**98**	**0**
4	Non-ferro	kt			**10**			0	10	**10**	**0**
5	Coating	kt			**0**			0	0	**0**	**0**
6	Electronics	kt			**0**			0	0	**0**	**0**
7	Misc.	kt			**0**			0	0	**0**	**0**
	Total weight	kt			**108**			1	107	**108**	**0**
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	PJ	5	1	**6**	**1**	**403**	0	0	**0**	**410**
9	of which, electricity (in primary PJ)	PJ	0	1	**1**	**0**	**403**	0	0	**0**	**404**
10	Water (process)	mln. m3	0	0	**0**	**0**	**32**	0	0	**0**	**32**
11	Water (cooling)	mln. m3	1	0	**1**	**0**	**1074**	0	0	0	**1075**
12	Waste, non-haz./ landfill	kt	297	4	**301**	**0**	**473**	1	0	**1**	**776**
13	Waste, hazardous/ incinerated	kt	0	0	**0**	**0**	**9**	0	0	**0**	**10**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	mt CO2 eq.	0	0	**0**	**0**	**18**	0	0	**0**	**18**
15	Ozone Depletion, emissions	t R-11 eq.	negligible								
16	Acidification, emissions	kt SO2 eq.	3	0	**3**	**0**	**104**	0	0	**0**	**107**
17	Volatile Organic Compounds (VOC)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
18	Persistent Organic Pollutants (POP)	g i-Teq	3	0	**3**	**0**	**3**	0	0	**0**	**6**
19	Heavy Metals	ton Ni eq.	1	0	**1**	**0**	**7**	0	0	**0**	**9**
	PAHs	ton Ni eq.	0	0	**0**	**0**	**1**	0	0	**0**	**1**
20	Particulate Matter (PM, dust)	kt	3	0	**3**	**3**	**4**	0	0	**0**	**10**
	Emissions (Water)										
21	Heavy Metals	ton Hg/20	0	0	**0**	**0**	**3**	0	0	**0**	**3**
22	Eutrophication	kt PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
23	Persistent Organic Pollutants (POP)	g i-Teq	negligible								

The following table lists the Life Cycle Cost (LCC) for this Base Case on the EU-27 level.

39 Screenshot reference to 2005 is misleading, but cannot be changed in the template; actual figures refer to 2009

Table 4-62: Base Case 1: CNC machining centres – Total EU-27 total annual expenditure

	Hor. M/C - 500x500 pallet, 4 Axis, ATC 150, Multifunctional *Item*	**LCC new product**		**total annual consumer expenditure in EU25**	
D	Product price	480000	€	5321	mln.€
E	Installation/ acquisition costs (if any)	0	€	0	mln.€
F	Fuel (gas, oil, wood)	0	€	0	mln.€
F	Electricity	137036	€	4218	mln.€
G	Water	2027	€	62	mln.€
H	Aux. 1: None	5162	€	159	mln.€
I	Aux. 2 :None	1689	€	52	mln.€
J	Aux. 3: None	1689	€	52	mln.€
K	Repair & maintenance costs	78209	€	2407	mln.€
	Total	**705813**	€	**12271**	mln.€

4.5.2 Base Case 2: CNC laser cutting machine tools

Laser cutting machine tools addressed by this base case fall under PRODCOM 28411110, stock figures as calculated in task 2 shown in Table 4-63.

Table 4-63: CNC laser cutting machine tools - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28411110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	98.662	122.098

However, industry data indicates, that the total installed stock of larger equipment with high power laser sources modelled in the base case in the EU-27 might be rather in the range of 15,000 units instead of 120,000 units. These **15,000 units** cover 2D laser cutting machine tools for working metal sheets, 3D laser cutting machine tools, laser tube cutting machines and combined stamping[40] / laser cutting machine tools with a unit value of several 100,000 Euros typically[41]. The discrepancy with the (already corrected) PRODCOM figures cannot be solved out. Consequently the base case figures will be applied to an estimated stock of 15,000 units in EU-27, and annual sales of 1,500 units.

[40] note: hydraulics not properly covered by this base case

[41] Compared to a unit value of nearly 80,000 Euros according to PRODCOM figures.

The following table lists the total extrapolated life cycle impacts for this Base Case on the EU-27 level for one year[42].

Table 4-64: Base Case 2: CNC laser cutting machine tools – Total EU-27 impacts per year[43]

Table . EU Total Impact of STOCK of Generic CNC Laser cutting machine tool in 2005 (produced, in use, discarded)

Nr	EU Impact of Products in 2005 (produced, in use, discarded)***	Date	Author
	Generic CNC Laser cutting machine tool	0	KSchi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	**Total**	BUTION		Disposal	Recycl.	**Total**	
	Materials	**unit**									
1	Bulk Plastics	kt			**0**			0	0	**0**	**0**
2	TecPlastics	kt			**0**			0	0	**0**	**0**
3	Ferro	kt			**16**			1	16	**16**	**0**
4	Non-ferro	kt			**1**			0	1	**1**	**0**
5	Coating	kt			**0**			0	0	**0**	**0**
6	Electronics	kt			**1**			0	0	**1**	**0**
7	Misc.	kt			**0**			0	0	**0**	**0**
	Total weight	kt			**18**			1	17	**18**	**0**
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	PJ	1	0	**1**	**0**	**31**	0	0	**0**	**32**
9	of which, electricity (in primary PJ)	PJ	0	0	**0**	**0**	**31**	0	0	**0**	**31**
10	Water (process)	mln. m3	1	0	**1**	**0**	**2**	0	0	**0**	**3**
11	Water (cooling)	mln. m3	0	0	**0**	**0**	**82**	0	0	**0**	**82**
12	Waste, non-haz./ landfill	kt	15	1	**16**	**0**	**36**	1	0	**1**	**53**
13	Waste, hazardous/ incinerated	kt	0	0	**0**	**0**	**1**	0	0	**0**	**1**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	mt CO2 eq.	0	0	**0**	**0**	**1**	0	0	**0**	**1**
15	Ozone Depletion, emissions	t R-11 eq.	negligible								
16	Acidification, emissions	kt SO2 eq.	1	0	**1**	**0**	**8**	0	0	**0**	**9**
17	Volatile Organic Compounds (VOC)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
18	Persistent Organic Pollutants (POP)	g i-Teq	0	0	**0**	**0**	**0**	0	0	**0**	**0**
19	Heavy Metals	ton Ni eq.	1	0	**1**	**0**	**1**	0	0	**0**	**1**
	PAHs	ton Ni eq.	0	0	**0**	**0**	**0**	0	0	**0**	**0**
20	Particulate Matter (PM, dust)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**1**
	Emissions (Water)										
21	Heavy Metals	ton Hg/20	1	0	**1**	**0**	**0**	0	0	**0**	**1**
22	Eutrophication	kt PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
23	Persistent Organic Pollutants (POP)	g i-Teq	negligible								

The following table lists the Life Cycle Cost (LCC) for this Base Case on the EU-27 level.

[42] Laser gas and cutting gas not included with their life cycle impacts

[43] Screenshot reference to 2005 is misleading, but cannot be changed in the template; actual figures refer to 2009

Table 4-65: Base Case 2: CNC laser cutting machine tools – Total EU-27 total annual expenditure

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	12	years
B	Annual sales	0,0015	mln. Units/year
C	EU Stock	0,015	mln. Units
D	Product price	400000	Euro/unit
E	Installation/acquisition costs (if any)		Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	0,11	Euro/kWh
H	Water rate		Euro/m3
I	Aux. 1: None	10	Euro/kg
J	Aux. 2 :None	0,8	Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	40000	Euro/ unit

4.5.3 Base Case 3: Metal working bending machine tools

This Base Case is meant to be a conscious abstraction, representing those product categories listed in Table 4-66.

Table 4-66: Metal working bending machine tools - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28413120	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	34.504	76.542
28413140	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	9.899	33.993
28413240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	9.266	17.591
28413310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	3.036	5.290
28413330	Presses for moulding metallic powders by sintering or for compressing scrap metal into bales	4.741	3.221
28413340	Other hydraulic presses, numerically controlled, for working metal	32.697	37.583
28413350	Hydraulic presses for working metal	not applicable	1.869
28413360	Non-hydraulic presses for working metal	not applicable	17.658
28413370	Other non-hydraulic presses, numerically controlled, for working metal	2.553	5.823
	Totals	**98.691**	**201.579**

The following table lists the total extrapolated life cycle impacts for this Base Case on the EU-27 level for one year[44].

Table 4-67: Base Case 3: CNC bending machine tools – Total EU-27 impacts per year[45]

Nr	EU Impact of Products in 2005 (produced, in use, discarded)***		Date	Author
	CNC Bending machine tool		Dec, 2011	KSchi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	**Total**	**BUTION**		Disposal	Recycl.	**Total**	
	Materials	**unit**									
1	Bulk Plastics	kt			0			0	0	0	0
2	TecPlastics	kt			0			0	0	0	0
3	Ferro	kt			248			0	248	248	0
4	Non-ferro	kt			1			0	1	1	0
5	Coating	kt			0			0	0	0	0
6	Electronics	kt			0			0	0	0	0
7	Misc.	kt			0			0	0	0	0
	Total weight	kt			249			0	249	249	0
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	PJ	4	0	4	1	8	0	0	0	13
9	of w hich, electricity (in primary PJ)	PJ	1	0	1	0	7	0	0	0	9
10	Water (process)	mln. m3	0	0	0	0	0	0	0	0	1
11	Water (cooling)	mln. m3	0	0	0	0	20	0	0	0	20
12	Waste, non-haz./ landfill	kt	200	0	200	0	9	0	0	0	210
13	Waste, hazardous/ incinerated	kt	0	0	0	0	0	0	0	0	0
	Emissions (Air)										
14	Greenhouse Gases in GWP100	mt CO2 eq.	0	0	0	0	0	0	0	0	1
15	Ozone Depletion, emissions	t R-11 eq.				negligible					
16	Acidification, emissions	kt SO2 eq.	1	0	1	0	2	0	0	0	3
17	Volatile Organic Compounds (VOC)	kt	0	0	0	0	0	0	0	0	0
18	Persistent Organic Pollutants (POP)	g i-Teq	3	0	3	0	0	0	0	0	3
19	Heavy Metals	ton_Ni eq.	1	0	1	0	0	0	0	0	1
	PAHs	ton Ni eq.	0	0	0	0	0	0	0	0	0
20	Particulate Matter (PM, dust)	kt	0	0	0	2	1	0	0	0	3
	Emissions (Water)										
21	Heavy Metals	ton Hg/20	0	0	0	0	0	0	0	0	1
22	Eutrophication	kt PO4	0	0	0	0	0	0	0	0	0
23	Persistent Organic Pollutants (POP)	g i-Teq				negligible					

The following table lists the Life Cycle Cost (LCC) for this Base Case on the EU-27 level.

44 Hydraulic oil not included with related life cycle impacts

45 Screenshot reference to 2005 is misleading, but cannot be changed in the template; actual figures refer to 2009

Table 4-68: Base Case 3: CNC bending machine tools – Total EU-27 total annual expenditure

	CNC Bending machine tool *Item*	LCC new product		total annual consumer expenditure in EU25	
D	Product price	100000	€	3168	mln.€
E	Installation/ acquisition costs (if any)	0	€	0	mln.€
F	Fuel (gas, oil, wood)	0	€	0	mln.€
F	Electricity	4704	€	78	mln.€
G	Water	0	€	0	mln.€
H	Aux. 1: None	0	€	0	mln.€
I	Aux. 2 :None	2628	€	44	mln.€
J	Aux. 3: None	0	€	0	mln.€
K	Repair & maintenance costs	14313	€	237	mln.€
	Total	**121645**	€	**3526**	mln.€

4.5.4 Base Case 4: Non-numerical controlled metal working machine tools

This Base Case is meant to be a conscious abstraction, representing those product categories listed in Table 4-60.

Table 4-69: Non-numerical controlled metal working machine tools - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28412140	Non-numerically controlled horizontal lathes, for removing metal	148116	100104
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	408178	320900
28412260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	6393	3636
28412270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)	49576	36325
28412335	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	8299	4668
28412345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	383	2024
28412355	Grinding machines for working metal; any one axis can be set to an accuracy of >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines	72575	49332
28412375	Non-numerically controlled sharpening (tool or cutter grinding)	43058	21950

	machines for working metal		
28412470	Sawing or cutting-off machines for working metal	**175033**	**137080**
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	**42817**	**48355**
28413260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	**144300**	**146934**
28413320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	**224**	**291**
	Totals	**1100947**	**873608**

The following table lists the total extrapolated life cycle impacts for this Base Case on the EU-27 level for one year[46].

[46] Hydraulic oil and cooling lubricants not included with their life cycle impacts

Table 4-70: Base Case 4: Non-numerical controlled metal working machine tool – Total EU-27 impacts per year[47]

Nr	EU Impact of Products in 2005 (produced, in use, discarded)***		Date	Author
	Non-NC controlled metal working lathe			0

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	unit									
1	Bulk Plastics	kt			0			0	0	0	0
2	TecPlastics	kt			0			0	0	0	0
3	Ferro	kt			11			1	10	11	0
4	Non-ferro	kt			1			0	1	1	0
5	Coating	kt			0			0	0	0	0
6	Electronics	kt			0			0	0	0	0
7	Misc.	kt			0			0	0	0	0
	Total weight	kt			12			1	12	12	0
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	PJ	1	0	1	0	94	0	0	0	96
9	of which, electricity (in primary PJ)	PJ	0	0	0	0	94	0	0	0	94
10	Water (process)	mln. m3	0	0	0	0	7	0	0	0	7
11	Water (cooling)	mln. m3	0	0	0	0	251	0	0	0	251
12	Waste, non-haz./ landfill	kt	43	1	44	0	110	3	0	3	156
13	Waste, hazardous/ incinerated	kt	0	0	0	0	2	0	0	0	2
	Emissions (Air)										
14	Greenhouse Gases in GWP100	mt CO2 eq.	0	0	0	0	4	0	0	0	4
15	Ozone Depletion, emissions	t R-11 eq.				negligible					
16	Acidification, emissions	kt SO2 eq.	0	0	0	0	24	0	0	0	25
17	Volatile Organic Compounds (VOC)	kt	0	0	0	0	0	0	0	0	0
18	Persistent Organic Pollutants (POP)	g i-Teq	0	0	0	0	1	0	0	0	1
19	Heavy Metals	ton Ni eq.	0	0	0	0	2	0	0	0	2
	PAHs	ton Ni eq.	0	0	0	0	0	0	0	0	0
20	Particulate Matter (PM, dust)	kt	1	0	1	1	1	0	0	0	3
	Emissions (Water)										
21	Heavy Metals	ton Hg/20	0	0	0	0	1	0	0	0	1
22	Eutrophication	kt PO4	0	0	0	0	0	0	0	0	0
23	Persistent Organic Pollutants (POP)	g i-Teq				negligible					

The following table lists the Life Cycle Cost (LCC) for this Base Case on the EU-27 level.

47 Screenshot reference to 2005 is misleading, but cannot be changed in the template; actual figures refer to 2009

Table 4-71: Base Case 4: Non-numerical controlled metal working machine tool – Total EU-27 total annual expenditure

	manually controlled lathe *Item*	LCC new product		total annual consumer expenditure in EU25	
D	Product price	5000	€	240	mln.€
E	Installation/ acquisition costs (if any)	0	€	0	mln.€
F	Fuel (gas, oil, wood)	0	€	0	mln.€
F	Electricity	14343	€	986	mln.€
G	Water	76	€	5	mln.€
H	Aux. 1: None	127	€	9	mln.€
I	Aux. 2 :None	51	€	3	mln.€
J	Aux. 3: None	0	€	0	mln.€
K	Repair & maintenance costs	1758	€	121	mln.€
	Total	**21354**	€	**1364**	mln.€

4.5.5 Base Case 5: Wood working machine tools: Table saw

Light stationary wood working machine tools, represented exemplarily by table saws, fall under three distinct PRODCOM codes, and it can be assumed, that the vast majority of products reported under these codes are light stationary wood working machine tools, although in exceptional cases also others might have been reported. Stock figures as calculated in task 2 are shown in Table 4-72.

Table 4-72: Table saws (and similar light stationary wood working machine tools) - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28491235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials *(98% of the market)*	1.231.220	1.241.318
28491237	Sawing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials (excluding band saws, circular saws)	1.774.961	2.252.145
28491250	Planing, milling or moulding (by cutting) machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	682.899	857.192
	Totals	**3.689.080**	**4.350.655**

The following table lists the total extrapolated life cycle impacts for this Base Case on the EU-27 level for one year.

Table 4-73: Base Case 5: Table saw – Total EU-27 impacts per year[48]

Table . EU Total Impact of STOCK of Light Stationary Wood Working Equipment / Table Saw in 2005 (produced, in use, discarded)

Nr	EU Impact of Products in 2005 (produced, in use, discarded)***	Date	Author
	Light Stationary Wood Working Equipment / Table Saw	0	Kschi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	**Total**	BUTION		Disposal	Recycl.	**Total**	
	Materials	**unit**									
1	Bulk Plastics	kt			**0**			0	0	**0**	**0**
2	TecPlastics	kt			**0**			0	0	**0**	**0**
3	Ferro	kt			**3**			0	3	**3**	**0**
4	Non-ferro	kt			**3**			0	2	**3**	**0**
5	Coating	kt			**0**			0	0	**0**	**0**
6	Electronics	kt			**0**			0	0	**0**	**0**
7	Misc.	kt			**0**			0	0	**0**	**0**
	Total weight	kt			**6**			0	6	**6**	**0**
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	PJ	0	0	**0**	**0**	**12**	0	0	**0**	**12**
9	of which, electricity (in primary PJ)	PJ	0	0	**0**	**0**	**12**	0	0	**0**	**12**
10	Water (process)	mln. m3	0	0	**0**	**0**	**1**	0	0	**0**	**1**
11	Water (cooling)	mln. m3	0	0	**0**	**0**	**31**	0	0	**0**	**31**
12	Waste, non-haz./ landfill	kt	10	0	**10**	**0**	**13**	0	0	**0**	**24**
13	Waste, hazardous/ incinerated	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	mt CO2 eq	0	0	**0**	**0**	**1**	0	0	**0**	**1**
15	Ozone Depletion, emissions	t R-11 eq.				negligible					
16	Acidification, emissions	kt SO2 eq.	0	0	**0**	**0**	**3**	0	0	**0**	**3**
17	Volatile Organic Compounds (VOC)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
18	Persistent Organic Pollutants (POP)	g i-Teq	0	0	**0**	**0**	**0**	0	0	**0**	**0**
19	Heavy Metals	ton Ni eq.	0	0	**0**	**0**	**0**	0	0	**0**	**0**
	PAHs	ton Ni eq.	0	0	**0**	**0**	**0**	0	0	**0**	**0**
20	Particulate Matter (PM, dust)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
	Emissions (Water)										
21	Heavy Metals	ton Hg/20	0	0	**0**	**0**	**0**	0	0	**0**	**0**
22	Eutrophication	kt PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
23	Persistent Organic Pollutants (POP)	g i-Teq				negligible					

The following table lists the Life Cycle Cost (LCC) for this Base Case on the EU-27 level.

48 Screenshot reference to 2005 is misleading, but cannot be changed in the template; actual figures refer to 2009

Table 4-74: Base Case 5: Table saw – Total EU-27 total annual expenditure

	Light Stationary Wood Working Equipment / Table Saw *Item*	LCC new product		total annual consumer expenditure in EU25	
D	Product price	610	€	134	mln.€
E	Installation/ acquisition costs (if any)	0	€	0	mln.€
F	Fuel (gas, oil, wood)	0	€	0	mln.€
F	Electricity	436	€	154	mln.€
G	Water	0	€	0	mln.€
H	Aux. 1: None	6	€	2	mln.€
I	Aux. 2 :None	0	€	0	mln.€
J	Aux. 3: None	0	€	0	mln.€
K	Repair & maintenance costs	19	€	7	mln.€
	Total	**1071**	€	**297**	mln.€

4.5.6 Base Case 6: Wood working machine tools: Horizontal panel saw

Horizontal panel saws represent a very typical product used in wood working although there is no dedicated PRODCOM code for these. It is anticipated, that these machine tools are reported under 28491235, which provides the best match in terms of terminology. Based on market insights and discussions with manufacturers a plausible stock is in the range of 2% (Table 4-60) of those products reported under this code (the vast majority being light stationary tools).

Table 4-75: Horizontal panel saws (and similar types of woodworking machine tools) - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28491235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials *(2% of the market)*	25.127	25.333
	Totals	**25.127**	**25.333**

The following table lists the total extrapolated life cycle impacts for this Base Case on the EU-27 level for one year.

Table 4-76: Base Case 6: Horizontal panel saw – Total EU-27 impacts per year[49]

Table . EU Total Impact of STOCK of Horizontal panel saw in 2005 (produced, in use, discarded)

Nr	EU Impact of Products in 2005 (produced, in use, discarded)***	Date	Author
	Horizontal panel saw	0	Pwi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	**Total**	BUTION		Disposal	Recycl.	**Total**	
	Materials	**unit**									
1	Bulk Plastics	kt			**0**			0	0	**0**	**0**
2	TecPlastics	kt			**0**			0	0	**0**	**0**
3	Ferro	kt			**6**			0	6	**6**	**0**
4	Non-ferro	kt			**0**			0	0	**0**	**0**
5	Coating	kt			**0**			0	0	**0**	**0**
6	Electronics	kt			**0**			0	0	**0**	**0**
7	Misc.	kt			**0**			0	0	**0**	**0**
	Total weight	kt			**7**			0	6	**7**	**0**
	Other Resources & Waste							debet	see note! credit		
8	Total Energy (GER)	PJ	0	0	**0**	**0**	**3**	0	0	**0**	**4**
9	of which, electricity (in primary PJ)	PJ	0	0	**0**	**0**	**3**	0	0	**0**	**3**
10	Water (process)	mln. m3	0	0	**0**	**0**	**0**	0	0	**0**	**0**
11	Water (cooling)	mln. m3	0	0	**0**	**0**	**9**	0	0	**0**	**9**
12	Waste, non-haz / landfill	kt	9	0	**9**	**0**	**4**	0	0	**0**	**14**
13	Waste, hazardous/ incinerated	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	mt CO2 eq	0	0	**0**	**0**	**0**	0	0	**0**	**0**
15	Ozone Depletion, emissions	t R-11 eq.				negligible					
16	Acidification, emissions	kt SO2 eq.	0	0	**0**	**0**	**1**	0	0	**0**	**1**
17	Volatile Organic Compounds (VOC)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
18	Persistent Organic Pollutants (POP)	g i-Teq	0	0	**0**	**0**	**0**	0	0	**0**	**0**
19	Heavy Metals	ton Ni eq.	0	0	**0**	**0**	**0**	0	0	**0**	**0**
	PAHs	ton Ni eq.	0	0	**0**	**0**	**0**	0	0	**0**	**0**
20	Particulate Matter (PM, dust)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
	Emissions (Water)										
21	Heavy Metals	ton Hg/20	0	0	**0**	**0**	**0**	0	0	**0**	**0**
22	Eutrophication	kt PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
23	Persistent Organic Pollutants (POP)	g i-Teq				negligible					

The following table lists the Life Cycle Cost (LCC) for this Base Case on the EU-27 level.

[49] Screenshot reference to 2005 is misleading, but cannot be changed in the template; actual figures refer to 2009

Table 4-77: Base Case 6: Horizontal panel saw – Total EU-27 total annual expenditure

	Horizontal panel saw *Item*	LCC new product		total annual consumer expenditure in EU25	
D	Product price	60000	€	78	mln.€
E	Installation/ acquisition costs (if any)	0	€	0	mln.€
F	Fuel (gas, oil, wood)	0	€	0	mln.€
F	Electricity	22736	€	46	mln.€
G	Water	0	€	0	mln.€
H	Aux. 1: None	0	€	0	mln.€
I	Aux. 2 :None	0	€	0	mln.€
J	Aux. 3: None	0	€	0	mln.€
K	Repair & maintenance costs	7477	€	15	mln.€
	Total	**90213**	€	**139**	mln.€

4.5.7 Base Case 7: Wood working machine tools: Throughfeed edge banding machine

This Base Case is meant to be a conscious abstraction, representing those product categories listed in Table 4-60. According to discussions with manufacturers of wood working machine tools, throughfeed edge banding machines typically would be reported as multi-purpose machines under PRODCOM code 28491220. As there is no distinct code for (the much smaller number of) wood working CNC machining centres also these are likely to be reported under this code, therefore only 90% of the market is allocated to the Base Case Throughfeed edge banding machines. Similar complexity is assumed also for multi-purpose machines where the workpiece is manually transferred between operations and – although featuring a different process – bending or assembling machines (code 28491265).

Table 4-78: Throughfeed edge banding machines (and similar types of wood-working machine tools) - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28491210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	80.874	85.973
28491220	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork, bone, hard rubber, hard plastics or similar hard materials *(90% of the market)*	85.839	121.444
28491265	Bending or assembling machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials[50]	56.602	51.460
	Totals	**223.315**	**258.877**

The following table lists the total extrapolated life cycle impacts for this Base Case on the EU-27 level for one year[51].

[50] Be aware, that „banding“ and „bending“ are different processes and bending machines are in included in this base case extrapolation only due to the similarity in complexity to throughfeed edge banding machines (see unit values)

[51] Glue not included with its life cycle impacts

Table 4-79: Base Case 7: Throughfeed edge banding machine – Total EU-27 impacts per year[52]

Table . EU Total Impact of STOCK of Throughfeed edge banding machine in 2005 (produced, in use, discarded)

Nr	EU Impact of Products in 2005 (produced, in use, discarded)***	Date	Author
	Throughfeed edge banding machine	0	Pwi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	**Total**	BUTION		Disposal	Recycl.	**Total**	
	Materials	**unit**									
1	Bulk Plastics	kt			**0**			0	0	**0**	**0**
2	TecPlastics	kt			**0**			0	0	**0**	**0**
3	Ferro	kt			**23**			1	22	**23**	**0**
4	Non-ferro	kt			**3**			0	3	**3**	**0**
5	Coating	kt			**0**			0	0	**0**	**0**
6	Electronics	kt			**0**			0	0	**0**	**0**
7	Misc.	kt			**0**			0	0	**0**	**0**
	Total weight	kt			**26**			1	25	**26**	**0**
	Other Resources & Waste							debet	see note! credit		
8	Total Energy (GER)	PJ	1	0	**1**	**0**	**23**	0	0	**0**	**24**
9	of which, electricity (in primary PJ)	PJ	0	0	**0**	**0**	**23**	0	0	**0**	**23**
10	Water (process)	mln. m3	0	0	**0**	**0**	**2**	0	0	**0**	**2**
11	Water (cooling)	mln. m3	0	0	**0**	**0**	**60**	0	0	**0**	**61**
12	Waste, non-haz./ landfill	kt	55	2	**57**	**0**	**27**	2	0	**2**	**86**
13	Waste, hazardous/ incinerated	kt	0	0	**0**	**0**	**1**	0	0	**0**	**1**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	mt CO2 eq	0	0	**0**	**0**	**1**	0	0	**0**	**1**
15	Ozone Depletion, emissions	t R-11 eq.	negligible								
16	Acidification, emissions	kt SO2 eq.	1	0	**1**	**0**	**6**	0	0	**0**	**7**
17	Volatile Organic Compounds (VOC)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
18	Persistent Organic Pollutants (POP)	g i-Teq	0	0	**1**	**0**	**0**	0	0	**0**	**1**
19	Heavy Metals	ton Ni eq.	0	0	**0**	**0**	**0**	0	0	**0**	**1**
	PAHs	ton Ni eq.	0	0	**0**	**0**	**0**	0	0	**0**	**0**
20	Particulate Matter (PM, dust)	kt	0	0	**0**	**1**	**0**	0	0	**0**	**1**
	Emissions (Water)										
21	Heavy Metals	ton Hg/20	0	0	**0**	**0**	**0**	0	0	**0**	**0**
22	Eutrophication	kt PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
23	Persistent Organic Pollutants (POP)	g i-Teq	negligible								

The following table lists the Life Cycle Cost (LCC) for this Base Case on the EU-27 level.

52 Screenshot reference to 2005 is misleading, but cannot be changed in the template; actual figures refer to 2009

Table 4-80: Base Case 7: Throughfeed edge banding machine – Total EU-27 total annual expenditure

	Throughfeed edge banding machine *Item*	LCC new product		total annual consumer expenditure in EU25	
D	Product price	60000	€	624	mln.€
E	Installation/ acquisition costs (if any)	0	€	0	mln.€
F	Fuel (gas, oil, wood)	0	€	0	mln.€
F	Electricity	18189	€	302	mln.€
G	Water	0	€	0	mln.€
H	Aux. 1: None	0	€	0	mln.€
I	Aux. 2 :None	0	€	0	mln.€
J	Aux. 3: None	0	€	0	mln.€
K	Repair & maintenance costs	7477	€	124	mln.€
	Total	**85666**	€	**1050**	mln.€

4.5.8 Base Case 8: Wood working machine tools: CNC machining centre

This Base Case is meant to be a conscious abstraction, representing those product categories listed in Table 4-81, i.e. the remaining 10% of the market reported under 28491220 (multi-purpose machines).

Table 4-81: CNC machining centre (and similar types of woodworking machine tools) - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
28491220	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork, bone, hard rubber, hard plastics or similar hard materials *(10% of the market)*	9.538	13.494
	Totals	**9.538**	**13.494**

The following table lists the total extrapolated life cycle impacts for this Base Case on the EU-27 level for one year[53].

[53] Hydraulic oil not included with their life cycle impacts

Table 4-82: Base Case 8: CNC machining centre (and similar types of woodworking machine tools) – Total EU-27 impacts per year[54]

Nr	EU Impact of Products in 2005 (produced, in use, discarded)***	Date	Author
	CNC machining center	0	Pwi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	**Total**	**BUTION**		Disposal	Recycl.	**Total**	
	Materials	**unit**									
1	Bulk Plastics	kt			0			0	0	0	0
2	TecPlastics	kt			0			0	0	0	0
3	Ferro	kt			5			0	5	5	0
4	Non-ferro	kt			0			0	0	0	0
5	Coating	kt			0			0	0	0	0
6	Electronics	kt			0			0	0	0	0
7	Misc.	kt			0			0	0	0	0
	Total weight	kt			5			0	5	5	0
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	PJ	0	0	0	0	8	0	0	0	8
9	of which, electricity (in primary PJ)	PJ	0	0	0	0	7	0	0	0	8
10	Water (process)	mln. m3	0	0	0	0	1	0	0	0	1
11	Water (cooling)	mln. m3	0	0	0	0	20	0	0	0	20
12	Waste, non-haz./ landfill	kt	5	0	5	0	9	0	0	0	14
13	Waste, hazardous/ incinerated	kt	0	0	0	0	0	0	0	0	0
	Emissions (Air)										
14	Greenhouse Gases in GWP100	mt CO2 eq.	0	0	0	0	0	0	0	0	0
15	Ozone Depletion, emissions	t R-11 eq.				negligible					
16	Acidification, emissions	kt SO2 eq.	0	0	0	0	2	0	0	0	2
17	Volatile Organic Compounds (VOC)	kt	0	0	0	0	0	0	0	0	0
18	Persistent Organic Pollutants (POP)	g i-Teq	0	0	0	0	0	0	0	0	0
19	Heavy Metals	ton_Ni eq.	0	0	0	0	0	0	0	0	0
	PAHs	ton Ni eq.	0	0	0	0	0	0	0	0	0
20	Particulate Matter (PM, dust)	kt	0	0	0	0	0	0	0	0	0
	Emissions (Water)										
21	Heavy Metals	ton Hg/20	0	0	0	0	0	0	0	0	0
22	Eutrophication	kt PO4	0	0	0	0	0	0	0	0	0
23	Persistent Organic Pollutants (POP)	g i-Teq				negligible					

The following table lists the Life Cycle Cost (LCC) for this Base Case on the EU-27 level.

54 Screenshot reference to 2005 is misleading, but cannot be changed in the template; actual figures refer to 2009

Table 4-83: Base Case 8: CNC machining centre – Total EU-27 total annual expenditure

	CNC machining center *Item*	LCC new product		total annual consumer expenditure in EU25	
D	Product price	300000	€	201	mln.€
E	Installation/ acquisition costs (if any)	0	€	0	mln.€
F	Fuel (gas, oil, wood)	0	€	0	mln.€
F	Electricity	92121	€	100	mln.€
G	Water	0	€	0	mln.€
H	Aux. 1: None	0	€	0	mln.€
I	Aux. 2 :None	0	€	0	mln.€
J	Aux. 3: None	0	€	0	mln.€
K	Repair & maintenance costs	37387	€	41	mln.€
	Total	**429507**	€	**341**	mln.€

4.5.9 Base Case 9: Welding equipment

This Base Case is meant to be a conscious abstraction, representing those product categories listed in Table 4-84. It is assumed that PRODCOM code 27903154 covers welding equipment, where the wire is fed automatically, but the electrode is hand-guided. There are two other codes (27903163, 27903172), which are for manual welding and other shielded arc welding, both with significant stock figures, but these are understood to be rather home use and semi-professional use products, with a basically different use scenario (much lower use times), hence these units are not properly represented by this base case.

Table 4-84: Welding equipment - Installed stock 1995 and 2009

PRODCOM	Description	1995	2009
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	1.678.333	1.271.472
	Totals	**1.678.333**	**1.271.472**

The following table lists the total extrapolated life cycle impacts for this Base Case on the EU-27 level for one year[55].

[55] Welding gas not included with their life cycle impacts

Table 4-85: Base Case 9: Welding equipment – Total EU-27 impacts per year[56]

Table . EU Total Impact of STOCK of MIG/MAG-Welding Equipment in 2005 (produced, in use, discarded)

Nr	EU Impact of Products in 2005 (produced, in use, discarded)***	Date	Author
	MIG/MAG-Welding Equipment	0	KSchi

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	**Total**	BUTION		Disposal	Recycl.	**Total**	
	Materials	**unit**									
1	Bulk Plastics	kt			**1**			1	0	**1**	**0**
2	TecPlastics	kt			**0**			0	0	**0**	**0**
3	Ferro	kt			**18**			1	17	**18**	**0**
4	Non-ferro	kt			**1**			0	1	**1**	**0**
5	Coating	kt			**0**			0	0	**0**	**0**
6	Electronics	kt			**5**			2	2	**5**	**0**
7	Misc.	kt			**0**			0	0	**0**	**0**
	Total weight	kt			**25**			4	21	**25**	**0**
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	PJ	3	1	**4**	**0**	**42**	0	0	**0**	**46**
9	of which, electricity (in primary PJ)	PJ	0	0	**0**	**0**	**42**	0	0	**0**	**42**
10	Water (process)	mln. m3	0	0	**0**	**0**	**3**	0	0	**0**	**3**
11	Water (cooling)	mln. m3	0	0	**1**	**0**	**113**	0	0	**0**	**113**
12	Waste, non-haz./ landfill	kt	55	2	**57**	**0**	**50**	2	1	**1**	**108**
13	Waste, hazardous/ incinerated	kt	0	0	**0**	**0**	**1**	3	0	**3**	**4**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	mt CO2 eq.	0	0	**0**	**0**	**2**	0	0	**0**	**2**
15	Ozone Depletion, emissions	t R-11 eq.	negligible								
16	Acidification, emissions	kt SO2 eq.	1	0	**2**	**0**	**11**	0	0	**0**	**12**
17	Volatile Organic Compounds (VOC)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**0**
18	Persistent Organic Pollutants (POP)	g i-Teq	0	0	**1**	**0**	**0**	0	0	**0**	**1**
19	Heavy Metals	ton Ni eq.	0	0	**0**	**0**	**1**	0	0	**0**	**1**
	PAHs	ton Ni eq.	1	0	**1**	**0**	**0**	0	0	**0**	**1**
20	Particulate Matter (PM, dust)	kt	0	0	**0**	**0**	**0**	0	0	**0**	**1**
	Emissions (Water)										
21	Heavy Metals	ton Hg/20	1	0	**1**	**0**	**0**	0	0	**0**	**1**
22	Eutrophication	kt PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
23	Persistent Organic Pollutants (POP)	g i-Teq	negligible								

The following table lists the Life Cycle Cost (LCC) for this Base Case on the EU-27 level.

56 Screenshot reference to 2005 is misleading, but cannot be changed in the template; actual figures refer to 2009

Table 4-86: Base Case 9: Welding equipment – Total EU-27 total annual expenditure

	MIG/MAG-Welding Equipment *Item*	LCC new product		total annual consumer expenditure in EU25	
D	Product price	1200	€	216	mln.€
E	Installation/ acquisition costs (if any)	0	€	0	mln.€
F	Fuel (gas, oil, wood)	0	€	0	mln.€
F	Electricity	2021	€	444	mln.€
G	Water	0	€	0	mln.€
H	Aux. 1: None	8680	€	1905	mln.€
I	Aux. 2 :None	0	€	0	mln.€
J	Aux. 3: None	0	€	0	mln.€
K	Repair & maintenance costs	50	€	11	mln.€
	Total	**11950**	€	**2575**	mln.€

The total consumption of shielding gas equals 600 million kg Argon, compared to an EU-27 production of 720 million Nm³ in 2010[57], equalling roughly 1.2 billion kg Argon. Although no distinct market data is available regarding Argon consumption for the various applications, it is plausible that at least half of the EU-27 consumption is for welding purposes. On the other hand this plausibility check indicates that by including the other two PRODCOM codes for manual and shielded welding at least the order of magnitude of gas consumption would increase maximum by a factor of two.

4.5.10 Base Cases Summary

4.5.10.1 Totals – Life Cycle Impacts

The total environmental impacts of the EU-27 stock per year are summarized in **Table 4-87**. It is evident, that metal working CNC machining centres are by far the most relevant Base Case and dominate the aggregated impacts of all Base Cases.

[57] EuroStat / PRODCOM, code 20111120, imports and exports negligible

Table 4-87: Summary Environmental Impacts EU-Stock per year per Base Case

		Base Cases									
		Metal working				Wood working					
main life cycle indicators	unit	(1) CNC machining centres (and similar)	(2) CNC Laser cutting machine tools	(3) CNC Bending machine tools (and similar)	(4) Non-NC metal working machine tools (and similar)	(5) Table saw (and similar)	(6) Horizontal panel saw (and similar)	(7) Throughfeed edge banding machine (and similar)	(8) CNC machining centre (and similar)	(9) Welding equipment	Totals
Total Energy (GER)	PJ	**410**	**32**	**13**	**96**	**12**	**4**	**24**	**8**	**46**	**645**
of which, electricity	TWh	38,4	3,0	**0,8**	**9,0**	1,1	0,3	2,2	0,7	4,0	**59,5**
Water (process)*	mln.m3	**32**	**3**	**1**	**7**	**1**	**0**	**2**	**1**	**3**	**50**
Waste, non-haz./ landfill*	kt	**776**	**53**	**210**	**156**	**24**	**14**	**86**	**14**	**108**	**1441**
Waste, hazardous/ incinerated*	kt	**10**	**1**	**0**	**2**	**0**	**0**	**1**	**0**	**4**	**18**
Emissions (Air)											
Greenhouse Gases in GWP100	mt CO2eq.	**18**	**1**	**1**	**4**	**1**	**0**	**1**	**0**	**2**	**28**
Acidifying agents (AP)	kt SO2eq.	**107**	**9**	**3**	**25**	**3**	**1**	**7**	**2**	**12**	**169**
Volatile Org. Compounds (VOC)	kt	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Persistent Org. Pollutants (POP)	g i-Teq.	**6**	**0**	**3**	**1**	**0**	**0**	**1**	**0**	**1**	**12**
Heavy Metals (HM)	ton Ni eq.	**8**	**1**	**1**	**2**	**0**	**0**	**1**	**0**	**1**	**14**
PAHs	ton Ni eq.	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**2**
Particulate Matter (PM, dust)	kt	**9**	**1**	**3**	**3**	**0**	**0**	**1**	**0**	**1**	**19**
Emissions (Water)											
Heavy Metals (HM)	ton Hg/20	3	1	**1**	**1**	0	0	0	0	1	**7**
Eutrophication (EP)	kt PO4	0	0	**0**	**0**	0	0	0	0	0	**0**

***=caution: low accuracy for production phase**
"0" means "< 0.5"

Total energy consumption (primary energy) of CNC metal working machining centres is in the range of 410 PJ per year, which is much more than for any of the other calculated Base Cases. Further relevant machine tools segments are non-NC metal working machine tools (97 PJ per year), welding equipment (46 PJ per year), industrial wood working machine tools (represented by horizontal panel saws, throughfeed edge banding machines, and CNC machining centres; 36 PJ per year) and CNC laser cutting machine tools (32 PJ per year). The total energy consumption of all Base Cases is 645 PJ per year, thereof 59,5 TWh electricity, and aggregated Greenhouse Gas emissions total at 28 million tonnes CO_2-equivalents. Given the fact, that all Base Cases are dominated by use phase impacts, similarly Base Case 1 is the largest contributor to total life

cycle impacts of machine tools in all categories. The Base Cases cover the most relevant market segments of machine tools covered by this study, but not all of them, which leads to an underestimation of total impacts; however the order of magnitude is plausible.

Oil-based auxiliaries where identified to be relevant for the impact category eutrophication, but even with these impacts included, the eutrophication on the total EU-27 level remains below 0,1 kt PO4.

Hagemann and Würz (VDW) cordially provided a top-down-estimate of electricity consumption of (metal working) machine tools in EU-27. Their calculations based on total EU-27 energy consumption and anticipated share of the manufacturing sector and thereof the industries using metal working machine tools are referenced in **Table 4-88**.

Table 4-88: Top-down estimate electricity consumption of metal working machine tools in EU-27 (estimate by VDW)

End-use energy consumption	unit	2000	2005	2006	2007	2008	2009
Totals EU-27 Eurostat: http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/main_tables	[kt oil eq]	1120145	1192536	1193356	1166798	1175235	1113671
Totals EU-27	[TWh]	13027	13869	13879	13570	13668	12952
Manufacturing sector (estimate: 20% of totals)	[TWh]	2605	2774	2776	2714	2734	2590
Machine tools using sectors (estimate: 10% of manufacturing sector totals)	[TWh]	261	277	278	271	273	259
Machine tools (estimate: 25% of relevant sectors)	[TWh]	65,1	69,3	69,4	67,8	68,3	64,8

The estimated total electricity consumption of 65 – 70 TWh per year confirms roughly our own bottom-up (Base Case) estimates, taking into account that our aggregated Base Cases do not fully cover all machine tools categories.

To give an impression of the significance of the identified aggregated impacts of machine tools the following table lists the electricity consumption identified for other prod-

uct groups in the course of EuP Preparatory Studies and the Impact Assessments (compilation by Reintjes et al.[58]).

Table 4-89: Electricity Consumption of other product groups under the Ecodesign Directive[59]

Lot	Product Group	Electricity consumption in 2020 TWh/a (EU25/27)	
		Business as usual	Ecodesign measure effective
ENER Lot 5	Television sets	132	104
ENER Lot 6	Standby and Off-mode losses	49	14
ENER Lot 7	External Power Supplies	31	22
ENER Lot 8/9	Tertiary Sector Lighting	260	222
ENER Lot 11	Electric Motors	1252	1117
ENER Lot 11	Circulators	55	32
ENER Lot 13	Domestic refrigerators and freezers	83	79-83
ENER Lot 19	Domestic Lighting (non-directional household lamps)	135	96

Total electricity consumption of machine tools (aggregated Base Cases) is roughly in the range of the 2020 prognosis for consumption for standby and off-mode losses (for consumer and office products) or circulators, but much lower than for electric motors. External power supplies are the only product group with significantly lower electricity consumption than identified for machine tools now, but for which an implementing measure has been adopted.

4.5.10.2 Totals – Life Cycle Costs

The total life cycle costs of the EU-27 stock per year are summarized in **Table 4-87**.

58 Ökopol GmbH. Analysis of Impact of Efficiency Standards on EU GHG Emissions (Ecodesign Directive); Task 3 Report – Outlook on the estimated GHG emissions reductions, September 2011 (EC, contract 070307/2008/506876/SER/C5)

59 Table lists only those product categories, for which an implementing measure has been adopted by early 2010

Table 4-90: Summary Life Cycle Costs EU-Stock per year per Base Case

		Base Cases									
		Metal working				Wood working					
		(1) CNC machining centres (and similar)	(2) CNC Laser cutting machine tools	(3) CNC Bending machine tools (and similar)	(4) Non-NC metal working machine tools (and similar)	(5) Table saw (and similar)	(6) Horizontal panel saw (and simi-lar)	(7) Throughfeed edge banding machine (and similar)	(8) CNC machining centre (and similar)	(9) Welding equipment	Totals
LCC new product – per unit											
D Product price	k€	**480**	**400**	**100**	**5**	**0,6**	**60**	**60**	**300**	**1,2**	
F Electricity	k€	**137**	**191**	**5**	**14**	**0,4**	**23**	**18**	**92**	**2**	
G Water	k€	**2**	**0**	**0**	**0**	**0**	**0**	**0**		**0**	
H/I/J Auxiliaries	k€	**9**	**181**	**3**	**0,2**	**0,006**	**0**	**0**		**9**	
K Repair & maintenance costs	k€	**78**	**30**	**14**	**1,8**	**0,02**	**7**	**7**	**37**	**0,05**	
Total	k€	**706**	**801**	**122**	**21**	**1**	**90**	**86**	**430**	**12**	
Total annual user ex-penditure in EU27 (EU stock)											
D Product price	mln. €	**5321**	**600**	**3168**	**240**	**134**	**78**	**624**	**201**	**216**	**10582**
F Electricity	mln. €	**4218**	**323**	**78**	**986**	**154**	**46**	**302**	**100**	**444**	**6651**
G Water	mln. €	**62**	**0**	**0**	**5**		**0**	**0**	**0**	**0**	**0**
H/I/J Auxiliaries	mln. €	**263**	**306**	**12**	**10**	**2**	**0**	**0**	**0**	**1905**	**2498**
K Repair & maintenance costs	mln. €	**2407**	**50**	**121**	**96**	**7**	**15**	**124**	**41**	**11**	**2872**
Total	mln. €	**12271**	**1279**	**3526**	**1364**	**297**	**139**	**1050**	**341**	**2575**	**22842**

For almost all types of machine tools electricity consumption constitutes a major share of total life cycle costs, ranging from roughly 4% for bending machine tools (under a “manual discrete” production scenario) to nearly 25% for laser cutting machine tools. By far the highest cost share for auxiliaries is with welding equipment, where welding gases represent 75% of the life cycle costs. Be reminded, that for simplification these life cycle calculations do NOT include any of the following cost parameters, which are the more decisive criteria for any economic consideration of manufacturers:

- Product output / productivity / yield loss
- Labour costs

The total annual user expenditure, aggregated for all Base Cases per year is 22.8 billion Euro, thereof roughly 6.7 billion Euro for electricity and 2.5 billion Euro for those auxiliaries considered in the Base Cases.

4.5.10.3 Market coverage

It has to be noted, that numerous PRODCOM codes cannot be covered by the chosen Base Cases as technology complexity and process types deviates significantly from the Base Case archetypes, not allowing any extrapolation. Only an increased number of Base Cases would have allowed a broader coverage of the total market. The following table summarises coverage of the EU-27 by Base Cases.

Table 4-91: Metal working machine tools – Coverage of installed stock by Base Cases

PRODCOM	Description	2009	Base Case coverage
28411110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	**18.978**	Base Case 2
28411130	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)	**8762**	Not covered due to process specifics
28411150	Machine tools for working any material by removal of material, operated by electro-discharge processes	**33246**	Not covered due to process specifics
28411170	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes	**114266**	Not covered due to process specifics
28411220	Horizontal machining centres for working metal	**33965**	Base Case 1
28411240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	**99614**	Base Case 1
28411250	Unit construction machines (single station) for working metal	**40955**	Not covered due to process specifics
28411270	Multi-station transfer machines for working metal	**22828**	Base Case 1
28412123	Numerically controlled horizontal lathes, turning centres, for removing metal	**34214**	Base Case 1
28412127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	**38005**	Base Case 1
28412129	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)	**44347**	Not covered (NC, but much less complex than BC1)
28412140	Non-numerically controlled horizontal lathes, for removing metal	**100104**	Base Case 4
28412160	Lathes, including turning centres, for removing	**53745**	Base Case 1

	metal (excluding horizontal lathes)		
28412213	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)	**34743**	Not covered (NC, but much less complex than BC1)
28412217	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)	**6859**	Not covered (NC, but much less complex than BC1)
28412223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	**36197**	Not covered (NC, but much less complex than BC1)
28412225	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)	**23858**	Not covered (NC, but much less complex than BC1)
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	**320900**	Base Case 4
28412240	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	**23136**	Not covered (NC, but much less complex than BC1)
28412260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	**3636**	Base Case 4
28412270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)	**36325**	Base Case 4
28412280	Threading or tapping machines for working metal (excluding drilling machines)	**141190**	Not relevant
28412305	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	**11152**	Not covered (NC, but much less complex than BC1)
28412315	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	**10852**	Not covered (NC, but much less complex than BC1)
28412325	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to accuracy >0.01mm	**5987**	Not covered (NC, but much less complex than BC1)
28412335	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	**4668**	Base Case 4
28412345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	**2024**	Base Case 4
28412355	Grinding machines for working metal; any one axis can be set to an accuracy >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines	**49332**	Base Case 4
28412365	Numerically controlled sharpening (tool or cutter grinding) machines for working metal	**43005**	Not covered (NC, but much less complex than BC1)

28412375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal	**21950**	Base Case 4
28412385	Honing or lapping machines for working metal	**290527**	Not covered due to process specifics
28412395	Machines for deburring or polishing metal (excluding gear finishing machines)	**49371**	Not covered due to process specifics
28412410	Broaching machines for working metal	**916**	Not covered due to process specifics
28412430	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)	**6401**	Not covered due to process specifics
28412470	Sawing or cutting-off machines for working metal	**137080**	Base Case 4
28412490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.	**16187**	Not covered due to process specifics
28413120	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	**76542**	Base Case 3
28413140	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	**33993**	Base Case 3
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	**48355**	Base Case 4
28413180	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	**0**	
28413220	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	**37512**	Not covered (NC, but much less complex than BC1)
28413240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	**17591**	Base Case 3
28413260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	**146934**	Base Case 4
28413280	Non-numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	**185759**	Not covered due to process specifics
28413310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	**5290**	Base Case 3
28413320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	**291**	Base Case 4
28413330	Presses for moulding metallic powders by sintering or for compressing scrap metal into bales	**3221**	Base Case 3
28413340	Other hydraulic presses, numerically controlled,	**37583**	Base Case 3

	for working metal		
28413350[60]	Hydraulic presses for working metal	**1869**	Base Case 3
28413360	Non-hydraulic presses for working metal	**17658**	Base Case 3
28413370	Other non-hydraulic presses, numerically controlled, for working metal	**5823**	Base Case 3
28413380	Other non-numerically controlled presses for working metal	**395426**	Not covered (much less complex than BC3)
28413410	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets	**7570**	Not covered due to process specifics
28413430	Thread rolling machines for working metal, sintered metal carbides or cermets	**14334**	Not covered due to process specifics
28413450	Machines for working wire (excluding draw-benches, thread rolling machines)	**187384**	Not covered due to process specifics
28413470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal	**319683**	Not covered due to process specifics
	Totals	**3.464.152**	

Table 4-92: Wood working machine tools – Coverage of installed stock by Base Cases

PRODCOM	Description	2009	Base Case coverage
28491210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	85.973	Base Case 7
28491220	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	134.938	Split: 10% Base Case 8; 90% Base Case7
28491233	Band saws for working wood, cork, bone and hard rubber, hard plastics or similar hard materials	171.091	Not covered due to process specifics
28491235	Circular saws for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	1.265.651	Split: 2% Base Case 6; 98% Base Case 5
28491237	Sawing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials (excluding band saws, circular saws)	2.252.145	Base Case 5
28491250	Planing, milling or moulding (by cutting) ma-	857.192	Base Case 5

60 In 2009 PRODCOM codes 28413340 and 28413370 where replaced by codes 28413350 and 28413360, which explains a stock of "0" for the latter categories for 1995, as these where covered by other categories at that time

	chines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials		
28491263	Grinding, sanding or polishing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	159.022	Not covered due to process specifics
28491265	Bending or assembling machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	51.460	Base Case 7
28491267	Drilling or morticing machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	144.628	Not covered due to process specifics
28491275	Splitting, slicing or paring machines for working wood, cork, bone, hard rubber, hard plastics or similar hard materials	284.247	Not covered due to process specifics
28491279	Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials, n.e.c.	378.955	Not covered, category not defined
	Totals	**5.787.311**	

Table 4-93: Welding, soldering and brazing equipment – Coverage of installed stock by Base Cases

PRODCOM	Description	2009	Base Case coverage
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	76.626	Industrial equipment covered by ENTR Lot 4
27903145	Electric machines and apparatus for resistance welding of metal	1.014.599	Not covered due to process specifics[61]
27903154	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)	1.271.472	Base Case 9
27903163	Other for manual welding with coated electrodes	1.868.230	Not covered, use phase impact much lower than BC 9
27903172	Other shielded arc welding	1.406.819	Not covered, use phase impact much lower than BC 9
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	209.110	Not covered, category not defined
27903190	Machines and apparatus for resistance welding of plastics	1.087.628	Not covered due to process specifics
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	139.121	Not covered, definition unclear
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding	59.533	Industrial equipment cov-

[61] resistance welding equipment can not be compared with arc welding equipment for various reasons, e.g. the transformer used is designed by its thermal performance in order to allow very short welding time with very high welding current; hence, efficiency has to be analysed differently and findings for arc welding cannot be directly applied for resistance welding

	hand-held blow pipes and electric machines and apparatus)		ered by ENTR Lot 4
	Totals	**7.135.147**	

Fraunhofer

Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 5 Report – Technical Analysis BAT and BNAT

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary – Task 5

In this report several Best Available (BAT) and Best Not yet Available (BNAT) Technologies were examined. According to the MEEuP methodology, the only technologies which should be considered are those which are about to enter the market within 2-3 years (BAT definition). However, as technologies which have been recently introduced to the market, or which have not yet been widely introduced, are highly relevant in order to reap the full improvement potential offered by today's technologies, these readily-available solutions are also covered in this task report.

Moreover, the presented solutions do not claim that certain machine tools are the most energy efficient, and therefore represent the best available or best not yet available technology. Instead, there are a large number of energy efficient solutions at the component level for BAT, and potentially as BNAT. Here, the modular system architecture of machine tools has to be taken into account for eco-design measures. Many of the components are manufactured by suppliers, and implemented by the machine tool manufacturers. There are some approaches which address non-energy related improvements, including media consumption, mass reduction, and productivity increase.

As shown, most BAT component solutions are compatible with each other and aid to realise energy efficient machine tools. However, the energy savings which may be realised largely depend on the combination of measures, and the savings potential cannot be just aggregated when more than one option is implemented. The listed examples therefore show existing machine tools and machining centres which are equipped with a selection of energy efficient components, and demonstrate their energy-saving potential. The measures have a strong influence on productivity and partly also the functionality of the machine tools; thus, eco-design solutions have to carefully consider conditions of application, in addition.

The assessment of the various technical eco-design measures is based on a survey among machinery and component manufacturers, and complemented by research on technical options. The assessment reveals that there is a multitude of options, each with a small energy savings potential in the range of 1%, but it can be anticipated that a combination of several options could lead to significant total savings. However, the large spread of answers given for most of the options once again confirms that the feasibility and suitability of any option has to be assessed carefully for the intended application.

The projects presented regarding BNAT which originated from the European area do not only cover solutions at the component level of machine tools. Instead, an overall examination in different areas of energy efficiency of machine tools has been conducted. The amount of technologies presented in both fields, BAT and BNAT, shows the growing importance and awareness to offer and to implement energy-efficient solu-

tions in machine tools, via the research, development and implementation efforts of the metal working machine tools manufacturers.

5 Task 5 – Technical Analysis BAT and BNAT

According to the methodological approach (MEEuP), Best Available Technology (BAT) entails a technical analysis not of the current product on the market but on currently available technology, expected to be introduced at product level within 2-3 years. However, as some technologies are just about to enter the market or are already introduced, but not implemented at large, the BAT chapter covers also these already available technologies as they represent an important improvement potential. The various sub-chapters indicate roughly the status of market availability. Best Not yet Available Technologies (BNAT) summarise the state-of-the-art in research and development for a product, indicating the long-term market possibilities. The environmental performance of BAT and BNAT both provide part of the input for the identification of the improvement potential (task 6).

Although there are some machine tools which are claimed to be environmentally friendly, or eco-efficient, as such it is rather not possible to define a complete machine tool as Best Available Technology (BAT), or Best Not yet Available Technologies (BNAT), as this could only refer to a very specific configuration and application scenario. The BAT / BNAT for machine tools rather is the result of BAT / BNAT at the components level. Therefore individual measures are described below. The advantage is the combarabilty of all machine tools independent of the production process.

As far as Best Not yet Available Technologies are concerned, it should be pointed out that according to CECIMO “there are improvement potentials which we do not know today but which will become available in the future. This goes together with the innovative spirit of the sector and it will have enormous impact on the cutting of energy consumption.” However, a quantification of these potentials is not yet possible.

There are a couple of intitiaves, which foster and promote in particular more environmentally benign approaches at the overall machine level:

The **"Blue Competence®"** initiative of the German Engineering Federation (VDMA) is a joint umbrella scheme for the whole engineering industry of Germany[1]. The German Machine Tool Builders’ Associatioon is a participant in the initative ("Blue Competence® machine tools”). For this intiative, several machine tools manufacturers

1 http://www.vdma.org/wps/wcm/connect/f0740d80477fca20b08cb76617c93b30/bro_bc_mabau_2011-07.pdf?MOD=AJPERES&CACHEID=f0740d80477fca20b08cb76617c93b30 Access: 01.12.2011

adress - in particular - energy-saving technologies, environmentally sustainable materials and resource-saving processes. Hence, the BATs are partly derived from technologies, which are covered by the “Blue Competence®” initiative. By signing up to the conditions of use, the machine tool builders accept their responsibilities for the natural environment and to climate protection, as well as affirming their readiness to enter into an active dialogue on this with both customers and vendors[2]. Material and mass reduction without loosing stiffness can help to reduce the energy consumption during acceleration processes. Heat and electrical power recovery reduce power loss. Therefore heat exchangers for preheating the components are focused on as a further objective criterion .

In parallel, an initiative by the VDMA and Fraunhofer IPA targets energy efficiency in automation technology: **"Green Automation"** intends to implement an integrated energy efficiency analysis of production in the early conceptual phase of product development. As part of this analysis, the simulation of energy consumption and other energy systems, such as pneumatics and hydraulics, is being undertaken to identify energy-efficient alternatives at an early stage, since these measures have a strong influence on the life cycle energy consumption of a product.[3]

Further initiatives are publicly funded, such as the European public private partnership **“Factories of the Future”**[4] or the Austrian funding programme **“Fabrik der Zukunft”,** and the German cluster **“Effizienzfabrik”**, which research future production technologies, including those relevant for machine tools and related machinery.

A distinctive mark, registered in accordance with the law, the UCIMU Mark is granted to a company, and not to a product, following strict, ongoing tests. The approximately 100 companies which have currently been awarded the UCIMU Mark (out of a total of more than 200 associates), starting from the beginning of 2011, will be able to affix the new symbol expressing the "Blue Philosophy" that governs the Italian production of the sector. [5]

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2 VDW: http://www.vdw.de/web-bin/owa/homepage?p_bereich=leistungsangebot&p_menue_id=1000000019&p_zusatzdaten=dok_zeige_ordner&p_zusatz_id=1989&p_sprache=e

3 Naumann, M.: Energieeffizienzsteigerung in der Automatisierungstechnik. Gießerei 97 (2010) 4, S. 86.

4 Ad-hoc Industrial Advisory Group Factories of the Future PPP: Strategic Multi-annual Roadmap, 20 January 2010

5 http://www.ipfonline.com/IPFCONTENT/news/sector-trends/ucimu-mark-is-now-dyed-in-blue-reflects-eco-compatible-production.php

There are numerous examples where the same manufacturing task could be realised with one technology or another, resulting in greater or fewer environmental impacts. One such example is TIG (tungsten inert gas) welding versus laser beam welding, assessed by Dahmen et al.[6] for a given production task, resulting in lower energy consumption, emissions and material consumption for laser beam welding. However, such optimisation options are a question of proper technology choice, not of the design of a machine as such. Therefore such cases – although they possess the potential for reducing environmental impacts - are explicitly excluded from the analysis provided below, whereas technology improvements, which come with an adapted machine concept, are included, such as machine tools applying minimum quantity lubrication.

Given the high significance of energy consumption in the use phase, as analysed in detail in Task 4, the focus of the BAT and BNAT analysis is on measures to reduce energy consumption in use. However, several BATs listed below have a positive effect not only on energy consumption in use, but also on non-energy use aspects. For example, the major share of BATs referred to in solution 6 also reduce the impact of consumables (dry machining, MQL – minimum quantity lubrication, etc.)

5.1 Definition of BAT

The presented solutions are the result of the survey of this study, market research and stakeholder information.

As indicated in previous tasks within this study, significant environmental impacts of machine tools are due to the consumption of energy during the use phase. Subsequently, eco-research within the machine tool industry has focused on improvement options to reduce energy losses during operating and stand-by modes; measures to improve other environmental aspects of machine tools are considered as well. In correspondence, another study by the Fraunhofer Gesellschaft assumes that cutting and chip removing machineries in particular provides a broad space for improvement options. This is due to the fact that lower energy and material efficiency is anticipated, compared with forming machine tools. Unlike most forming processes, cutting generates certain amounts of scrap metal and requires consumables such as cooling lubricants and additional energy for suction systems. Consequently a distinction is required when analysing forming and cutting processes, as both feature different

6 Dahmen, M.; Güdükkurt, O.; Kaierle, S.: The Ecological Footprint of Laser Beam Welding, Physics Procedia 5 (2010), p. 19-28

process and environmental characteristics. Despite the lack of systematic investigations into the energy-using profiles of machine tools, several studies revealed great improvement potential for energy saving operating modes, especially during periods of machine idleness.

Current research and development in the field of machine tools primarily deals with methods and technologies to increase the energy efficiency of machine tools. As indicated in task 1.1, it is common knowledge that on one hand, a major share of the total energy consumption is attributed to auxiliary equipment, such as the lubrication system, pneumatic unit, chip conveyor, and the like. On the other hand, significant energy losses can be related to machine tools' idle periods (see Figure 5-1). Depending on the scale of production, the share of total consumption for non-working processes fluctuates between 62 % (large scale) and 85 % (small scale).

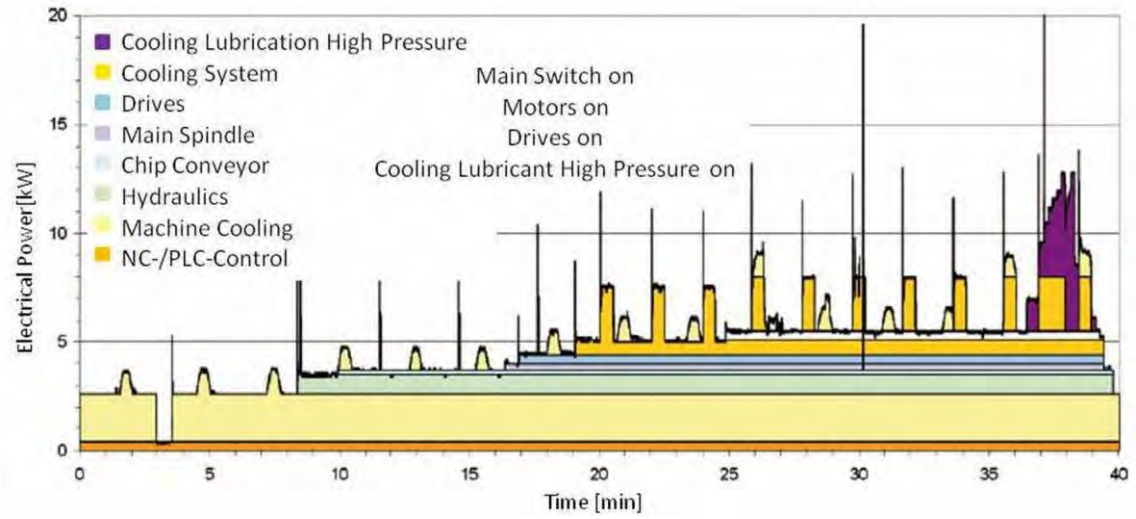


Figure 5-1: Electrical power consumption on component level for a Heller H 2000 milling center[7]

Efficient configurations of process parameters contribute to a decline of energy consumption when high speed cutting is applied. To reduce major shares of energy consumption (especially those deriving from base load, idle periods and periphery maintenance (control, lubrication), peripheral systems (e.g. room lighting, air conditioning)) can be reduced when abridging the processing time. Related to high-performance machining, the specific base load is lowered with increasing feed rates and cutting rates. Moreover, larger rates cause less specific cutting power demand.

7 Brecher, C. et al.: Ressourceneffizienz von Werkzeugmaschine im Fokus der Forschung. In: wt online 100 (2010) 7/8. pp. 559-564

As mentioned before, a major share of the overall energy consumption comes in particular from the base load demand of the machine tool, and also from the dynamic forces. To meet market demands of solid dynamic performances, the machine has to provide - and withstand - immense acceleration and braking processes, which lead to peak loads and increased energy expenditure.[8] Technologically, energy-efficient high speed cutting performance can be realized with the aid of parallel kinematics (PKM), which overcomes previous limits of dynamics and precision compared to serial Cartesian guide systems. Today, there are a few machines equipped with parallel kinematics[9], but this technology – although considered a mega-trend in the 1990s - was never broadly introduced to the market[10]. However, high-performance machining may also lead to higher abrasive wear of deployed tools which should be included into the ecological assessment and evaluation of high speed cutting.[11]

Another approach to cut down the time taken for machining is to shorten the process chain, which can be achieved e.g. by merging processing steps using adequate technologies. For example, rotational turning combines turning and grinding in one machining stage, causing shorter processing times. Machine tools equipped with this manufacturing technology are already placed on the market.[12]

8 Heisel U. et al.: Einsparpotentiale in der spanenden Fertigung.In: Fertigungstechnisches Kolloquium 2010. Stuttgart, 2010. pp. 201-236.

9 E.g. the Index C100 and C200, http://www.index-werke.de/mediadata/c200-0008e.pdf; Trumpf TruMatic 7000, http://www2.trumpf.com/3.img-cust/TruMatic_7000_en.pdf, accessed January 20, 2011.

10 fertigung: Megatrends der Zerspanungsbranche - Die Topps und Flops der Branche, Branchenreport, 13.09.2011, http://www.fertigung.de/2011/09/die-topps-und-flops-der-branche/

11 Klocke F., Schlosser, R., Tönissen, S., Prozesseffizienz durch Parameterwahl, wt Werkstattstechnik online, Düsseldorf, 2010, p. 346ff.

12 E.g. J.G. Weisser Söhne Werkzeugmaschinenfabrik, http://www.weisser-web.com/index.php?id=10&L=0, accessed January 24, 2011.

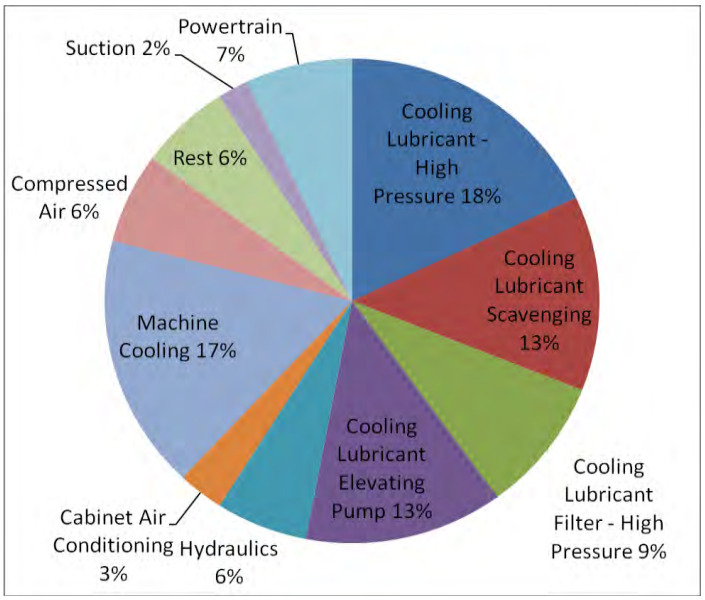


Figure 5-2: Annual energy consumption of components in three-shift operation[13]

Efficient configurations of process parameters contribute to a decline of energy consumption when high speed cutting is applied. To reduce major shares of energy consumption (especially those deriving from base load, idle periods and periphery maintenance (control, lubrication), peripheral systems (e.g. room lighting, air conditioning)) can be lowered when cutting the processing time. Related to high-performance machining, the specific base load is lowered with increasing feed rates and cutting rates. Moreover, larger pitches cause less specific cutting power demand. However, high-performance machining may also lead to higher abrasive wear of deployed tools, designated to be included into the ecological assessment and evaluation of high speed cutting.[14]

A German manufacturer of woodworking machine tools and facilities[15] has estimated that about 20 % of costs are purchasing (investment) costs, and that 80 % of costs occur in the use phase and recycling phase of woodworking machine tools. 90 % of the overall costs are attributed to energy consumption. 10 % of the costs relate to launching, training, spare parts, maintenance, personnel, taxes and assurance, refurbishment and disposal. The enterprise offers energy efficiency measures such as energy efficient

13 Rothenbücher, S.; Kuhrke, B.: Energiebündel auf dem Prüfstand, In: Werkstatt + Betrieb, September 2010, Karl Hanser Verlag, München

14 Klocke et al., *Prozesseffizienz durch Parameterwahl*, 2010

15 Moehringer GmbH, Wiesentheid, Germany

drives and machine control, as well as energy recovery for both new and used wood-working facilities.[16]

Overall, stakeholders offer the following solutions[17]:

- Application of drive axis and spindles by state of the art VAC-Drive Technology
- High efficiency motors (e.g. synchronous motors)
- Stand-by modes

5.1.1 Overview on realised eco-design solutions

BAT measures are displayed in Table 5-5. A detailed description of these follows thereafter.

Table 5-1: Overview of eco-design measures

Solution	Environmental impact	Implications	Impact
1. Mass Reduction of Moving Parts	material reduction, energy savings during acceleration, faster machining speeds and reduced through-put times	shift of material recycling challenges from steel and iron to fibre materials, plastics and lightweight metals	40 % lower mass, 30 % faster spindle acceleration
2. Software-based Energy Management	reduction of energy loss during non-productive times, energy and life time optimised process layout	differentiation between energy monitoring, component switch-off and process optimisation	23 % energy savings in three shift operation
3. Energy Recuperation of Drives and Power Electronics	energy savings while using energy-efficient components and during deceleration, system solutions improves efficiency in comparison to isolated applications	Savings with adapted system design layout	up to 60 % reduced energy input, up to 80 % of regenerated energy during braking
4. Tool Handling and Clamping	energy savings with new physical principles for handling and clamping	use of application oriented components	up to 40 % less energy
5. Hydraulic and Pneumatic Optimized Systems	energy savings with system adapted pumps, motors and auxiliary devices	Savings with adapted system design layout	Up to 66 % of energy savings
6. Energy-	reduction or elimination of cooling lubri-	only metalworking	energy reduc-

16 Source: http://www.moehringer.com/innovation

17 Offered solutions collected from questionnaire

Solution	Environmental impact	Implications	Impact
Efficient Cooling Lubricant Supply	cant within all related devices and processes, e. g. provision, handling equipment, conditioning and recycling/disposal	machine tools, niche application of new media, e. g. nitrogen	tion of between 20 % and 33 %
7. Cooling Systems and Use of Cabinet Heat	reduced electric losses and efficient cooling devices improves energy efficiency	system solution provided by power electronic suppliers	reduction of energy consumption of up to 45 %
8. Energy-efficient Tempering	energy savings with new heating principles, e. g. electric induction instead of furnace heating, fast provision of thermal stable machine tool's state with eliminated non-productive playback cycles and switch-on	process approaches for tempering, system approaches for machine tool improvement	85 % reduced energy input while using electric induction

This list of measures and general tendencies serves for a first orientation only. In partcular the stated impacts are meant to illustrate tendencies, but actual figures are highly dependent on the specific application.

5.1.2 Solution 1: Mass Reduction of Moving Parts[18]

5.1.2.1 Introduction

Finding generally valid energy efficient measures for every production facility is difficult. However, most machines have similar movement generation and allow therefore energy savings through the reduction of moving masses of machine tools. In the same time, longer durability of machine parts can be achieved due to smaller load.

The disadvantages of those lightweight constructions are mostly the flexibility regarding applied forces and the enhanced tendency to oscillate caused by a lack of damping. In order to counteract these negative effects of weight reduction, oscillations have to be actively suppressed, isolated or the excitation of vibrations has to be avoided.

This problem was approached within the project EcoFit which started in 2005, and was funded by the European Union. An international workgroup pursued the objective to drastically reduce moving masses of machine tools while maintaining machine accuracy and productivity. Any noted disadvantages were to be compensated via control engineering measures, using minimal energy expenditure.

18 This solution has an important restriction. Light Weight Design is applicable for light metals only in metal working processes. Nickel based alloys, Tool Steel, ADI, GJV and GJS cannot be cut with Lightweight Design Machine Tools.

5.1.2.2 Measures for mass reduction

Modern machine tools have to meet requirements such as accuracy, productivity and reliability. Due to these continuously increasing demands, extremely stiff mechanical systems are implemented with the capability to absorb arising inertia forces. As a consequence, the masses of the machine structure, such as moving machine components, have to be increased. Here, the majority of the mass serves the dynamic stiffness, whereas a fractional part performs kinematic tasks. The high amount of masses, in turn, require motors with high torque output which are able to increase the forces needed during acceleration and deceleration. Therefore, high energy consumption and costs arise.

In order to reduce machine masses and realize energy savings, two strategies can be pursued in the same time:

- Replacement of currently-used materials with lightweight alternatives.
- Structured optimization of machine components, allowing material reduction.

Both possibilities were examined within the project EcoFit.

5.1.2.3 Replacement of currently implemented materials with lightweight alternatives

An overview of different lightweight materials illustrates that not only the material characteristics but also the specific costs and the technical mastery are of high relevance when choosing a potential material. Therefore, it can be expected that titanium and carbon fibre reinforced carbon (CFRC) materials are only used in special cases. The higher the technological sophistication, the greater will be the use of hybrid structures of aluminium, polymer cement, steel and technical ceramics for lightweight constructions[19].

An example for weight reduction through the implementation of lightweight materials is given in the following:

A clamping device made of carbon fibre instead of steel is up to two-thirds lighter, and is even stronger and more rigid – with identical clamping force values.

19 P. Sekler,A. Dietmair,A. Dadalau, H. Rüdele,J. Zulaika,J. Smolik,A. Bustillo: Energieeffiziente Maschinen durch Massenreduktion, in Werkstattstechnik online, p. 320-327, Düsseldorf, 2007



Figure 5-3: Weight reduction of clamping device (source: Hainbuch)

Using a lathe, the time for spindle acceleration to maximum speed can be reduced by 30 % (see Figure 5-4). Therefore energy savings of 6 % are possible, assuming a machining time of 60 seconds and 20 % of braking and acceleration time for the machine spindle.[20]

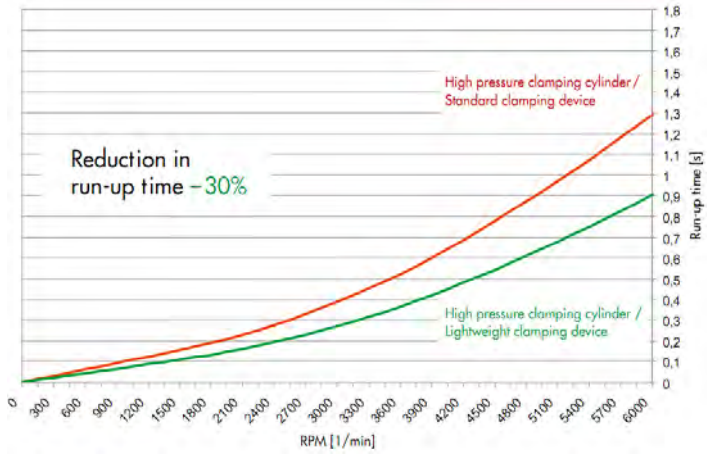


Figure 5-4: Standard and lightweight construction compared

Aluminium foam for moving parts can achieve significant energy savings. An example is the slides of a milling machine, produced since 2004[21]. These machine slides are 28% lighter than conventional slides and features higher speeds and acceleration than a massive slider, therefore also increasing the productivity of the machine tool.

Another example for the mass reduction of machine parts is given by a leading manufacturer of machine tools for sheet metal processing and laser-based production processes[22]. In cooperation with the Fraunhofer IWU, using a carbon fibre reinforced mate-

20 Hainbuch: Lighter and Easier, on the internet: www.hainbuch.com/cms/upload/english/brochures/HAINBUCH_CFK_en.pdf, last access: 22.12.2010

21 Machine tool: MIKRON HPM 1850U

22 Trumpf Sachsen GmbH, Neukirch, Germany

rial a crossbar of a laser cutting machine has been developed. This CFRC material is superior to metallic materials in many ways (e.g. stiffness, stability, damping, fatigue strength, thermal expansion). Through these advantages not only a mass reduction of 50 % has been achieved, but also a doubling of the component stiffness.[23]A further possibility to reduce weight is the use of polymer concrete structures for machine beds. Compared to steel structures, polymer concrete structures offer favourable characteristics in terms of heat conductivity and damping. However, these aspects must be analysed with due care throughout machinery design. Additionally, considerably less energy is required to produce a polymer concrete structure, and prices are less subject to market changes. Table 5-2 compares the properties of a steel structure with a polymer concrete structure and the environmental impact which arise in the manufacturing phase. Polymer concrete is produced with mineral aggregates, which are crushed to meet specific grain size, then washed and dried, before mixing with an epoxy resin at ambient temperature. Resin degassing and vibratory compaction during the moulding process allows for a more homogeneous and compact casting, free of air pockets. There are several recipes for epoxy polymer concrete, each one with different properties and customized for specific applications. [24]

Potential limitations to the use of polymer concrete include:

- Resistance to flame combustion: Direct impact of thermal beams on the structure should be avoided.
- Shrinkage: Might represent a problem in thick structures; high contraction leads to internal cracking appearance.
- Extra thermal processes: Although curing typically takes place at room temperature, some resin systems are heat-treated for added strength and stability.[25]

Table 5-2: Material Properties for Steel Structures and Polymer Concrete Structures[26]

23 Meltke, R.: CFK-Querbalken einer Trumpf-Laserschneidanlage, on the internet: http://publica.fraunhofer.de/eprints/urn:nbn:de:0011-n-1462706.pdf, last access: 7.01.2011

24 Ana Reis (expert appointed by ECOS - the European Environmental Citizen's Organization for Standardisation - to follow the preparatory study)

25 Ana Reis

Criteria	Cast Iron	Welded Base	Mineral Casting
Stiffness	High	Very High	Very Low
Dampening	Medium	Low	High
Thermal Stability	Fast reaction	Fast reaction	Slow reaction
Design Freedom	Less restricted	Restricted	Less restricted
Surface Quality	Low	Medium	High
Re-build	Good	Good	Possible
Lead Time	Very long	Medium	Short
Environmental Aspects	High initial energy consumption to build	High initial energy consumption to build	Low initial energy consumption

There are machinery manufacturers (e.g. from the wood working machine tools segment), which offer a broad range of machine tools with the machine bed made of mineral material, claiming a significantly lower primary energy consumption for the production of the mineral material compared to conventional steel-made machine beds[27]: The mineral material is stated to consume only 28% of the primary energy used for the same amount of steel.

The usage of lightweight materials in principle is possible for all machine tools with moving parts as long as reliability and performance are not hampered. The introduction of new materials, such as reinforced polymer, or carbon fibre materials and light-weight metals necessarily requires a thorough analysis of environmental, technical and cost impacts. For instance, lightweight materials are typically more costly than conventional materials.

In combination with other measures, the savings potential of lightweight materials reduces the energy savings effect of e.g. highly efficient motors and drives and recovery of breaking energy.

26 Ana Reis; Conrad, K.-J.: Taschenbuch der Werkzeugmaschinen. 2. Aufl. München: Carl Hanser Verlag, 2006

27 HOMAG Group: ecoPlus – Technology that really pays off, p. 19

Reis points out the following environmental aspects related to polymer concrete (based on a study by INEGI[28]):

- *Embedded Energy: The energy requirements to produce a polymer concrete structure is estimated as about 25% of that needed to produce an equivalent welded steel structure.*
- *Process steps/Production time reduction: Since mineral casted structures can be produced in a single-step, they are substantially faster available than traditional casting or steel welded parts. Normally the curing process can take up to 24 h. The cold casting process has no need for additional heat introduction, thus allowing energy to be saved.*
- *Lifetime/Chemical Resistance: Polymer concrete is chemically inert against aggressive materials such as oils, caustic solutions, acids and liquid-coolants.*
- *Recyclability: Polymer concrete can be deposited and potentially recycled. If crushed it can be re-used as a mineral casting filler.* [Remark by Fraunhofer: It should be acknowledged, that steel machine constructions can be recycled easily as secondary steel, whereas the recyclability and the recycling value of polymer concrete might be limited and, if at all, down-cycling can be anticipated as the most likely end-of-life scenario]

The results of the LCA study carried out (based on Eco-Indicator99), comparing the current steel welded structure and the polymer concrete alternative, are presented in Figure 5-5, and clearly confirm polymer concrete as a far more eco-friendly solution than the current welded-steel solution.

28 Unpublished source: Figueira J., Local manufacturer internal viability study of polymer concrete for machine-tools, 2010; no further details on machinery type provided

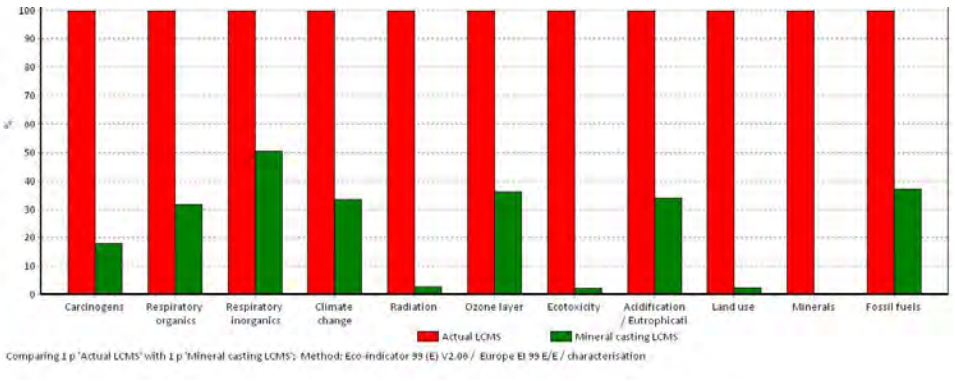


Figure 5-5: LCA results of the comparison between machines with steel welded and polymer concrete (mineral casting) structures

5.1.2.4 Structure optimization of machine components which allow material reduction

Another possibility to reduce the machine tool weight of moving parts, and to minimize energy consumption and costs, is by optimization of the structure. Crucial factors for evaluating structure quality are the following:

- mass
- static stiffness (tool deviation from the predefined path caused by applied forces)
- natural frequencies (definition of the dynamic and behaviour in the closed control loop)
- deflection (result of dead weight during acceleration).

Relating these factors satisfactorily should result in a measure for realizing a mass with the required needed characteristics.

Traditionally, the design engineer carries out these structure optimizations with the help of his/ her practical knowledge. In the past, several methods for automated topology optimization were increasingly developed and applied. Using finite element method (FEM) calculations, iterative adjustments of the initial structure to the reduced amount

of materials can be realized. Here, the result of the adjustments does not influence the mechanical characteristics of the materials.[29]

Mass reduction, i.e. mass optimization, is - in principle - possible for all machine tools. Besides the potentially additional design efforts there are no additional costs of implementing this option. On the contrary, material savings are directly related to cost savings.

5.1.3 Solution 2: Software-based Energy Management including Stand-By Mode[30]

5.1.3.1 Introduction

Measurements in the automotive industry have shown that the energy consumption in production during non-productive times still represents 60 % of the demand in normal production times.[31] Through the implementation of intelligent stand-by modes, which allow the user to set default times for shut-down of various machine units, energy savings can be achieved. The extension of these modes with “wake-up and warm-up” functions enables the machine to be set to operational status at a defined point, and to automatically heat up to the operating temperature.[32]

A German manufacturer of drive and control systems[33] offers a Stand-by manager for machine tools which switches automatically to stand-by mode when longer periods of inactivity occur. The possibility to manually configure Stand-by times (e.g. part shortages or end of a shift) by the user is also possible. During test periods with this manager implemented in a machining centre (MAG XS 211), the Institute for Production

29 P. Sekler, A. Dietmair, A. Dadalau, H. Rüdele, J. Zulaika, J. Smolik, A. Bustillo: Energieeffiziente Maschinen durch Massenreduktion, in Werkstattstechnik online, p. 320-327, Düsseldorf, 2007

30 Result of the questionnaire: over 40 % offer this solution

31 Sigma Pool: Sigma REPORT Nr.19, p.5, Vol. 19, 2010

32 Deckel Maho Gildemeister: DMG EnergySave, on the internet: http://www.dmg.com/presse_id,d1204024fd31842ac125772a00480938?opendocument&p=3&kap=$$$$$, last access: 22.12.2010

33 Bosch Rexroth AG, Lohr am Main, Germany

Management (PTW) in Darmstadt realized energy savings of 23 % of total energy consumption during three shift operation.[34]

5.1.3.2 Solution areas

- **Energy monitoring**: Software-based energy monitoring programs enable the user to gain detailed insights into the energy consumption of the production process. Thus, by making energy flows transparent, subsequent economic and ecological measures can be taken. With regard to the ecological relevancy, major areas of energy consumption (at the machine or component level) can be identified. Currently, there is a broad range of energy monitoring software available on the market, some of which additionally include intelligent add-ons, e.g. supporting applications for efficient process management and optimization. To name a few on a holistic level (meaning whole production plants), there are b.data (mainly for economical purposes), SIMATIC powerrate, SIMATIC PCS 7, and SIMATIC WinCC[35]. It should be pointed out that so-called TCO (total cost of ownership) programs also contribute to better energy management, also from an environmental point of view, as major energy consumers are identified and depicted in monetary values.
- **Machine stand-by management:** There are several products for the automated minimization of energy consumption in idle periods, e.g. DMG AUTO-shutdown by a leading manufacturer of metal working machine tools[36] or HOLZMA ecoLine by a manufacturer of woodworking machines[37]. Another wood working machinery manufacturer implemented an eco-mode for its edge banding machines, which turns off all drives except the heating of the gluing unit as soon as workpieces cease to be fed into the machine, and, if no workpiece is processed during the following 6 minutes, the heating unit is also switched off, resulting in an almost 100% reduced power consumption compared to the operational mode[38]. In extension to a machine's stand-by mode, a

34 Rothenbücher, S.; Kuhrke, B.: Energiebündel auf dem Prüfstand, Zeitschrift für spanende Fertigung Werkstatt+Betrieb, S. 130-137, 143. Jahrgang, September 2010

35 Siemens AG, München, Germany products

36 Gildemeister AG, Bielefeld, Germany

37 Holzma Plattenaufteiltechnik GmbH, Calw-Holzbronn, Germany

38 HOLZ-HER: Energieeffizienz von HOLZ-HER-Kantenanleimmaschinen, letter to customers, July 8, 2011

further distinction among operating modes increases the energy efficiency. For example, the operating modes can be divided into stand-by, warm-up, idle, and productive modes. As energy losses due to base load have been identified as a core source of energy wastage, research activities have increased in the field of intelligent stand-by modes (current research projects will be discussed in detail in 5.1.12.5). PROFIenergy by a German manufacturer of drive and automation systems and software solutions[39] goes beyond energy management systems for single machines. It is specifically designed for the overall energy monitoring of the whole plant, including auxiliary consumption, such as lighting and ventilation units. In extension to machine related stand-by management systems, in which unnecessary components during idle periods are switched off, plant-related systems also control logistic systems, whole production islands and transfer lines. To facilitate the integration into an existing production plant, PROFIenergy is a data interface based on the industrial Ethernet standard PROFINET.

- **Energy optimized motion control:** By the aid of control integrated tools, cycle times and energy consumption for each NC set can be analyzed. This way, developers have to define the energy efficient sequence of motions for machining. In this regard, a German manufacturer of drive and control systems[40] offers the following products:
  - *IndraMotion MTX cta*
  - *IndraMotion MTX ega*

Software-based energy management is applicable for all CNC machine tools. Software related costs are relevant, and it might be necessary to equip machinery components with additional sensors to control these modules.

39 Siemens AG, München, Germany

40 Bosch Rexroth AG, Lohr am Main, Germany

5.1.4 Solution 3: Energy Recuperation of Drives and Power Electronics, and Super Premium Efficiency Motors

5.1.4.1 Introduction

After every acceleration process of a drive, a braking process is needed. The energy from the drives' moving masses can largely be reconverted to electrical energy.

There are already existing CNC controls which are designed for regenerative and non-regenerative breaking. Braking resistors transform the kinetic energy arising from the braking process into heat in the non-regenerative supply module. A regenerative supply module instead returns this energy to the power grid. The decision regarding whether to choose one of these modules depends on the expected type of machine operations. An important factor to take into account regarding energy consumption is the expected number of tool exchanges.

The following example explains the differences between these two modules in more detail: A milling operation with 15 kW power consumption is interrupted cyclically by a tool change. Starting the spindle requires a peak power of approx. 60 kW. Whilst the regenerative supply module briefly returns 48 kW to grid power, with the non-regenerative supply module, the kinetic energy is converted to heat. Due to the high power requirement of metal cutting, the more frequently the milling process is interrupted by tool changes, the more that the mean input power requirement is reduced. The regenerative supply module works more efficiently as soon as the time interval between two tool changes is less than 100 s (equals 0.6 tool changes per minute). In processes with many tool changes per minute, a regenerative supply module often proves to be the better choice. During contour milling with infrequent tool changes, the advantages are on the side of the non-regenerative system[41].

41 HEIDENHAIN: Aspects of Energy Efficiency in Machine Tools, November 2010, on the internet: http://www.heidenhain.it/fileadmin/pdb/media/img/Energieeffizienz_WZM_en.pdf, last access: 22.12.2010

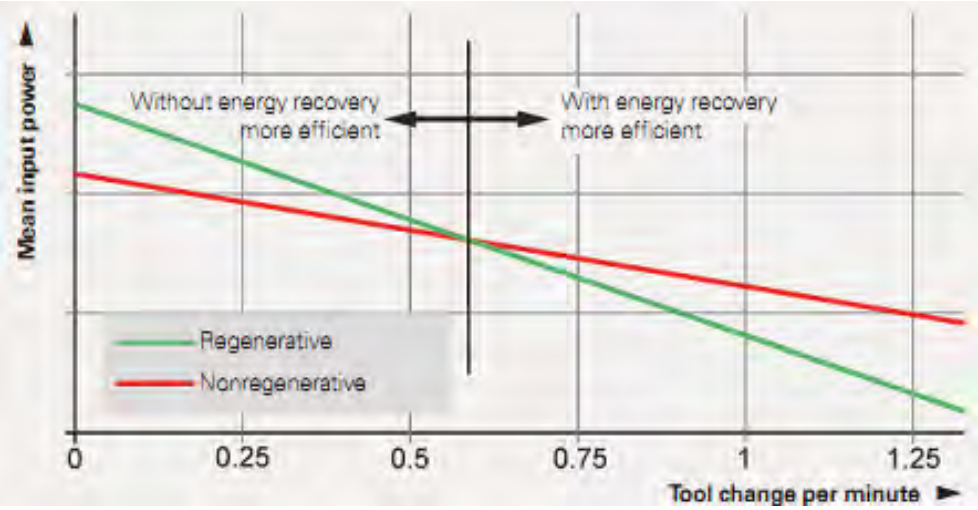


Figure 5-6: Efficiency analysis of a supply module in the version with and without regenerative braking (source: HEIDENHAIN)

5.1.4.2 Main drives/feed drives/drives in other sub-systems and transmission

The following BATs apply for main and feed drives of machine tools, as well as for those of hydraulic and pneumatic systems (e.g. incorporated in pressured air units, lubrication units, disposal units, etc.). Drives and electric motors in particular are of special interest due to the fact that they are the main supplier of mechanical energy for machine tools; thus, they are an important energy consumption source, and determine the energy efficiency of components connected to them, such as pumps, compressors, spindles, and the like. Such circumstances are depicted in Figure 5-7.[42]

[42] Note: The inherent performance improvement of particular electric motors has already been subject to legislation, as described in Task 1.3.

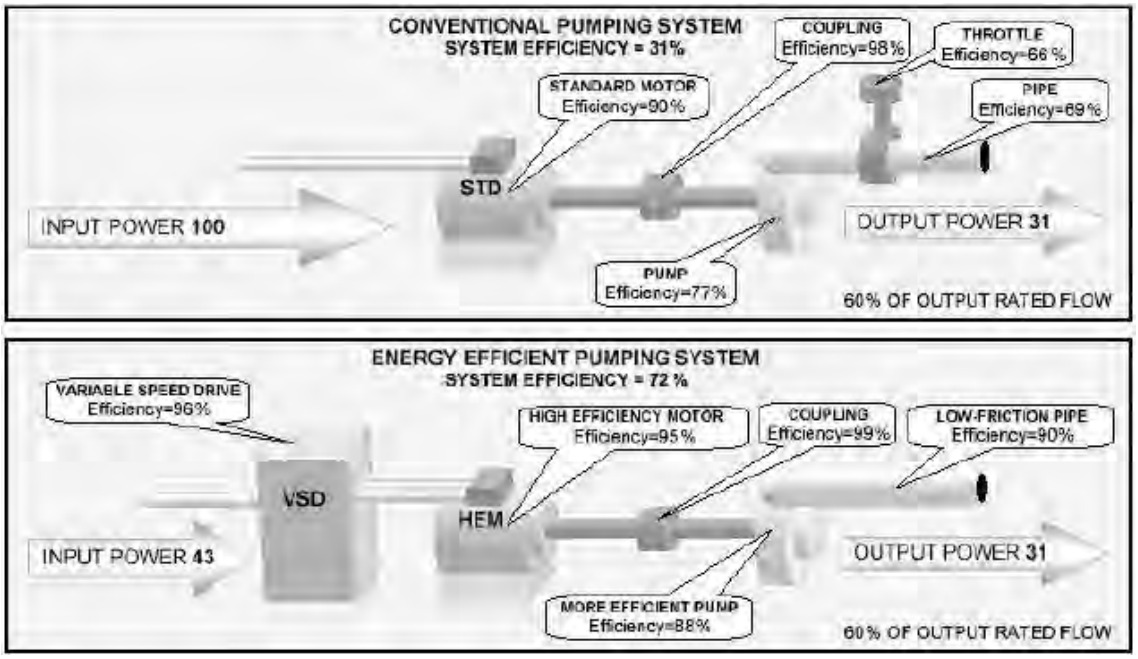


Figure 5-7: Comparison of conventional and energy efficient components[43]

- **Application specific design**: The over dimensioning of drives causes excessive energy consumption. Thus, application specific aspects should be involved during the design phase. Substituting the motor with a larger motor at the same current level results in increased energy efficiency due to reduced ohmic losses. There are several software tools on the market supporting application specific design[44]. However, CLASP states in a stakeholder comment: “From our experience, motor over-sizing is often over-stated, with induction motors having a similar efficiency at 50% to their performance at 100%. Since bigger motors are inherently more efficient, optimum sizing is not that critical except for applications where there will be widely varying loads with greater time at low power levels".

- **Speed control:** The control of engine speed enables the adequate and application specific supply of kinetic energy for various tasks. As far as AC (alternating voltage) motors are applied, this could be done by the use of frequency converters. For example, with regard to subsequent applications, the pressure

43 Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques for Energy Efficiency, 2008, p. 197.

44 there are several software tools on the market supporting application specific design, such as *IndraSize* by Bosch Rexroth AG, Lohr am Main, Germany, and Sizer by Siemens AG, München, Germany

range of a pneumatic system can be readjusted by means of a frequency converter to meet specific requirements[45]. “Speed control is only really relevant to auxiliary processes (…) . Many items on a machine tool have to be speed controlled anyway for their functionality, and so there is no further potential.”[46]

- **Direct drive instead of ball screw drives:** Besides higher robustness and less abrasive wear, if high feed forces (e.g. for high speed cutting) are applied, direct drives consume less energy than ball screw drives. This is due to the powertrain of ball screw drives, which heat up during processing.[47]

- **Brake energy feedback:** The infeed unit is capable of feeding back the braking energy to the main power supply. Differentiated by the power range of specific applications, there are several products already available, such as the Sinamics family by a German manufacturer of drive and automation systems and software solutions[48]**.** The power supply modules have to be designed both for regenerative and non-regenerative braking, which is typically the case already for CNC machine tools, to implement this feature. However, the energy savings effect again depends again on the application. Regarding milling operations, regenerative supplies save energy in processes experiencing numerous tool changes per minute[49], whereas in contour milling, where infrequent tool changes are common, non-regenerative systems are said to be probably the better choice[50].

- **Reducing maximal acceleration:** Reducing the maximum acceleration in the setpoint results in a better exploitation of the motor's efficiency. In this case, the overload capability of the motor is not utilized (CECIMO)

- **Reducing transmission losses:** If belt drives are applied for transmitting the mechanical energy away from the electric motor, conventional V-belts should be replaced by other belts whenever possible. Alternatives would be cogged V-

45 Product example: IndraDrive by Bosch Rexroth AG, Lohr am Main, Germany

46 Stakeholder comment by CLASP

47 Röders GmbH, Soltau, Germany

48 Siemens AG, München, Germany

49 Heidenhain identified for one use case a break-even-point at 0,6 tool changes per minute

50 Dr. Johannes Heidenhain GmbH, Heidenhain Corp. Schaumburg, Ill.: Even metal working operations can be optimized for energy efficiency with no adverse impact on productivity, Energy Efficiency & Technology, Sept 1, 2011

belts and synchronous belts. If applicable, direct coupling should be chosen (e.g. direct drives for spindles).[51]

- **Replacing inverter units:** Switching from 200V to 400V inverter units leads to an increase in energy efficiency due to a reduction of ohmic losses. (CECIMO)

Linear motion systems

In the field of linear motion systems for precision machine-tools, which include linear guides and the actuator, three principal kinematic solutions are widely used on the market:

- Linear guide, ballscrew and servomotor
- Linear guide, pinion-rack and servo-reducer + motor
- Linear guide and Direct drive (linear motor)

Field experience shows the favourite areas of application for these 3 technologies:

Stroke<6m low to average dynamic: ball screws

Stroke>6m average to high dynamic: rack and pinion with servo-reducer and motor

High to very high dynamic: linear motors

According to a statement provided by the French manufacturer REDEX "a solution based on rack and pinion with servo-reducer and motor has an optimal power consumption compared to direct drive solution since torque requirements in phases of acceleration and deceleration are lowered.

Another advantage is to provide smaller motors for the same application and, in turn, better power efficiency, smaller cables and drives.

Typical curves of torque vs. speed and automation laws (inertia matching) imply that servo-motor are equipped with reducers. Best eco-design practices imply using a high efficiency gearbox (planetary gearbox with optimized design)."[52],[53]

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51 BREF Energy Efficiency, p. 203, 2008

52 Example calculation by REDEX: 5% efficiency improvement on a 10kW motor and 30% use rate over 1 year means more than 1MWh saved per machine axis and per year.

53 The French manufacturer REDEX SA developed a range of high quality servo-planetary reducers specifically for multi-axis machine tools, which incorporate low friction seals, gear

For milling spindle heads REDEX describes the approach as follows:

“High quality reducers are requested for spindles (milling machines) when the torque has a high value (> 1000 Nm). High-torque motors and drives have poor efficiency and increase machine power consumption.

Due to very high spindle speeds (from 4000rpm up to 15000rpm) the main power loss factor in spindle reducers is oil splash. Efficient reducers should integrate a dry sump lubrication (oil mist spread on gears) to avoid power consumption due to oil bath stirring.

In that case, reducer is included inside the spindle axis. This solution provides dry sump lubrication and avoids thermal loss through splash lubrication. The total mass of the spindle axis is lowered in comparison of a solution with belt and pulleys.”

Bearings

- **Using low friction roller bearings:** Specific roller bearings technologies have a friction coefficient between 0.0004 and 0.001, while conventional slide guides offer a coefficient around 0.1.[54]

Advanced Power electronics

- **Avoidance of transformers:** Instead of using conventional transformers which have power losses of approximately 4 %, voltage-proof converters which are of higher efficiency should be used. (CECIMO)
- **Speed control / variation speed drives:** see Part / tool relative motions → Main drives/feed drives/drives in other sub-systems and transmission → Speed control.
- **Power factor correction:** There are certain products on the market which allow to increase the efficiency of energy transmission systems by automated power factor correction, for example:

  SINAMICS S120[55]

sets quality 5 (ISO 1328), low drag torques. According to the manufacturer, the yield of the reducer is increased by 2% minimum compared with a conventional planetary reducer. Average efficiency at nominal speed is superior to 97%.

54 Bosch Rexroth AG, Lohr am Main, Germany

55 Siemens AG, München, Germany

- **Latest generation IGBTs (Insulated-gate bipolar transistor):** IGBTs are the key semiconductor components for power electronics and determine with their electrical characteristics the efficiency of the power electronics circuitry. A manufacturer of semiconductors and system solutions for automotive and industrial electronics[56] claims to have reduced switching losses and increased efficiency to "best-in-class" for their IGBTs for 600 and 1200 V applications, which are common in e.g. welding equipment[57].

Efficiency of small motors

Larger motors in the range of several kW are those which dominate the energy consumption in machine tools, but for auxiliary systems and smaller machine tools (such as edge bending machines and planing machines) small motors below 750 W are also common. Numerous measures can be considered to improve the efficiency of these motors, but it depends highly on the actual use and application within a machine for which a motor is used, to judge, whether improvements are feasible, and if they may lead to relevant energy savings. Table 5-3 lists technical measures to reduce losses of small motors, although most of these approaches are applicable for larger motors as well.

Type of Loss to Reduce	Technology Option Applied
I^2R Losses[58]	Use copper die-cast rotor cage
	Remove skew on conductor cage
	Increase cross-sectional area of rotor conductor bars
	Increase end ring size
	Changing gauges of copper wire in stator
	Manipulate stator slot size
	Decrease the radial air gap
	Change run-capacitor rating
Core Losses	Improve grades of electrical steel
	Use thinner steel laminations
	Anneal steel laminations
	Add stack height (*i.e.*, length, add electrical steel lami-

56 Infineon Technologies AG, Neubiberg, Germany

57 Technology Media: Infineon Breaks Switching and Efficiency Limits with 3rd Generation High Speed 600 V and 1200 V IGBTs, May 5, 2010, http://www.infineon.com/cms/en/corporate/press/news/releases/2010/INFIMM201005-048.html, accessed January 17, 2011

58 electrical power loss caused by the current flowing through a component

	nations)
	Use high-efficiency lamination materials
	Use plastic bonded iron powder
Friction and Windage Losses	Use better bearings and lubricant
	Install a more efficient cooling system

Table 5-3: Summary of Technology Options for Improving Efficiency of Small Motors[59]

IE4 motors

- **Super premium efficiency motors complying with the IE4 level** as defined in Technical Specification IEC 60034-31 are just entering the market: Whereas ABB as one of the market leaders in motors in 2009 still stated, that IE4 motors are not yet on the market[60], in 2010 they introduced IE4 motors in the range from 75 to 355 kW output[61]. Similarly, WEG announced their range of IE4 motors for industrial applications with outputs of 0,37kW up to 7,5 kW in early 2011[62]. The IE4 level requires efficiency to be roughly 1 % above the IE3 for the higher output range. At the lower end the IE4 level is 4 % higher. The IE4 level is achievable with new motor technologies, such as permanent magnet synchronous motors, for which automation, pumps and CNC machines are fields of application, but which are more costly than conventional motors. Part-load efficiency is also stated as being much higher than with induction motors[63]. Switched reluctance motors are another emerging technology to achieve higher efficiency levels, but their main disadvantages comprise ripple torque, high vibration level and high acoustic noise.

59 U.S. Department of Energy: Small Electric Motors Final Rule Technical Support Document, Chapter 3: Market and Technology Assessment, March 9, 2010, Washington D.C.

60 ABB: Fachwissen IEC 60034-30 Norm zu den Wirkungsgradklassen für Niederspannungsmotoren, 2009

61 Efficiency regulations for low voltage motors, ABB external presentation, July, 2010

62 WEG's new WQuattro Super Premium Efficiency motor exceeds the requirements of impending IE4 classification, January 12, 2011, http://www.weg.net/se/Media-Center/News/Products-Solutions/WEG-s-new-WQuattro-Super-Premium-Efficiency-motor-exceeds-the-requirements-of-impending-IE4-classification

63 De Almeida, A.: Overview of Energy Saving Motor Technologies Emerging on the Market, Motor Summit 2010, October 28, 2010, Zurich, http://www.motorsystems.org/files/otherfiles/0000/0051/EMSA_G_Session1_Almedia_Technologies.pdf

Considering the complete drive system, basic approaches for improving energy efficiency of drives are listed inTable 5-4.

Motors (types, engineering design)
• Energy efficient motors (e.g., Cu rotors, lamination stacks) • Use of permanent magnets • Superconductivity (e.g. superconductive windings, bearings, …) • Selection of suitable motor type
Drive, power converter
• Efficient partial load operation • Starting, acceleration, breaking, stopping (ramping) • Operation control, idling • Power converter component innovations (e.g., IGBT, diodes, SiC,…) • Improvement of circuit topology (e.g., resonant, matrix,…) • Power drive design (e.g., line-frequency rectifier switching) • Regenerative drives
Drive system engineering
• System component selection (selection of motor, gear, box, pipes) • Design, dimensioning (matched power rating) • Adapting to requirements of specific processes
Integration - mechatronics
• Direct drives (replacement of gear boxes by speed control) • Compact drives (motor and power drive integration) • Enhanced functionalities relevant for energy consumption

Table 5-4: Summary of Basic Approaches for Improving Energy Efficiency of Drives[64]

64 ECPE: Power Electronics Potentials and Basic Political Conditions for Improving Energy Efficiency of Electric Devices, 2009

5.1.5 Solution 4: Tool Handling and Clamping

5.1.5.1 Metalworking machine tools

- **Clamping devices:** Clamping tools can be designed e.g. as hydraulic, pneumatic or electro-mechanical clamping devices. Electro-mechanical, pneumatic as well as hydraulic systems can be optimized e.g. by eliminating energy consumption in idle conditions. For hydraulic systems this can be done by storing energy, e.g. in accumulators, or by using load sensing pump systems (see numerous options mentioned in sub-sections 5.1.6.2 Hydraulic Modules/Systems and 5.1.6.3 Pneumatic Modules/Systems). Which technology the machine tool manufacturer may choose depends on several factors, e.g. dimensions and weight of the work piece. Other aspects are the reliability or the durability reached by applying maintenance measures. These are proved for hydraulic systems. Most of the machine tools are equipped with hydraulic clamping devices [S032_MM-005.2012][65]. There are a few companies offering electro-mechanical clamping devices[66,67,68]. Manufacturers of electro-mechanical clamping devices claim as advantages a higher degree of adjustability, and leaner machine design due to the omission of the hydraulic unit[69], and reduced maintenance costs, but these claims were not verified by the study authors nor is there any other published scientific or independent verification to substantiate the claims made by the providers of electrical clamping devices. On the other hand, hydraulic systems can provide high forces within limited spaces, due to their physical characteristics. In conclusion, a comparison of the energy consumption of hydraulic, pneumatic and electro-mechanical clamping systems is not possible, in general. Such an energy comparison has to be done on a case

65 MM-Round-Table-Gespräch: Hydraulik fordert Elektromechanik in der Energieeffizienz heraus, MM MaschinenMarkt 5 2012, p. 32-35

66 E-Quipment, see http://www.roehm-spanntechnik.ch/fileadmin/Downloads/Produkte/Flyer_E-QUIPMENT_de_web.pdf, accessed January 17, 2011.

67 iJaw, see http://www.forkardt.com/news/ijaw/ijaw_flyer_e.pdf, accessed January 17, 2011.

68 electromechanical actuators by Hainbuch, see http://www.hainbuch.com/7/products/clamping-cylinders/electromechanical-actuators436/, accessed January 17, 2011.

69 Which might result in less material consumption for machinery design

by case basis, taking into account the relative advantages of the different technologies, with regard to the whole machine tool.

- **Energy-efficient part fixing:** Other market solutions for energy-efficient part fixing in milling machine tools and machining centres are rotary tables, combining electromechanical and/or hydraulic indexing for high accuracy, absorption of high forces and torques as well as good response behaviour. Self-impeding fixtures, and friction-reduced guidance, are used for decreasing energy consumption.[70],[71],[72] ,[73],[74]

- **Efficient sealing of spindle systems:** To reduce operational costs, particularly for pressurized air in the field of spindle technology, an energy-efficient brush seal system has been developed by a German manufacturer of high precision spindles[75] as an alternative for air-lock systems (which require pressurized air), causing a reduction of pressurized air and subsequently additional energy supply down to zero. Several companies already take advantage of this technology.[76]

- **Using non-pneumatic lubrication systems for spindles:** For the bearing lubrication of spindles, another technology causing a minimal consumption of natural resources has been invented by a German manufacturer of high precision spindles[77]. As an alternative for oil-air-lubrication systems, permanent grease lubrication technologies do not cause additional energy demand. Cur-

70 See http://www.zollern.de/en/drive-technology/direct-drives.html, accessed August 25, 2011

71 See http://www.moriseiki.com/english/mail/user/ue0901a2ss/0901uec01.html, accessed August 25, 2011

72 See http://www.weiss-gmbh.de/New-Products.831.0.html?&L=1, accessed August 25, 2011

73 See http://www.fibro.de/folgeseite.asp?area=hauptmenue&site=pressemitteilungen&cls=02&id=44, accessed August 25, 2011

74 See http://www.rotary-table-1.com/nc-tilting-rotary-table/01.htm, accessed August 25, 2011

75 Weiss Spindeltechnologie GmbH, Schweinfurt, Germany

76 Heuchemer, B.: Energieeffizienz – Energiemanagement bei (Werkzeug-)Maschinen, Symposium „Energieeffiziente Werkzeugmaschinen“, Düsseldorf, February 24, 2010.

77 Weiss Spindeltechnologie GmbH, Schweinfurt, Germany

rently, this technology is partly spread among industry.[78] According to CETOP and VDMA (Fluidtechnik)[79] oil-air lubrication is considered indispensable for high speed cutting applications: The only way to reduce energy [consumption] is to use oil with lower viscosity and to reduce air pressure. The oil contamination of work pieces can be reduced or prevented by optimized seals.

- **Multi spindle systems:** Besides reducing machining intervals and downtimes, multi spindle systems significantly reduce the overall energy consumption of machining centres. As an example, the energy demand of a two spindle system is only 20 % higher than that of a single spindle system, which is basically due to the high energy demand for base load operation and peripheral systems. Examining the energy usage per workpiece, the machining process requires 40 % less energy.[80]

5.1.5.2 Woodworking machine tools

- **Reducing noise emissions:** Vacuum clamping systems are predominately used during the machining of composite boards, leading to vibration and noise disturbances. This can be avoided by applying an active clamping device based on piezo-stack actuators.[81] This option is a variant of the electrical clamping option described for metal working machine tools, as above.

5.1.6 Solution 5: Optimized Hydraulic and Pneumatic Systems

5.1.6.1 Introduction

In the field of hydraulic systems, several products featuring environmental improvements are already placed in the market. Either on-off mode or variable speed drive can be used to reduce the energy consumption of such hydraulic systems. As a case study example, the characteristic power consumption and hydraulic pressure of a conventional hydraulic pump for a typical application scenario is depicted in Figure 5-8.

78 Heuchemer, B., ref 76.

79 Stakeholder comments

80 Heisel U., Stehle, T., ref 8, p. 197ff.

81 Hesselbach et al., Development of an active clamping system for noise and vibration reduction, CIRP Annals - Manufacturing Technology, Volume 59, Issue 1, 2010

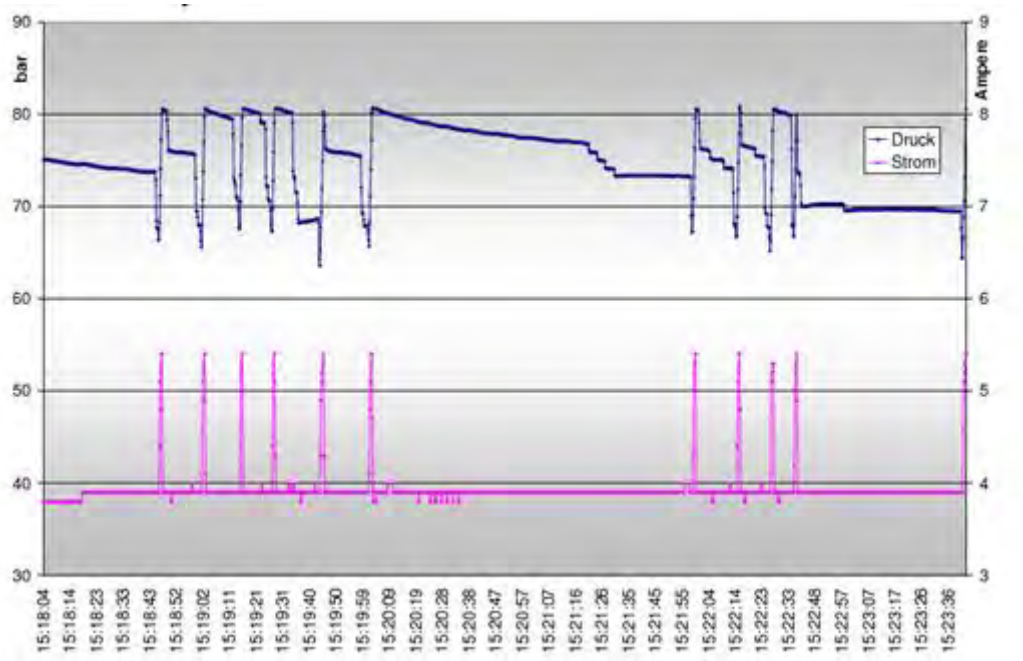
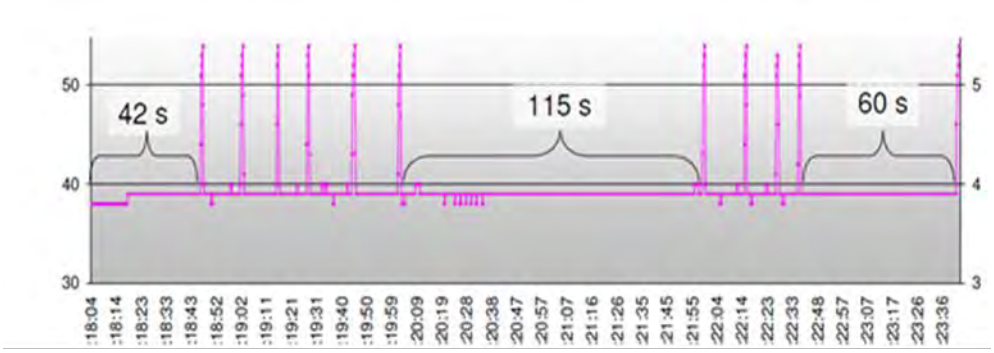


Figure 5-8: Power consumption and hydraulic pressure during conventional pump operation[82]

In Figure 5-9, for the same operation scenario, energy savings are calculated resulting from the incorporation of on/off switching in non-productive times, accounting for 25% of the total energy consumption.

82 Stakeholder Comment HYDAC / VDMA, e-mail M. Scheidt, March 13, 2012



- **Saving potential when switching off for 217sec:**
  - 25% of P(n)=163 KJ / cycle
- **Saving potential**: 4165 kWh → 416 €
- **Additional investment costs**: One-time adjustment of the control

Figure 5-9: Energy savings for a hydraulic pump by switching off in non productive times[83]

Saving resources through the variability of process parameters is furthermore recognized by the hydraulic industry. Anecdotally, besides providing additional flexibility for the user (e.g. by choosing application specific operating points regarding flow rate and pressure), savings between 50 % and 70 % compared to a conventional hydraulic system are claimed by a provider of screw spindle pumps, which are applied in machine tools usually for lubrication systems).[84] These significant differences are primarily attributed to the use of frequency converters, which enable speed adaption. As far as today's hydraulic and pump system industry is concerned, which is partly involved in the machine tool market as suppliers of sub systems, the subject of environmentally-compatible products has already reached the market, not least because of the implementation of ecodesign requirements for electric motors (Commission Regulation (EC) No 640/2009). The advertisement of environmentally-friendly product features is furthermore adapted as part of the marketing strategy, e.g. the Blueflux technology series by a Danish manufacturer of pumps[85]: Motors for pump systems introduced to the

83 Stakeholder Comment HYDAC / VDMA, e-mail M. Scheidt, March 13, 2012

84 Knoll Maschinenbau GmbH, Screw spindle pumps type KTS, Issue 10-2010, http://www.knollmb.de/fileadmin/knoll_mb/pumpen/dokumente/DB_KTS_DE.pdf, accessed January 17, 2011.

85 Grundfos Holding A/S, Bjerringbro, Denmark

market in 2011 are already compliant with the 2017 requirements of the EuP motors implementing measure (namely, that motors from 0.75-375 kW must either meet the IE3 standard, or the IE2 standard equipped with a variable frequency drive [VFD])[86].

Besides the energy aspect of fluid systems, the analysis of hydraulic oil consumption for press brakes / bending machine tools / hydraulic presses (Task 4, Base Case 3[87]) revealed the moderate environmental relevancy of upstream mineral oil production for hydraulics, in some of the impact categories. Some measures may be undertaken to reduce hydraulic oil consumption, and thus also waste oil generation, which comprise: usage of external oil purifiers, or usage of hydraulic oils with better characteristics (e.g., high oxidation resistance, enhanced antiwear and rust protection etc). These measures should result in longer replacement cycles, but should not adversely affect process performance. However, it should be noted that these measures are not related to the machinery design per se, and are thus not implicated in any design options.

5.1.6.2 Hydraulic Modules / Systems

The following list of approaches was provided by VDMA Fluidtechnik, and revised based on feedback and requests for clarifications by other stakeholders.

The energy efficiency of hydraulic and pneumatic modules / systems significantly depends on its specified function. The more detailed the specification (e.g. level of automation, precision, quality, etc.), the more efficient the system can be designed. This comprises the optimal choice of the auxiliary devices (axial pumps, gear pumps, vane pumps, etc.), the pump system (several or one single pump), the pump size, and the motor (both to avoid over-dimensioning, and to reach high efficiency). It depends on the application as to which of the measures listed below can be used, and to what extent improvements can be achieved, via their use.

- **Optimized cooling of the motor:** To improve the cooling capacity, the motor can be integrated into the oil reservoir. Hence, the motor can be run above the nominal point, which makes it possible to use smaller motors. Moving masses as well as the starting current are reduced.

86 http://energy.grundfos.com/en/high-efficiency-motor-technology/grundfos-blueflux%C2%AE--eup-ready-pumps, accessed January 17, 2011.

87 Note also, that in case of the machining centre (Base Case 1) and other Base Cases, hydraulic oil has a minor environmental impact according to the analysis in Task 4

- **Adaptable levels of pressure:** Pressure adjustment using adjustable pressure valves or zero-pressure circulation.
- **Pressure adjustments for different actuators:** To avoid losses due to pressure reduction, all actuators should be designed for a mutual level of pressure. If not applicable, pressure-controlled drive systems should be integrated to provide the adequate amount of energy for each sub-process. Alternatively, a pressure intensifier can be used.
- **Use of hydraulic accumulators:** Hydraulic accumulators can be used for temporary storage of hydraulic energy, to achieve the best possible match between the pump drive (accumulator charging circuits) and the load cycle, and to compensate for demand peaks (so that drives and pumps with a lower output rating can be used).
- **Adaptable levels of flow rate:** The use of throttle control for a hydraulic system leads to throttle and bypass losses. These losses vanish if the control system is replaced by displacement control. Alternatively, the volume flow can be controlled by means of variable speed drives.
- **Reducing inner leakages:** E.g. by the use of poppet valves in the accumulator charging circuit, leading to fewer reload intervals, and thus less use of the motor or leakage optimised spool valves.
- **Use of optimized valves:** For example, impulse valves (energy demand only during switching procedure), valve connectors with automated reduction of the holding current (reducing energy demand), and valves with 8 Watt magnets (reducing energy demand).
- **Use of hydraulic clamping tools:** Hydraulic clamping tools which consist of cylinder and poppet vales are almost completely closed, meaning that nearly no further energy is needed during clamping.
- **Extending the field of application of hydraulics:** The efficiency can be raised if additional tasks are carried out by the hydraulic system, which may also lead to a reduction in equipment of other modules (e.g. by taking over the generation of high pressure of cooling lubricants).
- **Prevention of nipple collapse:** Flexible hydraulic line systems have a bottleneck at the connection point between the fitting and line owing to their design, which causes considerable shortfalls in efficiency in hydraulic systems. The

pressing in of the hose and connecting fitting additionally aggravates the bottleneck situation as a result of the collapsing nipple. During nipple collapse the cross-section of the orthogonal flow direction is reduced. The flow pressure and velocity deviates from the given optimum. Using self-adjusting press-fit- socket hoses, the bottleneck can be substantially relieved (see Figure 5-10).[88]

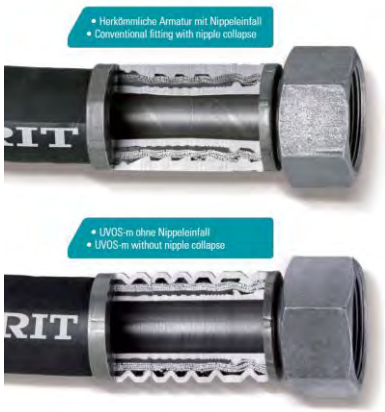


Figure 5-10: Fitting with and without nipple collapse.[89]

Variable speed drives (VSDs) for pumps in hydraulic systems are most relevant where a machine works with varying volume flows. This is typically the case for primary shaping processes, such as injection moulding and die casting, where energy savings potentials of 80% are stated, solely from the introduction of VSD[90,91]. For such types of machinery the payback time is said to be less than one year.

BATs for hydraulic systems are relevant for almost all CNC machine tools.

5.1.6.3 Pneumatic Modules / Systems

The first step in achieving energy saving is to optimize the size of the pneumatic system (after the air compressor) by taking into account the flow characteristics of compo-

88 Voswinkel GmbH, Meinerzhagen, Germany

89 Voswinkel news, on the internet: http://www.voswinkel.net/fileadmin/_elemente/presse/2010-06-16_VOSWINKEL_News_2010.pdf, accessed: 24.10.2011

90 Schmidt, S.: Interview “Amortisation meist schon im ersten Betriebsjahr durch Energieeinsparung”, Industrieanzeiger Nr. 15/KW 25/2010, stated example is a die cast machine, for which installed load could be reduced from 11 kW to 1,7 kW

91 Note that machine tools for primary shaping as such are not in the scope of this study as a “machine tool”, but the hydraulics system is considered a module in “related machinery”

nents, and by using proprietary sizing software. The following improvement suggestions for increased energy efficiency of pneumatic systems are derive from the research project EnEffaH (Energy efficiency in manufacturing in the area of drive and handling technology)[92], and were revised according to additional stakeholder comments received in the course of the study:

- **Application-specific dimensioning**: This means ensuring that pneumatic cylinders are sized to produce the force that is required. Oversizing cylinders leads to increased consumption of compressed air, which is then wasted.
- **Energy-optimized engineering of the machinery:** Drives are frequently overdimensioned, which leads to a higher air demand, and hence energy loss. As a consequence it is important to adjust the pneumatic system to the specific needs. Targeting a pressure reduction to the majority of equipment may allow the installation and use of a pressure booster to smaller air consumers at higher pressure requirements (for example pneumatic clamps). Such equipment suits elements where higher pressure is needed.
- **Application-specific compressed air quality**: To meet the demands of specific applications, the compressed air runs through a drying process and several filter stages. The number of filter stages significantly influences the energy demand of the system. Hence, centralized treatment of compressed air can be a beneficial option. Reducing impurities in the air taken in by the compressor can improve system efficiency, and can increase the life and performance of end-use equipment. Efficiency can be improved by:
    - Treating air to the minimum required standard
    - Correctly installing and maintaining the treatment system, and making sure it is adjusted following any change in demand
    - In all filter bowls the use of an automatic drain function increases filter efficiency, and reduces air loss
    - On compressors, ensure timed solenoid condensate drains are set correctly, or alternatively use more efficient no-loss type electric condensate drains

92 provided by Festo AG & Co. KG, Esslingen, Germany

- Use of differential manometers or element service indicators for filter element status monitoring, in order to reduce pressure losses.

- **Reducing tube length and diameter /dead volume:** If the distance between valve and cylinder increases, longer connecting tubes are needed. For each switching procedure, the pressured air within the tubes is accounted as dead volume and cannot be used for operation. By minimizing the length and diameter of tube lines within the pneumatic system, energy losses due to dead volume will be reduced to a minimum.

- **Minimizing losses due to leakages:** Leakages can lead to a significant over-consumption of energy. Possible measures would be the use of volume flow monitoring systems, which indicatively provide information about the existence of leakages, and the need to remove or close off unneeded compressed air lines. Direct investigation of leaks can be carried out e.g. by the aid of ultrasonic acoustic detectors.

- **Single acting pneumatic cylinder:** If only one drive chamber is needed, springs can be deployed for power absorption during the stroke motion. Thus, the return stroke is realized without the use of further air supply, but it has to be considered, that additional driving force is needed to compensate for the force exerted by the spring.

- **Pressure reduction (system):** Depending on the application, a reduction of the system air pressure level by e.g. 1 bar can reduce air consumption without unwanted performance losses.

- **Pressure reduction (non-productive times)**: In non-productive times, the air can be cut off, due to the fact that, generally, low pressure is sufficient to maintain sealing systems etc. when the machine is turned off or in low power mode.

- **Targeted cut-off from air supply:** If no retention forces are needed, as soon as the drive reaches the end position, the air supply can be cut-off by the valve, to avoid unnecessary pressure build-up within the drive chamber. This option can be integrated into the control of machine tools, and requires application-specific dimensioning of the pneumatic system, and optimised generation of pressure.

- **Use of multiple valves:** Using several different valves for a single pneumatic drive enables working with bridge circuits for more energy-efficient and productive operation. In this way, starting and brake movements can be optimized and

performed at short notice. The measure is designed to be integrated into the control of the machine tool. As this option is very specific and increases construction expenditure, its implementation is only useful for a rather small range of machine tools.

- **Pressure reduction:** Where the return stroke requires only minor forces, a pressure regulator consisting of two switching thresholds and some buffer capacity can be applied. It is important to keep certain security aspects in mind, related to the implementation of pressure reduction, and the need to ensure that the functionality of the cylinder prevails.
- **Sectorization of the pneumatic circuit**: The whole pneumatic circuit is not operative while the machine is in production mode. Sectorizing the circuit allows the shutting-off of those pneumatic elements that are not working, and thus reduces/eliminates leaks from those elements.
- **Optimized valve switching:** As the driving of valves requires electrical energy, it should be examined whether an energy-oriented switching strategy may significantly contribute to a decrease in energy consumption. However, it should be mentioned that this option affects only a small amount of machine tools and that it applies more to vacuum technology.
- **Blow Guns:** Blow guns are versatile in their usage, and are commonly used to clean components and surfaces. Having the blow gun fitted with a Venturi-type nozzle delivers the same performance with up to 30 % less air. Using multi-stage Venturi-type nozzles can result in operating efficiencies of 150 %. However, the VDMA states that the reduced use of air cannot be exactly assessed.[93]
- **Air ejectors:** Air ejectors with a Venturi-type nozzle deliver the same performance with up to 30 % less air. Again the VDMA states that the reduced use of air cannot be assessed exactly.[94]
- **Cascaded levels of pressured air:** For applications which are in need of multi-staged levels of pressure (e.g. in processing PET bottles), reusing the exhaust air from high pressure levels as supply air for those at lower levels may be considered. For such use cases (such as PET manufacturing), in which several

[93] VDMA Fluid Power / Power Transmission

[94] VDMA Fluid Power / Power Transmission

pressure levels are required, and play a dominating role, this option is already established to a great extent.

- **Variable speed compressors**: Adaptation of the speed of the compressor to the pneumatic requirements of the process eliminates unnecessary energy consumption and efficiency during part-load operation.
- **Start/Stop system for compressors**: Electronically-controlled start/stop strategies for compressors will disconnect compressors which are not necessary for completing the task, because of low air demand.
- **Choice of materials and light weight**: The component weight should be taken into account when sizing a system, due to the fact that heavier components can have the effect of oversizing the system.
- **Housekeeping and maintenance:** A well-maintained compressed air system needs less energy to deliver the required pressure and flow rate, by adopting best practices. By optimising system design performance, this will achieve better energy efficient results.[95]

In addition, there are some options which are currently technically realizable, but did not yet meet market maturity. In conclusion, the options listed in the following are rather to be considered as potential BATs in the following years.

- **Pneumatic cylinder with optimized drive surface:** For some applications, the maximum driving force is solely needed for one direction, such as for lifting operations. However, the same pressurized air is used for the back stroke. Despite that fact that the piston rod reduces the drive surface for the back stroke, it might be still over-dimensioned, so that pressure losses occur. By means of constructive adjustments, the drive surface for the return stroke can be downsized, which subsequently leads to reduced energy consumption. However, it should be pointed out that such design modifications conflict with industrial design standards for pneumatic cylinders, and therefore this measure does not have a potential for application in the foreseeable future. Hence this measure is to be considered a best not yet available technology (BNAT) - see 5.1.12.5.
- **Pneumatic cylinder with multiple chambers:** Multiple chambers in pneumatic cylinders are useful if multi-purpose processes are at hand. In this regard, the

95 Carbon Trust www.carbontrust.co.uk

adequate chamber is selected according to how much lifting force is required for the operation. Selecting a duplex or triplex actuator where a double or triple piston arrangement offers twice or three times the normal force, from the operating pressure, thus allowing for pressure reduction. At the moment, the implementation of this measure is hampered due to a shortened product life, which must first be solved. Accordingly, this option is to be considered a BNAT.

- **Using exhaust air:** Due to the fact that expansion work from the exhaust air is barely used, the incorporation of further modules for is usage could be considered. One module could be micro turbines[96] for energy recovery, to be placed at the vent connection. With regard to the costs associated with this measure, this approach is solely financially rewarding if large-scale recovery can be achieved. Alternatively, under the implementation of a closed pressured air circuit, the accumulated exhaust air could be returned to the compressor, and again be pressurized. This measure involves additional safety aspects which need to be considered. Also, the quality of the exhaust air and its suitability for further application in a circuit is important. Given the complexity that this approach adds to the machinery design, and the limited energy savings which could be achieved in theory (but no realisation of such a system is as yet known), this option will not be evaluated further.

Deriving from the Reference Document on Best Available Techniques (BREF) for energy efficiency from 2008, a bundling of several single measures were identified to improve the efficiency for compressed air systems (Figure 5-11), which partly covers similar improvement options as stated above. However, it should be noted that only a small number of machine tools have integrated compressed air generation, and thus in-built compressors. Typically, compressed air is generated externally, and most of the measures listed below are not applicable within the system boundaries of typical machine tools.

[96] There are several multi-purpose micro turbines available; however, no specific products can be named in this narrow field of application.

Energy savings measure	% applicability (1)	% gains (2)	% potential contribution (3)	Comments
System installation or renewal				
Improvement of drives (high efficiency motors)	25	2	0.5	Most cost effective in small (<10 kW) systems
Improvement of drives (speed control)	25	15	3.8	Applicable to variable load systems. In multi-machine installations, only one machine should be fitted with a variable speed drive. The estimated gain is for overall improvement of systems, be they mono or multi-machine.
Upgrading of compressor	30	7	2.1	
Use of sophisticated control systems	20	12	2.4	
Recovering waste heat for use in other functions	20	20 – 80	4.0	Note that the gain is in terms of energy, not of electricity consumption, since electricity is converted to useful heat
Improved cooling, drying and filtering	10	5	0.5	This does not include more frequent filter replacement (see below)
Overall system design, including multi-pressure systems	50	9	4.5	
Reducing frictional pressure losses (for example by increasing pipe diameter)	50	3	1.5	
Optimising certain end use devices	5	40	2.0	
System operation and maintenance				
Reducing air leaks	80	20	16.0	Largest potential gain
More frequent filter replacement	40	2	0.8	
		TOTAL	**32.9**	

Table legend:
(1) % of CASs where this measure is applicable and cost effective
(2) % reduction in annual energy consumption
(3) Potential contribution = applicability * reduction

Figure 5-11: Energy saving measures in compressed air systems, adapted from the BREF for energy efficiency (p. 208).

A **sensor-based monitoring of pneumatic systems** does not reduce energy consumption as such, but helps to identify leakages, and optimal operation conditions for the whole system. The pneumatic system has to be complex to a certain extent, so that sensor-based monitoring is justified and useful. Such monitoring might reduce power consumption for pneumatic systems in the range of a few percent.

As pneumatics play a minor overall role for machine tools and as pressurised air or vacuum are typically supplied by an central external system, the potential of improved pneumatic systems is limited for machine tools, but relevant for related machinery.

5.1.7 Solution 6: Resource- and Energy-Efficient Cooling Lubricant Supply

5.1.7.1 Introduction

Coolant supply to machine tools is one of the components with the highest energy consumption during machining. There, the energy demand is between 20 and 33 % depending on the machining method.[97] This aspect is relevant in the metal working industry. 98.5 % of machine tools need lubricant in this branch[98] – from overflow lubrication to minimum quantity lubrication (MMS). For woodworking machine tools it is not relevant. The following technologies show how energy savings can be achieved in this field.

Several pilot projects have been launched in the field of dry machining recently; meaning that by aims of specific technologies, market introduction already took place for efficient cooling lubricant supply. Already in 2001, with funds from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, a programme was started for lubricant-free aluminium machining at a German manufacturer of aluminium rims[99]. By developing a specially-coated tool, with an internal bore for additional cooling, and the adjustment of process parameters, the usage of lubricants was reduced to zero. The use of lubricants goes hand-in-hand with a significant reduction in overall energy consumption, mainly due to secondary external effects on machinery,

97 Kalhöfer, E.: Ungenutzte Einsparpotenziale in der spanenden Fertigung, In: Economic Engineering, p. 56-59, Vol. 5, 2008

98 Result survey

99 BBS International GmbH, Schiltach, Germany

i.e. no lubricant supply, circulation and emulsion cracking. The results derived from the programme are depicted in Table 5-5.

Table 5-5: Expected resource savings from the implementation of dry machining at BBS Kraftfahrzeugstechnik AG[100]

Environ-mental impact	Wet machining	Dry machining	Savings
Lubricants consumption	71.292 kg/a	0	100 %
Water con-sumption	2.163 m^3/a	32 m^3/a	98,5 %
Energy con-sumption	**643.630 KWh/a**	**278.853 KWh/a**	**56,7 %**

Although the above savings potential regarding lubricants consumption seems substantial, the analysis in Task 4 (Base Case 1, machining centres) unveils a rather minor environmental improvement potential regarding upstream impacts, when reducing the consumption of cooling lubricants.

5.1.7.2 Resource-efficient technologies

Additional technologies for the reduction of cooling lubricant in machining are as follows:

- **Minimum quantity lubrication (MQL):** The advantage of MQL where the lubricant constitutes a lost lubricant is the omission of whole machine components (e.g. purifiers, treatment plants)[101] and therefore less energy consumption.

  Due to the large amounts of generated heat in grinding processes, there is a lack of MQL technologies applicable for grinding machines. A new approach is based on the use of a hybrid MQL-low temperature CO2 system, in which droplets are directly applied onto the abrasive grains, and frozen with CO2 immediately afterwards.[102]

100 http://www.bmu.de/foerderprogramme/doc/2358.php, accessed 10.01.2011.

101 SKF LubriLean: Minimalmengen-Schmiersysteme (MMS), on the internet: http://www.skf.com/portal/skf_lub/home/products?contentId=873205&lang=de, last access: 7.01.2011

102 Sanchez et al., *Machining evaluation of a hybrid MQL-CO2 grinding technology*, 2010

The use and maintenance of lubricant circulation systems consume high amounts of material and energy. Therefore, a German manufacturer of cutting machines[103] and three project members developed an optimized solution for the supply and mixing of a MQL lubricant called Aerosol. This oil-aerosol mixture is directly prepared in the tool holder (requiring a two-canal system) instead of an external MQL-aggregate which normally diminishes the aerosol quality.[104]

- **Coolant lubricant supply through pressure control valves (PQ-Tronic-System):** A German manufacturer of conveying and filter systems for chips and cooling lubricants[105] conducted several tests regarding the coolant supply. Using screw-spindle pumps with controllable pressure control valves they discovered an energy consumption reduction of 11 %. Due to the fact that the used valves can be controlled and the pressure during tool changes can therefore be almost completely reduced to zero, these savings are achieved. If the cooling lubricant processing plant is equipped with pressure control valves with constant speed and controlled variable pressure, then energy savings of 36 % are possible. Nevertheless, the highest energy consumption reductions can be seen with the new PQ-Tronic-System, which allows energy savings of up to 70%. This technology applies frequency-controlled pumps with variable pressure, volume flow and speed adjustments.[106] Similarly, another pump manufacturer states significant savings potentials of 40-60% when coolant pumps in machine tools are equipped with variable speed drives. Design requirements effective for water pumps are basically also suitable for “clean side” pumps for cooling lubricants (whereas for pumps for chip removal, this might not be the case)[107].

- **Optimised pipe dimension for coolant lubricant supply:** The pumping medium is responsible for pressure loss through development of friction on pipe walls. This pressure loss depends on the pipe diameter and has to be compensated for by the pump. Enlarging the pipe diameter, the pressure loss is lower

103 A. Monforts Werkzeugmaschinen GmbH & Co. KG, Mönchengladbach, Germany

104 Deutges, D.: Weniger ist mehr, In: Zeitschrift für spanende Fertigung Werkstatt+Betrieb, p. 138-139, 143. Jahrgang, September 2010

105 Knoll Maschinenbau GmbH, Bad Saulgau, Germany

106 Drehteil + Drehmaschine: Energieeinsparmöglichkeiten im Kühlschmierstoff-Management, p. 32-41, Vol. 5, 2010

107 personal communication with Grundfos, Denmark

and the pump requires less energy (Table 5-2, example 2). The following example provides evidence for this statement:

Table 5-6: Increased pump performance using different pipe diameters

	Pipe Diameter	Emulsion Flow	Distance	Flow velocity	Pressure loss	Increased pump performance
1. example	20mm	200l/min	10m	10,6 m/s	4,42 bar	2,5 kW
2. example	40mm	200l/min	10m	2,7 m/s	0,12 bar	0,1kW

The flow velocity in example 2 is less than in example 1, but sufficient for the coolant lubricant supply.[108]

- **Cryogenic machining**: Especially in the field of machining super alloys (such as nickel-based alloys, titanium-based alloys), extremely high process temperatures are realized. Oil-based cooling fluids are somewhat ineffective, due to the fact that they vaporize close to the cutting edge at high temperature. Hence, they do not access the tool or the chip. Alternatively, cryogenic cutting fluids can be used. The coolant is usually liquefied nitrogen at -196°C, which is a safe fluid with no hazardous causes to the environment. Cryogenic machining contributes to faster performance, higher quality and reduced costs.[109]

- **High pressure jet assisted machining (HPJAM):** In contrast to conventional machining, HPJAM delivers small flow rates of common lubricants under high pressure (up to 300 MPa), in order to penetrate closer to the shear zone at which the highest temperatures occurs. Thus, the consumption of cutting fluids is lowered, and performance is increased.[110]

- **Direct oil drop supply system (DOS):** The cutting fluid is pressurized at 0.4 MPa and supplied to an oil discharge unit. The DOS nozzle is positioned in such a way that the oil drop hits the rake face of the cutting edge along the lead angle of the endmill cutter. The nozzle itself features two separate air supply

108 Drehteil + Drehmaschine: Energieeinsparmöglichkeiten im Kühlschmierstoff-Management, p. 32-41, Vol. 5, 2010

109 Pusavec et al., *Transitioning to sustainable production – Part I: application on machining technologies*, 2010

110 Pusavec et al., *Transitioning to sustainable production – Part I: application on machining technologies*, 2010

pipes, which significantly suppress peak temperatures. In comparison to conventional minimum quantity lubrication, the occurrence of oil mist is abandoned and the consumption of lubricants is reduced. Additionally, potential harm from cleaning processes ceases.[111]

- **Heat exchangers for preheating components:** The heating can supply new starting points for energy optimization by inductive and conductive systems. It allows time- and pinpoint heating and is particularly suitable for the drawing of high-performance steels and magnesium. These techniques can offer advantages regarding the investment costs and on space requirement. In addition, as for example with inductive systems, higher flexibility is offered. The regulation of the coil power enables different temperatures over the length of the component, without design changes to the heating system. Therefore the strength varies in the component, which may be positive for the following processes. The energy consumption of the process on its own is much higher than the typical “cold” deep-drawing. The advantage of the “warm drawing” is the repeatability as well as economic and ecological savings for all subsequent processes (e.g., elimination of additional straightening processes).[112]

- **Vegetable oils as lubricants:** Under the reformulation of additives, chemical and genetic modification, vegetable oils (e.g. canola oil, coconut oil, olive oil, palm oil, soybean oil, etc.) may substantially substitute petroleum-based lubrication fluids in the long run.[113]

- **Cooling lubricants without mineral oil:** Concepts to replace mineral oils in cooling lubricants use biopolymer-solutions, which offer similar properties to those of conventional cooling lubricants. These sustainable materials save up to 90 % of energy use for production compared to oil-based lubricants.[114]

  Optimisation of the cooling lubricant system actually is relevant for all larger machine tools processing hard materials, i.e. metal, ceramics, stone and glass. Efficient usage of cooling lubricants actually results in costs savings throughout the lifetime of the machine tool.

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111 Aoyama et al., *Development of a new lean lubrication system for near dry machining process*, 2008

112 Munde, *Bei der Warmumformung die Energiebilanz im Blick*, 2010

113 Shashidhara et al., *Vegetable oils as a potential cutting fluid—An evolution*, 2010

114 Carl Bechem GmbH, Hagen, Germany

- **Increase of life cycle of lubricants:** One way to reduce the consumption of cooling lubricant is closed-loop recovery of used cooling lubricants. Numerous industrial solutions are available[115], which are largely related to peripheral filters and units, or centralising the cooling lubricants supply system.

- **Technical measures for reducing cooling lubricants emissions** comprise housing, filtering and deposition[116] [117]. In more detail, the following problems are observed, which can be addressed with technical measures within machine tools:

    - Suction nozzle placed too close to the working area, which frequently leads to an extraction not only of mist, but also larger spilled droplets, which results in a much higher amount of cooling lubricants liquid entering the abatement system than required

    - Suction air flow set too high

    - Non-optimal design of suction pipes, where metal chips might block the nozzle

    - Extraction system should not only cover the working area, but also other sources of mist emissions, which are outlets for chips, workpiece and tools, storage units for chips and cooling lubricants, and drains.

  An optimized extraction system can improve the abatement process and reduce the exposure significantly[118]. This must be analysed and considered in the machinery design process, and requires – despite some general principles to be observed - an adaptation to be made to the specifics of the machine tool.

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115 E. g. http://www.leiblein.com/coolant-technology.html, http://www.westfalia-separator.com/applications/marine/lube-oil-and-hydraulic-oil-marine.html, http://cleaner-production.de/fileadmin/assets/pdfs/Externe_Projektbeschreibungen/cpg_newsletter-2006-02-01-en.pdf, accessed March 25, 2012.

116 Pfeiffer, W.: Absaugen und Abscheiden von Kühlschmierstoffemissionen an geschlossenen Werkzeugmaschinen – Einführung, BGIA-Report 9/2006, Absaugen und Abscheiden von Kühlschmierstoffemissionen, Zusammenfassung der Vorträge anlässlich einer Fachveranstaltung am 11. Mai 2006 in Bonn

117 BGIA: Dämpfe und Aerosole beim Umgang mit Kühlschmierstoffen, Ausgabe 0045 · 8/2009 617.0-BGIA:638.1

118 Detzer, R.: Lufttechnische Maßnahmen in Maschinenhallen, BGIA-Report 9/2006, Absaugen und Abscheiden von Kühlschmierstoffemissionen, Zusammenfassung der Vorträge anlässlich einer Fachveranstaltung am 11. Mai 2006 in Bonn

5.1.8 Solution 7: Cooling Systems and Use of Cabinet Heat

5.1.8.1 Introduction

Cooling purposes are an important energy relevant part of the energetic system of machine tools. Especially power electronics are a system heat source. Machine tool manufacturers implement energy-efficient devices in their constructed products to decrease friction-related energy losses. To eliminate the need for extra cooling systems on its EDM machining centres, a leading Swiss machine tool manufacturer[119] uses compact, low-heat motors to eliminate the need for cooling machine drive systems. The integrated approach for energy savings is the improved efficiency of power electronics. The friction-induced heat is reduced, with decreased electric losses in the cabinet components.

5.1.8.2 Solution approach

One possibility is therefore the control cooling through machine integrated cabinets. Heat exchangers are employed for process cooling. A German system climate control manufacturer's[120] solutions reduce the energy consumption by 45 % in comparison to other cooling systems. These results are achieved by a combination of innovative ventilators and cooling compressors, with properly arranged heat exchangers and electronic filling quantity control for refrigerants.[121]

5.1.9 Solution 8: Energy-efficient Tempering

5.1.9.1 Electric inductive heating

Primarily in the field of cold metal forming technologies, the adequate and process oriented tempering of workpieces is required for stable operation. Conventionally, workpieces are brought to process temperature in a heat constant dipping bath, causing an immense need for heating energy. Alternatively, electric inductively heating systems are more efficient (up to 85 %).Via electromagnetic induction, eddy currents are generated within the workpieces, leading to a subsequent heating, which is also much faster

119 Agie Charmilles Management AG, Schaffhausen, Germany

120 Rittal GmbH & Co. KG, Herborn, Germany, being the first one to introduce this approach

121 http://www.rittal.de/downloads/PrintMedia/PM1/de/ReferenzbroschuereHMI_IE.pdf. Last access: 18.01.2011

than conventional heating. In this regard, several pilot projects for the implementation of electric inductive heating have been launched.[122]

5.1.9.2 Thermal compensation

Depending on the scaling and complexity of the machine, the warm-up period before machining is time intensive and leads to a fair amount of energy consumption. Alternatively, for numerically controlled machines, this process can be dropped with appropriate programming of the CNC control system and the use of sensors. Thus, thermal influences will be adjusted by means of automated corrections. So far, there are several machine tool manufacturers using this technology.[123]

5.1.9.3 Minimized pre-heated glue volume

For edge banding machines one manufacturer developed a nozzle system to apply glue to the edges, whereas others use glue rollers, and claim a lower electricity consumption of up to 90% while the machine is heating up[124]. Table 5-7 provides an example calculation of this effect, totalling in a savings potential of roughly 500 kW per year.

Table 5-7: Energy consumption calculation for glue application in edge banding machine tools (by HOLZ-HER, adapted)

		Nozzle system	Roller based system	
Power		2.3 kW	Glue rollers	1.6 kW
			Pre-heating unit	4.6 kW
Heating-up times	(two times daily at start of operation and after lunch)	2 x 3.5 min @ 2.3 kW = 16.10 kWmin/d		15 min @ 6.2 kW + 8 min @ 6.2 kW = 142,6 kWmin/d
Cool down		none		2 x 7 min @ 1.6 kW = 22,40 kWmin/d
Total electricity con-		16.10 kWmin/d		165 kWmin/d

122 See http://www.bmu.de/foerderprogramme/pilotprojekte_inland/doc/45575.php, accessed January 10th, 2011.

123 E.g. Stama (http://www.werkzeugmaschinen-liebetrau.de/Prospekte_files/Verkaufsprogramm_Stama.pdf), brother (http://www.w-r-brother.de/documents/Katalog.pdf, accessed January 21, 2011).

124 HOLZ-HER: Energieeffizienz von HOLZ-HER-Kantenanleimmaschinen, letter to customers, July 8, 2011

sumption		
@ 200 working days/a	53.7 kWh/a	550 kWh/a

This manufacturer claims furthermore, that during normal operation up to 63% less energy is consumed with this system, due to the fact that only the amount which is actually applied to the edges is heated (roughly 4 kW savings, resulting from the 2.3 kW vs. the [1.6 kW+ 4.6 kW] stated in the table above).

5.1.10 Solution 9: Energy-efficient Welding

Increasing productivity, i.e. the welding speed and the reduction of re-work requirements, typically also leads to a more efficient welding process in terms of energy and resource consumption per weld, but also weld costs. Vice versa, any measure that hampers weld quality and increases processing time usually results in additional environmental impacts. Having said this, the following measures have to be considered as environmental improvements only if productivity is not adversely affected. However, some of the measures even increase process efficiency.

Optimising the welding process as such is a complex task, and is subject to steady technological progress regarding welding gas composition, welding wire composition, weld geometries, and materials to be welded.

5.1.10.1 Efficiency of welding power sources

Welding power sources have undergone major technical changes from bulky transformers to inverters. The mass of the power sources, material costs and multi-process capabilities and process controllability were major reasons, which drove this development, which is also related to major gains in power conversion efficiency. However, the potential of this technology has already largely been exploited, as this change took place in the last 10 to 15 years. MIG/MAG welding as the dominant process is well advanced in this respect. Among Manual Metal Arc welding equipment, the transition from transformer type to inverter type equipment is already well advanced. Also among equipment for TIG welding, which is the third important process, but not a mass process, a similar change from transformer type to inverter type took place. However, for submerged arc welding this transition has only just begun.[125]

[125] EWA WG EQUIPMENT, meeting of 13 September 2011, Frankfurt

Inverter type power supplies are occasionally also called medium frequency DC (MFDC) power supplies. For a couple of years now there has been a trend towards medium frequency resistance welding, which works at typically 1000Hz: A three-phase 50Hz alternating current is rectified and supplied to an inverter, which converts the current to a medium frequency of 1000Hz and passes this through a transformer/rectifier, which is typically integrated into the welding gun, resulting in a DC welding current. Some of the advantages of this technology are[126]

- Significant energy savings due to shorter weld times
- Improved and consistent power factor (99% achievable)
- Better weld quality, as the effect of electrical line disturbances on the welding process are minimised
- Higher productivity, as intercool states between cycles are eliminated, which shortens weld times

The efficiency gains of inverters over transformers are related to a couple of design features:

- Use of (more efficient) ferrite cores in the (comparatively small) transformers in the inverter
- Lower resistance through smaller secondary side components and overall shorter wiring due to smaller unit sizes
- Use of efficient power electronics components and related circuitry design
- Operating at higher frequencies, usage of capacitors for interim energy storage
- Above efficiency effects result in less cooling requirements and thus less energy consumption for fans

Table 5-8 lists typical efficiency levels of arc welding power sources, based on estimates by EWA WG Equipment[127]. See Task 4, Section 4.1.3.9, for a more distinct weighted energy efficiency of arc welding power sources. Note that there is a 2005

[126] Medium frequency welding of metal components, Metal Matters, Issue 15, Autumn 2009

[127] These values do not apply for resistance welding equipment as the transformer used is designed by its thermal performance in order to allow very short welding time with very high welding current

standard for measuring welding power source efficiency (Annex M of IEC 60974-1 ed.3).

Table 5-8: Typical Efficiency Levels of Arc Welding Power Sources

	Power source efficiency
Rotating type machine[128]	45%
"Transformer type" single phase	65% to 70%
"Transformer type" three phases	70% to 75%
"Chopper type" three phases	70% to 75%
"Inverter type" single phase	75% to 80%
"Inverter type" three phases	80% to 85%

Further improvements are now related to advanced inverter technology. According to EWA estimates, the maximum achievable efficiency for arc welding power source might be 90%. Natural Resources Canada[129] states that "modern inverter power sources have energy conversion efficiencies near 90 percent, with idling power consumption in the order of 0.1 kW." Similarly, some welding equipment suppliers claim energy efficiencies of up to "88-90% with a 95% minimum power factor (at rated output)"[130], "90%"[131], 88-91% efficiency for a 3-phase power inverter[132]. Such efficiency increase could be partly realized through better electronics circuitries, but much more through more material in coils, mainly copper for the windings. Such a change has an adverse effect on resource consumption (copper, iron), and again adds weight to the unit, which hampers the mobility of the welding equipment. According to EWA, the efficiency increase as stated above will not be achievable for:

- AC arc welding power sources that need a second DC/AC converter (additional loss), for example, TIG, Plasma, some new MIG low energy process, to reduce frequency of the current intrinsically delivered by the inverter power source to a frequency compatible with the welding process;

128 not sold on EU market anymore, but could be found in operation still in a few workshops

129 http://oee.nrcan.gc.ca/industrial/equipment/arc-welding/759

130 Lincoln Electric: http://www.lincolnelectric.com/en-us/equipment/robotic-automation/products-and-systems/Pages/automation-power-sources.aspx; products: Power Wave® 455M & 455M/STT, Power Wave® 655R,

131 Fronius: http://www.axson.se/res/broschyrer_pdf/fro_bro_time_twin_eng.pdf, product: Time Twin

132 Thermal Arc: http://www.thermadyne.com/IM_Uploads/DocLib_2140_84-2626.pdf, product: PowerMaster 500P

- resistance welding power sources that are designed in accordance with the thermal requirement of short welding cycles (typically below 1 second) and not for maximum current at 100% duty.

Regarding idle power consumption Hsu (2010) takes stud welding equipment as an example, and cites that where previous generation welding machines consumed 113 W in idle mode and an additional 50 W for welding gun and feeder, latest stud welding equipment now consumes 7.5 W, with no power for feeder and gun, as the equipment switches into a sleep mode when idle[133].

Air-flow cooled welding units can feature a fan, which is switched off, when the equipment is in idle mode and at cold state[134], which allows reduced power consumption in this mode[135].

5.1.10.2 Maximum Energy Transfer

Besides power conversion efficiency (transfer from mains power to arc power), welding processes may be characterized by their ability to transfer the energy from the arc to the workpiece. Typical heat transfer rates are listed below, related to specific technologies, which are each used for specific applications.

Table 5-9: Heat Transfer Rates of Arc Welding Processes

Process	Heat transfer to workpiece
Submerged arc welding (SAW)	1.0
Manual metal arc (MMA) **Shielded metal arc welding (SMAW)**	0.8
Cored wire welding **Flux cored arc welding (FCAW)**	0.8
Metal active gas/Metal inert gas (MAG/MIG) **Gas metal arc welding(GMAW)**	0.8
Tungsten inert gas (TIG) **Gas tungsten arc welding (GTAW)**	0.6
Plasma arc welding	0.6

133 Hsu, C.; Phillips, D.: Stud Welding Technologies for a Greener Future, Welding Journal, October 2010, p.38-42

134 Depending of the temperature of the power source, the fan may be on during idle mode (see definition in Table 7-2) in order to reach cold state before the next welding period. The fan automatically stops at cold state.

135 See for example Fan-on-Demand™ cooling system by Miller Electric Mfg Co., http://www.millerwelds.com/resources/articles/welding-guide-power-efficiency/

Submerged arc welding technology transfers the heat completely to the workpiece, making it the most efficient process. However, these technology specifics can be influenced by equipment design measures only to a very limited extend.

In a research project a test procedure was developed to determine the welding efficiency, i.e. the ratio of heat energy transferred into the material and electric energy supplied to the arc[136]. For MIG/MAG welding processes efficiencies (η) of 0,72 for spray arc, 0,77 for pulsed arc and 0,82 for short arc (average values for a given welding task) were measured with the developed test procedure, which roughly confirms the above stated heat transfer rate of 0,8.

5.1.10.3 Optimised shielding gas supply

Indirect energy consumption is related to gas consumption, in particular for shielded arc welding processes. Optimised gas flow and avoidance of wasted gas could reduce the environmental impact of welding significantly. Where centralized gas supply systems in industrial applications are used, numerous measures could help to reduce gas consumption, such as:[137]

- using adjustable flow devices
- optimising system pressure settings
- properly calibrating flow meters

The main source of gas consumption is the insufficient maintenance of gas circuits, e.g. leakage, damaged hoses, and old hoses. Proper maintenance measures such as periodic tests to detect leakage and periodic change of hoses are advisable.

However, these measures are not related to the welding equipment design. Measures directly related to the welding unit as such are:

- Minimising the volume between flow device and torch tip (at the wire feeder), which decreases the time required for the flow to reach the set flow rate and, in

136 IFS Chemnitz, Status report March 2010, research project " Bestimmung von Wirkungsgraden moderner Schutzgasschweißverfahren", 2008-2010, AiF-Nr. 15.562 BR, http://www.dvs-ev.de/fv/neu/getfile.cfm?PID=444&file=ZB_15.562B_10-1.pdf

137 Standifer, L.R.: Shielding gas consumption efficiency-- Part I: Spend a penny, save a dollar, thefabricator.com, February 19, 2001

turn, the amount of gas wasted by momentary excess flow or overflow. This is particularly relevant for high cycle rates, such as tack welds, where the welding process is frequently interrupted[138]. The volume could be reduced by placing the flow device closer to the torch tip and/or by reducing the inner diameter of the hose[139]. Welding gas savings of "40 to 50%" are reported, but this depends on the previous status quo, the actual use scenario, and the experience of the welder to adapt the welding conditions to an optimum for his intended purpose.

- using a welding gas regulator that provides a consistent gas flow from arc-on to arc-off, allowing welders to set a lower flow rate. Such optimized regulators are reported to "reduce the time between gas and arc ignition at the beginning of a weld, and between arc-out and gas-off, resulting in less wasted gas".[140]

Excessive shielding gas consumption could also have an adverse effect on weld quality. A high volume flow of shielding gas can result in a turbulent gas flow and actually induce atmospheric contamination of the weld puddle, i.e. limiting the intended shielding effect. An optimised gas flow thus also has a positive (environmental) effect on productivity (less re-work), product (i.e. weld) quality and lifetime.

5.1.10.4 Reduction of spatter losses

An efficient welding process requires a maximum use of welding wire material. Losses occur through spatter losses. There are systems which facilitate the reduction of spatter losses. This spatter loss, which can be reduced significantly by using an optimized shielding gas (blend), is reflected in the "deposition efficiency" of the welding process. Typical deposition efficiencies of shielded arc-welding processes are listed in Table 5-10[141].

Table 5-10: Typical deposition efficiencies of shielded arc-welding processes (according to PRAXAIR)

	Typical Deposition Efficiencies
Gas Tungsten Arc Welding (GTAW / TIG):	95%-100%

[138] Standifer, L.R.: Shielding gas consumption efficiency-- Part I: Spend a penny, save a dollar, thefabricator.com, February 19, 2001

[139] Uttrachi, J.: MIG Shielding Gas Control and Optimization; W A Technology; July 2011, http://www.netwelding.com/Shielding_Gas_Control_Download.pdf

[140] Heston, T.: Better shielding gas flow, efficient welding - Automotive supplier reduces gas consumption, optimizes welding; thefabricator.com, October 21, 2010

[141] PRAXAIR: Shielding Gases – Selection Manual, 1998

Gas Metal Arc Welding (GMAW / MIG):	88%-98%
Flux Cored Arc Welding (FCAW, gas shield):	85%-90%
Flux Cored Arc Welding (FCAW, self shield):	75%-85%
Plasma arc welding (PAW)	95%-100%
Shielded Metal Arc Welding (SMAW, stick)	50%-65%

The use of argon blends is reported to result in the highest levels of deposition efficiency. A secondary effect of less spatter losses, higher deposition efficiencies and the use of appropriate shielding gases is the lower generation of fumes, which is a critical aspect for the workers' environment.[142]

The choice of the welding gas actually is not related to the design of the welding equipment, but is an aspect for user information.

5.1.10.5 Adapted Stud Welding Current

For specific welding processes an adaptation of the waveform avoids wasting energy. In the case of stud welding, which is extensively used in automotive manufacturing, construction, ship building and the like the process works as follows: The stud is pushed against the workpiece to make contact. While a low pilot current is applied, the stud is lifted to draw a small pilot arc current. For a set time the current is increased to the intended welding current level to melt stud and workpiece. Plunging the stud back into the workpiece extinguishes the arc and completes the weld. Thereafter the welding current is turned off and the welding tool removed. The synchronization of current turn-off and plunge is a critical process, and a technology was introduced to adapt the current waveform generated by an inverter, and controlled by a digital signal processor with the stud motion[143]. The resulting plunge current waveform is depicted in Figure 5-12. Hsu (2010) cites an estimated energy savings potential of up to 9% and 24% respectively for drawn arc stud welding with and without ferrule. The shorter the process cycles, the higher the savings potential.

[142] Note, that both aspects, fume generation and welding wire consumption are not addressed in the Base Case calculation in Task 4

[143] Hsu, C.; Phillips, D.: Stud Welding Technologies for a Greener Future, Welding Journal, October 2010, p.38-42

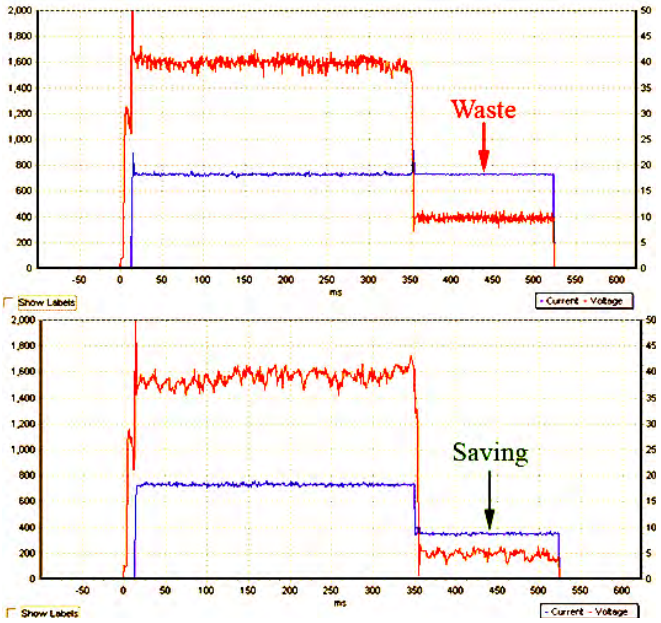


Figure 5-12: Stud Welding: Conventional (above) vs. reduced plunge current waveform (below)

5.1.11 Solution 10: Productivity and processing time

Increasing productivity, i.e. actual throughput, is frequently stated as one major measure to reduce energy consumption per workpiece output. Processing time is key in this regard.

CECIMO provided a detailed analysis as a stakeholder input to verify this aspect exemplarily (data as provided by CECIMO, without further verification by Fraunhofer):

According to research performed by Agie Charmilles SA … faster machining saves up to 30% of energy [analysis refers to electro-discharge wire-cutting machines]. *The measurements were taken on SodickA500 and Robofil310 machines, which are widespread in use; FI440ccs is in full production, but is an older concept than CUT20 … .*

The results show that an older machine under standard conditions (SodickA500 std.), uses 3.86 times the energy of the newer machine with optimized parameters (CUT20 opt.). It means that the optimized machine saves 74% of the energy of the old, non-optimized machine, by performing the same work with the same quality output.

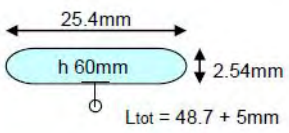
The measurements show that typical savings between standard and optimized (maximized Cutting Rate) are 27% to 45% for all four machines [Ernst R. Bühler & Orio Sargenti, Agie Charmilles SA].

Table 5-11: Energy measurements on metal working machine tools (research data provided by Agie Charmilles)

CR_mm²/min	CP_mm²/kWh	use_kWh	machine	Tech.	CP math_mm²/kWh	use math_kWh
87,2	607	4,813	SodickA500	std.	741	4,11
150,0	1096	2,667	SodickA500	opt.	1275	2,43
98,2	960	3,043	Robofil310	std.	835	3,66
146,1	1320	2,213	Robofil310	opt.	1242	2,50
131,5	912	3,203	FI440ccs	std.	1118	2,76
205,1	1315	2,222	FI440ccs	opt.	1743	1,81
130,0	1557	1,877	CUT20	std.	1105	2,79
229,5	2341	1,248	CUT20	opt.	1951	1,63
5,0					43	70,10
10,0					85	35,10
20,0					170	17,60
40,0					340	8,85
60,0					510	5,93
80,0					680	4,48
100,0					850	3,60
120,0					1020	3,02
140,0					1190	2,60
160,0					1360	2,29
180,0					1530	2,04
200,0					1700	1,85
220,0					1870	1,69
240,0					2040	1,56
245,0					2083	1,53
250,0					2125	1,50

CR_mm²/min:	250
CP_mm²/kWh:	2557
Use_kWh:	1,09
Height_mm:	60
Length_mm:	48,7
a:	8,50
b:	0,10
c:	350

The benchmark workpiece is depicted in Figure 5-13, and is cut from a 60 mm steel plate with a 0,25 mm brass wire.



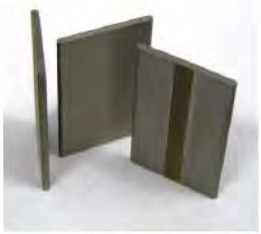


Figure 5-13: EDM benchmark workpiece layout[144]

The energy use in kWh for the various machines matched with the cutting rate is shown in Figure 5-14, according to measurements by Agie Charmilles SA.

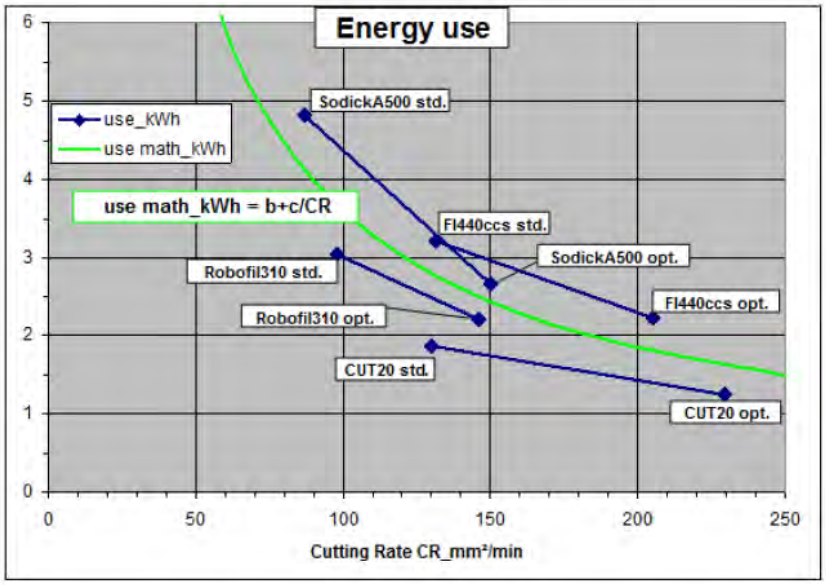


Figure 5-14: Energy use vs. Cutting rate[145]

Figure 5-15 depicts for the various tested machines the cutting power (CP) in mm²/kWh versus the cutting rate (CR) in mm²/min.

[144] Ernst R. Bühler & Orio Sargenti, Agie Charmilles SA

[145] Ernst R. Bühler & Orio Sargenti, Agie Charmilles SA

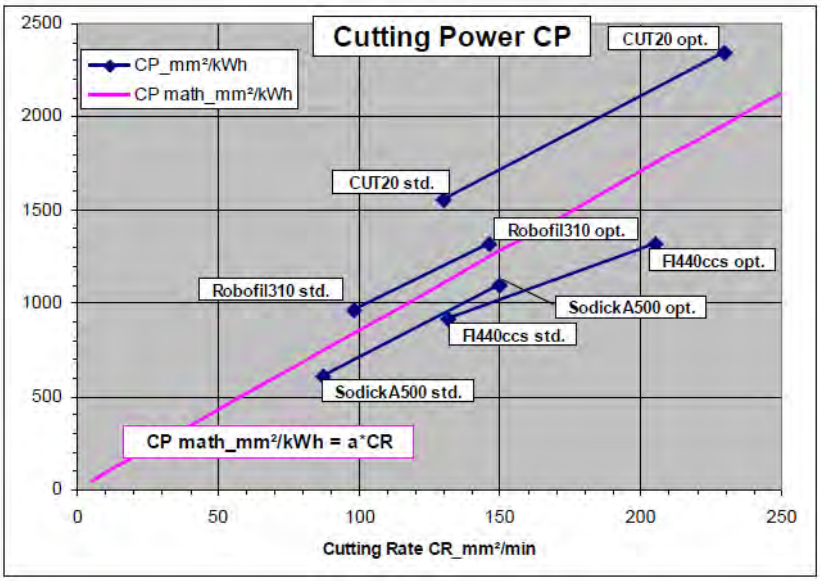


Figure 5-15: Cutting power vs. Cutting rate[146]

Similar findings regarding the energy savings aspect of faster processing were made also by others[147], but again for specific applications, or with slightly outdated data[148].

5.1.12 Examples for the Implementation of BAT

5.1.12.1 System approach for cutting machines

A German manufacturer of machine tools and components for the metal working industry[149] offers a reconfigurable platform based on three variants with the same components and technology modules. The sliding machine table is designed exactly the same way for all machines. Only performance-and quality-determining components, such as the bearings for engines and main spindle, and the guiding principle of the main spindle sleeve, are adapted to the needs of the particular user. The modular system includes, among others, four different spindles. There is a universal standard spindle, a high-

146 Ernst R. Bühler & Orio Sargenti, Agie Charmilles SA

147 Diaz, N.; Helu, M.; Jarvis, A.; Tönissen, S.; Dornfeld, D.; Schlosser, R.: Strategies for Minimum Energy Operation for Precision Machining[Strategies for Minimum Energy Operation for Precision Machining; Laboratory for Manufacturing and Sustainability, University of California, Berkeley, and WZL, RWTH Aachen

148 Rowe, W.B.; Jin, T.: Temperatures in High Efficiency Deep Grinding (HEDG); CIRP Annals - Manufacturing Technology Volume 50, Issue 1, 2001, Pages 205-208

149 Emag Holding GmbH, Salach, Germany

performance spindle, a precision spindle and a spindle for the multi-use technology with extended C-axis accuracy. The bearings of the Z-axis can either be hydrostatic or conventional roller bearings. Depending on the application, there are several tool revolver positions and numerous automation-options available.

The standard version is designed primarily for job order productions and turned parts manufacturers. The second version is designed as a front-operated production machine, which can be individually adapted to the processing requirements. The third version focuses on multi-technology applications. The modular concept allows quick modifications such as tool module changes. Additionally, energy-efficient motors with integrated energy recovery are used, together with low-watt valves (using 70 % less power than conventional valves), and control panels without active cooling..[150]

Furthermore, the energy saving potential of a vertical pick-up turning machine was defined. Some of these potentials are realized with the newest generation of machine tools, as shown in Figure 5-16.[151]

150 www.emag.com/nc/de/emag-gruppe/presseinformationen/bilderarchiv/presse-detailansicht/news/2/emag-vlc-250-universell-auf-die-produktionsanforderungen-konfiguriert.html. Zugriff: 05.08.2010.

151 Hegener, G.: Energieffizienz beim Betrieb von Werkzeugmaschinen – Einsparpotenziale bei der Auswahl der Fertigugnstechnologie. In: Fertigungstechnisches Kolloquium 2010. Stuttgart, 2010. pp 281-292

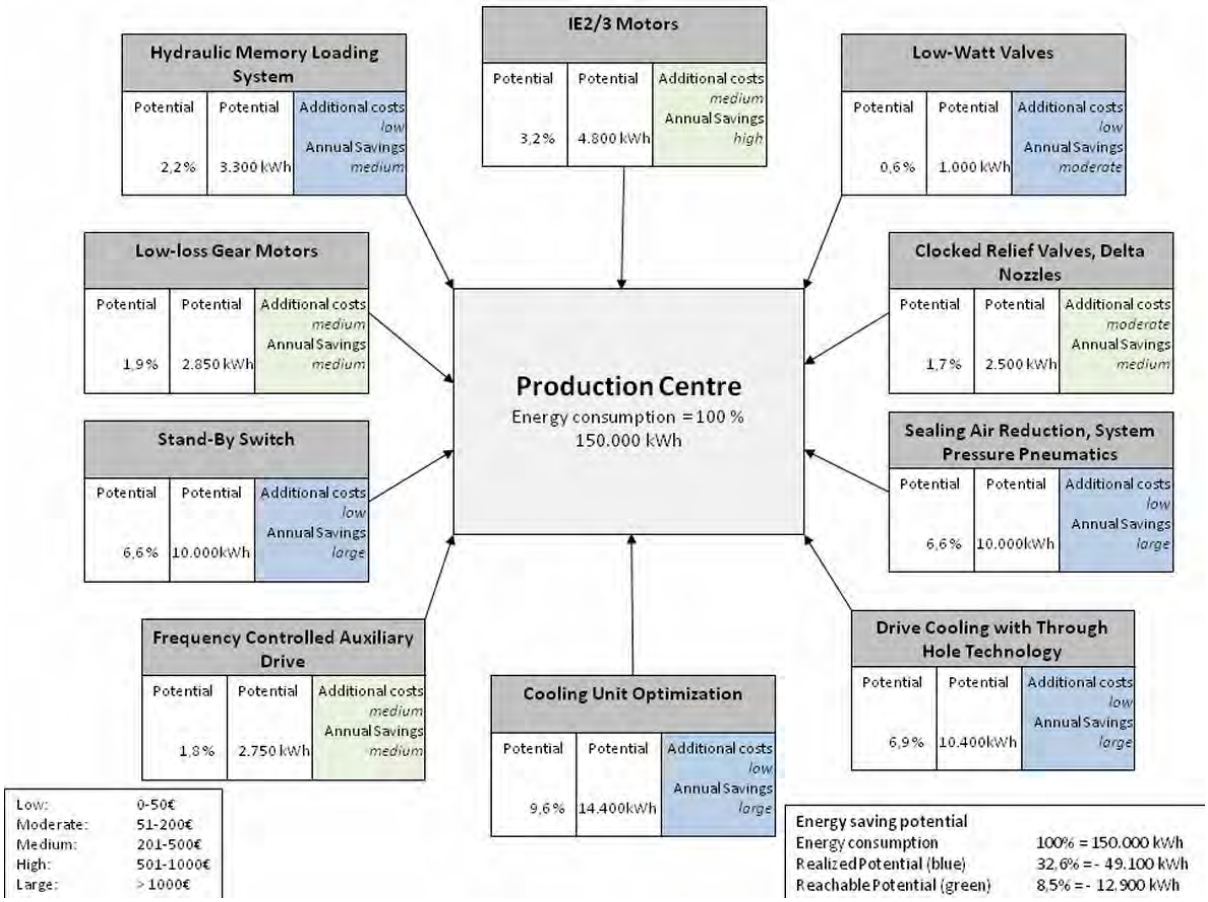


Figure 5-16: Energy Saving Potentials[152]

One of a leading machine tool manufacturer's[153] vertical double-spindle machining centres is designed as a modular system. It is made for parallel 5-axis complete machining in one clamping situation, with up to four work pieces simultaneously. The position of the two spindles relative to one another in the X- and Z-direction can be adjusted, NC-controlled via a torque drive in a range of + / - 0.5 mm. This can compensate for different tool lengths and clamping heights, and can eliminate reverse reclamping. In addition, energy efficiency options offered include regenerative drives, energy-efficient transformers, power safe functions that switch off auxiliary units in production breaks, aggregate cooling on central circulation and a frequency-controlled high-pressure pump, which requires 60 % less energy. The main goal is to reduce the

152 ibidem

153 Chiron-Werke GmbH & Co. KG, Tuttlingen, Germany

set-up times, for example, with integrated workpiece changing facilities, since an average energy intake of 80 % was identified during these periods.[154]

On typical multi-spindle machines, spindles and their drive motors are both located within the machine's spindle drum, thus creating the need to cool the drum, and necessitating the consumption of more energy. A Czech machine tool manufacturer[155] eliminated having to cool its machine drums through an innovative design. The company's design relocates all spindle drive motors away from the machine's drum. Drive motors reside at the machine end, opposite the end housing the spindle drum. An extra plus is that the design requires motors with a lower power consumption.[156]

A German company offering machine tools[157] focuses on lightweight, energy recovery systems, the processing-dependent regulation of components for standby, and warm-up cycles and reduced air demand. For example, 80 % of their roller guides and spindles are equipped with long-term grease lubrication instead of energy-intensive alternatives. Mineral casting beds are used to preserve resources. Another important aspect of energy and resource efficiency is a detailed analysis of the customer's demand. At the beginning of the design phase, intense customer interviews are made that lead to a performance-based design and dimensioning of the systems.[158]

A further German machine tool manufacturer[159] offers energy recovery of the main spindle, reduced power consumption at auxiliary process time, and standby options, which are adjustable by the customer. There is also an "energy save" software that identifies the down time automatically, on the basis of the current uses, and puts the machine into hibernation. Another measure to increase the energy efficiency of machine tools is seen in the simulation of device and processing with an option of virtual machines.[160]

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154 www.chiron.de/index.php?id=981&type=98&L=0&tx_ttnews%5Btt_news%5D=222&tx_ttnews%5BbackPid%5D=962&cHash=74ef879a3f. Zugriff: 08.08.2010.

155 Tajmac-ZPS, a. s., Zlin, Czech Republic

156 N. N.: Power Up. An Energy-Saving Program. In: American Machinist. (2009) 8, pp. 14-17.

157 Maschinenfabrik Berthold Hermle AG, Gosheim, Germany

158 www.pressebox.de/pressemeldungen/maschinenfabrik-berthold-hermle-ag/boxid/330862. Zugriff: 08.08.2010.

159 Gildemeister AG, Bielefeld, Germany

160 www.dmgecoline.com/de-DE/6-news. Zugriff: 10.08.2010.

5.1.12.2 Solutions for particular sub-systems

A leading machine tool and systems manufacturer[161] is planning in the future to exhibit cryogenic machining with liquid nitrogen, utilized via a through-spindle, through-tool cooling system. In milling and boring, liquid nitrogen consumption is about 0.04 litres per minute per cutting edge. It enables higher cutting speeds for increased metal removal and longer tool life. This technology improves lifecycle costs, and is a candidate solution for improved sustainability, since the following are all avoided: mist collection, filtration, wet chips, contaminated workpieces and disposal costs. Moreover, less energy consumption is provided without the pumps, fans and drives needed for handling coolant. The U.S. development will also be introduced in Europe.[162]

To conserve energy, the MAG Specht 500/630 horizontal machining centre eliminates machine warm-up time, sleeps when idle, incorporates regenerative drives and uses half the normal coolant requirements. The machine also offers minimum quantity lubrication (MQL) operation. MQL eliminates the need for chip flushing coolant and the associated energy costs for pumps, filter media and chip drying.[163]

With the help of a system by a renowned German manufacturer of drive and automation systems and software solutions[164] the energy efficiency of machine tools can be improved by dynamic analysis of mechatronic systems and electric drive technology. The control of secondary processes, such as cooling or tool changes, and the demand-driven operation of auxiliary drives for machine-near logistics causes these energy savings.

161 MAG Industrial Automation Systems, Sterling Heights, USA

162 http://www.mag-ias.com/en/mag-news/press-archive/archive/archive2/press-archive/2010/breakthrough-in-cryogenic.html

163 N. N.: Power Up. An Energy-Saving Program. In: American Machinist. (2009) 8, pp. 14-17.

164 Siemens AG, München, Germany



Figure 5-17: Monforts UniCen504[165]

A megatrend in the development of eco-efficient machine tools is the modularization and reconfiguration in order to adapt the machine tool rapidly to the requirements of the dynamic market.[166][167]. Customers' demand for increasingly complex components, with high variety and small lot sizes, in combination with short-term contracts, require various machine tools for manufacturing companies. This leads to higher investment and maintenance costs. The goal of the combined Project KombiMasch (shortening the process chain for manufacturing rotationally symmetrical components, by process combination in modular machine tools) was to develop a combined machine tool which integrates several processing methods. The machine tool combines soft turning, milling and drilling, hardening and coating by laser and the hard turning and milling. Currently available machine tools on the market usually specialize in only one manufacturing process.[168]

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165 Deutges, D: Laserunterstütztes Drehen von Keramik. In: Uhlmann, E. (Hrsg.): Berliner Runde 2008 – Neue Konzepte für Werkzeugmaschinen. Berlin, 2008. pp. 77-85

166 Nyhuis, P.; Reinhart, G.; Abele, E.: Wandlungsfähige Produktionssysteme: Heute die Industrie von morgen gestalten. Hannover: PZH Produktionstechnisches Zentrum, 2008

167 Nyhuis, P.; Fronia, P.; Pacho, J.; Wulf. S.: Wandlungsfähige Produktionssysteme. Ergebnisse der BMBF-Vorstudie "Wandlungsfähige Produktionssysteme". In: wt Werkstattstechnik online 99 (2009) 4, pp. 205-210

168 Deutges, D.: Verkürzung der Prozesskette zur Fertigung rotationssymmetrischer Bauteile durch Verfahrenskombination in modular aufgebauten Werkzeugmaschinen.

5.1.12.3 Lightweight solutions

In the FP6 funded project "ECOfit Eco-efficient machine-tools by means of radical mass and energy needs reduction", new approaches to energy saving in the operation of machine tools by reducing the moving masses were investigated. The project aimed at increasing machine tool energy efficiency via the use of elastic structural components with controlled flexibility, through using mechatronic elements.[169] The ECOfit project reported significant improvements in terms of both life cycle impacts of materials production for machinery construction, and power consumption in the use phase due to reduced moved masses. Zulaika et al. state as an outcome:

- Average reduction of 35 % in the energy consumed by the prototype during positioning motions with respect to a conventional machine (see Figure 5-18)
- Average reduction of 18 % in the energy consumed by the machine feed-drive while machining
- Additional 7 % reduction in the energy consumed by the rotating spindle

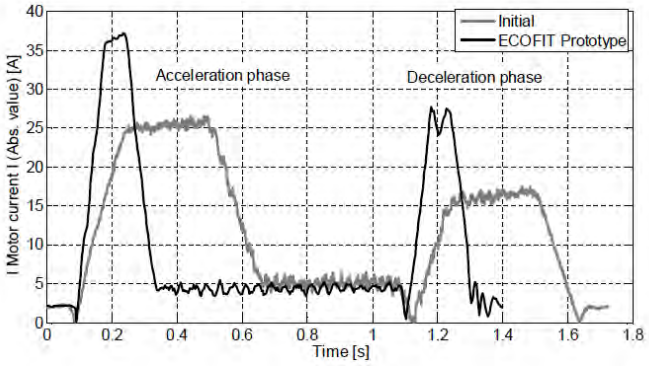


Figure 5-18: Motor current of prototype with lightweight construction compared to a conventionally designed machine[170]

The ECOfit project also provided an LCA, conforming to ISO 14040, of its prototype developments, showing the total life cycle benefits of the approach, although at a

www.produktionsforschung.de/PFT/verbundprojekte/vp/index.htm?VP_ID=1338. Access: 10.08.2010.

169 Sekler, P.; Dietmair, A.; Dadalau, A.; Rüdele, H.; Zulaika, J.; Smolik, J.; Bustillo, A.: Energieeffiziente Maschinen durch Massenreduktion. In: wt Werkstattstechnik online 97 (2007) 5, pp. 320-327.

170 Zulaika, J.J.; Dietmair, A.; Campa, F.J.; López de Lacalle, L.N., Verbeeten, W.: Eco-efficient and Highly Productive Production Machines by Means of a Holistic Eco-Design Approach, E/E 3rd Conference on Eco-Efficiency, June 9-11, 2010, Egmond an Zee, The Netherlands

higher initial investment due to more sensors, more active devices and more control systems than with a conventional machine.

5.1.12.4 Hydraulic-free machining centres

A German company offering machine tools[171] exhibited the first machining centre[172] in the world with no hydraulics in September 2010. Whether this can be considered Best Available Technology or not is heavily debated among technologists, as machine tools without hydraulics can claim some important advantages on the one hand, but on the other hand the inherent potential of optimised hydraulic systems should not be ignored.

On this machining centre, workpieces can be clamped electromechanically, and all tools released electromechanically. The replacement of a hydraulic system by an electromechanical system logically eliminates the consumption and disposal of hydraulic oil. This eliminates also the risk of leakages. From a technical perspective maintenance requirements are reduced, and all the test cycles for the hydraulic pressure accumulator with all its safety valves are avoided. In addition, hoses and seals do not need to be replaced, which leads to an improved technical capacity of machining centres.[173,174]

In one specific case, the shift from a hydraulic system to all-electromechanical resulted in energy savings of 4 % for the machining centre investigated, and the technical adaptation does not result in any additional costs.[175] It is argued that machinery internal electromechanical clamping systems might be limited by work space constraints compared to hydraulic systems, which can be placed externally to the machine tool, thus avoiding limiting the work space. This might be a decisive criterion in certain applications. It should also be noted that optimised hydraulic systems with e.g. two-way pilot valves, which permanently maintain the required pressure, are said to result as well in power savings, if coupled with appropriate power management measures. Thus,

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171 Grob-Werke GmbH & Co. KG, Mindelheim, Germany

172 based on a GROB G350 standard machine with Siemens 840 sl MDynamics controls and a GROB 18,000 rpm HSK-63 motor spindle

173 GROB: The first machining center with no hydraulics, September 27, 2010, http://www.grobgroup.com/en/2010/09/27/september-the-first-machining-center-with-no-hydraulics/

174 Fertigung – das Fachmagazin für die Metallbearbeitung: Blick in die Zukunft – Branchenreport, November 3, 2011, http://www.fertigung.de/2010/11/blick-in-die-zukunft-2/

175 Fertigung – das Fachmagazin für die Metallbearbeitung: Blick in die Zukunft – Branchenreport, November 3, 2011, http://www.fertigung.de/2010/11/blick-in-die-zukunft-2/

measures to reduce power consumption in idle times of hydraulic systems and components is key to achieving significant energy savings also with hydraulic systems, which leads to the conclusion, that hydraulic-free machine tools cannot be considered as Best Available Technology per se, but that the specific application scenario and required performance has to be considered with due care. In particular, for applications where the higher achievable body force of hydraulic systems is essential, hydraulic-free machine tools are not an option at all[176], and safety requirements of ISO 13849 partly cannot be met by electrical clamping devices and other electrical components.

5.1.12.5 Summary

All these solutions show different possibilities to integrate energy saving modules into machine tools.[177] The immediately greener image, and long-time cost savings, are the benefit of the implementation of such solutions. However, it is important to reach the demanded productivity and quality required, as well as the energy efficiency. The examples presented combine economical and ecological advantages. It is a profound misunderstanding to talk of a trade-off between the economic and environmental dimensions. Instead it is relevant to draw up a common target tracking to reach the aims.

5.1.13 Evaluation of options

The evaluation of the various improvement options stated and listed above required an approach which allowed a broad coverage of the whole machine tools market, but does not address individual machine tools. For this latter purpose, an assessment matrix was developed and presented at the 2nd Stakeholder Meeting of this study, and stakeholders were invited to provide evidence and estimates regarding the potential of these measures. Annex Assessment Matrix Survey provides documentation of the questionnaire published on the project website.

5.1.13.1 Metal working machine tools

CECIMO cordially supported the survey and assessment regarding improvement options, but adapted the initial assessment matrix to the systematics of ISO 14955 (draft), i.e. deviated from the structure of improvement options outlined above.

176 Kuttkat, Bernhard: Spannsysteme - Röhm forciert die Elektrifizierung, MaschinenMarkt, November 11, 2010

177 Only some examples. Much more are available.

CECIMO coordinated the inquiry among machinery manufacturers from the metal working machine tools market and finally received replies from 18 companies from the three different metal working branches cutting machine tools, servo presses and mechanical presses, and hydraulic presses. The main group are cutting tool manufacturers.

The evaluation of the energy efficiency of functional units by CECIMO takes regard of six functional modules:

M1: Machining (machine process, motion and control)
M2: Process conditioning and cooling
M3: Workpiece handling
M4: Tool handling / die change
M5: Recyclables and waste handling
M6: Machine cooling / heating.

Energy efficiency measures examine the relation of impact on the number of functions between 0 % (no impact), between 0 % and 100 % (total added amount of impact in different functions) and 100 % (total impact on a single function).

The share of each of the functional modules in the total machinery energy consumption, classified into the metal working machine tool technology, is displayed in Figure 5-19**:** In all the three types of machine tool classes the main share of energy consumption concerns the machining process itself (i.e. module M1). The physical necessity of providing energy to shape the workpieces into parts is the core task of machine tools, and therefore dominates the share of energy consumption against the functional modules. It figures out the state of energy efficiency measures where process, motion and control features require the most energy. Machine tool cooling and heating (M6) shows the second largest amount of consumed energy. Workpiece handling (M3) has the second largest share of energy consumption in the category "servo and mechanical presses". The third largest share in the category of "cutting machine tools" is process conditioning and cooling (M2), dependent mainly on the amount of cooling lubrication and installations for transport and storage. This corresponds with energy consumption for recyclables and waste handling (M5) of cutting machine tools. Here, the lubrication means used for cooling has to be mainly purified and disposed.

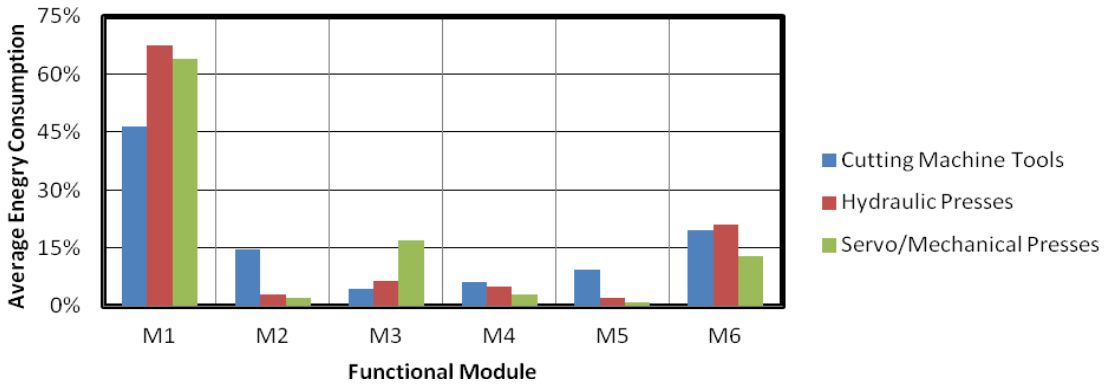


Figure 5-19: Energy consumption allocation per functional module and type of machine tool [CECIMO]

The functional modules are correlated in CECIMO's survey to 10 machine tool components:

1: Overall machine
2: Drive units
3: Hydraulic system
4: Cooling and lubrication system (manufacturing process related)
5: Cooling system / Die cooling/ Lubrication system (components related)
6: Power electronics / Electric system
7: Machine concept (cutting machine tools) Pneumatic system (presses)
8: Peripheral devices
9: Simulation
10: Control

According to the survey, for cutting machine tools, the main energy efficiency potentials are to be seen in component groups 2 (drive units) and 3 (hydraulic system), followed by the groups 4 (lubrication system), 5 (die cooling/lubrication system) and 7 (machine concept). Hydraulic, servo and mechanical presses show energy efficiency potentials in component groups 3 (hydraulic system) and 2 (drive units), followed by groups 7 (pneumatic system) and 9 (simulation).

The following summary of replies is subdivided into the 3 machine tools types: cutting machine tools, servo presses and mechanical presses, and hydraulic presses.

It must be noted that the respondents typically gave deviating estimates regarding savings potential, cost effects and market penetration of certain options, but there is mostly a consensus on tendencies. The following sections therefore present, via graphical

illustrations, the number of respondents per category regarding estimated improvement potential and related investment cost impacts. In the tables, the variances are condensed to “tendencies” (percentages are understood as orientation values, i.e. if a majority of respondents replied with an estimated savings potential of 0.5 – 1.5% a value of 1% is taken as tendency). These figures will be subsequently used as approximations for calculations in Task 6. In these tables, a conservative figure is typically stated for cost effects (higher weighting of estimates indicating a larger cost increase) and for energy efficiency potentials (rather a lower percentage is stated, if this is the estimate of several respondents).

The numbering of the options follows ISO 14955 (draft).

5.1.13.1.1 Cutting

Regarding the **overall machine** from the replies given, some tendencies are evident: The energy savings potential by most respondents is estimated to be in the range between 0 and 1,5% of the total machinery energy consumption (Figure 5-20). Individual respondents also state a larger savings potential of even above 5% for 3 of the 4 options. Only the option “reduction of friction” (1.2) has a very minor potential, if at all.

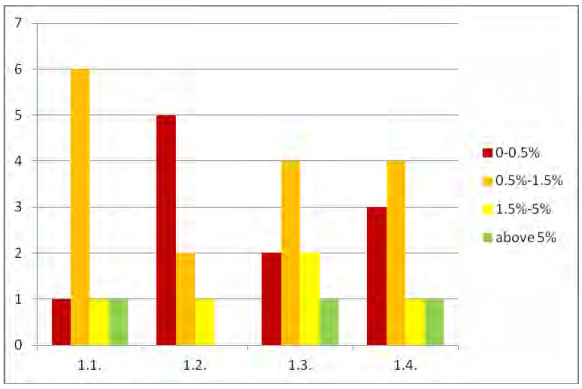


Figure 5-20: Total machinery energy savings potential – Overall Machine

Regarding the overall machine concept, the respondents state a large variation of additional machinery costs with the implementation of options. For each of the options, the full spectrum of answers is covered. At least 2 of the respondents state for each option a cost of more than 3% of the total machinery costs, but there are always two respondents, which replied that there was no cost difference at all (Figure 5-21).

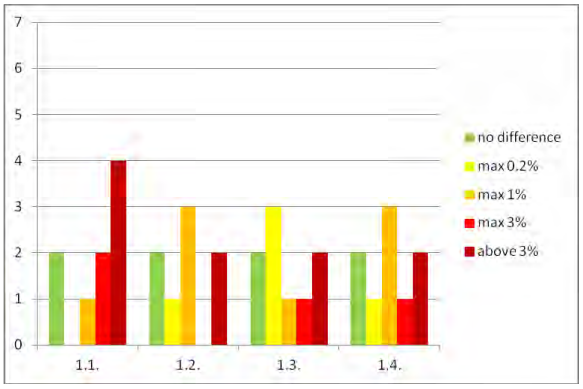


Figure 5-21: Cost effects (machinery invest) – Overall machine

Figure 5-22 depicts the market penetration of individual improvement options regarding the overall machine concept, according to the replies stated by the respondents (averaged values). It has to be noted, that the respondents had in mind their specific market segment, which leads to a broader variation in the stated market penetration. The replies depict the trend that options are increasingly applied in new machines, but that the level of implementation (not considering the aspect of feasibility) rarely exceeds 50%.

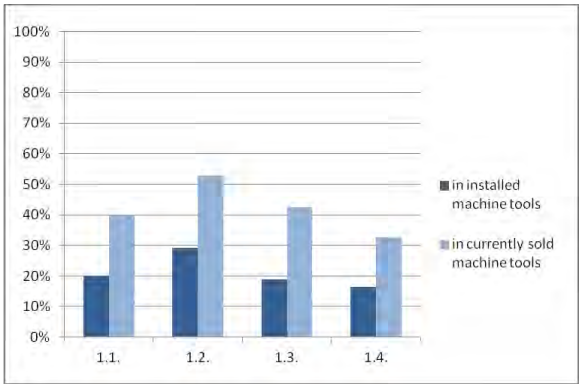


Figure 5-22: Market penetration – Overall machine

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
1.1 minimisation of moved masses	5%	1%	20%	40%
1.2 reduction of friction	1%	0,5%	29%	53%
1.3 optimization of the electrical design	1%	1%	19%	43%
1.4 design for instant machining without warm up	1%	1%	17%	33%

Table 5-1: Assessment of Measures - Overall Machine

The table above lists the values for the overall machine concept, which are used as approximations for calculations in Task 6.

Regarding the **drive units**, the survey unveils a rather small stated energy efficiency potential for most of the options: For almost all options most estimates are in the range 0%–0,5% of total energy savings, but also in this case frequently at least one respondent states a large potential above 5% energy savings for individual measures (Figure 5-23). The most promising options may be concluded as “inverter controlled motors for auxiliary units” (2.7) and “Use of torque motors” (2.3).

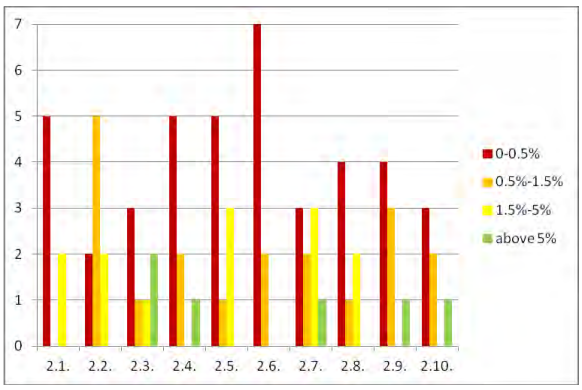


Figure 5-23: Total machinery energy savings potential – Drive units

Replies regarding the cost effects of optimised drive units again cover a broader range of estimates. However, several options are assessed with a rather low machinery cost increase, such as “regenerative feedback of Inverter system (servo motor/spindle)” (2.1). On the other hand, options with a larger energy savings potential are those which are assumed to be costly (such as 2.3 and 2.7), although this opinion is not shared by all respondents (Figure 5-24).

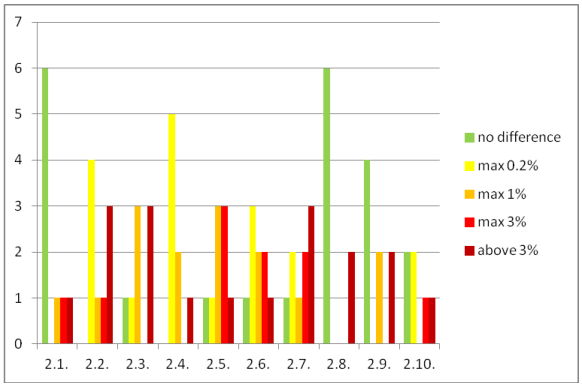


Figure 5-24: Cost effects (machinery investment) – Drive units

Figure 5-25 depicts the market penetration of individual improvement options regarding drive units, according to the replies stated by the respondents (averaged values). The replies depict the trend that the options are increasingly applied within new machines, and for some options the level of implementation (not considering the aspect of feasibility) exceeds 70%, whereas for other options a rather low market penetration is observed – in particular those with a moderate savings potential (2.3, 2.7).

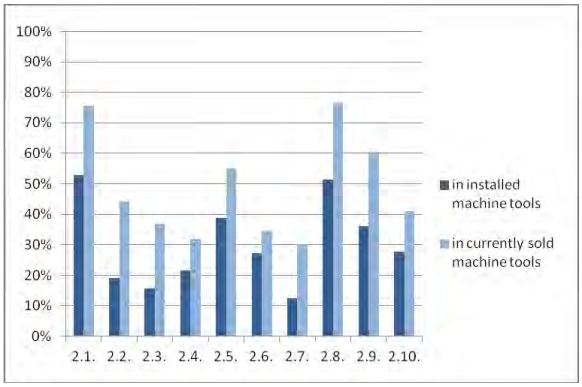


Figure 5-25: Market penetration – Drive units

The table below lists the values for the drive units which will be used as approximations for subsequent calculations in Task 6. For some of the options the range of replies is too broad to state a tendency – in this case "n.a." (not applicable) is stated.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
2.1 Regenerative feedback of Inverter system (servo motor/spindle)	0%	0,5%	53%	76%
2.2 Use of energy efficient motors for auxiliary units	3%	1%	19%	44%
2.3 Use of torque motors	1%	1%	16%	37%
2.4 High efficient gear unit	0,2%	0,5%	22%	32%
2.5 Mass free compensation of load for vertical axes	3%	1%	39%	55%
2.6 Use of break to control movement of axes	3%	0,5%	27%	34%
2.7 Inverter controlled motors for auxiliary units	5%	1%	12%	30%
2.8 400V inverter systems to substitute 200V systems	0%	1%	51%	76%
2.9 Spindle-design without belt and pulleys	n.a.	1%	36%	61%
2.10 Intelligent magnetic flux control	n.a.	0,5%	28%	41%

2.1 Regenerative feedback of Inverter system (servo motor/spindle)	0%	0,5%	53%	76%
2.2 Use of energy efficient motors for auxiliary units	3%	1%	19%	44%
2.3 Use of torque motors	1%	1%	16%	37%
2.4 High efficient gear unit	0,2%	0,5%	22%	32%
2.5 Mass free compensation of load for vertical axes	3%	1%	39%	55%
2.6 Use of break to control movement of axes	3%	0,5%	27%	34%
2.7 Inverter controlled motors for auxiliary units	5%	1%	12%	30%
2.8 400V inverter systems to substitute 200V systems	0%	1%	51%	76%
2.9 Spindle-design without belt and pulleys	n.a.	1%	36%	61%
2.10 Intelligent magnetic flux control	n.a.	0,5%	28%	41%

Table 5-2: Assessment of Measures - Drive units

Regarding the **hydraulic system** from the replies given, only “Speed controlled pumps” (3.2) and “Discontinuous operating pumps” (3.1) are likely to have a remarkable savings potential in the range of 1% of total machinery energy consumption (Figure 5-26). For several options there seem to be no relevant energy savings potential at all, namely “Fixed orifice blades to control the system pressure” (3.5), “Leakage monitoring” (3.6), and “Use of hydraulic system with optimized components” (3.7).

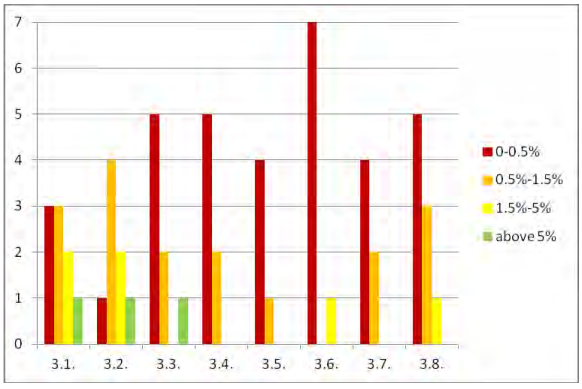


Figure 5-26: Total machinery energy savings potential – Hydraulic system

The options with significant energy savings potential (3.1, 3.2) are related to a cost increase below 1% by most respondents, although a full range of replies (including “above 3%”) is given, overall.

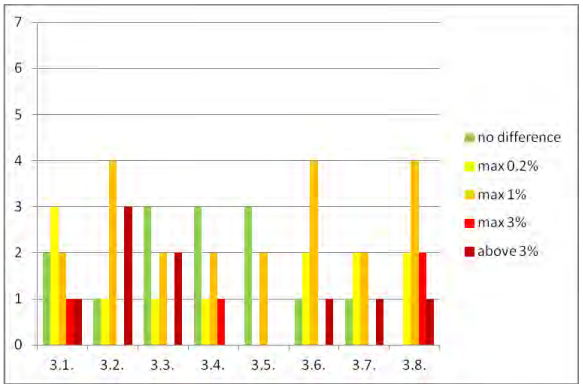


Figure 5-27: Cost effects (machinery invest) – Hydraulic system

Figure 5-28 depicts the market penetration of individual improvement options regarding hydraulic systems, according to the replies stated by the respondents (averaged values). The replies depict the trend that the options are increasingly applied in new machines, but that the level of implementation (not considering the aspect of feasibility) in all cases is below 40%.

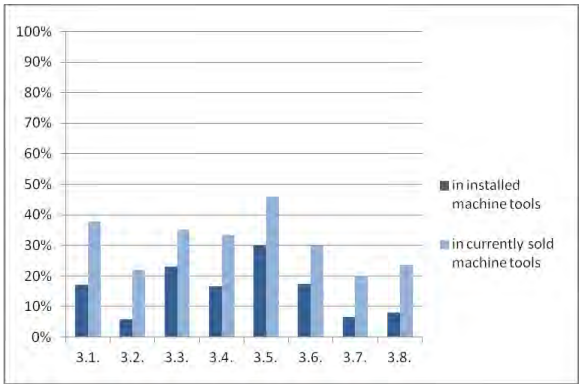


Figure 5-28: Market penetration – Hydraulic system

The table below lists the values for hydraulic systems which will be used as approximations for the subsequent calculations in Task 6. For some of the options the range of replies is too broad to state a tendency – in this case “n.a.” (not applicable) is stated.

Measure	**Cost effects (investment) Increase in total machinery invest (tendency)**	**Total machinery savings potential (tendency)**	**Market share**	
			in installed machine tools	in currently sold machine tools
3.1 Discontinouous operating pumps	1%	1%	17%	38%
3.2 Speed controlled pumps	1%	1%	6%	22%
3.3 Optimize hydraulic system design	n.a.	0,5%	23%	35%

3.4 Optimized piping	1%	0,5%	17%	33%
3.5 Fixed orifice blades to control the system pressure	1%	0,5%	30%	46%
3.6 Leakage monitoring	1%	0,5%	18%	30%
3.7 Use of hydraulic system with optimized components	n.a.	0,5%	7%	20%
3.8 Inverter controlled motors for auxiliary units	3%	0,5%	8%	23%

Table 5-3: Assessment of Measures - Hydraulic system

Regarding the **cooling lubrication system** the survey unveils a rather small energy efficiency potential stated for most of the options (Figure 5-29). The most relevant option is “Apply minimal quantity lubrication (MQL) when feasible “ (4.2), for which several respondents stated an energy savings potential above 5%. For all other options there were at least two statements per option stating that the energy savings potential was at maximum 0,5%, if at all, but also one to two statements per option, stating that the potential was in the range 1,5% – 5%.

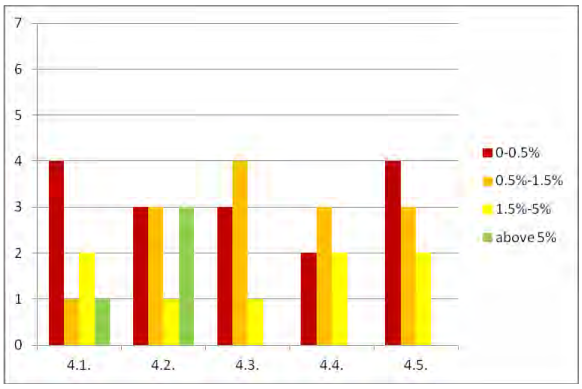


Figure 5-29: Total machinery energy savings potential – Cooling lubrication system

Replies regarding the cost effects of optimised cooling lubrication systems show that the one option with the highest savings potential is also the one which could have the highest potential effect on machinery costs (4.2). However, there were also some statements noting that MQL does not make a cost difference (Figure 5-30). For all other options, the replies cover the range between “no cost difference” and “maximum 3% cost increase”, unveiling again the fact that cost effects are also highly dependent on the application.

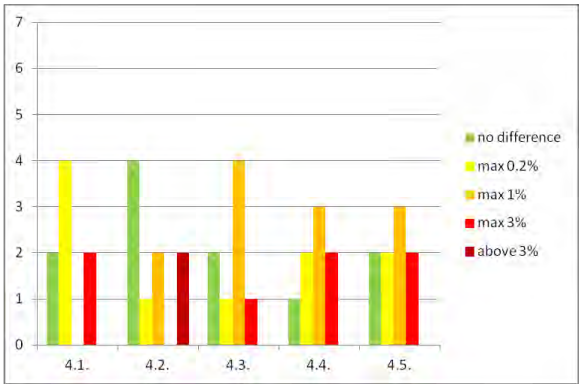


Figure 5-30: Cost effects (machinery investment) – Cooling lubrication system

Figure 5-31 depicts the market penetration of individual improvement options regarding cooling lubrication systems, according to the replies stated by the respondents (averaged values). The replies depict the trend that the options are increasingly applied in new machines, but that the level of implementation (not considering the aspect of feasibility) is below 50% for all options.

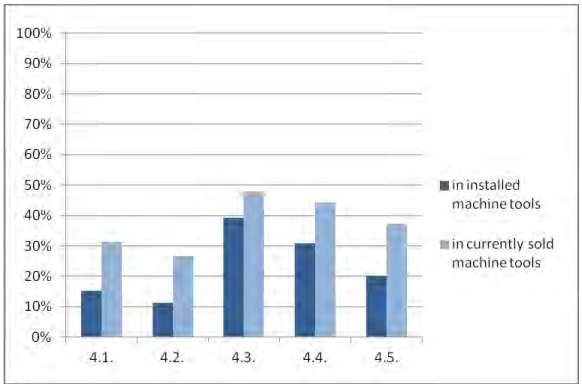


Figure 5-31: Market penetration – Cooling lubrication system

The table below lists the values for the drive units which will be used as approximations for calculations which follow on in Task 6. For some of the options the range of replies is too broad to state a tendency – in this case “n.a.” (not applicable) is stated.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
4.1 Discontinuous operating pumps	0,2 %	0,5%	15%	31%
4.2 Apply minimal quantity lubrication (MQL) when feasible	n.a.	0,5%	11%	27%
4.3 Adjustable pressure for cooling	1%	0,5%	39%	48%

lubrication				
4.4 Controlled flow rate	1%	1%	31%	44%
4.5 Inverter controlled motors for lubrication system	1%	0,5%	20%	37%

Table 5-4: Assessment of Measures - Cooling lubrication system

Regarding the **cooling system,** the survey indicates a relevant level of savings potential for "Thermal management regarding machine tool or its modules" (5.2), but estimates equally cover the full range of possible replies from 0%-0,5%, to above 5% (Figure 5-32). For the other options some estimates indicate savings potentials above 0,5%, although there are always a larger number of respondents being rather critical about achievable savings.

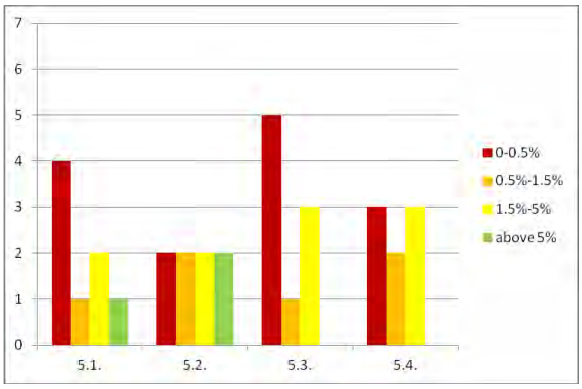


Figure 5-32: Total machinery energy savings potential – Cooling system

Replies regarding the cost effects of optimised cooling systems again cover a broader range of estimates. All options are shown with the possible cost effects in Figure 5-34.

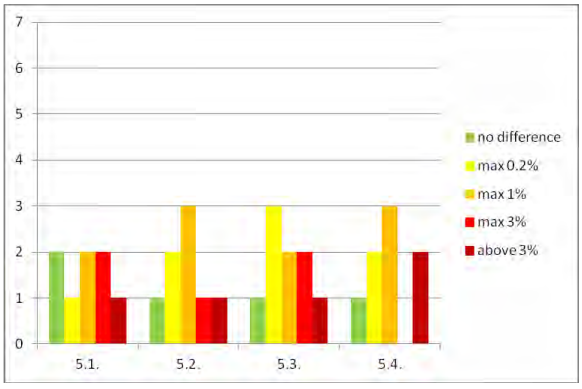


Figure 5-33: Cost effects (machinery investment) – Cooling system

Figure 5-34 depicts the market penetration of individual improvement options regarding the cooling system, according to the replies stated by the respondents (averaged

values). The replies depict the trend that the options are increasingly applied in new machines, but that in all cases current market penetration is at maximum 30%.

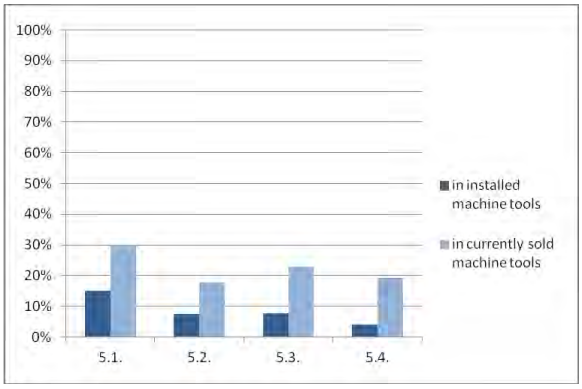


Figure 5-34: Market penetration – Cooling system

Table 5-5 lists the values for cooling systems which were meant to be used as approximations for calculations in Task 6. However, as the stated cost range was too broad to allow for a qualified assessment, no such calculations pertaining to cooling systems will be made in Task 6.

Measure	Cost effects (investment) Increase in total machinery invest (range)	Total machinery savings potential	Market share	
			in installed machine tools	in currently sold machine tools
5.1 Thermal management of all cooling devices	n.a.	0,5%	15%	30%
5.2 Thermal management regarding machine tool or its modules	n.a.	n.a.	7%	18%
5.3 Apply direct cooling of components depending on process	n.a.	0,5%	8%	23%
5.4 Apply efficient cooling system	n.a.	1%	4%	19%

Table 5-5: Assessment of Measures - Cooling system

Regarding **power electronics** from the replies given, it is evident that the energy savings potential by almost all respondents is estimated to be negligible (Figure 5-35).

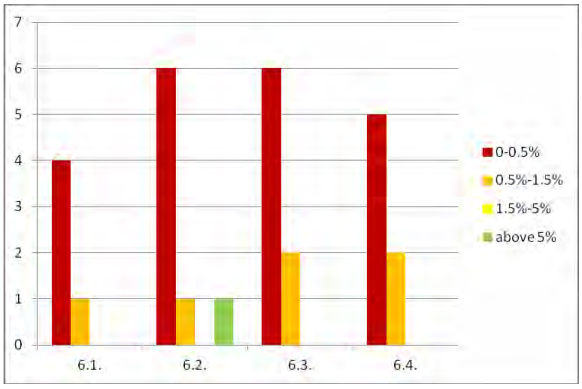


Figure 5-35: Total machinery energy savings potential – Power electronics

Minor savings potential, but at least no major cost difference is the conclusion which may be drawn from the statements given, with respect to the cost effects of improvement options, related to power electronics (Figure 5-36).

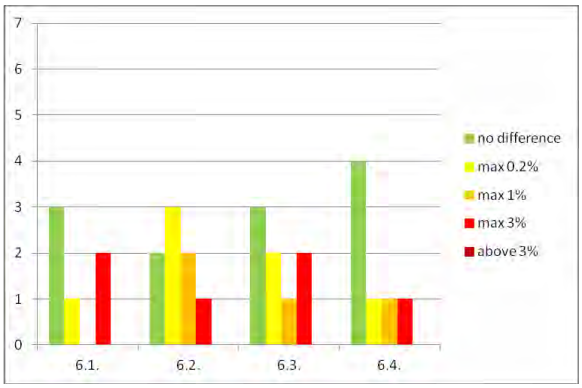


Figure 5-36: Cost effects (machinery invest) – Power electronics

Figure 5-37 depicts the market penetration of individual improvement options regarding power electronics according to the replies stated by the respondents (averaged values).

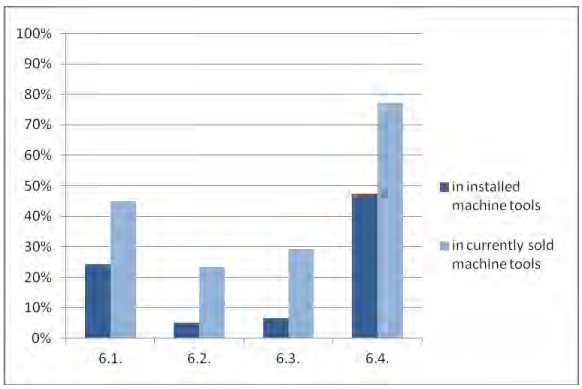


Figure 5-37: Market penetration – Power electronics

The table below lists the values for power electronics which will be used as approximations for calculations in Task 6.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
6.1 Avoidance of transformers by use of voltage-proof converter	3%	0,5%	24%	45%
6.2 High efficiency transformer	1%	0,5%	5%	23%
6.3 Converter with power factor correction	1%	0,5%	6%	29%
6.4 Controlled switching power supply for auxiliary power 24V	0,2%	0,5%	48%	77%

Table 5-6: Assessment of Measures - Power electronics

Regarding the **machine concept,** from the replies given some tendencies are evident (Figure 5-38): Despite the fact that there was always at least one respondent stating an energy efficiency potential below 0,5% for some of the options, other respondents state a larger savings potential, namely for “Multi spindle-/ multi workpieces machining” (7.5), “Complete machining all sides” (7.6), and “Combination of various technologies (turning + milling + laser + grinding etc.)” (7.7). It should be noted that presumably the respondents, when stating the energy savings potential for these options, did not have in mind the absolute energy consumption, but were rather considering the savings per workpiece, i.e. related to output. For some other options there is also a stated significant savings potential (several estimates in the ranges above 0,5% savings potential): “Optimised compressed air system with minimal losses” (7.9), “Single master switch-off” (7.10), “Individual switched-off capability for specific modules” (7.11), “Intelligent shutdown procedures” (7.12), “Leak indicator, on demand monitoring” (7.13).

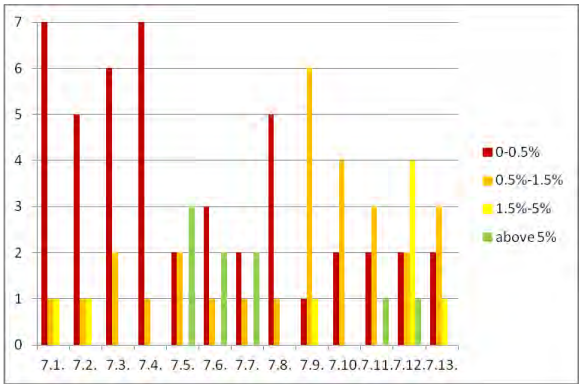


Figure 5-38: Total machinery energy savings potential – Machine concept

The options with the highest stated savings potentials are also those with the highest additional costs, which is logical, as the named concepts (7.5, 7.6, 7.7) require a radical change of the machine tool. In fact, these options actually result in a basically different machine (Figure 5-39). For the remaining options with a significant potential, a broad range of cost estimates is given: For options 7.9, 7.10, 7.12 each, at least two statements indicate no cost difference, as well as a maximum 3% cost difference; this again reveals that the implications of measures have to be judged individually for different machine tools (types).

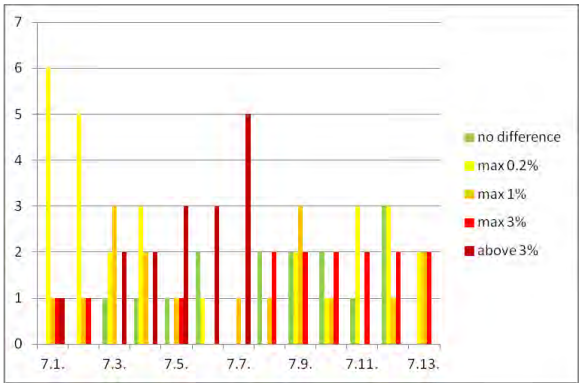


Figure 5-39: Cost effects (machinery investment) – Machine concept

Figure 5-40 depicts the market penetration of individual improvement options relating to the machine concept, according to the replies stated by the respondents (averaged values). The replies display a trend that the options are increasingly applied in new machines, and explicitly the trend towards even more complex machine tools is obvious (7.5, 7.6, 7.7). The level of implementation (not considering the aspect of feasibility) rarely exceeds 50%.

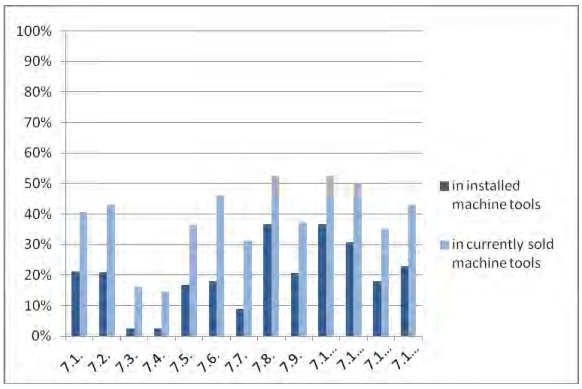


Figure 5-40: Market penetration – Machine concept

The table below lists the values for the overall machine concept, which will be used as approximations for calculations in Task 6. For some of the options, the range of replies

is too broad to state a tendency – in this case “n.a.” (not applicable) is stated. For options 7.5, 7.6 and 7.7, a figure of >3% is stated and no fixed value; this is because these options actually signify a change of the whole machine technology.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
7.1 Thermal management regarding control cabinet	1%	0,5%	21%	41%
7.2 Switching valves with low Watt technology / alternative control via use pulse width modulation (PWM)	1%	0,5%	21%	43%
7.3 Alternative work piece clamping	n.a.	0,5%	3%	16%
7.4 Alternative tool clamping	n.a.	0,5%	2%	14%
7.5 Multi spindle-/ multi workpieces machining	>3%	5%	17%	36%
7.6 Complete machining all sides	>3%	1%	18%	46%
7.7 Combination of various technologies (turning + milling + laser + grinding etc.)	>3%	5%	9%	31%
7.8 Dismantling ability of machine / reuse of materials	3%	0,5%	37%	53%
7.9 Optimised compressed air system with minimal losses	3%	1%	21%	38%
7.10 Single master switch-off	1%	1%	37%	53%
7.11 Individual switched-off capability for specific modules	3%	1%	31%	50%
7.12 Intelligent shut-down procedures	3%	3%	18%	35%
7.13 Leak indicator, on demand monitoring	3%	1%	23%	43%

Table 5-7: Assessment of Measures - Machine concept

Regarding **peripheral devices,** there is only one option stated in ISO 14955 (Figure 5-41), which is a very generic one: “Controlled peripheral devices like mist extraction, chip conveyer, etc” (8.1)

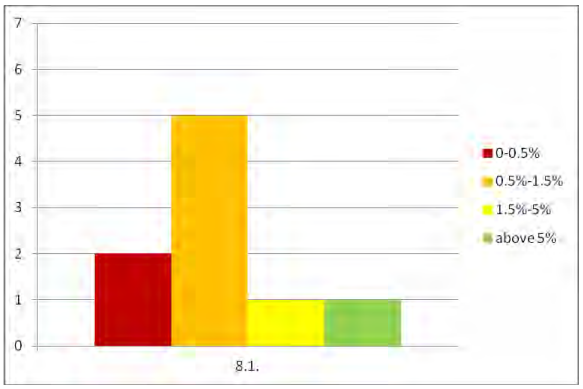


Figure 5-41: Total machinery energy savings potential – Peripheral device

For this option, a relevant energy savings potential is stated, and a rather low cost effect, although also in this case it should be noted that there are deviating replies (Figure 5-42).

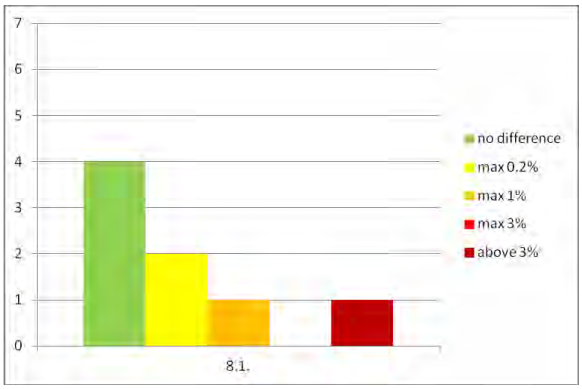


Figure 5-42: Cost effects (machinery investment) – Peripheral device

Figure 5-41 depicts the market penetration for this option according to the replies stated by the respondents (averaged values). Market penetration is on a rather low level.

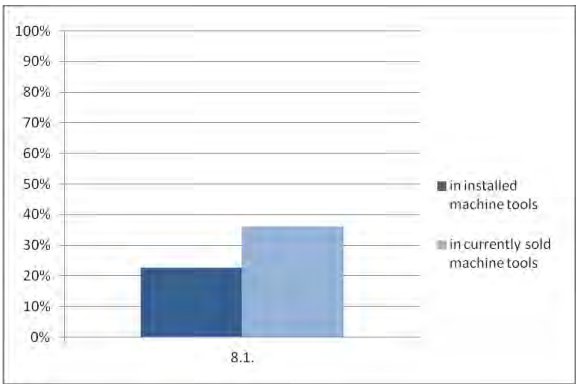


Figure 5-43: Market penetration – Peripheral device

The table below lists the values for peripheral devices, which will be used as approximations for calculations in Task 6.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
8.1 Controlled peripheral devices like mist	0,2%	1%	23%	36%

extraction, chip conveyer, etc

Table 5-8: Assessment of Measures - Peripheral device

Simulation is a distinct option in ISO 14955. Assessment of this option by the respondents is depicted below regarding energy savings potential (Figure 5-44), cost effects (Figure 5-45), and market penetration (Figure 5-46).

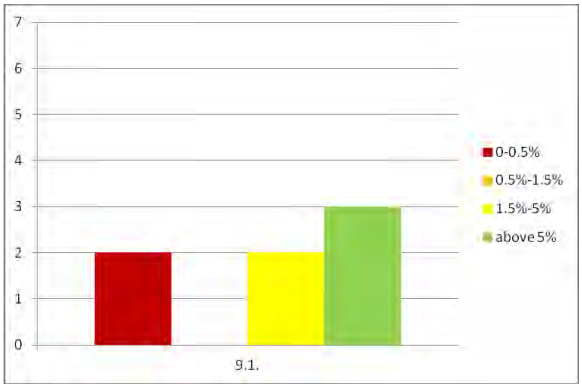


Figure 5-44: Total machinery energy savings potential – Simulation

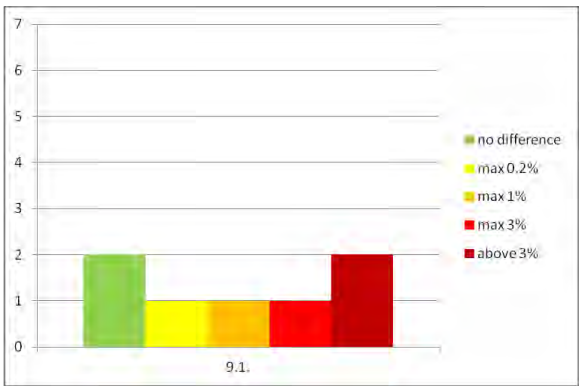


Figure 5-45: Cost effects (machinery invest) – Simulation

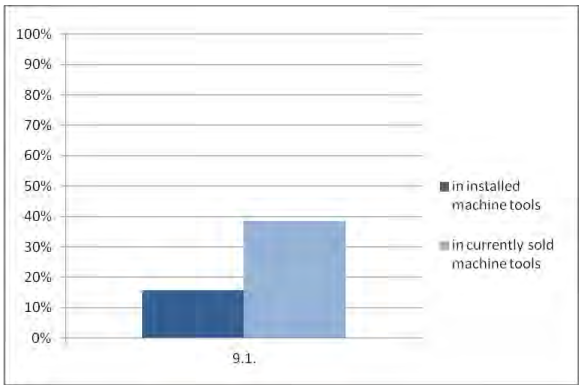


Figure 5-46: Market penetration – Simulation

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
9.1 Optimisation of work piece processing by simulation off-machine ; avoidance of inefficient operating time	n.a	5%	16%	39%

Table 5-9: Assessment of Measures - Simulation

Regarding the **control unit,** the survey (Figure 5-47) reveals a rather small energy efficiency potential stated for “Screen saver for operating terminal and work space lighting to be switched-off, when not in use” (10.2), a moderate savings potential for “Default setting for operating condition (costumer specific unit switch-off)” (10.1), as stated by several of the respondents, and a very significant potential for “Minimise non-productive time” (10.3).

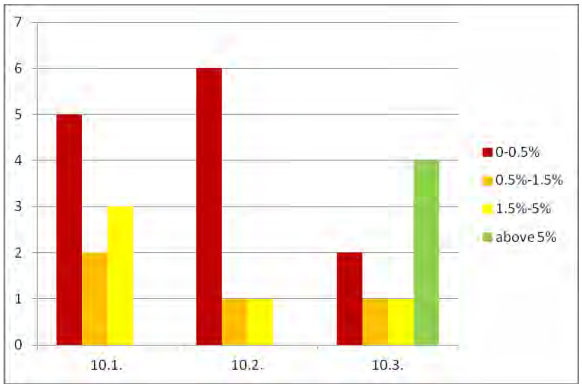


Figure 5-47: Total machinery energy savings potential – Control

The latter (10.3) is assumed by the respondents to be realised with no cost change. This is presumably based on the assumption that this measure could be realised through organisational improvements, rather than by dedicated technical means. Also for the other two options a majority of the respondents anticipates no cost difference (Figure 5-48).

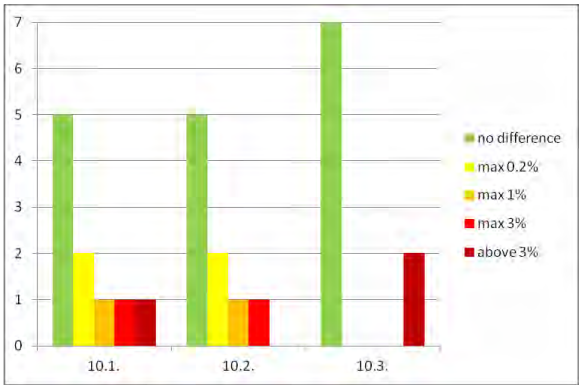


Figure 5-48: Cost effects (machinery investment) – Control

Figure 5-49 depicts the market penetration of individual improvement options regarding control, according to the replies stated by the respondents (averaged values). The replies depict the trend that the options are increasingly applied in new machines, but that uptake does not exceed 50% until now. However, it should be noted that for a very generic option, such as “minimise non-productive time”, a sound market penetration rate is difficult to define.

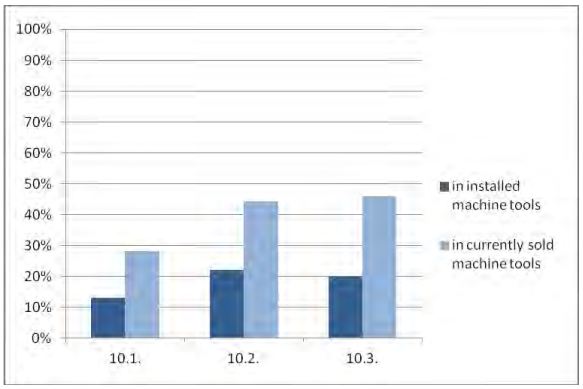


Figure 5-49: Market penetration – Control

The table below lists the values for control which will be used as approximations for calculations in task 6.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
10.1 Default setting for operating condition	0%	1%	13%	28%

(costumer specific unit switch-off)				
10.2 Screen saver for operating terminal and work space lighting to be switched-off, when not in use	0,2%	0,5%	22%	44%
10.3 Minimise non-productive time	0%	5%	20%	46%

Table 5-10: Assessment of Measures - Control

5.1.13.1.2 Cutting - 2012 Update

The above evaluation is based on feedback received from CECIMO in mid-2011. In April 2012 CECIMO provided an update for cutting machine tools, based on data received from another 12 respondents in this segment. The updated data on total machinery energy saving potentials (Figure 5-50) and potential change in machinery investment (Figure 5-51) are depicted below. Compared to the initial 2011 replies, the updated figures show, for many measures, a more pessimistic assessment regarding potential savings, although overall trends remain the same. Therefore the later analysis in Task 6 is still based on the initial 2011 data.

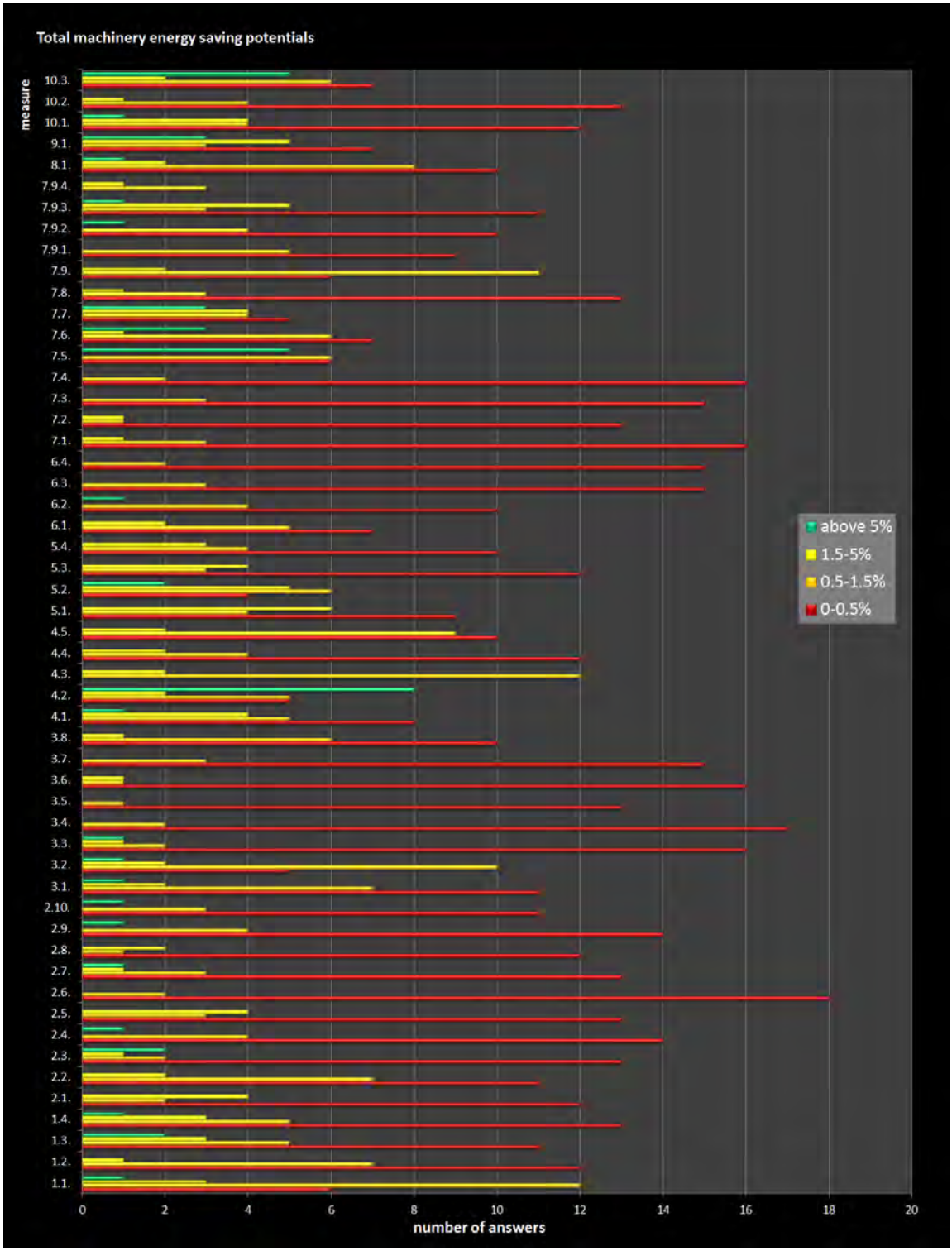


Figure 5-50: Total machinery energy saving potentials – 2012 Update

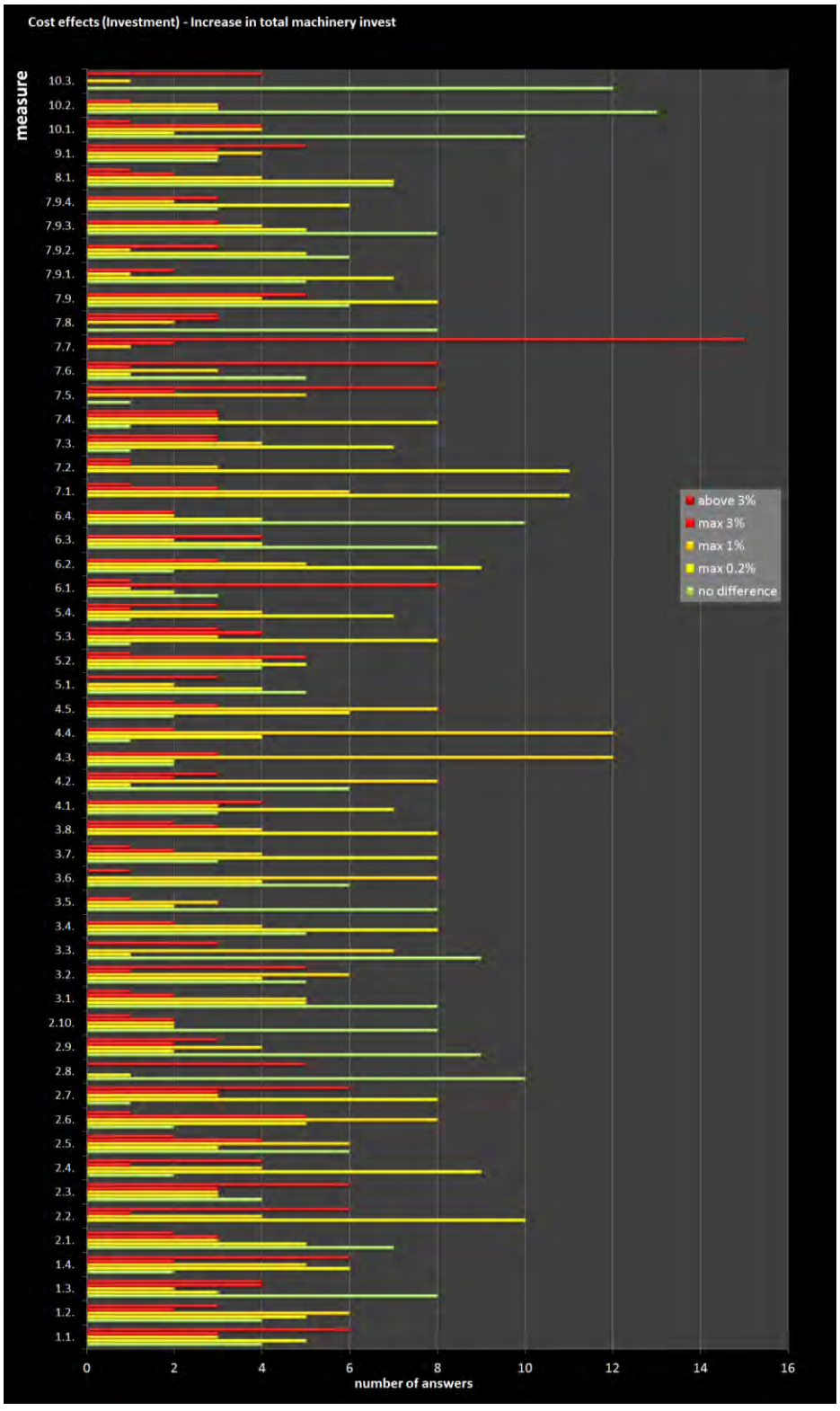


Figure 5-51: Increase in total machinery invest – 2012 Update

5.1.13.1.3 Hydraulic & servo presses

For metal working presses CECIMO received 3 replies to the survey from machinery manufacturers, one for servo presses/ mechanical presses, and two for hydraulic presses.

The tables below list the measures for these types of machine tools according to ISO 14955 (draft, tables B1, B2) and state the estimates given regarding cost effects, total machinery energy savings and market share. Figures stated for servo presses / mechanical presses are those from the one respondent[178]; figures stated for hydraulic presses are meant to be tendencies based on the two respondents.

The minimization of moved masses (1.1) for both hydraulic and servo presses, but more relevant for the latter, unveils a high improvement potential, which comes - according to the respondents - at no additional cost. For servo presses, the market penetration of this approach is stated to be in the range of 50%, for servo presses currently sold. A high savings potential is also stated for highly efficiency cushions (1.5), but at significant additional costs (Table 5-12).

ISO 14955 table B1	ISO 14955 table B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
			Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
1.1	1.1	Minimisation of moved masses	0%	0%	1%	5%	80%	95%	20%	50%
1.2	1.2	Reduction of friction	0,2%	0,2%	0,5%	1%	95%	95%	95%	95%
1.3	1.3	Optimization of the overall machine design	0%	0%	0,5%	3%	70%	90%	50%	90%
1.4	1.4	Counterbalance system for vertical axes	5%	1%	3%	1%	40%	60%	95%	90%
1.5	1.5	High efficiency cushions	5%	1%	3%	5%	<1 %	0%	0%	100 %

[178] Note, that the questionnaire defined ranges for costs and energy savings, which are now approximated in the tables with distinct values

1.6		High efficient decompression	3%		0,5%		0%	0%		
1.7		Use regenerative circuit for differential cylinders	1%		0,5%		20%	50%		
1.8	1.6	Die clamping	1%	1%	0,5%	0,5%	50%	90%	50%	90%

Table 5-12: Assessment of Measures - Overall machine

Among the measures addressing the drive units (Table 5-13) there are several options with a stated high efficiency potential, such as the use of multi-pressure accumulator systems for the main axis (2.6), or a directly-coupled energy storing drive system for the main axis (2.7) in hydraulic presses, both still with a very low market penetration , but with a major impact on machinery costs. Similarly, for servo presses, the use of direct drive systems (2.7) is stated to have a high energy saving potential, but again at higher costs. The optimization of the dynamic parameters (2.2) of servo presses involves a high energy savings potential without any (major) cost difference. Inverter controlled motors for auxiliary units (2.9) in servo presses are stated to be of high energy saving potential and minor additional costs. Some other options also come with promising energy savings potential at low to moderate additional costs, which is particularly relevant as the drive unit, as such, in presses is the most energy consuming module.

ISO 14955 table B1	**ISO 14955 table B2**	**Measure**	**Cost effects (investment) Increase in total machinery invest (tendency)**		**Total machinery savings potential (tendency)**		**Market share hydraulic presses**		**Market share servo presses**	
			Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
2.1	2.1	Regenerative feedback of inverter system (e.g. servo motor, AFE-technology)	3%	1%	0,5%	5%	0%	0%	40%	100 %
2.2	2.2	Optimisation of the dynamic parameters	1%	0%	0,5%	5%			0%	0%
	2.3	Minimisation of spare capacity/customer specific layout of motors		0%		1%			40%	100 %
	2.4	Minimisation of spare capacity/customer specific layout of inverter system		0%		1%			90%	100 %

2.5		Provide most efficient drive system	3%		3%		50%	85%		
	2.5	Optimized axis servo motors		0%		1%				
2.6		Use of multi-pressure accumulator system for main axis	5%		5%		5%	3%		
	2.6	Use of energy efficient motors for auxiliary units		0,2%		1%			50%	90%
	2.7	Use of direct drive systems		5%		5%			1%	50%
2.8		Direct coupled energy storing drive systems for main drives	5%		5%		0%	8%		
	2.8	High efficient gear unit								
	2.9	Inverter controlled motors for auxiliary units		0,2%		3%			0%	20%
2.9	2.10	Indirect coupled energy storing drive systems for main drives	5%	0,2%	5%	0,5%	0%	0%	5%	90%
2.3	2.11	Optimisation of installed motor power	1%	0%	0,5%	3%	43%	55%	50%	90%
2.4	2.12	Use of energy efficient motors	0,2%	1%	1%	3%	25%	55%	0%	100 %
	2.13	Use of energy efficient pumps		0,2%		1%			5%	50%
2.10	2.14	Intelligent drive management	3%		3%	5%	0%	5%	0%	30%
2.7	2.15	Use of energy efficient pump-motor units	1%	0,2%	0,5%	1%	55%	90%	0%	0%

Table 5-13: Assessment of Measures - Drive units

For the hydraulic system, the ISO 14955 (draft) lists numerous improvement options. The assessment by the machinery manufacturers indicates a small improvement potential for many of the options (Table 5-14). All options assessed with a higher energy savings potential (3 or 5%) are related to significant cost increases. Some measures according to the respondent can be implemented without additional costs on hydraulic presses. These measures comprise:

- Choice of pump systems which match the requirement profile (3.1.1)
- Selecting the correct size pump to avoid over-dimensioning, and operation of the pump in the optimal efficiency range (3.1.3)
- On/Off or stand-by mode, giving due consideration to safety criteria (3.2.5)
- Avoidance of internal leakage (3.3.2)
- Use of energy-efficient pulse valves (3.4.1)

Several options are related to minor cost increases, of up to 0.2 % of the total machinery investment.

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machinery	in currently sold	in installed machinery	in currently sold
3.1	Selection of the optimal drive subsystem (motor-pimp system)	5%	0,2%	5%	0,5%	40%	45%	20%	90%
3.1.1	Choice of the pump systems which match the requirement profile	0%	0,2%	1%	1%	95%	95%	20%	80%
3.1.2	Power on demand	5%	0,2%	3%	1%	10%	30%	20%	80%
3.1.3	Selecting the correct size pump to avoid over-dimensioning, and operate the pump in the optimal efficiency range	0%	0%	1%	1%	95%	95%	50%	100 %
3.1.4	Temporary storage of hydraulic energy	1%	0%	1%	0,5%	100 %	100 %	50%	100 %
3.2	Match the pressure level to the load cycle and to the different actuators on the machine	0,2%	0%	1%	0,5%	60%	80%	80%	100 %
3.2.1	Pressure adjustment using adjustable pressure relief valves or zero-pressure circulation	0,2%	0,2%	0,5%	1%	100 %	100 %	50%	100 %
3.2.2	Usage of actuators which are designed to operate at the same pressure level (no pressure reduction losses)	3%	0%	0,5%	0,5%	70%	70%	80%	100 %
3.2.3	Pressure adjustment using pressure-controlled drive systems	5%		5%		38%	53%		
3.2.4	Use of pressure intensifiers for individual actuators which require higher pressure	0,2%	0,2%	0,5%	0,5%	20%	20%	20%	100 %
3.2.5	On/Off or stand-by mode, giving due consideration to safety criteria	0%		0,5%		100 %	100 %		
3.3	Reduce hydraulic losses	3%	0%	1%	0,5%	40%	60%	80%	100 %
3.3.1	Displacement control systems	3%	0,2%	3%	0,5%	45%	65%	30%	80%
3.3.2	Avoid internal leakage	0%	0%	0,5%	0,5%	70%	70%	40%	80%
3.3.3	Optimize the design of the hydraulic lines and reduce hydraulic resistance	1%	0,2%	0,5%	0,5%	70%	90%	80%	100 %
3.3.4	Distributed supply strategies		0,2%		0,5%			80%	100 %
3.4	Reduce power consumption on solenoid operated valves	0,2%	0%	0,5%	0,5%	0%	10%	90%	100 %
3.4.1	Energy efficient pulse valves	0%	0%	0,5%	0,5%	0%	10%	0%	0%

3.4.2	Energy efficient valve connectors	0,2%	0,2%	0,5%	0,5%	0%	0%	0%	0%
3.4.3	Use of low Watt solenoids	0,2%	0%	0,5%	0,5%	0%	0%	80%	100 %
3.5	Leakage monitoring	1%	0,2%	1%	0,5%	0%	10%	0%	0%
3.6	Low flow resistance	3%	0,2%	0,5%	0,5%	80%	100 %	90%	90%
3.7	High-efficiency auxiliary pressure generation	1%	0,2%	1%	0,5%	100 %	100 %	20%	80%
3.8	Warm-up cycle	1%	0,2%	0,5%	0,5%	35%	60%	40%	80%
3.9	Oil temperature	0,2%	0,2%	0,5%	0,5%	98%	100 %	100 %	100 %
3.10	Oil cooling	0,2%	0%	0,5%	0,5%	95%	100 %	50%	90%
3.11	ISO 4413 shall be applied		0%		0,5%			100 %	100 %

Table 5-14: Assessment of Measures - Hydraulic Systems

Only few options are stated for the lubrication system – and savings potentials are minor (Table 5-15).

ISO 14955 table	**Measure**	**Cost effects (investment) Increase in total machinery invest (tendency)**		**Total machinery savings potential (tendency)**		**Market share hydraulic presses**		**Market share servo presses**	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
4.1	Lubrication flow depending on demand	0,2%	0,2%	0,5%	0,5%	10%	60%	30%	50%
4.2	Low flow rate for lubrication pump	0%	0%	0,5%	0,5%	90%	90%	50%	70%

Table 5-15: Assessment of Measures - Lubrication system

The survey unveils a moderate total energy savings potential for die cooling, and the lubrication system in servo presses, in particular: All options listed in ISO 14955 are attributed with a small energy savings potential, but also with no or minor cost increases. For hydraulic presses, fewer options are stated and these tend to be more costly (Table 5-16).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
5.1	Thermal management of all cooling devices including cooling device for machine tool and/or its modules	1%	0,2%	0,5%	0,5%	100 %	100 %	30%	80%
5.1.1	Avoid losses								
5.1.2	Losses to be dissipated by air or water cooling	1%	0,2%	0,5%	0,5%	80%	80%	50%	80%
5.1.3	Optimized ventilation		0,2%		0,5%			0%	0%
5.2	Apply direct cooling of components depending on process	0%	0%		0,5%	100 %	100 %	0%	0%
5.3	Apply demand depending cooling	0,2%	0%	1%	0,5%	100 %	100 %	0%	0%

Table 5-16: Assessment of Measures - Die cooling/lubrication system

Power electronics show a moderate total energy savings potential, but as a very high market penetration is already stated for these approaches, there is a very limited potential for further improvements, according to the respondents (Table 5-17).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
6.1	Avoidance energy losses of power supplies	0,2%	0,2%	0,5%	0,5%	45%	100 %	40%	95%
6.2	High efficiency transformer	0,2%	0,2%	0,5%	0,5%	60%	100 %	60%	95%
6.3	Apply the simultaneity factor when designing the power system	0%	0%	0,5%	0,5%	60%	90%	60%	95%
6.4	Converter/inverter with power factor correction	3%		0,5%		10%	100 %		
6.5	Thermal management regarding control cabinet	3%	3%	0,5%	0,5%	0%	0%	20%	70%

Table 5-17: Assessment of Measures - Power electronics

The pneumatic system is related with significant energy savings potential in both hydraulic and servo presses, but again, it is rather the multitude of individual options, rather than any single option which has an outstanding potential (Table 5-18).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed ma-	in currently sold	in installed ma-	in currently sold
7.1	Switching valves with low Watt technology, pulse width modulation (PWM), valves with detent (where permissible)	0,2%	0,2%	0,5%	0,5%	0%	20%	40%	80%
7.2	Optimised compressed air system with minimal losses								
7.2.1	Reduction of dead volume (Vcut)	0,2%	0,2%	0,5%	0,5%	40%	80%	40%	80%
7.2.2	Directed switch off of not needed branches	0%	0%	0,5%	0,5%	90%	90%	0%	0%
7.2.3	Dimensioning of tubes and pipes	1%	1%	0,5%	0,5%	90%	90%	90%	90%
7.2.4	Correct layout of pneumatic drives	0,2%	0,2%	0,5%	0,5%	80%	80%	80%	80%
7.2.5	Reduction of pressure	0,2%	0,2%	0,5%	0,5%	70%	70%	70%	70%
7.2.6	Influence of leakage	1%	1%	1%	1%	0%	0%	0%	0%
7.2.7	Optimise cylinder force for the required function	0,2%	0,2%	1%	1%	90%	90%	90%	90%
7.2.8	ISO 4414 shall be applied		0%		0,5%			100 %	100 %

Table 5-18: Assessment of Measures - Pneumatic system

For peripheral devices the energy savings potential is stated to be minor (Table 5-18).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (range)		Total machinery savings potential		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
8.1	Controlled peripheral devices like mist extraction, scrap conveyer, etc	0%	0%	0,5%	0,5%	90%	90%	90%	90%

Table 5-11: Assessment of Measures - Peripheral device

Measures listed under simulation in ISO 14955 (draft), which actually involve aspects of general process information, are related to significant energy saving potentials, according to the respondents: The provision of customer information to reduce consumption of resources (9.3) is linked to an effect on energy consumption. Most options, according to the respondents, are already implemented in currently-sold machine tools (Table 5-18).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
9.1	Optimisation of work piece processing by die try-out	0%	0%	0,5%	0,5%	30%	60%	30%	60%
9.2	Provisions to reduce scrap production	1%	0,2%	0,5%	0,5%	20%	80%	30%	90%
9.3	Provide customer information to reduce consumption of resources	0%	0%	1%	1%	20%	20%	20%	50%

9.3.1	Information to user on energy efficient use of the machine e.g. on/off programming of auxiliary devices (user's manual, instruction)	0,2%	0,2%	3%	1%	10%	70%	10%	50%
9.3.2	Information to user on optimized movements of axis		0,2%		1%			0%	0%
9.3.3	Information to user on usable energy		0%		0,5%			10%	80%
9.4	Minimize non-productive time	1%	0,2%	0,5%	0,5%	50%	80%	50%	90%
9.5	Optimize productivity by reducing cycle time per part	1%	0,2%	1%	3%	60%	90%	50%	90%

Table 5-12: Assessment of Measures – Simulation

With regard to machinery control, significant energy savings are stated for the three listed options, although for the energy-optimized default setting for operating condition (10.1), no statement regarding its energy saving potential was made by the respondents.

ISO 14955 table B1/B2	**Measure**	**Cost effects (investment) Increase in total machinery invest (range)**		**Total machinery savings potential**		**Market share hydraulic presses**		**Market share servo presses**	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
10.1	Energy optimized default setting for operating condition - energy level - (customer specific drive management)	0,2%	0,2%		1%	40%	70%	40%	90%
10.2	Automatic operating state switching	0,2%	0,2%	0,5%	0,5%	0%	<1%	0%	0%
10.3	Recording of current energy consumption together with energy relevant production data	0,2%	0,2%	0,5%	1%	0%	0%	0%	50%

Table 5-13: Assessment of Measures – Control

5.1.13.1.4 Module manufacturer / provider perspective

Whereas the above analysis is based on feedback from machinery manufacturers, providers of sub-systems / modules also provided input to the survey. These respondents are affiliated to:

- Bosch Rexroth AG
- CETOP (Comité Européen des Transmissions Oléohydrauliques et Pneumatiques / European Fluid Power Committee)
- REDEX SA

Assessments given by these stakeholders are summarised in the table below, again transferring the ranges stated to distinct values, understood to be tendencies, not exact savings and costs.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Comments by stakeholders
Software-based Energy Management incl. Stand-By Mode			
2.1 Energy monitoring	0%	3%	Software based solutions have no additional cost effect. Optional solutions with additional hardware
2.2 Machine stand-by management	0%	5%	Software based solutions have no additional cost effect
2.3 Energy-optimized motion control	0%	1%	Current solutions are motivated by cycle time optimization. These solutions also have impact on energy efficiency
2.4 other: Plant based energy management	0%	5%	Standardised communication profiles allow energy management over several machines by using the existing production network infrastructure.
Energy Recuperation of Drives, Power Electronics, and Super Premium Efficiency Motors			
3.1 Application specific design of drives	0%	1%	
3.2 Speed control	1%	3%	This topic varies broadly between different types of drives. Servo Drives are 100% speed controlled. Auxiliary devices with speed control are very limited in market penetration
3.3 Direct drive instead of ball screw drives			This depends on the specific case in every different machine

3.4 Brake energy feedback	3%	3%	Typical high end machines made in Europe have nearly 100% market penetration for servo drives. Low and medium range machines from Asia usually have no feedback
3.5 Reducing maximal acceleration	0%	0,5%	Has no energy saving effect, because the cycle time will rise. Therefore more energy will be consumed
3.10 Wattless current compensation	0,2%	0,5%	
3.11 Latest generation IGBTs	0,2%	1%	
3.12 Super premium efficiency motors	1%	1%	
3.13 other: use of high quality gears sets qualtity	1%	1%	(REDEX SA)
5.25 other: use of low friction seals	1%	0,5%	(REDEX SA)
6.8 other: Lubrication optimized	3%	3%	(REDEX SA)
Hydraulic and Pneumatic Optimized Systems			
5.1 Optimized cooling of the motor	0%	0,5%	
5.2 Adaptable levels of pressure	0,2%	3%	
5.3 Pressure adjustments for different actuators	1%	3%	Depending on application
5.4 Use of hydraulic accumulators	0,2%	3%	
5.5 Substitution of technologies	1%	3%	
5.6 Reducing inner leakages losses	0,2%	0,5%	
5.7 Use of optimized valves	0,2%	0,5%	
5.8 Use of hydraulic clamping tools	0%	3%	
5.9 Extending the field of application of hydraulics	0%	5%	e.g. hydraulic boosted cooling lubricant supply
5.10 Prevention of nipple collapse	0,2%	0,5%	
5.11 Application specific compressed air quality	0%	0,5%	The evaluation is related to the proposed change in our comments
5.12 Reducing channels of supply / dead volume	0,2%	0,5%	
5.13 Minimizing losses due to leakages (pneumatics)	0,2%	0,5%	
5.14 Pneumatic Cylinder with optimized drive surface	0,2%	0,5%	
5.15 Pneumatic Cylinder with multiple chambers	0,2%	0,5%	Only applicable for specific applications
5.16 Single acting pneumatic cylinder	0%	0,5%	
5.17 Targeted cut-off from air supply	0%	0,5%	
5.18 Use of multiple valves	0,2%	0,5%	
5.19 Pressure reduction	0%	1%	See comment on Task 5 report, 5.1.6.3: pressure reduction (system)
5.20 Using exhaust air	1%	0,5%	If improvements are possible is not proved today
5.21 Optimized valve switching	0%	0,5%	

5.23 Sensor based monitoring of pneumatic systems	0,2%	0,5%
5.24 other: Energy optimized engineering of machinery	0%	5%
Energy-Efficient Cooling Lubricant Supply		
6.1 Minimum quantity lubrication	3%	1%
6.2 Coolant lubricant supply through pressure control valves	1%	3%
6.3 Optimised pipe dimension for coolant lubricant supply	0%	0,5%

Table 5-14: Assessment according to module manufacturers

According to these assessments the following options are of key interest, as they potentially result in significant energy savings at no or low additional costs:

- Any measure under “Software-based energy management incl. stand-by mode”
- Application-specific design of drives
- Adaptable levels of pressure in hydraulic/ pneumatic systems, and pressure reduction
- Use of hydraulic accumulators.

5.1.13.2 Wood working machine tools

No manufacturer of wood working machine tools replied to the call for assessing the outlined improvement options. Therefore Fraunhofer bilaterally consulted manufacturers, and developed the assessment based on the information sourced at these meetings. The assessment for wood working machinery is summarized in the table below.[179]

There are a couple of relevant options for energy savings, particularly stand-by management, optimization and adequate of vacuum systems, and control of extraction systems (technical measures, which depend on a suitable centralized extraction system).

[179] For clarification, this assessment was made by Fraunhofer based on technology insights, but not by machinery manufacturers. This assessment was shared with one manufacturer before being published in this report to seek their confirmation of the stated tendencies.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery energy savings potential (tendency)	Comment
Mass Reduction of Moving Parts			
1.1 Lightweight materials	3%	0,5%	Aluminium instead of steel for moving parts
1.2 Material reduction	3%	0,5%	
1.3 Less parts to be moved	0,2%	1%	in case of panel saw: only saw blade is raised, not the motor
Software-based Energy Management incl. Stand-By Mode			
2.1 Energy monitoring	1%	1%	
2.2 Machine stand-by management	0,2%	5%	
2.3 Energy-optimized motion control	3%	0,5%	
Energy Recuperation of Drives, Power Electronics, and Super Premium Efficiency Motors			
3.1 Application specific design of drives	0%	1%	
3.2 Speed control	1%	1%	
3.3 Direct drive instead of ball screw drives	1%	0,5%	
3.4 Brake energy feedback	1%	1%	relevant for CNC (short processing cycles, frequent tool changes)
3.5 Reducing maximal acceleration	1%	1%	
3.6 Reducing transmission losses	0,2%	0,5%	
3.7 Replacing inverter units	0,2%	0,5%	400 V instead of 200 V
3.8 Using low friction roller bearings	0,2%	0,5%	
3.9 Avoidance of transformers	0,2%	0,5%	
3.10 Power factor correction	1%	3%	
3.12 Super premium efficiency motors	3%	1%	
3.13 efficient motors also <750 W	1%	1%	
Tool Handling and Clamping			
4.1 Electrical clamping devices	1%	3%	electro-mechanical clamping could replace vacuum for larger (CNC) machines, but reduces flexibility
4.2 Efficient sealing of spindle system		0,5%	typically no air-lock systems used, hence no savings
4.3 Non-pneumatic lubrication for spindles	1%	1%	relevant for CNC
4.4 Multi spindle systems	5%	3%	savings related to increased productivity, not per machine
4.5 Softstarter	1%	1%	for saws (typically larger sawing mills), reducing initial

			power consumption
Hydraulic and Pneumatic Optimized Systems			hydraulics applied in presses and for lubrication systems in CNC machines
5.1 Optimized cooling of the motor	0,2%	0,5%	
5.2 Adaptable levels of pressure		0,5%	
5.3 Pressure adjustments for different actuators		0,5%	
5.4 Use of hydraulic accumulators		0,5%	
5.5 Substitution of technologies		0,5%	
5.6 Reducing inner leakages losses		0,5%	
5.7 Use of optimized valves		0,5%	
5.11 Application specific compressed air quality	1%	1%	relevant for equipment with e.g. air tables
5.12 Reducing channels of supply / dead volume	0,2%	1%	
5.13 Minimizing losses due to leakages (pneumatics)	0,2%	1%	
5.14 Pneumatic Cylinder with optimized drive surface	0,2%	1%	
5.15 Pneumatic Cylinder with multiple chambers		0,5%	
5.16 Single acting pneumatic cylinder	0,2%	1%	
5.17 Targeted cut-off from air supply	0,2%	1%	
5.18 Use of multiple valves	0,2%	0,5%	
5.19 Pressure reduction	0,2%	1%	
5.21 Optimized valve switching		0,5%	
5.23 Sensor based monitoring of pneumatic systems	1%	1%	
5.24 optimised blowing nozzles	0,2%	1%	e.g. for chips and dust removal
5.25 load-dependent air table control	1%	1%	relevant for larger equipment with air tables
5.26 speed-controlled vacuum pumps with frequency converters in conjunction with an intelligent closed-loop control (to adjust the volume output to match the current need)	3%	1%	
5.27 vacuum system equipped with multi-pump systems with intelligent activation / deactivation of individual pumps on a needs basis	3%	1%	
5.28 line-controlled blow-off device to adapt air consumption to actual needs	1%	1%	

Table 5-15: Assessment of eco-design options for wood working machine tools

5.2 Definition of BNAT

5.2.1 Introduction

Besides industrial initiatives such as "Blue Competence", by the VDW (German Machine Tool Builders' Association), there is a strong push via domestic policy in Germany to promote sustainable technologies in manufacturing. In the frame of the nationwide platform called "Effizienzfabrik", numerous projects have been launched to advance resource efficiency in manufacturing, some of which directly tackling machine tools. These innovation platforms started in September 2009, and will end in August 2013. To provide insights, a brief description of machine tool-related activities are summarized in Table 5-19, of which some will be discussed later in further detail.

Table 5-19: Scope related R&D activities to promote sustainable technologies in the frame of Effizienzfabrik

Project	Target figures	Consortium	Scope related Field of application
BEAT Overall assessment of the energy efficiency of alternative technology chains	Development of a method to compare the production lines on a process level depending on available data, such as cutting parameters, and to configure single processes by means of energetic aspects. *Means*: ▪ Collecting energy and resource consumption figures of single processes considering auxiliary processes and consumables ▪ Comparison of collected data with physically active principles ▪ Creation of benchmark figures for the assessment of the energy and resource efficiency of processes ▪ Analysis of technological chains ▪ Assessment of alternative technology chains from an energetic point of view ▪ Implementation of models and a benchmark figures system into a software application ▪ Recognition of implementing measures (guideline creation)	Daimler AG, Effizienz-Agentur NRW, PE International Experts in Sustainability, Robert Bosch GmbH, RWTH Aachen	Production plants
e-SimPro Efficient production machinery through simulation dur-	Simulation of the energy consumption of machine tools depending on specific process demands, *Means*: ▪ Experimental examination to iden-	EMAG Salach Maschinenfabrik GmbH, August Steinmeyer GmbH & Co. KG, FESTO AG & Co. KG, HANDTE	Metal working machine tools

Project	Target figures	Consortium	Scope related Field of application
ing development	tify relevant components in the simulation ▪ Development of models to calculate the energy use of single components ▪ Development of a method to determine the load profile of single components during cutting process ▪ Development of software modules ▪ Piloting development and implementation of selective optimization measures ▪ Assessment of the configured machining concepts in regard to the overall economic efficiency	Umwelttechnik GmbH, HYDAC International GmbH, Siemens AG, TU Darmstadt (PTW), Volkswagen AG	
EnergieMSP Energy demand optimised motor spindle and adapted electrical powertrain	Reduce or improve the energy consumption of the overall system main spindle of a machine tool by using loss minimizing spindle components and optimisation through lightweight construction	Franz Kessler, PTW, ARADEX, Schaeffler, OTT-JAKOB Spantechnik, Mecatronix, KLuB, MAPAL	Spindle systems of metal working machine tools
ENERWELD Efficient thermal joining processes	Assessment and optimisation of thermal joining processes in regard to energy efficiency	Technische Universität Berlin (IWF), Benteler Automobiltechnik GmbH, EWM Hightec Welding GmbH, JENOPTIK Automatisierungstechnik GmbH, JENOPTIK Laser GmbH, Klaas Alu-Kranbau GmbH, PLATOS Planung technisch-organisatorischer Systeme GmbH, RIFTEC GmbH, RWE Power AG (assoziierter Partner), Welding Alloys Deutschland Schweißlegierung GmbH,	Welding, soldering, brazing machines
EnHiPro Energy and	Enabling SME to implement organisational and technological measures to increase efficiency and to assess the impact	TU Braunschweig (IWF), Introbest GmbH & Co, ifu	Production plants of small and

Project	Target figures	Consortium	Scope related Field of application
auxiliary consumables optimised production	on energy and consumables used as well as traditional production figures *Means*: ▪ Measurement of energy and consumables consumption ▪ Data processing and management ▪ Assessment and visualisation ▪ Development of measurements for optimisations	Hamburg GmbH, Intronic GmbH & Co., mts Maschinenbau GmbH, Spinnweberei Uhingen GmbH, SSV Software Systems GmbH, Syslog GmbH	medium sized enterprises
EnoPRO Energy optimized path planning to increase efficiency in machine tools		Gildemeister Turning Machines, EXAPT Systemtechnik, meteocontrol, RWTH Aachen (WZL)	
EWOTeK Increasing efficiency of machine tools through optimisation of technologies for operating components	Fundamental examination of the power demand of machine tools Optimising energy demand of machine tools Raising market acceptance of energy efficient technologies Raising consciousness of users regarding energy efficiency	Gebr. Heller Maschinenfabrik GmbH, BKW Kälte-Wärme-Versorgungstechnik GmbH, Bosch Rexroth AG, INDEX-Werke GmbH & Co. KG Hahn & Tessky, Knoll Maschinenbau GmbH, RWTH Aachen (WZL), Siemens AG	Metal working machine tools
FlexWB Targeted design of component properties to increase energy efficiency within the process chain of warm forming	Development and realization of new process chains for warm forming without using ovens Produce components with specific material properties within certain areas of the component itself	Neue Materialien Bayreuth GmbH, Audi AG, Daimler AG, Fraunhofer IWU, preccon Robotics GmbH, Schuler SMG GmbH & Co. KG, SMS Elotherm GmbH, ThyssenKrupp Steel Europe AG	Machinery for modifying material properties, warm forming machine tools
FunkProMikro Function-oriented controlled micro manufacturing processes	Developing methods and strategies to describe the permissible deviation in shape of the workpiece in regard to its later function; as well as for the manufacturing process control, as well as for the assessment of the expected functional quality.	Werth Messtechnik GmbH, Continental Automotive GmbH, Daimler AG, Friedrich-Alexander-Universität Erlangen-Nürnberg, Heidelber-	Machine tools

Project	Target figures	Consortium	Scope related Field of application
		ger Druckmaschinen AG, Karlsruher Institut für Technologie (KIT), MAG Boehringer Werkzeugmaschinen GmbH	
KAMASS High performance parts through efficient cold forming	Revealing the high potential of cold forming for producing high performance parts appropriate to operational demands, especially for alternating load. Reducing production chains. Replacing more resource intensive manufacturing technologies (comparable production chains, e.g. forging – heat treatment – cutting post treatment)	ZF Sachs AG, SSF-Verbindungsteile GmbH, Universität Erlangen-Nürnberg, Wezel GmbH	(Cold forging) machine tools
LaFueSol Laser Welding of Glass Tubes for Solar Thermal Collectors	Energy-efficient welding of glass tubes Development of an online analysis of the residual stresses generated in glass Development of a unit to record temperature fields using an IR camera for process control Reduced cycle time Construction of a prototype to demonstrate the complete concept/process	Laser Zentrum Hannover e. V., Herbert Arnold GmbH & Co. KG, ilis GmbH, IRCAM GmbH, Kollektorfabrik	Laser welding machines
MAXIEM Maximizing energy efficiency of machine tools	Demonstrating the potential savings by the means of configuring a prototypical machine tool, using the most efficient components and auxiliary units available on the market. *Means*: Precise determination of the energy consumption of cutting machine tools, also on component level. Construction of characteristic usage profiles, models, and calculation in order to identify consumers of energy. Systematic identification and quantification of the most promising regulating variables to reduce energy demand. Implement calculated potential savings by	Alfing Kessler Sondermaschinen GmbH, Audi AG, BMW AG, Bosch Rexroth AG, Daimler AG, Grob-Werke GmbH & Co. KG, Gebr. Heller Maschinenfabrik GmbH, MAG Powertrain, Fachgebiet Produktionsmanagement, Technologie und Werkzeugmaschinen (PTW), Siemens AG, Power Generation, Studer Schaudt GmbH, Volkswagen AG	Metal working machine tools

Project	Target figures	Consortium	Scope related Field of application
	setting up a demonstrative machine. Creation of a guideline and handbook for developers and purchaser of cutting machine tools. Development of methods for the objective assessment of the energy efficiency of cutting machine tools and its components.		
NCplus Process and value driven controlled machine tool	Developing prototypical technologies which facilitate a process and value driven operation of cutting machine tools.	Deckel Maho Pfronten GmbH, CAMAIX GmbH, Franz Kessler GmbH, Hydac International GmbH, KME Germany AG, Mayr GmbH, Perpendo GmbH, Bosch Rexroth AG, Institut für Fertigungstechnik und Werkzeugmaschinen, Leibniz Universität Hannover, Walter AG, Otto Bock Healthcare GmbH	Metal cutting machine tools

5.2.2 Metalworking machine tools - solutions

Regarding metal working machine tools, a need for research has been identified in the field of process stability, where energy losses of up to 80 MJ per kg (cutting), and 50 MJ per kg (forming) arise, due to the occurrence of scrap.[180] Thus, anticipatory process monitoring is required, in conjunction with the use of appropriate tools, such as sensors or optical inspection systems. As far as the latter case is concerned, the research project MobiKAM comprises the development of a mobile energy self-sufficient optical sensor, e.g. for measuring and testing in the working area. In this way, a more reliable and transparent machining is facilitated.[181] [182]

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180 Putz, M.: Herausforderungen an Systeme und Prozesse in der energieeffizienten/ressourceneffizienten Produktion, Symposium „Energieeffiziente Werkzeugmaschinen“, Düsseldorf, February 24, 2010.

181 See https://mobikam.ipk.fraunhofer.de/pam/?rq_AppId=31303137&rq_TargetId=31303030 (German description only), accessed January 20, 2011.

182 Project time: 01.01.2008 to 30.06.2011

The research project ECOMATION deals with measures for reducing the energy demand of cutting machine tools by means of control and feedback control systems, on the premise that the manufacturing process itself is not interfered with. This is being achieved by the choice of suitable process steps and parameters, which will be determined by experimental examination. In this way, energy optimisation can be achieved without influencing the actual machining process.[183] [184]

The aim of the Collaborative Research Center project SFB 467 "Transformable Corporate Structures of Multi Variant Serial Production" is the development of models, methods and procedures to increase the versatility in manufacturing companies. This includes the investigation of the versatility of machine tools and assembly systems. The solution approaches are based on modular systems. The research activities involve planning tools for the automatic configuration planning to develop versatile systems. Project Area C "Transformable technical systems", of the SFB 467, examined the technical implementation and support of adaptability in production and information technology tasks.. Convertible processing systems are based on the principle of reconfigurability, whereas the base of this adaptability is formed by self-sufficient, mechatronic modules and a self-regulating control system.[185] [186] [187] [188] [189]

In the context of surface technology, great importance is attached to the cleaning of parts after the process to minimize “external” losses of lubrications.[190] Cleaning is the removal of residual lubricants, including process liquids as well as remaining sub-

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183 Heisel, U., et al., ref 8, p. 221ff.

184 Project time: 2009 to 2015

185 Heisel, U.; Wurst, K.-H.; Kircher, C.: (Re)konfigurierbare Werkzeugmaschinen – notwendige Grundlage für eine flexible Produktion. In: wt Werkstattstechnik online 96 (2006) 5, pp. 257-265.

186 Heisel, U.; Wurst, K.-H.: Konzeption und Entwicklung mechatronischer Module für wandelbare Bearbeitungssysteme und Untersuchung deren Auswirkungen auf die Gestaltung von Fertigungseinrichtungen. www.tfb059.uni-stuttgart.de/teilprojekte/tp3/. Access: 31.08.2010.

187 Kircher, C.; Seyfarth, M.; Wurst, K.-H.: Modellbasiertes Rekonfigurieren von Werkzeugmaschinen. In: wt Werkstattstechnik online 94 (2004) 5, pp. 179-183.

188 Westkämper, E.: Modulare Produkte - Modulare Montage. In: wt Werkstattstechnik 91 (2001) 8, pp. 479-482.

189 Project time: 1997 to 2005

190 König, U.: Oberflächentechnik für Maschinen der Metallbearbeitung – Technologien, Potentiale, Anwendungen. In: FTK 2006, pp. 333 – 344, Ges. f. Fertigungstechnik, Stuttgart, 2006.

stances from preceding processes. The total removal of cooling lubricant residuals and chips is usually performed by an aqueous or organic rinsing medium. A significant amount of energy is required for the transfer of the contaminated elements into this cleaning medium, and for the subsequent lubricant regeneration, as well as for the lubrication process itself, , e.g. for the heating or vacuum generation.[191] The project B 2 “Energy efficient cleaning and dry machining” of the CRC 1026 “Sustainable Manufacturing – Shaping Global Value Creation” will comprise research strategies for in-process-cleaning, using dry ice blasting.

The project ConTemp (Self-Learning Control of Tool Temperature in Cutting Processes) is expected to produce two innovative developments:

- Firstly, a new cutting tool system with an integrated high performance micro-cooling device, that enables the application of a closed coolant circuit. The advantage is the elimination of the contamination of the cooling liquid. Therefore a reduction of cleaning costs and waste disposal is possible.
- Secondly, the development of a self-learning control platform that reacts to changes of the process conditions, thus maintaining a constant temperature at the tool tip, optimising the process results.[192] [193]

The project METEOR (more technology-oriented reconfigurable machine tools) develops the adaptation of machine tools and transfer lines to the dynamics of the market. In this case, these production systems are designed independently from the product itself and current life cycle. For this project, the equipment is built from standardized components with standardized interfaces, and combined in a common work space to bring together different manufacturing processes.[194] [195] [196] [197]

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[191] Marktübersicht Reinigungsanlagen. In: Metalloberfläche, Volume 61, Issue 5, 2007.

[192] See http://www.contemp.org/index.php?id=28, accessed March 25 , 2012

[193] Röder, M.: Smarte Werkzeuge für harte Werkstoffe. In: FUTUR 14 (2012) 1, pp. 10-11.

[194] Abele, E.; Wörn, A.: Chamäleon im Werkzeugmaschinenbau. In: ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb 99 (2004) 4, pp. 152-156.

[195] Abele, E.; Wörn, A.: Economic Production with Reconfigurable Manufacturing Systems (RMS). In: Wissenschaftliche Gesellschaft für Produktionstechnik (WGP). Annals of the German Academic Society for Production Engineering. Braunschweig: Vol. XII/1 (2005), pp. 189-192.

[196] Stanik, M.: Der Rekonfigurierbarkeit gehört die Zukunft. In: Werkstatt und Betrieb, 137 Jahrgang, Carl Hanser Verlag, München, Wien, (09) 2004, pp. 24-30.

The aim of the project Loewe (life cycle-oriented machine tool) was to reduce the life-cycle cost of machine tools by adapting the modular designed constructions to new production tasks (Figure 5-52). Furthermore, the issue of modularization extended the life time of the machine tool by using modules with defined interfaces. These types of interfaces are not only a mechanical connection, but they also support the supply of energy and auxiliary materials. The control configuration is realized by using transponders, which are used as object data sources.

Furthermore, the modular, adaptable Loewe tool also provides information on the state of the machine and its components for a life cycle monitoring system. The integration of sensory and intelligent components in the machine tool allows the maximization of performance, ensures availability and permanently monitors actual costs. Additional hard- and software-based systems may be required to recognize, process and store lifetime-relevant and cost-effective properties. In addition to the above, a software system was developed which allows the calculation and projection of relevant life-cycle costs during the development, implementation, use, maintenance and disposal of machine tools.[198] [199] [200] [201]

[197] Projet time 01.10.03 to 31.10.07

[198] Dekena, B.; Möhring, H.-C.; Harms, A.; Vogeler, S.; Noske, H.: Können teure Werkzeugmaschinen auf längere Sicht günstiger sein?. In: wt Werkstattstechnik online 95 (2005) 7/8, pp. 519-523.

[199] Denkena, B.; Jacobsen, J.: Senkung der Lebenszykluskosten von Werkzeugmaschinen durch Komponentenüberwachung. In: Zeitschrift für wirtschaftlichen Fabrikbetrieb ZWF 101 (2006) 7-8, pp. 440-443.

[200] Denkena, B.; Harms, A.; Jacobsen, J.; Möhring, H.-C.; Jungk, A.; Noske, H.: Lebenszyklusorientierte Werkzeugmaschinenentwicklung. In: wt Werkstattstechnik online 7/8-2006, S. 441-446.

[201] Project time: 01.04.04 to 31.08.07

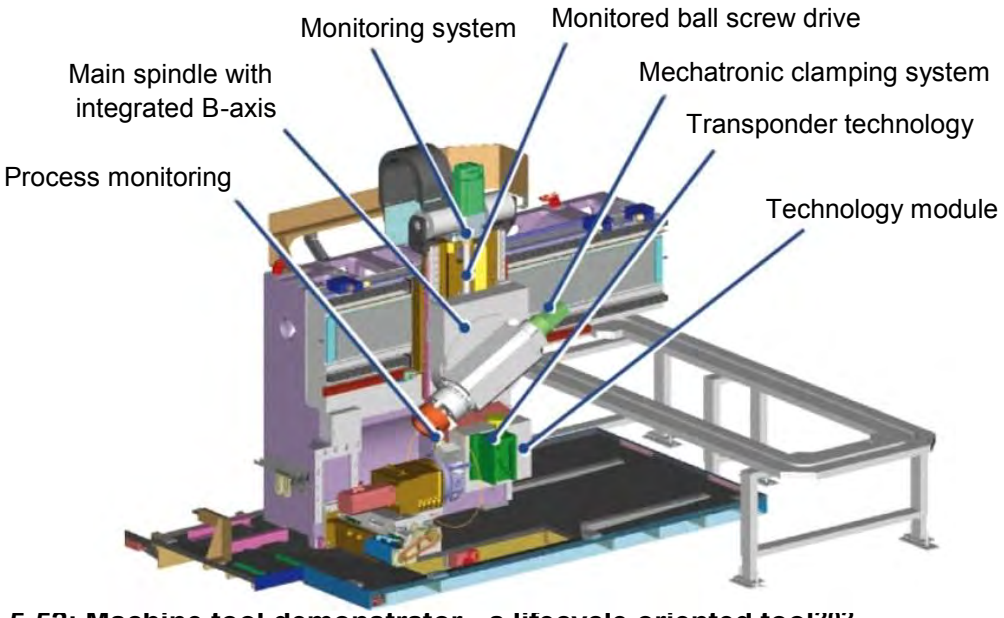


Figure 5-52: Machine tool demonstrator - a lifecycle oriented tool[202]

5.2.3 Modularisation, versatility and optimisation of energy consumption

The mobility of production technology refers to a new level of versatility. Only through the transformation of a company is it possible to operate outside a flexibility corridor. Adaptability is seen as solution-neutral potential that is going beyond flexibility, and can be activated in case of need to make adjustments to changing conditions.[203][204] Critical to ensuring a high pattern of mobility is a highly modular design. Under the joint project ProMotion (design and operation of mobile production systems) the design and operation of mobile production systems were studied.

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202 Denkena, B.; Harms, A.; Jacobsen, J.; Möhring, H.-C.; Jungk, A.; Noske, H.: Lebenszyklusorientierte Werkzeugmaschinenentwicklung. In: wt Werkstattstechnik online 7/8-2006, S. 441-446.

203 Wiendahl, H.-P.: Wandlungsfähigkeit - Schlüsselbegriff der zukunftsfähigen Fabrik. In: wt Werkstattstechnik 92 (2002) 4, pp. 122-125.

204 Wiendahl, H.-P.; El Maraghy, H. A.; Nyhuis, P.; Zäh, M. F.; Wiendahl, H.-H.; Duffie, N. A.; Brieke, M.: Changeable manufacturing - classification, design and operation. In: CIRP Annals. Manufacturing Technology 56 (2007) 2, pp.783-809.

The aim of the ProMotion project was to use mobility, both within a site and across sites, as a new degree of freedom, and thus to increase the location and structural variability. Relocation of the equipment at the customer's site is often not provided, or is achievable only with great effort. The possibility to easily move the machine tool has to be considered, and achieved, in the design phase of the machine. Under this project, a special "mobile"[205] machine was designed (Figure 5-53). It is a machining centre with up to a maximum of 5-axle units, and a hanging round machine table. The flexible configuration of the system is realised through the modularization in a product-independent machine platform, and a shift of the entire system, via the solid frame construction. Filling the building columns with polymer concrete, which primarily serves to provide the vibration damping, also reduces the foundation requirements.[206] [207] [208] [209]

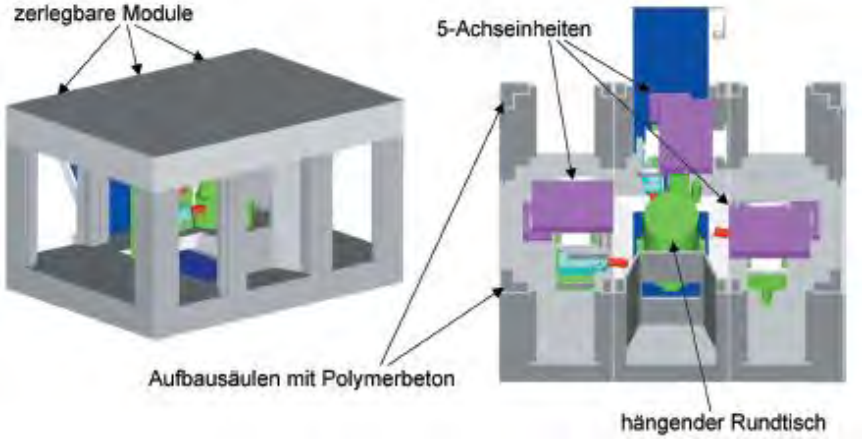


Figure 5-53: Design of a special mobile machine for machining[210]

The joint research project MAXIEM (maximizing the energy efficiency of machine tools) focused on the energy efficiency of cutting machine tools. The aim s to demonstrate

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205 But note, that in the terminology defined in task 1, this modular machine tool is considered "stationary" and consequently still is in the scope of the study.

206 Zäh, M. F.; Cisek, R.; Sudhoff, W.; Redelstab, P.: Mit Mobilität zu mehr Strukturvariabilität. In: wt Werkstattstechnik online 93 (2003) 4, pp. 327-331.

207 Zäh, M. F.; Sudhoff, W; Rosenberger, H.: Bewertung mobiler Produktszenarien mit Hilfe des Realoptionsansatzes. In: Zeitschrift für wirtschaftlichen Fabrikbetrieb ZWF 98 (2003) 12, pp. 646-651.

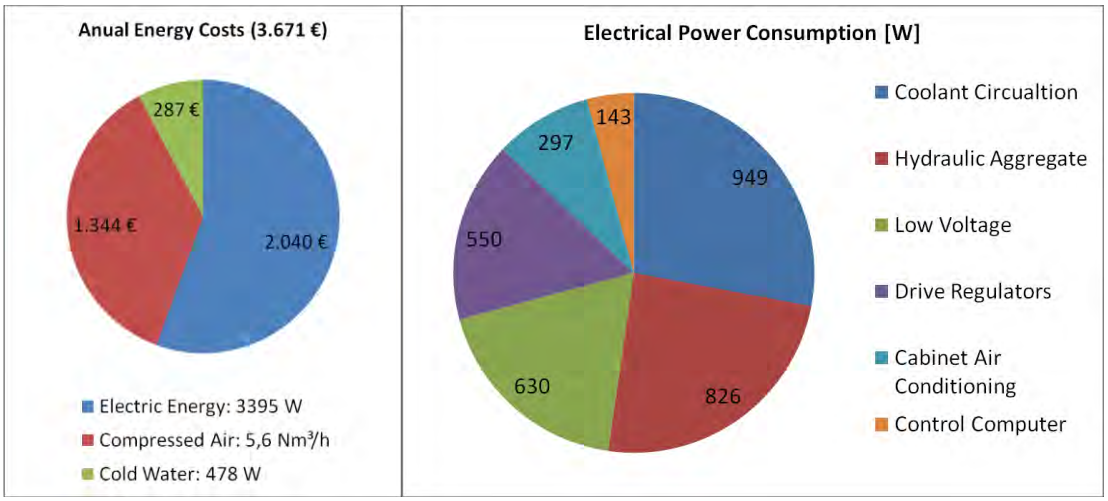
208 Zäh, M. F.; Bayrer, P.: Gestaltung und Betrieb mobiler Produktionssysteme. Abschlussbericht des Forschungsprojektes ProMotion. Utz Verlag, München 2004.

209 Project time: 01.06.2001 to 31.12.2004

210 Zäh, M. F.; Cisek, R.; Sudhoff, W.; Redelstab, P.: Mit Mobilität zu mehr Strukturvariabilität. In: wt Werkstattstechnik online 93 (2003) 4, pp. 327-331.

the savings potentially available through the configuration of a prototype machine tool, by integrating the most efficient components and aggregates available in the market today. The potential of an optimized components control were evaluated. This shows, firstly, the machine-side potential that can be achieved by appropriate design, and secondly, the opportunities that result from an optimized and coordinated operation, identification and implementation.

As a result of ABC analysis, hydraulics, cooling systems for cabinet and drives, coolant system, exhaust, air purge, low voltage power supply, as well as filter components, were identified as modules with the highest potential for reducing energy consumption. Main spindle, fans, contactors and relays, mounting systems, lighting and counterbalance brake own medium, feed drives, axle clamp, bearings, guides, lubrication, and control have the least potential for fuel economy. Criteria were mainly power consumption and service life, with a basic load of the machine of P = 3 kW. Figure 5-54 shows the annual consumption of energy, and the power consumption of components, in working condition for a machining centre.[211][212][213] [214]



211 Abele, E.; Kuhrke, B.; Rothenbücher, S.: Energieeffizienz von Werkzeugmaschinen maximieren. www.maschinenmarkt.vogel.de/themenkanaele/produktion/zerspanungstechnik/articles/251269/. Access: 06.04.2010

212 Abele, E.: Entwicklungstrends zur Erhöhung und Bewertung der Energieeffizienz spanender Werkzeugmaschinen. In: Tagungsband Energieeffiziente Produkt- und Prozessinnovationen in der Produktionstechnik. 25.-26.06.2010, Chemnitz.

213 Kuhrke, B.; Erdle, F.: Energieeffizienz als Investitionskriterium. In: Werkstatt und Betrieb. 143 (2010) 1-2, Hanser Verlag, München, pp. 30-33.

214 Part of „Effienzentfabrik“

Figure 5-54: Annual costs for electric power sources, compressed air and cold water, and power consumption of individual components during working conditions[215]

The research project e-Simpro (energy-efficient machines by Simulation in Product Development) optimized the development of energy-efficient machine tools by simulating the energy needs of the machine tool and its components, as a function of specific process requirements. This included the development and testing of software prototypes that simulated the energy consumption of machine tools, including the power supply modules. In an iterative process, which included modelling, implementation and verification, the models were detailed until an adequate picture of reality was reached. The technology was transferred to the partner configuration tools, for developing energy-efficient machinery. These concepts of energy-optimized machines were evaluated and tested.[216] [217]

Design rules and structure examples of cutting machine tools were installed for the modular structure of machine tools, considering the economic and ecological aspects of design, regarding product recycling.[218] These rules and examples deal primarily with product recycling, and provide a good basis for the module structure and design, as well as proceedings and design rules. Furthermore, a blueprint for the creation of new products with regard to the product recycling is thus developed. Through the results presented, designers are able to extend the life cycle of components and machine tools, and consider the environmental aspects in more detail, in addition.

The energy consumption of electric motors is the cause of over 90 % of the entire life cycle costs. However, on the other hand, the costs of the electrical motors account for only 10 % of the purchase cost of the entire machine tool. Electronic speed controls can reduce the energy consumption of electric drives by up to 25 %. In addition, the process control is easier, and wear and noise emissions are also reduced. Due to the power consumption of the electronic speed control itself, their use is worthwhile only for

215 Abele, E.; Kuhrke, B.; Rothenbücher, S.: Energieeffizienz von Werkzeugmaschi-nen maximieren. www.maschinenmarkt.vogel.de/themenkanaele/produktion/zerspanungstechnik/articles/251269/. Access: 06.04.2010

216 www.esimpro.de. Access: 14.08.2010.

217 Part of „Effizenzfabrik“

218 Niethammer, R. M.: Modulare Werkzeugmaschinengliederung unter dem Gesichtspunkt wirtschaftlicher und ökologischer Gestaltung zum Produktrecycling. Dissertation TU Bergakademie Freiberg, 1997.

machines that are operated primarily at part load. 48 % of manufacturing companies already use this technology.[219]

The goal of the project EnergieMSP (energy demand optimized spindle motor and electric drive train adapted) was to improve the efficiency of a motor spindle for machining with a defined cutting edge. Three optimization fields were focused on: electric propulsion, power-loss minimized spindle components and lightweight construction. In addition to the efficiency-optimized development of frequency converters and motor drives, spindle-bearings with minimized friction and the use of fibre reinforced plastics are investigated.[220] [221]

The research project EWOTeK (increased efficiency of machine tools by optimizing the technology for components) was to reduce the total energy consumption of machine tools, using – on the one hand – its basis as the measurement of the dynamic performance retrieval of machine tools, and on the other hand, the optimization of selected components. Dimensioning machine tools - and their components - based on transparent energy consumption promises substantial improvements regarding energy efficiency.[222] [223] The project NCplus attempts to uncover the energy use of the clamping-related machinery. Only 20 % to 80 % of the energy consumption is used for the added value. The remaining energy provides related aggregates, most of them running to set machine tools in Stand-By Mode. Similar to EWOTeK, the objective of NCplus was to optimize the dynamic performance of machine components.[224][225] [226]

Track 1 of the EU-funded research consortium project NEXT (Next Generation Production Systems) is the development of machine tools based on eco-efficient criteria for their design and life cycle. These include the use of reusable materials, their full recycling, thus reducing energy consumption as well as achieving production without

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219 Schröter, M.; Weißfloch, U.; Buschak, D.: Energieeffizienz in der Produktion – Wunsch oder Wirklichkeit? Energieeinsparpotenziale und Verbreitungsgrad energieeffizienter Techniken. In: Modernisierung der Produktion. Mitteilungen aus der ISI-Erhebung 51 (2009).

220 www.energiemsp.de/. Access: 16.08.2010.

221 Part of „Effizenzfabrik"

222 www.ewotek.de/de/default.html. Access: 13.09.2010.

223 Part of „Effizenzfabrik, project time 01.07.2009 to 30.06.2012

224 http://www.ncplus.de/ Access: 18.01.2011.

225 http://www.technikwissen.de/libary/news/2010/05/424_54653.pdf, pp 426.

226 Part of "Effizienzfabrik", project time 01.07.2009 to 30.06.2012

waste.[227] The joint research project PROLIMA (Environmental Product Lifecycle Management for building Machine Tools) was also devoted to the life-cycle design of machine tools, and included the development of eco-efficient construction methods, and technical rules.[228]

PROLIMA comprised the methodological design and selection of sustainable use concepts for power systems in machine and plant construction, and was based on the integration of services and the physical product in so-called power systems. Furthermore, this strategy focuses on integrating economic and environmental aspects in a holistic sustainability assessment. To achieve these objectives, all levels of an organization, above all the strategic level, have to be involved.[229]

The EnEffCo-project on energy efficiency controlling uses in the automotive industry and its suppliers is an example of reducing energy consumption by making the main sources of energy consumption transparent, including the temporal pattern of consumption. By recognizing the possibilities of postponement of the energy demand, the so-called functional energy storage, cost savings can be achieved. In addition, the energy consumption efficiency of relevant sectors is calculated and evaluated. Different levels of the value chain in automotive production, in terms of dependencies between consumption patterns and production processes, were investigated. Within simulations of operating modes of system components, relevant energy consumption, cost-and energy-efficient production plans were developed (Figure 5-55). Via these measures, different scenario can be drawn up, and then evaluated for energy-efficient design within the manufacturing process.[230][231] [232]

227 http://www.nextproject.eu/ Access: 10.10.2010

228 www.prolima.net/projects/objetives_html. Access: 01.09.2010.

229 Michalas, N.: Methodik zur Gestaltung von nachhaltigen Nutzungskonzepten im Maschinen- und Anlagenbau. RWTH Aachen, Dissertation, 2002.

230 www.dai-labor.de/act/laufende_projekte/eneffco/. Access: 14.08.2010

231 Schreck, G.: Energieeffizienzcontrolling in der Automobilproduktion. In: Futur 12 (2010) 2, pp. 6-7.

232 Project started in 2009

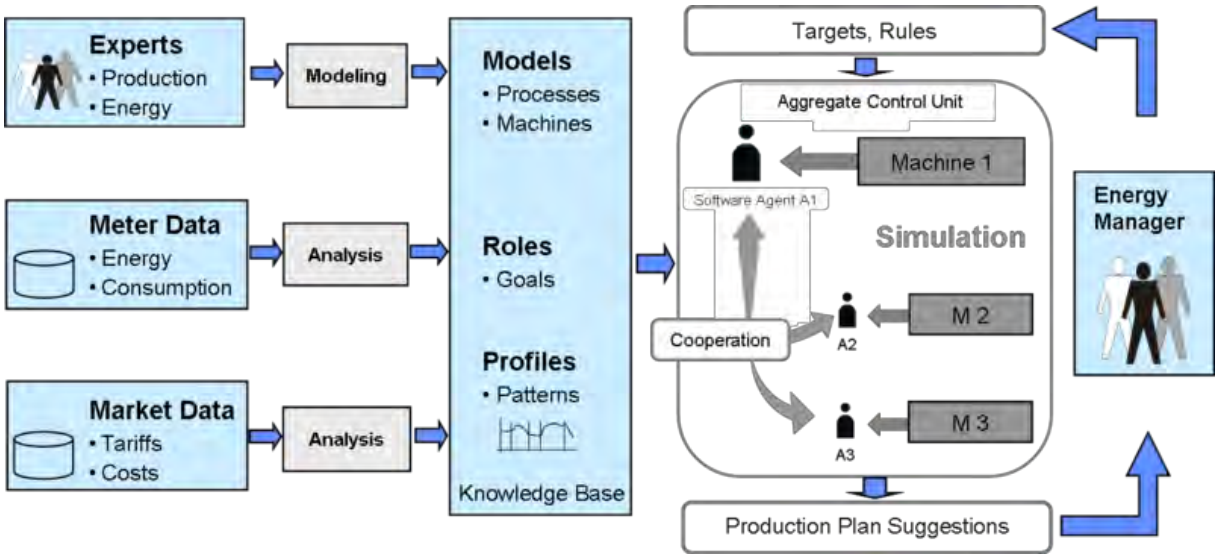


Figure 5-55: Model to identify systems with relevant energy consumption[233]

5.2.4 Wood working machine tools BNATs

No substantial research for particularly eco-designed or energy efficient solutions of wood working machine tools was identified.

5.2.5 Welding equipment BNATs

Welding processes and technologies are subject to intensive research. Frequently specific material types or combinations are in the focus of R&D, to open new fields of applications for welding operations, to increase the performance of processes and to enhance the quality of the welds. Some research projects specifically address technology developments, which are likely to enhance environmental performance as well. Relevant projects on a European level are listed below:

The project SafeFlame (Development of oxy-hydrogen flame for welding, cutting and brazing)[234] intends to overcome some drawbacks of the oxy-acetylene flame, which are becoming more significant with increasing health and safety and environmental concerns. Besides occupational health and safety, the project intends to develop a process to generate oxy-hydrogen flames by the combustion of oxygen and hydrogen produced locally, using an electrochemical cell. According to the project outline, “this

233 www.dai-labor.de/act/laufende_projekte/eneffco/. Access: 14.08.2010

234 SafeFlame - Development of oxy-hydrogen flame for welding, cutting and brazing, FP7, SME-2011-2 Research for SME associations, 2011-2014

approach has the following advantages over oxy-acetylene heating: The cell is highly portable, reducing transportation costs and increasing the flexibility of the process. The fuel is water, which is widely available and low cost. The process requires electricity to generate the gases but is >60% efficient." However, a dedicated LCA comparing on-site generation with the conventional purchase of gas in cylinders is not yet available.

The project SmartDress (Adaptive Tip dress Control for Automated Resistance Spot Welding)[235] is one of the examples where better process control is targeted, resulting possibly in higher productivity and weld quality, and having a positive secondary environmental impact: SmartDress will develop a fully automated adaptive control system that will optimise, monitor and maintain tip quality in high volume automotive production operations, where resistance spot welding is widely used. The project is motivated by the insight that significant losses of output occur as a consequence of frequent production line stoppages, predominantly caused by weld quality issues, which in turn arise from poor maintenance of consumable tips on resistance spot welding guns.

Information technology as an enabler for more efficient welding processes is currently being researched in the project RLW NAVIGATOR (Remote Laser Welding System Navigator for Eco & Resilient Automotive Factories)[236], which "aims to develop an innovative Process Navigator to configure, integrate, test and validate applications of Remote Laser Welding (RLW) in automotive assembly. ... RLW is emerging as a promising joining technology for sheet metal assembly due to benefits on several fronts including reduced processing time (50-75%), and decreased factory floor footprint (50%), reduced environmental impact through energy use reduction (60%), etc. Currently, RLW systems are limited in their applicability due to an acute lack of systematic ICT-based simulation methodologies to navigate their efficient application in automotive manufacturing processes. ... Firstly, the most critical obstacle that currently prevents the successful implementation of RLW is the need for tight dimensional control of part-to-part gaps during joining operations, essential to ensure the quality of the stitch. Secondly, the existing assembly system architecture must be reconfigured to provide the opportunity to evaluate the RLW system in terms of its feasibility to perform all re-

235 SmartDress - Adaptive Tip dress Control for Automated Resistance Spot Welding, FP7, SME-2011-1 Research for SMEs, 2011-2013

236 RLW NAVIGATOR - Remote Laser Welding System Navigator for Eco & Resilient Automotive Factories, FP7, FoF-ICT-2011.7.4 Digital factories: Manufacturing design and product lifecycle management, 2012-2014

quired assembly tasks. This will provide crucial information about the most advantageous workstation/cell reconfiguration, which will serve as the basis for optimal robot path planning to reduce joining process time and workstation level efficiency assessment." The effectiveness of this approach still has to be proven, and requires a close software-based interaction of the welding equipment with a remote system.

The power electronics components and circuitry of welding power sources are subject to research and continuous improvement at several research institutions[237], but the related publications do not provide an outlook on achievable efficiency improvements.

5.3 Future industrial trends

5.3.1 Energy use monitoring and optimisation

The data collection for various systems such as electrical power, compressed air and steam complicate the uniform collection of energy data. Consistent network structures, such as between management and production, allow an easier system-wide collection of data. Long-term acquisition collects energy-related data in longer intervals of typically 15 minutes by the power company. This results in small amounts of data, but power-peaks cannot be reflected. The short-term data collection in the usual time range of less than 10 ms has the advantage of being able to accurately identify power peaks. Disadvantages are the size of the collected data set, and the associated complex evaluation. To promote energy efficiency as early as possible in the plant- and product-design phase, the following steps need to be accomplished:

- identification and prevention of unproductive consumer of energy by measuring the consumption levels
- linking the energy data collected with job-related information such as produced quantities

237 See e.g.: Navarro-Crespin, A. ; Casanueva, R. ; Azcondo, F.J. ; Performance Improvements in an Arc Welding Power Supply Based on Resonant Inverters, IEEE Industry Applications Society Annual Meeting (IAS), 3-7 Oct. 2010; Klumpner, C. ; Corbridge, M. ; A two-stage power converter for welding applications with increased efficiency and reduced filtering, IEEE International Symposium on Industrial Electronics, ISIE 2008, June 30 - July 2 2008; Sugimura, H. ; Fathy, K. ; Sang-Pil Mun ; Doi, T. ; Mishima, T. ; Nakaoka, M.; Three-Level Phase Shifted soft transition PWM DCDC power converter with high frequency link for arc welders and its extended version, IEEE 6th International Power Electronics and Motion Control Conference, IPEMC '09, 17-20 May 2009

- analysis, and evaluation, of the collected energy data.

Trends noted are to use overall energy data for optimizing the consumption in the use phase, and also for customized design and construction of machines and their connections in the material flow.

5.3.2 Reading system controls or installation of sensors

The information from the control is evaluated for determining the energy consumption. The system can collect relevant data from the actuators and sensors itself, as well as from the communication between them and the superordinate controlling system.

5.3.3 Energy monitoring systems

These energy monitoring systems are used for display and storage of energy data. The report includes the archiving function of energy data in databases, their visualization and analysis. Fundamental functions are the identification of peak loads, the calculation of energy indicators, alerts when exceeding limits, efficiency monitoring and system analysis when parameters have changed. Mobile energy monitoring systems consist of mobile testing units, which allow flexible and rapid system analysis even with non-upgradable machines. The technology opens up new service areas for service providers.

5.3.4 Integration of energy efficiency in the control room

The control console acts as the link between corporate management and controlling, and displays energy data, disorders of energy consumption and limit violations. There is the possibility to pass requirement- and offer-improved control data directly to energy-related components. This also includes the shutdown of components during the non-production time. Furthermore, working time models with staggered pause times and manual shifting operations can be developed. The complete integration of all the systems includes the coordination of cycle times and energy loads within the cycle times of parallel or sequentially related system components.

PROFIenergy represents an energy management system that is currently implemented by the industry. The “Profibus User Organisation e.V.” develops a protocol that defines unified functions and mechanisms for energy control for all relevant machinery components. The system is vendor-independent, and will allow an automatic, time-driven and needs-based connection and disconnection of components during production. The concept includes the definition of various power modes, and the integration of relevant

data, such as the starting time to allow full production capabilities at the beginning of production.[238]

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238 Hiersemann, R.: Integration von Energiemonitoring - Funktionalitäten in Anlagenleitstände Möglichkeiten und Grenzen. In: Fraunhofer IOSB (Hrsg.): Tagungsband Innovationen Produzieren. 09.-10.06.2010, Karlsruhe, pp. 139-152.

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Daikin Industries Ltd, Osaka, Japan see http://www.daikinpmc.com/en/special/supereco/goodpoint/save/index.html?ID=en_special_sidenavi

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Deckel Maho Gildemeister, DMG EnergySave, on the internet: http://www.dmg.com/presse_id,d1204024fd31842ac125772a00480938?opendocument&p=3&kap=$$$$$, last access: 22.12.2010

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6 Annex Assessment Matrix Survey

The following pages document the Assessment Matrix, which was published to seek input by stakeholders on improvement potentials.

Fraunhofer

Energy-Using Product Group Analysis

Lot 5: Machine tools and related machinery

Improvement Options: Assessment Matrix

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March 28, 2011

Background

Ecodesign of Energy-related Products (ErP) Directive 2009/125/EC (recast of the former EuP Directive 2005/32/EC) establishes a framework for setting Eco-design requirements (e.g. energy efficiency) for all energy related products and, thus, it is going to affect environmental and/or energy efficiency specifications of such products sold in Europe in the future. For further details on the ErP Directive, please visit the European Commission's websites:

http://ec.europa.eu/enterprise/eco_design/index_en.htm

This Product Group study is the first step in considering whether and which eco-design requirements could be set for machine tools and related machinery falling into the broad scope of this study. The objective of the study is to analyse these products and recommend ways to improve their energy and environmental performance. The study shall provide the necessary information for the next phases (carried out by the European Commission); in particular a consultation forum with the stakeholders, impact assessment, and possible draft implementing measures.

You can follow the progress of the study and also register as a stakeholder on the project website www.ecomachinetools.eu .

Purpose of this Assessment Matrix

This survey is intended to quantify achievable improvement potentials of machine tools. Given the complexity of machine tools and the specifics of the numerous applications it is important to get the order of magnitude right, not to seek detailed quantifications.

Submission of Data

Please, respond to this survey latest by **May 2, 2011**, if possible, to allow for a timely consideration throughout the study. If you need more time to reply, let us know. Feel free to distribute this questionnaire among other stakeholders. Reply to

schischke@ecomachinetools.eu

Guidance to fill in the matrix

The measures are an abridged list of improvement options outlined in the **Task 5 report, chapter 5.1.**:

http://www.ecomachinetools.eu/typo/reports.html?file=tl_files/pdf/EuP_LOT5_Task5_Draft_11-02-28_v10.pdf

Add additional measures you are aware of.

Column: "Cost effects (investment): Increase in total machinery invest (range)"

State the likely **purchase price increase "per (typical) machine"** (*not* per module etc.) when implementing any given approach in the machinery design. This will be taken into account for the life cycle costing and weighted against any savings.

Column: "Module related energy savings potential"

State the energy savings roughly achievable **in the use phase related to the relevant machine module (e.g. hydraulics system, drive systems)**, compared to a machine, which has not implemented this option.

Column: "Total machinery energy savings potential"

State the energy savings roughly achievable **in the use phase of an (average) machine tool**, compared to a machine, which has not implemented this option.

Column: "Other environmental impacts of the approach"

If there are other than energy savings related to an optimization, this should be stated here. Again, referring to the total typical consumption of the whole machine.

Column: "Market penetration"

Most of the optimization options are likely to be already implemented in a certain market share of installed and newly introduced machine tools. Consequently, implementing an option now in all machines where this approach is feasible will result in a lower overall improvement potential, if only a minor market segment still needs to implement this option.
Please make an estimate, which **percentage of the market share** (**in terms of units**, not economics) already implemented this option, making the distinction of **"installed" (i.e. currently operating)** and **"currently sold" (i.e. in 2011)**. Percentage should refer to the market segment, where this option makes sense. Example: For options for reduced cooling lubricants consumption the market penetration should be stated as percentage of all machine tools using cooling lubricants, not as percentage of all machine tools.

Column: "Limitations / remarks"

State for which market segments / under which conditions the individual measures are technically feasible / reasonable, if certain improvements can be achieved only with proprietary solutions, and if other limitations apply to your estimates made in any of the categories.

Contact Details

Organization:

Name:

Telephone:

E-mail:

Replies refer to

- ☐ Metal working machine tools
- ☐ Wood working machine tools

☐ Other machine tools:

Reply only to those measures, for which you can claim a certain expertise ("educated guess"). Skip the others. Feel free to complement your feedback with any additional information or statement.

My / our field of expertise:

Do you agree to be listed in the report as one of the respondents to this survey? (name and affiliation, without stating your individual replies)

☐ yes ☐ no

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	In **installed** machine tools	In **currently sold** machine tools	
Mass Reduction of Moving Parts														Weight (material) savings						
1.1 Lightweight materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
1.2 Material reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
1.3 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
1.4 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
Software-based Energy Management incl. Stand-By Mode																				
2.1 Energy monitoring	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
2.2 Machine stand-by management	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
2.3 Energy-optimized motion control	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
2.4 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
2.5 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	In **installed** machine tools	In **currently sold** machine tools	
Energy Recuperation of Drives, Power Electronics, and Super Premium Efficiency Motors																				
3.1 Application specific design of drives	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.2 Speed control	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.3 Direct drive instead of ball screw drives	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.4 Brake energy feedback	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.5 Reducing maximal acceleration	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.6 Reducing transmission losses	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.7 Replacing inverter units	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.8 Using low friction roller bearings	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.9 Avoidance of transformers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.10 Wattless current compensation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	In **installed** machine tools	In **currently sold** machine tools	
3.11 Latest generation IGBTs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.12 Super premium efficiency motors	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.13 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.14 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
Tool Handling and Clamping																				
4.1 Electrical clamping devices	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.2 Efficient sealing of spindle system	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.3 Non-pneumatic lubrication for spindles	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.4 Multi spindle systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.5 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.6 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
Hydraulic and Pneumatic Optimized Systems														Hydraulic oil savings						

Improvement Options: Assessment Matrix

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	In **installed** machine tools	In **currently sold** machine tools	
5.1 Optimized cooling of the motor	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.2 Adaptable levels of pressure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.3 Pressure adjustments for different actuators	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.4 Use of hydraulic accumulators	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.5 Substitution of technologies	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.6 Reducing inner leakages losses	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.7 Use of optimized valves	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.8 Use of hydraulic clamping tools	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.9 Extending the field of application of hydraulics	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.10 Prevention of nipple collapse	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.11 Application specific compressed air quality	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	In **installed** machine tools	In **currently sold** machine tools	
5.12 Reducing channels of supply / dead volume	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.13 Minimizing losses due to leakages (pneumatics)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.14 Pneumatic Cylinder with optimized drive surface	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.15 Pneumatic Cylinder with multiple chambers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.16 Single acting pneumatic cylinder	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.17 Targeted cut-off from air supply	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.18 Use of multiple valves	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.19 Pressure reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.20 Using exhaust air	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.21 Optimized valve switching	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.22 Cascaded levels of pressured air	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.23 Sensor based monitoring of	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	In **installed** machine tools	In **currently sold** machine tools	
pneumatic systems																				
5.24 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.25 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
Energy-Efficient Cooling Lubricant Supply														Cooling lubricant savings						
6.1 Minimum quantity lubrication	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.2 Coolant lubricant supply through pressure control valves	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.3 Optimised pipe dimension for coolant lubricant supply	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.4 Cryogenic machining	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.5 High pressure jet assisted machining	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.6 Direct oil drop supply system	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.7 Vegetable oils as lubricants and hydraulic fluids	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	in **installed** machine tools	In **currently sold** machine tools	
6.8 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.9 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
Cooling Systems and Use of Cabinet Heat																				
7.1 Machinery integrated heat exchangers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
7.2 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
7.3 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
Energy-efficient Tempering																				
8.1 Electric inductively heating	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
8.2 Thermal compensation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
8.3 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
8.4 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Thanks for your input.

We will evaluate the replies for the revision of the Task 5 report and will complement the survey findings with further evidence from the ongoing technology analysis.

Fraunhofer

Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 6 Report – Improvement potential

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary – Task 6

Based on the improvement options identified in the BAT analysis of task 5, this task report now calculates the effect of these design options being implemented consecutively, their monetary consequences in terms of Life Cycle Cost for the user, their environmental costs and benefits, and pinpoints solutions with the Least Life Cycle Costs. This analysis builds on the Base Cases of Task 4. Although the implementation of options now refers each to “one unit of machine tool”, this is not meant to reflect real-world machine tools, but it does already include a consideration of market penetration rates.

For each of the Base Cases a consecutive order of design options has been identified, from one single option for simple non-numerically controlled (non-NC) machine tools, up to 22 options for highly complex machine tools. This range of complexities confirms again the philosophy that a multitude of options for numerically controlled (NC) machine tools can (and should) be considered. The analysis shows that the combination of options leads to moderate Total Energy savings potentials at the point of Least Life Cycle Costs, which are in the range of 3%-5% for the most relevant Base Cases, amongst which is the highly-relevant Base Case on CNC machining centres, but also Base Cases from the wood working sector. For welding equipment a Total Energy savings potential of 11,5% at Least Life Cycle Costs has been calculated. The sensitivity analyses conducted (including variation of use patterns, shift models, lifetime and energy costs) largely confirm the trends identified in the baseline analysis.

In general, there is no single option with a large environmental improvement potential. Moderate savings as stated can be realised only with the implementation of several individual options, via what could be called “good machinery design”. As this analysis was meant to address certain archetypal machine tools on a very generic level, it should not be ignored that there might be much larger environmental and energy savings potentials for particular machine tools under certain conditions, e.g. for specific applications.

6 Task 6 – Improvement potential

The scope of Task 6 is to identify design options, their monetary consequences in terms of Life Cycle Cost for the user, their environmental costs and benefits, their economic impacts, and to pinpoint the solution with the Least Life Cycle Costs (LLCC) and the Best Available Technology (BAT). The assessment of monetary Life Cycle Costs is relevant to indicate whether design solutions might impact the total user's expenditure over the total product life.

6.1 Identification of Design Options

The identification of design options is closely related to the analysis in Task 5, where numerous options are listed and were assessed. These options, reflecting both technology trends and environmentally motivated measures, complemented by further evidence, is now matched with the Base Cases calculated in Task 4. It has to be acknowledged that the assessment of design options in Task 5 is almost exclusively based on input from European manufacturers of machine tools, even though a large share of machine tools are also imported to the EU-27. There are no data available regarding the technical and environmental performance and related savings potentials of these imported machine tools, as such.

A multitude of design options is identified and is subject to an assessment as follows, in each case:

- Does this design option affect those input values of the EcoReport in the base case analysis which are of outstanding environmental relevancy?
- Based on a first screening: are there any technological, social, or economic hurdles foreseeable which might definitely hinder the implementation of this design option?

The environmental improvements of these options will be assessed quantitatively by using the EuP EcoReport.

Furthermore, options are not examined further, when they fulfil any of the following criteria:

- Significant negative impact on the functionality of the product, from the perspective of the user,
- Health and safety are adversely affected,

- Significant impact on industry's competitiveness,
- They have the consequence of imposing proprietary technology on manufacturers.

The following design options identified in Task 5 are related to **non-energy in use aspects**, but could not be generalised, or were related only to a low or moderate savings potential. However, in individual cases these options might be relevant, but could not be addressed in the following quantified analysis of improvement options[1]:

- Machine bed made of polymer concrete or similar (but observe end-of-life implications)
- Material savings aspect of light-weight components
- Machinery features, which reduce material cut-offs / waste (e.g. skeleton-free punching)
- Design measures to minimise cooling lubricants mist generation and enhance extraction
- Cooling lubricants saving effect of dry machining, MQL processes (as long as productivity is not hampered)
- Monitoring and control, leakage detection of media supply systems (cooling lubricants, process gases etc.) and related measures to reduce consumption of these media.

6.1.1 Metal working machine tools

6.1.1.1 Base Case 1 - CNC machine tools

Based on the estimates regarding improvement potentials and related cost effects stated in the Task 5 report, a consecutive implementation of options has to be modelled. According to the methodology for preparatory studies, the implementation of options has to start with those environmental improvements which feature the highest decrease of life cycle costs, followed by those measures which further reduce environmental impacts, but at higher life cycle costs. Using this approach, an order of options

[1] Note that besides these design options the analysis below actually covers a couple of non-energy in use options, such as design measures to change the material used for light-stationary woodworking machine tools, and to reduce excessive welding gas consumption

has been established for CNC machining centres, as listed in **Table 6-1**. Cost effects and total machinery savings potential are as stated for cutting processes in Task 5 (measures are numbered as in Task 5 as well)[2]. Some of the options are distinct measures, whereas others are open to a combination of several measures, see e.g. option 9, Combination of several hydraulic system related measures: In this case it is estimated, that with a proper selection of hydraulics-related measures, usually an improvement of 3% should be possible with at an additional 5% purchase cost investment in machinery.

A correction factor is introduced to reflect the fact that all measures are already implemented in a certain market share. Thus, neither the savings potential, nor the cost increase should be applied to all machine tools covered by this Base Case, but only to the remaining market share[3].

Table 6-1: Design Options for Base Case 1

Measure	**Cost effects (investment) Increase in total machinery invest (tendency)**	**Total machinery savings potential (tendency)**	**Market share**	
			in currently sold machine tools	Correction factor to consider already achieved market penetration
Option 1				
10.3 Minimise non-productive time	0%	5%	46%	0,54
Option 2				
2.8 400V inverter systems to substitute 200V systems	0%	1%	76%	0,24
Option 3				
2.1 Regenerative feedback of Inverter system (servo motor/spindle)	0%	0,5%	76%	0,24
Option 4				
8.1 Controlled peripheral devices like mist extraction, chip conveyer, etc	0,2%	1%	36%	0,74
Option 5				
7.10 Single master switch-off	1%	1%	53%	0,47

[2] This data is based on the 2011 survey data, but notice that later 2012 updates indicate a lower savings potential for some of the measures. However, as our analysis and aggregation followed a rather conservative approach and takes a lower potential in case of a large spread of replies, this uncertainty is already factored in. Furthermore, none of the stakeholder comments received challenged the estimates given in Table 6-1.

[3] This approach and correction factor however neglects that certain options might not be relevant for a certain machine tool at all, and thus 100% market share is practically impossible in some cases.

Option 6						
Combination of several power electronics related measures						
6.2 High efficiency transformer	1%	2%	0,5%	1,5%	23%	0,5
6.3 Converter with power factor correction	1%		0,5%		29%	
6.4 Controlled switching power supply for auxiliary power 24V	0,2%		0,5%		77%	
Option 7						
Combination of several cooling lubrication system related measures						
4.1 Discontinuous operating pumps	0,2 %	3%	0,5%	2%	31%	0,6
4.3 Adjustable pressure for cooling lubrication	1%		0,5%		48%	
4.4 Controlled flow rate	1%		1%		44%	
4.5 Inverter controlled motors for lubrication system	1%		0,5%		37%	
Option 8						
Combination of several overall machine related measures						
1.2 reduction of friction	1%	3%	0,5%	2%	53%	0,6
1.3 optimization of the electrical design	1%		1%		43%	
1.4 design for instant machining without warm up	1%		1%		33%	
Option 9						
Combination of several hydraulic system related measures						
3.1 Discontinouous operating pumps	1%	5%	1%	3%	38%	0,65
3.2 Speed controlled pumps	1%		1%		22%	
3.3 Optimize hydraulic system design	n.a.		0,5%		35%	
3.4 Optimized piping	1%		0,5%		33%	
3.5 Fixed orifice blades to control the system pressure	1%		0,5%		46%	
3.6 Leakage monitoring	1%		0,5%		30%	
3.7 Use of hydraulic system with optimized components	n.a.		0,5%		20%	
Option 10						
Combination of several drive units related measures						
2.2 Use of energy efficient motors for auxiliary units	3%	10%	1%	3%	44%	0,5
2.3 Use of torque motors	1%		1%		37%	
2.4 High efficient gear unit	0,2%		0,5%		32%	
2.5 Mass free compensation of load for vertical axes	3%		1%		55%	
2.6 Use of break to control movement of axes	3%		0,5%		34%	
2.7 Inverter controlled motors for auxiliary units	5%		1%		30%	
Option 11						
7.9 Optimised compressed air system with minimal losses	3%		1%		38%	0,62

Option 12				
7.11 Individual switched-off capability for specific modules	3%	1%	50%	0,5
Option 13				
7.5 Multi spindle-/ multi workpieces machining	>3%	5%	36%	0,64
Option 14				
7.7 Combination of various technologies (turning + milling + laser + grinding etc.)	>3%	5%	31%	0,69

This list does not include measures, which are an alternative option to those already listed here (e.g. 6.1 Avoidance of transformers... is an alternative measure to 6.2 High efficiency transformers...). In these cases only the option is listed, which is likely to have the better effect at lower costs. Furthermore, simplification measures are not listed here, for which very high implementation costs have been stated, which constitute a basically changed processing concept (e.g. Minimum Quantity Lubrication), or for which a broad span of implementation costs have been stated. When interpreting the assessments based on this list it is therefore important to keep in mind, that:

- estimates regarding costs and savings from the various respondents have been merged with a rather conservative approach, i.e. costs where a larger spread is appropriate are averaged with a rather higher value, and efficiency gains are given a lower value
- there are many more measures to achieve similar savings, which means that vice visa the above list cannot be considered as a recommended list of options to be implemented, as this depends on application and specific design.

For comparison, **Table 6-2** provides a summary of improvement potentials explored for various CNC machine tools within an eco-design project in the Basque country[4], applying a Life Cycle Analysis, followed by checking the feasibility of implementing numerous eco-design options. The analysis unveils, that for a given “real world” machine tool, there are typically numerous measures which could be applied, but most of these typically each result in minor improvements, together totalling significant savings. The range of improvements which could be realised is immense, and varies between 1,8% and 48% of the total life cycle impacts. These examples illustrate that it is not justifiable to state a “general” improvement potential..

Table 6-2: Examples of Optimisation Measures Applied for CNC Machine Tools

[4] For details, see: IHOBE: Guías sectoriales de ecodiseño – Máquina herramienta, February 2010

Measure	Goratu Movable Milling Machine GMM	Danobat Turning Machine Tool NA-500/GL	Tornos Gurutzpe Horizon-tal Ma-chining Tool	Fagor Mechani-cal Press SDM2-400-2400-1200	Onapres Hydraulic Press EVT-225-4,6-AS
Measure	**Total Life Cycle Impacts Reduction**				
Reduce standby	-1%	-0,8%	-2,3%		
Replace steel foundation by polymer concrete		< 1%	-0,6%		
Burnishing for surface treatment			-1%		
Biodegradable lubricants			-0,3%		
Water-based painting, or-ganic-solvent free			-0,4%		<<1%
Recuperation of energy				-30%	
Synchronising the process throughout the line (re-duced standby time)				-2%	
Use of direct servo-drives				-12%	
Lubrication oil mist extrac-tion and reuse				-2%	
Use of lightweight material / reduce weight of moving parts				-2%	-1%
Implementation energy management system (whole line)					-30%
(External) reuse of heat generated at the stamping process					(external)
Condition monitoring / predictive maintenance		relevant, but not quantified			
Optimized extraction sys-tem	-0,4%				
Optimized noise insulation material	-0,1%				
Implementing multiple processes (milling and turning)	-12,6%[5]				
Total	**-14,1%**	**-1,8%**	**-4,6%**	**-48%**	**-31%**

[5] Related to installed total connected load

6.1.1.2 Base Case 2 - Laser cutting machine tools

For laser cutting machine tools (Base Case 2) the above stated savings potentials are not directly applicable as the energy consumption profile looks completely different, and is dominated by the laser source, followed by the chiller unit (see task 4, 4.1.3.2). Some studies have identified fibre laser sources as the more energy efficient technology compared to the more conventional CO2 lasers. The overall energy efficiency of CO2 lasers is stated to be at roughly 10% compared to 30% for fibre lasers, basically due to the physics of the technology. This results in some comparisons where fibre lasers are recommended over CO2 lasers[6,7]. The analysis by Devoldere et al. refers to processing of 1mm thick steel sheets. Energy consumption (electricity only) figures are listed in **Table 6-3**.

Table 6-3: Comparison CO2 laser and fibre laser processing (Devoldere et al.)

Laser type[8]	CO2	fibre	CO2	fibre	CO2	fibre
Shifts (@ 8h/day, 250 days/a)	**1**		**2**		**3**	
Occupation rate	84,9% of total production time					
Power consumption per mode per year (kWh)						
Off mode[9]	11.889	0	8.372	0	4.854	0
Start-up	1.400	1.400	1.400	1.400	280	280
Production (@5kW laser output)	80.825	64.184	161.650	128.369	242.474	192.553
Move table	3.686	3.661	7.373	7.322	11.059	10.982
Stand-by	5.158	3.993	10.315	7.986	15.473	11.979
Total kWh	**102.958**	**73.238**	**189.109**	**145.076**	**274.140**	**215.794**

6 Devoldere, T.; Dewulf, W.; Deprez, W.; Duflou, J.R.: Energy Related Life Cycle Impact and Cost Reduction Opportunities in Machine Design: The Laser Cutting Case, Proc. 15th CIRP International Conference on Life Cycle Engineering, Sydney, Australia, ISBN 1-877040-67-3. pp. 412-419.

7 Oliveira, M.; Santos, J.P.; Almeida, F.G.; Reis, A.; Pereira, J.P.; Rocha, A.B.: Impact of Laser-Based Technologies in the Energy-Consumption of Metal Cutters: Comparison between Commercially Available Systems, Journal Key Engineering Materials, Vol. 473, 2011, pp. 809-815

8 CO2: model LVD Axel 3015 S; fibre: hypothetical configuration

9 CO2 laser assumed to be in „winter off“ during 4 month, with higher chiller power consumption

A similar analysis was undertaken by Oliveira et al. [10], comparing the processing of a 1 mm carbon steel sheet for 1 hour with a 4,5 kW CO2 laser, a 2,5 kW CO2 laser and a 2,0 kW fibre laser. The latter features significantly lower power consumption.

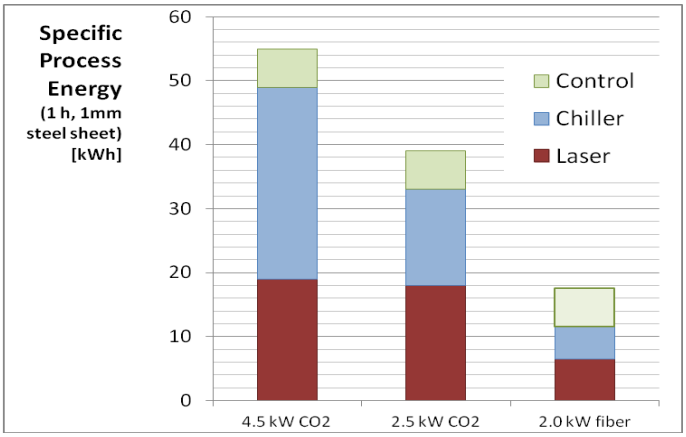


Figure 6-1: Specific Process Energy for Laser Cutting (adapted from Oliveira et. al[11])

Another technical comparison is provided in **Table 6-4** for 3kW laser systems[12].

Table 6-4: Comparison CO2 laser and fibre laser processing (statements by Laser Photonics)

	CO2 Laser (3000W)	Fibre Laser (3000W)
Reliability (MTBF)	Only around 20,000 hours	50,000 to 100,000 hours
Electrical Power Requirements	Laser Consumption: 54 kW Chiller Consumption: 32 kW (Estimate)	Laser Consumption: 14 kW Chiller Consumption: 11kW (Estimate)
Maintenance	Estimated Purge Gas Consumables: Nitrogen, Carbon Dioxide, Helium Estimated Gas Cost: $7.66/h	Minimum Maintenance Low Consumables No cleaning of or alignment of mirrors for beam path
Power Efficiency	6-7%	Greater than 30%
Cooling	50,000 BTU	10,000 BTU

[10] Oliveira, M.; Santos, J.P.; Almeida, F.G.; Reis, A.; Pereira, J.P.; Rocha, A.B.: Impact of Laser-Based Technologies in the Energy-Consumption of Metal Cutters: Comparison between Commercially Available Systems, Journal Key Engineering Materials, Vol. 473, 2011, pp. 809-815

[11] Data for control unit of the fibre laser set equal with the control units of CO2 lasers, as observed differences are not technology related according to Oliveira et al.

[12] http://www.laserphotonics.com/products/fiber-cutting-series/fiber-vs-co2-comparison

A more balanced technical comparison is provided in **Table 6-5**, outlining pros and cons of both technologies, based on industry sources. Actually it is evident, that the field of application for both systems overlaps when considering steel and aluminium sheets up to 4-5 mm, which is an important market segment, and here solid state fibre lasers are the (environmentally) better option, but are not suitable for thicker sheets, and therefore limit the flexibility of using fibre lasers in machinery. As companies, in particular contract manufacturers, might change their production portfolio over time, fibre lasers can therefore not be recommended as a general "blanket" improvement option. The improvement option could be instead to provide sound customer information about pros and cons, and likely costs and energy effects of both technologies, allowing customers to make a choice regarding which technology fits best to their production strategy, and to choose fibre lasers if suitable.

The potential of a further change from CO2 to fibre lasers has to consider the current market share of technologies. In 2008 the global market share of CO2 lasers for material processing was 37%, and for solid state lasers 43% (thereof 7% fibre and 36% rod and disk). The remaining 20% are mainly excimer lasers (for e.g. photolithography)[13]. Although highly speculative in absence of reliable data, a calculated improvement option in the next section is that 10% of the laser cutting machines represented by Base Case 2 are fibre lasers instead of CO2 lasers, this option occurring due to an informed decision by machine tools users[14]. This option is calculated with 25% lower energy consumption[15] for this 10% portion of the market.

Table 6-5: Technical and Performance Comparison CO2 Laser and Fibre Laser processing

	CO2 Laser	Fibre Laser / Solid State Laser
Cutting velocities	Faster than Fibre lasers in materials thicker than 5mm as the laser can be absorbed better at higher levels of incidence	Faster than CO2 lasers in thin materials, due to higher absorption coefficient of most metals
Quality	Quality is consistent throughout all thicknesses of material; from a sheet	comparable up to 5mm; the thicker the sheet, the rougher the edges;

13 Mayer, A.: Economic Downturn Hits Laser Market at Record High, Laser Technik Journal, Vol. 6, Issue 3, May 2009

14 An assumption of 10% is not based on any insights in likely changes, but is rather meant to allow an estimate of the effect of a change in this order of magnitude

15 Based on the exemplary investigations stated above – but notice, that these 25% are only realistic for certain applications, and in no way should lead to the simplified statement that fiber lasers are better than CO2 lasers per se

	thickness of about 4 mm cut quality is better than with fibre lasers	higher focussing ability/ reduced kerf size
Flexibility	High, suitable for all material thicknesses	Low regarding sheet thickness, only suitable for materials up to 5mm in thickness
Materials	Well suited for construction steel, stainless steel and aluminium, but not for copper	Well suited for construction steel, stainless steel and aluminium, non-ferrous metals such as copper and brass
Cost per part	Higher for sheet thickness up to 5 mm	less than the CO2 laser, up to 5mm in sheet thickness; rougher edges might require an additional deburring process
Safety	CO2 laser light (10µm) is absorbed by the cornea (no risk of irreparable damage to the retina)	Strict safety precautions must be taken as the laser can pass straight through to the eye's retina
Beam guidance	mirror optics	fibre optics (advantageous compared to alignment of mirrors), one laser source could feed several cutting machines

Efficient chiller units can save a significant share of power consumption in use[16], which includes efficient components for compressors, an adapted power management (switch on and off of compressors as needed, see also power consumption profiles for laser cutting machine tools in Task 4), or alternatively an interface to a central cooling system, which might allow heat recovery from the chiller. This effect is calculated as option 2 with a conservative savings potential of 5% energy consumption (which actually might be realised externally to the machine, not internally)[17].

It should be noted that no benchmark for laser cutting machine tools is available, neither to this study's authors, nor does it seem that such data is available to machine tools manufacturers. Hence, achievable savings potentials beyond the above stated assumptions cannot be verified. It can be anticipated that several of the improvement options stated for CNC machine tools are applicable to laser cutting machine tools as well, but given the major difference in machine construction and power consumption profiles no estimate could be made, regarding which savings could be realised, at which costs. According to industry experts, further improvement potentials for laser cutting machine tools are rather marginal.

[16] See e.g.: TRUMPF: Ressourceneffizienz – Nachhaltig denken – effizient handeln, brochure

[17] Default correction factor 0,5

6.1.1.3 CNC Metal working bending machine tools

Based on the estimates regarding improvement potentials and related cost effects stated in the Task 5 report for hydraulic presses, a consecutive implementation of options has to be modelled[18]. An order of options established for CNC metal working bending machine tools is listed in **Table 6-6**. Cost effects and total machinery savings potential are as stated for hydraulic presses in Task 5 (measures are numbered as in task 5 as well). Some of the options are distinct measures, whereas others are open to a combination of several components, see e.g. option 14, Combination of several control related measures.

A correction factor is introduced to reflect the fact, that all measures are already implemented in a certain market share, thus neither the savings potential, nor the cost increase should be applied to all machine tools covered by this Base Case, but only to the remaining market share.

Table 6-6: Design Options for Base Case 3

ISO 14955 table B1	Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share (hydraulic presses)	
				in currently sold machine tools	Correction factor to consider already achieved market penetration
Option 1					
9.3	Provide customer information to reduce consumption of resources	0%	1%	20%	0,8
Option 2					
3.4.1	Energy efficient pulse valves	0%	0,5%	10%	0,9
Option 3					
9.1	Optimisation of work piece processing by die tryout	0%	0,5%	60%	0,4
Option 4					
3.3.2	Avoid internal leakage	0%	0,5%	70%	0,3
Option 5					

[18] The survey yielded two replies for hydraulic presses and one reply for servo presses. As a direct comparison of both technologies is not intended (as the different fields of application have to be considered for such an analysis), and as the improvement options are different for both technologies, only the replies for hydraulic presses have been considered here.

3.1.1	Choice of the pump systems which match the requirement profile	0%		1%		95%	0,05
Option 6							
8.1	Controlled peripheral devices like mist extraction, scrap conveyer, etc	0%		0,5%		90%	0,1
Option 7							
7.2.2	Directed switch off of not needed branches	0%		0,5%		90%	0,1
Option 8							
4.2	Low flow rate for lubrication pump	0%		0,5%		90%	0,1
Option 9							
6.3	Apply the simultaneity factor when designing the power system	0%		0,5%		90%	0,1
Option 10							
1.1	Minimisation of moved masses	0%		1%		95%	0,05
Option 11							
1.3	Optimization of the overall machine design	0%		0,5%		90%	0,1
Option 12							
2.4	Use of energy efficient motors	0,2%		1%		55%	0,45
Option 13							
3.2	Match the pressure level to the load cycle and to the different actuators on the machine	0,2%		1%		80%	0,2
Option 14							
Combination of several control related measures							
10.2	Automatic operating state switching	0,2%	0,4%	0,5%	1%	<1%	1,0
10.3	Recording of current energy consumption together with energy relevant production data	0,2%		0,5%		0%	
Option 15							
Combination of several pneumatic system related measures							
7.1	Switching valves with low Watt technology, pulse width modulation (PWM), valves with detent (where permissible)	0,2%	1,0%	0,5%	2,5%	20%	0,3
7.2.1	Reduction of dead volume (Vcut)	0,2%		0,5%		80%	
7.2.4	Correct layout of pneumatic drives	0,2%		0,5%		80%	
7.2.5	Reduction of pressure	0,2%		0,5%		70%	
7.2.7	Optimise cylinder force for the required function	0,2%		1%		90%	
Option 16							
3.4.2	Energy efficient valve connectors	0,2%		0,5%		0%	1,0
Option 17							
3.2.4	Use of pressure intensifiers for individual actuators which require higher pressure	0,2%		0,5%		20%	0,8
Option 18							
4.1	Lubrication flow depending on demand	0,2%		0,5%		60%	0,4
Option 19							
Any of the following:							

2.8	Direct coupled energy storing drive systems for main drives	5%	5%	5%	5%	8%	1,0
2.9	Indirect coupled energy storing drive systems for main drives	5%		5%		0%	
2.10	Intelligent drive management	3%		3%		5%	
Option 20							
3.2.3	Pressure adjustment using pressure-controlled drive systems	5%		5%		53%	0,47
Option 21							
3.3.1	Displacement control systems	3%		3%		65%	0,35
Option 22							
2.6	Use of multi-pressure accumulator system for main axis	5%		5%		3%	0,97

This list does not include measures, which are an alternative option to those already listed here. In these cases only the option is listed, which is likely to have the better effect at lower costs. Furthermore, for simplification measures are not listed here, for which very high implementation costs have been stated, which constitute a basically changed processing concept or for which a broad span of implementation costs have been stated.

6.1.1.4 Base Case 4 - Non-numerical controlled metal working machine tools

As distinct from CNC metalworking machines and laser cutting machines, non-numerical metal working machines tool are less complex and feature a smaller number of modules. Additionally, due to a low extent of operating hours per year, which is in the area of around 1500 hours per year (see task 4, 4.1.3.4), some improvement options do not pay off, as the anticipated life cycle costs of such actions are not proportionate with the expected benefit, such as energy monitoring devices. In reference to identified BATs in Task 5 a check-up between potential solutions and its feasibility for implementation in non-numerical machine tools are assessed, see **Table 6-7**. The table reveals a lack of research and opportunities to raise the eco-efficiency of such machines, which corresponds with the fact that they consume a lot less energy than CNC machines, for which a broad set of implementation opportunities deriving from the BATs are provided.

Table 6-7: Suitability of BATs for non-numerical controlled metal working machine tools - screening

Solution	Suitability for non-numerical controlled metal working machine tools
Mass Reduction of Moving Parts	Marginally suitable, too few operating hours to compensate additional costs
Software-based Energy Management including Stand-By Mode	Marginally suitable, too few operating hours to compensate additional costs

Energy Recuperation of Drives, Power Electronics, Super Premium Efficiency Motors	Marginally suitable in regard to energy recuperation, too few start and stop motions, too few drives (in range of 1-2 drives per machine); suitable in regard to efficient motors
Tool Handling and Clamping	Not suitable, too few operating hours to compensate additional costs; operations usually do not require sophisticated tool handling and clamping solutions
Hydraulic and Pneumatic Optimized Systems	Marginally suitable, in general pneumatic and hydraulic systems rarely found in non-numerical controlled machine tools; too few operating hours to compensate additional costs
Energy-Efficient Cooling Lubricant Supply	Not suitable, in general lubrication system rarely found
Cooling Systems and Use of Cabinet Heat	Not suitable, in general cabinets not necessary, generation of heat during process is negligible
Energy-efficient Tempering	Not suitable, process accuracy does not require tempering (cutting), too few operating hours to compensate additional costs (forming)
Productivity and processing time	Not suitable, sophisticated productivity targets not followed by using non-numerical controlled machines

Just to name a dedicated example, **regenerative drives** are usually not suitable for non-NC machine tools, as the path required for returning the energy and the related power electronics components generate additional losses, which leads to even higher power consumption with regenerative drives. Automatic, frequent tool change (i.e. braking), which is common for CNC machine tools does not happen in the case of non-NC machine tools typically (see task 5, 5.1.4.1).

Motors as the dominating component with respect to energy consumption remain the only subject for relevant improvement options. However, motors typically used in non-NC machine tools are already regulated by Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors, and have had to meet the IE2 efficiency level since June 2011, followed by more stringent requirements to follow in 2015 and 2017, respectively. With these electric motor requirements, significant improvements are already underway, compared in particular to the stock of older non-NC machine tools, and the only remaining option is to encouragethe speedy replacement of this old stock by the new, more efficient generateon of machinery. As a technical option, an early implementation of IE3 motors (which are readily available) instead of IE2 is calculated: Compared to IE2 an IE3 motor (5.5 kW P_N, 4 poles, 50 Hz) has to meet an energy efficiency of 89,6%, instead of 87,7%, which means nearly an energy saving of 2,2%. According to IEC 60034-31:2009 “the typical price increase could be between 10% to 30% per efficiency class improvement”. Anticipating that an IE2 motor in the power range relevant for non-NC machine tools costs maximum €500, an IE3 motor

increases the total purchase price of a non-NC machine tool as a worst-case assumption by €150 (option 1).

6.1.2 Wood working machine tools

6.1.2.1 Base Case 5 - Light-stationary machine tools

Given their limited complexity, the possibility for improvements is limited regarding light-stationary wood working tools, as reflected by the Base Case 5 Table saw..

Among small wood working machine tools machine tables made of aluminium are frequently used. An alternative are machine tables made of cast iron instead of aluminium (option 1), as (primary) iron has a smaller environmental impact than (primary) aluminium. However, iron adds weight to the machine tool, which might be less relevant for e.g. radial arm saws, which are used stationary in workshops, but severely impacts user-friendliness in case of small machine tools, which are used at changing locations, i.e. construction sites, where low weight is important. There is no direct cost comparison available, comparing a machine table made of cast iron with aluminium, but generally speaking, based on evidence from the automotive sector, aluminium alloys are more costly than the currently used steel and cast irons that they might replace. Nevertheless, compared to cast iron and steel, cast aluminium components are potentially less costly due to reduced manufacturing cycle times, as – among some other advantages - machinability is enhanced, and they are more easily produced to near net shape. Contrary to cast parts, wrought aluminium and magnesium components are almost always more costly to produce than their ferrous counterparts.[19] In our analysis, no cost difference is applied, in the absence of a dedicated comparative case.[20]

Based on an input by EPTA there is technically the option of higher motor efficiencies[21]. This is calculated with an energy savings potential of 5%, meaning a power consumption in active mode of 0,95 kWh at 73,7% motor efficiency (option 2), instead of 1 kWh at 70% as stated by EPTA as the current status of sold units.

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[19] Ghassemieh, E.: Materials in Automotive Application, State of the Art and Prospects; in: New Trends and Developments in Automotive Industry, Edited by: Marcello Chiaberge, Publisher: InTech, January 2011, ISBN 978-953-307-999-8

[20] But it should be noted, that EPTA raised severe doubts in a stakeholder comment, that cost neutrality applies

[21] motor efficiency is currently the subject of ErP Lot 30 preparatory study and motors for these products are expected to be in scope

These improvements according to EPTA could be realised through following measures, but at a higher purchase price of estimated 25 Euros and additional material consumption[22]:

- Reduce the lamination leakage[23]
- Optimise the airflow
- Choose the best raw material for winding
- Optimise the winding
- Optimise the motor surface

6.1.2.2 Base Cases 6, 7 & 8 - Large wood working machine tools

Larger crafts and industry-use wood working machine tools are covered by three Base cases in Task 4: Horizontal panel saw (Base Case 6), Throughfeed edge banding machine (Base Case 7) and CNC machining center (Base Case 8).

Based on the estimates regarding improvement potentials and related cost effects stated in the Task 5 report, a consecutive implementation of options has to be modelled. According to the methodology for preparatory studies, the implementation of options has to start with those environmental improvements, which feature the highest decrease of life cycle costs, followed by those measures, which further reduce environmental impacts, but at higher life cycle costs. With this approach an order of options is established as listed in **Table 6-8**, but not all of them are applicable for all three of the Base Cases 6, 7 & 8. Cost effects and total machinery savings potential are as stated for cutting processes in Task 5 (measures are numbered as in Task 5 as well). As no dedicated feedback on market penetration of certain options was provided by stakeholders, a default value of 50% market penetration is applied, except for option 6, Minimized pre-heated glue volume, where a correction factor of 0,1 is applied as the Base Case 7. The Throughfeed edge banding machine is meant to be representative

[22] Approximated with additional 2,15 kg copper winding wire, corresponding to an environmental impact as stated by EPTA (the related LCA study was not accessible to Fraunhofer, but correlations are plausible)

[23] Power stray losses caused by the design of transformer cores (stacking layers of thin steel laminations)

for more market segments than solely those applying glue to edges (see Task 4 for market coverage).

Table 6-8: Design Options for Base Cases 6 - 8

Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery energy savings potential (tendency)		Base Case relevancy and default correction factor for market penetration		
					BC 6: Horizontal panel saw	BC 7: Through-feed edge banding machine	BC 8: CNC wood working machining center
Option 1							
3.1 Application-specific design of drives	0%		1%		0,5	0,5	0,5
Option 2							
2.2 Machine stand-by management	0,2%		5%		0,5	0,5	0,5
Option 3							
1.3 Less parts to be moved	0,2%		1%		0,5	n.a.	n.a.
Option 4							
4.1 Electrical clamping devices	1%	1%	3%	1%	n.a.	n.a.	0,5
or a combination of:							
5.12 Reducing channels of supply / dead volume	0,2%		1%				
5.13 Minimizing losses due to leakages (pneumatics)	0,2%		1%				
5.14 Pneumatic Cylinder with optimized drive surface	0,2%		1%				
5.15 Pneumatic Cylinder with multiple chambers			0,5%				
5.16 Single acting pneumatic cylinder	0,2%		1%				
5.17 Targeted cut-off from air supply	0,2%		1%				
5.18 Use of multiple valves	0,2%		0,5%				
5.19 Pressure reduction	0,2%		1%				
Option 5							
5.24 Optimised blowing nozzles	0,2%		1%		0,5	0,5	0,5
Option 6							
-.- Minimized pre-heated glue volume	2,5%		10%		n.a.	0,1	n.a.
Option 7							
Combination of measures for improved electronics / power supply							
3.6 Reducing transmission losses	0,2%	0,6%	0,5%	1,5%	0,5	0,5	0,5

3.7 Replacing inverter units / 400 V instead of 200 V	0,2%		0,5%				
3.9 Avoidance of transformers	0,2%		0,5%				
Option 8							
5.25 load-dependent air table control	1%		1%		0,5	n.a.	n.a.
Option 9							
2.1 Energy monitoring	1%		1%		0,5	0,5	0,5
Option 10							
3.13 efficient motors also <750 W	1%		1%		0,5	0,5	0,5
Option 11							
5.28 line-controlled blow-off device to adapt air consumption to actual needs	1%		1%		n.a.	n.a.	0,5

This list does not include measures which are an alternative option to those already listed here. In these cases, the only option listed is that which is likely to have the better effect at lower costs. Furthermore, for simplification, measures are not listed here, for which very high implementation costs are assumed, or which constitute basically a process-changing concept.

6.1.3 Base Case 9 - Welding equipment

For welding equipment, three distinct options have been identified on the general level represented by the Base Case:

Option 1: Arc welding DC Power source efficiency 85% instead of an average 75% (weighted stock average as stated in task 4, 4.1.3.9)[24].

Option 2: No analysis is available regarding the shielding gas savings potential, overall. As some sources indicate a significant savings potential (see task 5, 5.1.10.3), this study calculates with **a 10% gas saving through a combination of state-of-the-art measures** (increasing the purchase price by 20% as a conservative estimate).

Option 3: Idle power consumption of less than 10 W is achievable when the fan has automatically stopped, and is realised for e.g. stud welding equipment. It might be required that thorough power management is implemented, which switches the welding equipment to such a sleep mode (see task 5, 5.1.10.1). Whereas in larger industrial units this feature does not add significantly to product costs, it might be significant for

[24] In the draft task 6 report option 1 was based on a power source efficiency of 90% initially, which was considered BNAT by EWA and not a feasible option as of today.

smaller, simpler units, but data is missing to substantiate this aspect. However, long-term costs for related power electronics circuitries and components will drop further.

There is much more potential for increasing the efficiency of welding, but this is related to the right choice of welding technology and welding gas for the intended application. This is a matter of thorough process planning, welder education and information, but not of welding equipment design as such. Therefore this option is not taken into account here to avoid the impression, that a certain technology could be replaced completely by another. Such a choice always has to consider the intended application.

6.2 Analysis BAT and LLCC

The objective is to identify, amongst the options analysed, the Least Life Cycle Cost (LLCC) option and the Best Available Technology (BAT).

This task includes as a general approach, following MEEuP:

- Ranking of the individual design options by LCC (e.g. option 1, 2, 3, compared to the Base Case), see **Figure 6-2**.

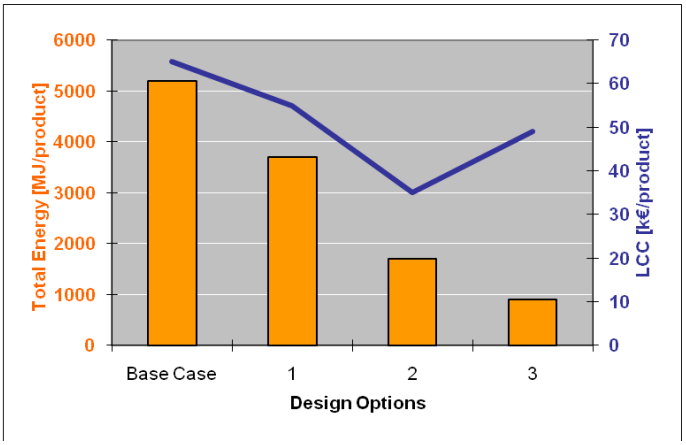


Figure 6-2: Methodological Approach: Base Case in Comparison with Design Options

- Estimation of the accumulative improvement and cost effect of implementing the ranked options simultaneously (e.g. option 1, option 1+2, option 1+2+3, etc.), also taking into account the above possible side-effects
    - Here, the only options which will be considered are those which can be applied in a cumulative manner.

- In some cases, simply adding the cost and benefits/impacts of the different options will not be relevant, and in fact might generate double counting, or underestimate some scale effects.

- Ranking of the cumulative design options, drawing a LCC-curve and identifying the Least Life Cycle Cost (LLCC) point and the point with the Best Available Technology (BAT), see **Figure 6-3**, illustratively.

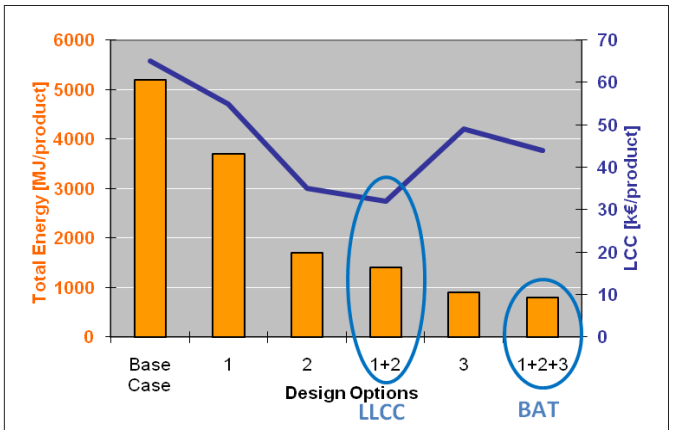


Figure 6-3: Methodological Approach: Identifying LLCC and BAT

It might also be the case, that one combination of improvement options indicates the point of LLCC for one market segment (i.e. base case improvement), but a different combination for another market segment.

6.2.1 Base Case 1: CNC 4-axis multifunctional milling centre

Improvement options listed in **Table 6-1** are analysed as follows: The base case assessment from Task 4 is adjusted now by the investment cost changes and energy savings in the use phase, each considering the correction factor. Option 2 includes option 1, option 3 includes option 1 and 2, and so forth. For each consecutive option the cost increase as a share of the initial machinery cost is added (which neglects the fact, that a combined implementation might be less costly, than only the addition of two measures):

$$C_{invest,i} = C_{invest,BC} \cdot (1 + \sum_{n=1}^{i} c_n \cdot cf_n)$$

The purchase price C_{invest} of a machine tool for a given option i is calculated as the initial purchase price $C_{invest,BC}$ for the base case, multiplied by one and the sum of cost

increase c_n (as decimal figure) for each option n=1 to i multiplied by the correction factor cf_n.

Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before:

$$E_i = E_{BC} \cdot \prod_{n=1}^{i} (1 - e_n \cdot cf_n)$$

Use phase energy consumption E for any option i is calculated as the Base Case energy consumption E_{BC} multiplied by the product of 1 minus energy reduction e_n (in decimal figures) times correction factor cf_n for each option n.

Options 13 (multi-spindle / multi workpieces machining) and 14 (combination of various technologies, turning / milling / laser / grinding etc.) are depicted here as well for comparison, but these involve major changes of the machinery concept as such. Whereas these options can be highly relevant for manufacturing a high number of uniform, complex products, this might result in even increasing environmental impacts, if machine tools are “oversized” for rather simple applications.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 1 is depicted in **Figure 6-4**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-9**, but these run largely in parallel with the indicator Total Energy.

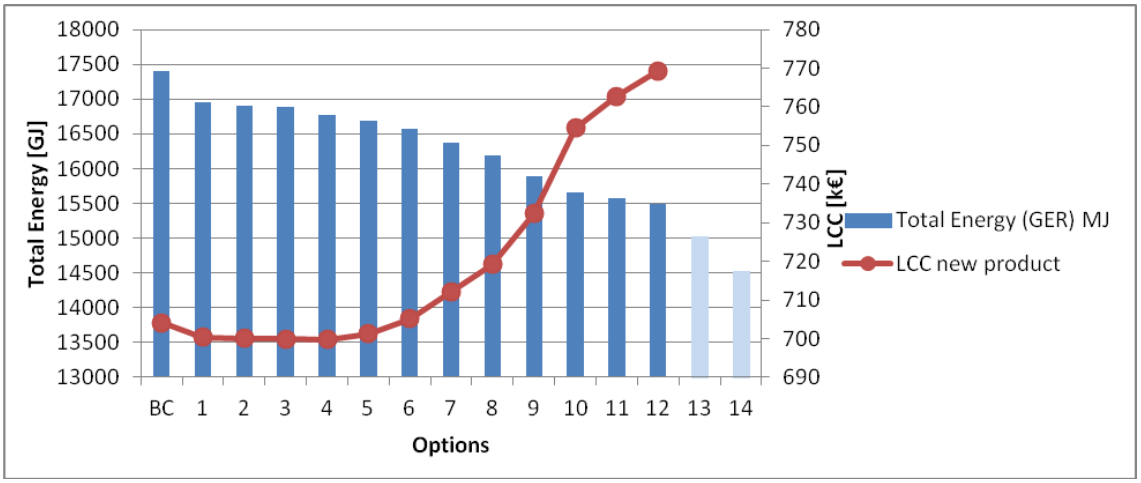


Figure 6-4: Base Case 1 – Total Energy and LCC per Option

The point of Least Life Cycle Costs is option 4 (including consecutive implementation of options 1-3). The point of Least Life Cycle Costs is only marginally lower than the Life Cycle Costs of the initial Base Case, namely 0.6%, at nearly 4% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. However, this statement holds true only for such a very general analysis. The replies received from manufacturers indicate, that for specific machine tools or market segments there are significant savings potentials at low or moderate costs, but this has to be assessed carefully on a case-by-case basis and cannot be stated as a general finding.

Table 6-9: Improvements for Base Case 1 (one product, full life cycle, life cycle costs)

				Option													
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11	12	13	14
8	Total Energy (GER) MJ	MJ	17400660	16949075	16910018	16890568	16773263	16694976	16572442	16379184	16191904	15888258	15661538	15568309	15492036	15019771	14525142
9	of which, electricity (in primary MJ)	MJ	16817509	16365925	16326867	16307417	16190113	16111825	15989292	15796033	15608754	15305108	15078387	14985159	14908886	14436620	13941991
10	Water (process)	ltr	1370986	1340880	1338276	1336980	1329159	1323940	1315771	1302887	1290402	1270159	1255044	1248829	1243744	1212260	1179285
11	Water (cooling)	ltr	44687823	43483596	43379444	43327576	43014765	42805998	42479243	41963886	41464474	40654752	40050163	39801554	39598160	38338785	37019774
12	Waste, non-haz./ landfill	g	46953141	46429554	46384269	46361718	46225710	46134940	45992870	45768797	45551657	45199597	44936727	44828634	44740200	44192635	43619141
13	Waste, hazardous/ incinerated	g	420434	410027,7	409128	408680	405976	404173	401349	396896	392580	385583	380359,1	378211	376453	365571	354173
	Emissions (Air)																
14	Greenhouse Gases in GWP100	kg CO2 eq.	781852	762145,4	760441	759592	754473	751057	745709	737276	729103	715852	705958	701890	698561	677952	656366
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Acidification, emissions	g SO2 eq.	4622775	4506492	4496435	4491426	4461220	4441061	4409509	4359745	4311520	4233331	4174951	4150944	4131304	4009696	3882329
17	Volatile Organic Compounds (VOC)	g	11311	11140,74	11126	11119	11075	11045	10999	10926	10856	10741	10655,82	10621	10592	10414	10228
18	Persistent Organic Pollutants (POP)	ng i-Teq	380132	377171,6	376916	376788	376019	375506	374703	373436	372209	370218	368732,3	368121	367621	364526	361284
19	Heavy Metals	mg Ni eq.	425045	417297,3	416627	416294	414281	412938	410836	407520	404307	399098	395208	393609	392300	384198	375712
	PAHs	mg Ni eq.	48479	47588,96	47512	47474	47243	47088	46847	46466	46097	45499	45052,49	44869	44719	43788	42814
20	Particulate Matter (PM, dust)	g	681534	679049,9	678835	678728	678083	677652	676978	675916	674886	673215	671968,5	671456	671036	668439	665718
	Emissions (Water)																
21	Heavy Metals	mg Hg/20	153274	150362,5	150111	149985	149229	148724	147934	146688	145481	143523	142060,9	141460	140968	137923	134734
22	Eutrophication	g PO4	1656	1641,949	1641	1640	1637	1634	1630	1624	1619	1609	1602,363	1599	1597	1583	1567
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	LCC new product	Euro	704123	700423	700103	699944	699693	701308	705104	712161	719266	732378	754521	762685	769260		

Note that there are numerous options when consecutively implemented, which lead to a steady decrease of Total Energy consumption, resulting in 11% savings (but also 9% higher Life Cycle Costs), once all options 1-12 are implemented.

However, this is less than stated elsewhere for metal working machine tools, see e.g.

- claim by SORALUCE[25], that applying the eco-design standard UNE 150.301:2003 yielded a milling machine tools development with an environmental impact reduction of 15% compared to a previous model.
- Savings potential of nearly 50% stated for a mechanical press, see **Table 6-2**, p. 10

The reasons for the above range of figures might be as follows:

- Comparisons made by manufacturers and in research projects typically compare an improved machine tool with a benchmark, where none of the measures has been implemented, and which typically represents a former technology generation. In this study any efficiency gains calculated take into account the issue that most of the measures already have a certain market penetration (our benchmark is the average machine tool brought on the market today)
- Company sources stating high savings potentials (“up to 50%”) might have made these claims based on non-realistic use scenarios, which do not reflect the likely production scenario[26].

6.2.2 Base Case 2: Laser cutting machine tool

For laser cutting machine tools, as a rather smaller market segment among CNC machine tools, the LLCC analysis has to remain on a rather superficial level as dedicated data is limited. Two options – which are rather assumptions – are outlined in 6.1.1.2. The resulting graph of consecutively implementing both is depicted in **Figure 6-5**.

25 http://www.danobatgroup.com/eng/ne/soraluce-the-first-machine-tool-sector-company-to-obtain-ecodesign-certification, accessed February 17, 2012

26 See e.g. statement by Abele et al. in: Abele, E.; Kuhrke, B.; Rothenbücher, S.: Energieeffizienz von Werkzeugmaschinen maximieren, MaschinenMarkt, 22.02.2010

For both options, no changes of investment costs and running costs (besides energy and gas) are considered, although fibre lasers tend to require a higher investment, but less maintenance.

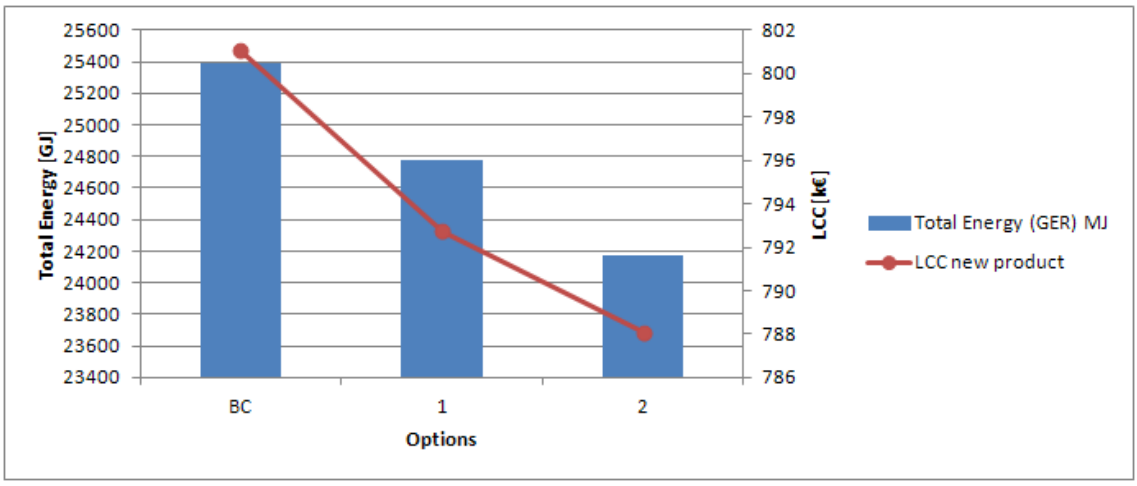


Figure 6-5: Base Case 2 – Total Energy and LCC per Option

Corresponding with the assumptions, Total Energy consumption goes down by 4,8% with implementation of options 1 and 2. LCC (neglecting effects stated above) go down by 1,6%.

Table 6-10: Improvements for Base Case 2 (one product, full life cycle, life cycle costs)

	Other Resources & Waste		BC	1	2
8	Total Energy (GER) MJ	MJ	25389099	24772959	24172223
9	of which, electricity (in primary MJ)	MJ	24810686	24194546	23593810
10	Water (process)	ltr	2003416	1962340	1922291
11	Water (cooling)	ltr	65832860	64189820	62587856
12	Waste, non-haz./ landfill	g	39949001	39234622	38538102
13	Waste, hazardous/ incinerated	g	797117	782919	769077
	Emissions (Air)				
14	Greenhouse Gases in GWP100	kg CO2 eq.	1132108	1105220	1079004
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0
16	Acidification, emissions	g SO2 eq.	6757147	6598491	6443802
17	Volatile Organic Compounds (VOC)	g	14198	13966	13740
18	Persistent Organic Pollutants (POP)	ng i-Teq	258003	253965	250027
19	Heavy Metals	mg Ni eq.	962102	951531	941225
	PAHs	mg Ni eq.	109536	108321	107138
20	Particulate Matter (PM, dust)	g	627519	624131	620827
	Emissions (Water)				
21	Heavy Metals	mg Hg/20	509232	505259	501386
22	Eutrophication	g PO4	9398	9379	9361

23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0
	LCC new product	Euro	801056	792743	788095

6.2.3 Base Case 3: CNC Metal working bending machine tools

Improvement options listed in **Table 6-6**, p. 16, are analysed as follows: The base case assessment from Task 4 is now adjusted by the investment cost changes and energy savings in the use phase, each considering the correction factor. Option 2 includes option 1, option 3 includes option 1 and 2, and so forth. For each consecutive option the cost increase as a share of the initial machinery cost is added (which neglects the fact that a combined implementation might be less costly than only the addition of two measures). Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 3 is depicted in **Figure 6-6**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-11**, but these run largely in parallel with the indicator Total Energy.

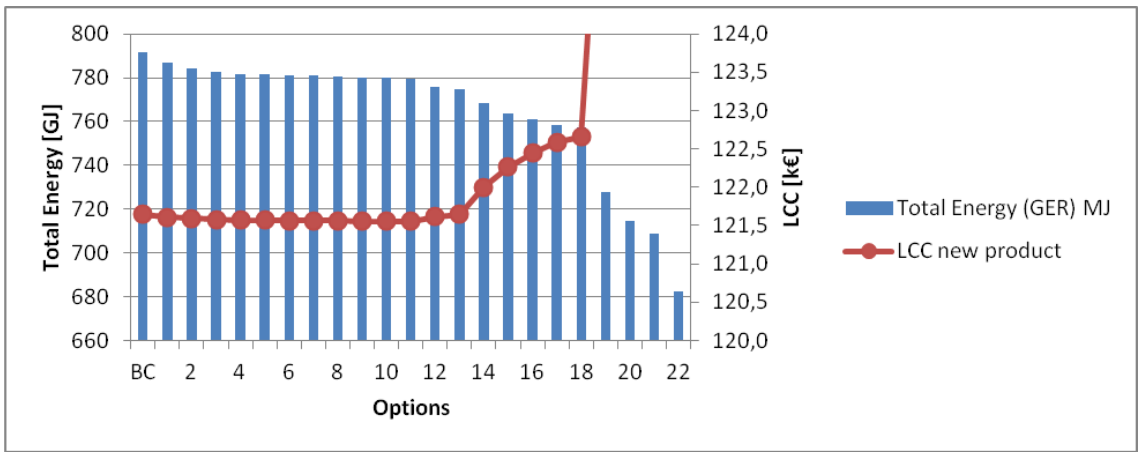


Figure 6-6: Base Case 3 – Total Energy and LCC per Option

The point of Least Life Cycle Costs is option 11 (including consecutive implementation of options 1-10), but Life Cycle Costs changes throughout these options are marginal and reach a cost savings potential of less than 0,1% at option 11, at 1,5% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. The implementation of option 18 features an aggregated result of 0,8% higher Life Cycle Costs at Total

Energy savings of slightly more than 4%. All other options beyond no. 18 result in excessive additional costs (in average), but are nevertheless worthwhile to explore for an individual machine tool, as they feature relevant energy savings potentials.

It should be borne in mind that these figures apply to a highly abstract case. The replies received from manufacturers indicate that for specific machine tools, or specific market segments, there are significant savings potentials available at low or moderate costs, but this has to be assessed carefully on a case-by-case basis, and cannot be stated as a general finding.

Table 6-11: Improvements for Base Case 3 (one product, full life cycle, life cycle costs)

				Option													
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11	12	13	14
8	Total Energy (GER) MJ	MJ	791721	786670	784380	782686	781770	781550	781325	780993	780636	780279	779922	779566	775761	774525	768440
9	of which, electricity (in primary MJ)	MJ	664416	659365	657074	655380	654465	654245	654019	653687	653330	652974	652617	652260	648456	647219	641134
10	Water (process)	ltr	43844	43507	43354	43241	43180	43165	43150	43128	43105	43081	43057	43033	42780	42697	42291
11	Water (cooling)	ltr	1676825	1663355	1657247	1652730	1650289	1649702	1649100	1648215	1647264	1646312	1645361	1644409	1634265	1630967	1614740
12	Waste, non-haz./ landfill	g	7126470	7120614	7117958	7115994	7114933	7114678	7114416	7114031	7113618	7113204	7112790	7112376	7107966	7106532	7099477
13	Waste, hazardous/ incinerated	g	23430	23313	23260	23221	23200	23195	23190	23182	23174	23166	23158	23150	23062	23033	22893
	Emissions (Air)																
14	Greenhouse Gases in GWP100	kg CO2 eq.	40064	39844	39744	39670	39630	39621	39611	39596	39581	39565	39550	39534	39368	39314	39048
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Acidification, emissions	g SO2 eq.	197102	195801	195211	194775	194540	194483	194425	194339	194248	194156	194064	193972	192992	192674	191107
17	Volatile Organic Compounds (VOC)	g	1577	1575	1574	1573	1573	1573	1573	1573	1573	1572	1572	1572	1571	1570	1568
18	Persistent Organic Pollutants (POP)	ng i-Teq	98776	98743	98728	98716	98710	98709	98708	98705	98703	98701	98698	98696	98671	98663	98623
19	Heavy Metals	mg Ni eq.	34741	34654	34615	34586	34570	34566	34562	34557	34551	34544	34538	34532	34467	34446	34341
	PAHs	mg Ni eq.	4395	4385	4381	4377	4375	4375	4375	4374	4373	4373	4372	4371	4364	4361	4349
20	Particulate Matter (PM, dust)	g	81261	81234	81221	81212	81207	81205	81204	81202	81200	81198	81197	81195	81174	81167	81133
	Emissions (Water)																
21	Heavy Metals	mg Hg/20	19182	19150	19135	19124	19118	19117	19115	19113	19111	19109	19106	19104	19079	19071	19032
22	Eutrophication	g PO4	397	397	397	397	396	396	396	396	396	396	396	396	396	396	396
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	LCC new product	Euro	121645	121607	121590	121577	121570	121569	121567	121564	121562	121559	121556	121554	121615	121646	122000

			Option							
	Other Resources & Waste		15	16	17	18	19	20	21	22
8	Total Energy (GER) MJ	MJ	763904	760924	758543	757452	727813	714604	708795	682429
9	of which, electricity (in primary MJ)	MJ	636599	633618	631238	630146	600507	587299	581489	555124
10	Water (process)	ltr	41989	41790	41632	41559	39583	38702	38315	36557
11	Water (cooling)	ltr	1602646	1594698	1588350	1585440	1506403	1471179	1455687	1385380
12	Waste, non-haz./ landfill	g	7094218	7090762	7088002	7086737	7052373	7037057	7030322	6999753
13	Waste, hazardous/ incinerated	g	22789	22720	22665	22640	21957	21653	21519	20911
	Emissions (Air)									
14	Greenhouse Gases in GWP100	kg CO2 eq.	38850	38720	38617	38569	37275	36699	36446	35295
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0	0	0	0	0
16	Acidification, emissions	g SO2 eq.	189939	189172	188559	188278	180646	177244	175748	168959
17	Volatile Organic Compounds (VOC)	g	1566	1565	1564	1564	1553	1548	1546	1536
18	Persistent Organic Pollutants (POP)	ng i-Teq	98593	98574	98558	98551	98357	98270	98232	98059
19	Heavy Metals	mg Ni eq.	34263	34212	34171	34153	33644	33418	33318	32866
	PAHs	mg Ni eq.	4340	4334	4330	4328	4269	4243	4232	4180
20	Particulate Matter (PM, dust)	g	81108	81092	81079	81073	80910	80837	80805	80660
	Emissions (Water)									
21	Heavy Metals	mg Hg/20	19003	18984	18968	18961	18770	18685	18648	18478
22	Eutrophication	g PO4	396	396	396	396	395	394	394	393
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0	0	0	0	0
	LCC new product	Euro	122266	122444	122586	122658	127436	129687	130693	135345

6.2.4 Base Case 4: Non-numerical controlled metal working machine tools

The only identified option for non-NC machine tools is the implementation of IE3 motors (instead of IE2), which is depicted as option 1 in **Figure 6-7**.

IE3 motors represent the point of Least Life Cycle Costs with Total Energy savings of 2,1% and LCC savings of 0,8%. However, these LCC savings are realized over an anticipated lifetime of 18 years, which is far beyond any ROI industry is used to.

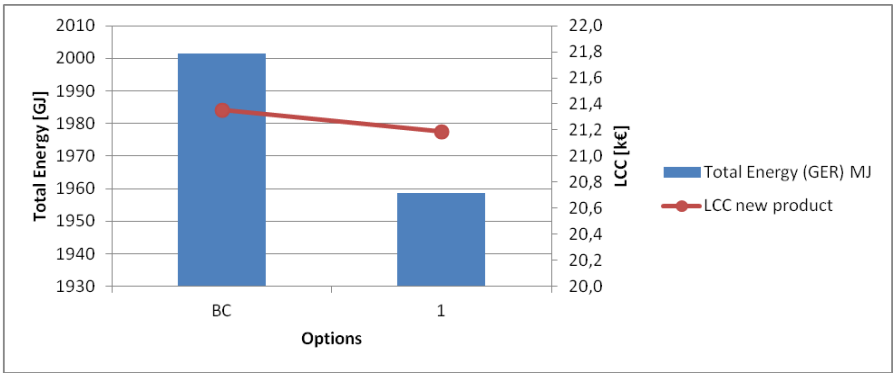


Figure 6-7: Base Case 4 – Total Energy and LCC per Option

What is not displayed with these figures is the fact that, compared to the existing stock of non-NC machine tools, those currently placed on the market are already much more energy efficient, due to the mandatory requirement to implement IE2 motors.

Table 6-12: Improvements for Base Case 4 (one product, full life cycle, life cycle costs)

	Other Resources & Waste		BC	1
8	Total Energy (GER) MJ	MJ	2001356	1958529
9	of which, electricity (in primary MJ)	MJ	1949841	1907013
10	Water (process)	ltr	140188	137333
11	Water (cooling)	ltr	5194965	5080759
12	Waste, non-haz./ landfill	g	3241703	3192047
13	Waste, hazardous/ incinerated	g	45382	44396
	Emissions (Air)			
14	Greenhouse Gases in GWP100	kg CO2 eq.	89136	87267
15	Ozone Depletion, emissions	mg R-11 eq.	0	0
16	Acidification, emissions	g SO2 eq.	514995	503967
17	Volatile Organic Compounds (VOC)	g	1382	1366
18	Persistent Organic Pollutants (POP)	ng i-Teq	22894	22614
19	Heavy Metals	mg Ni eq.	44060	43326
	PAHs	mg Ni eq.	9525	9441

20	Particulate Matter (PM, dust)	g	135054	134819
	Emissions (Water)			
21	Heavy Metals	mg Hg/20	14313	14037
22	Eutrophication	g PO4	113	112
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0
	LCC new product	Euro	21354	21189

6.2.5 Base Case 5: Wood working machine tools: Table saw

The number of calculated improvement options for light stationary machine tools is limited. Results are depicted in **Figure 6-8**, which shows the implementation of option 1 (cast iron instead of bulk aluminium parts), followed by a consecutive implementation of option 2 (energy efficient motors), i.e. “option 1+2”.

For comparison also the sole effect of option 2 is depicted separately, followed by a consecutive implementation of option 2 (energy efficient motors), i.e. “option 1+2”. With the calculated use scenario the Life Cycle Costs do not decrease at all.

Despite energy savings in use, the additional material consumption for more energy efficient motors over-compensate these savings.

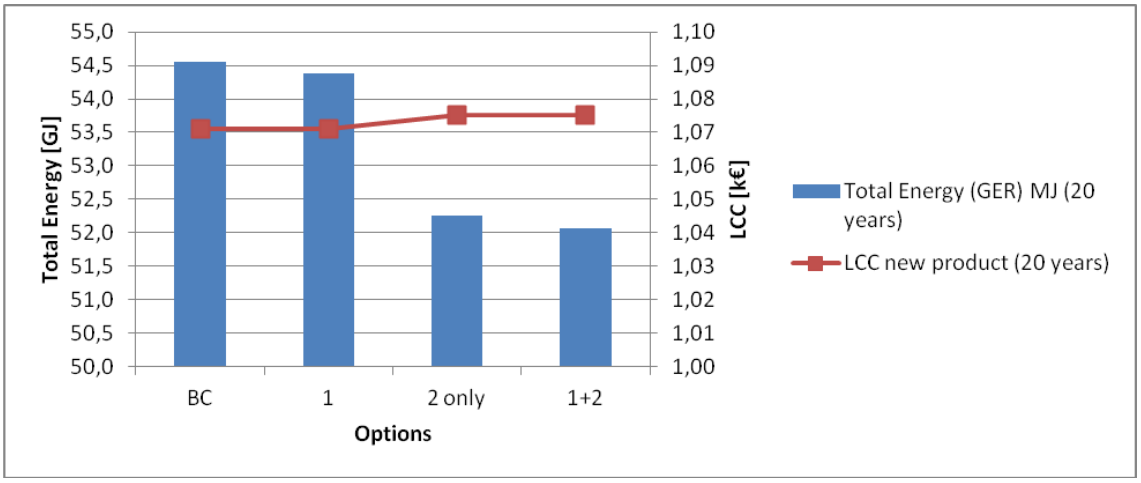


Figure 6-8: Base Case 5 – Total Energy and LCC per Option

These results also correspond with findings made by the US Department of Energy, which stated a minimum payback period of 8,5 years for efficient small motors, partly

much more for the higher efficiency benchmarks[27]. The payback period according to our scenario equals roughly 20 years.

Table 6-13: Improvements for Base Case 5 (one product, full life cycle, life cycle costs)

				Option		
	Other Resources & Waste		BC	1	1+2	2
8	Total Energy (GER) MJ	MJ	54556	54107	52068	51799
9	of which, electricity (in primary MJ)	MJ	52619	52596	49996	49971
10	Water (process)	ltr	3528	3539	3387	3364
11	Water (cooling)	ltr	140134	140156	133229	133156
12	Waste, non-haz./ landfill	g	108158	104084	151264	144689
13	Waste, hazardous/ incinerated	g	1751	1751	1692	1692
	Emissions (Air)					
14	Greenhouse Gases in GWP100	kg CO2 eq.	2423	2398	2325	2300
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0
16	Acidification, emissions	g SO2 eq.	14360	14239	14297	14223
17	Volatile Organic Compounds (VOC)	g	32	32	33	31
18	Persistent Organic Pollutants (POP)	ng i-Teq	821	571	673	563
19	Heavy Metals	mg Ni eq.	1108	1119	1250	1199
	PAHs	mg Ni eq.	414	254	261	261
20	Particulate Matter (PM, dust)	g	2162	2251	2570	2253
	Emissions (Water)					
21	Heavy Metals	mg Hg/20	523	472	490	470
22	Eutrophication	g PO4	4	4	5	4
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0
	LCC new product	Euro	1071	1071	1075	1075

6.2.6 Base Case 6: Wood working machine tools: Horizontal panel saw

Improvement options listed in **Table 6-8**, p. 22, are analysed as follows: The base case assessment from Task 4 is adjusted now by the investment cost changes and energy savings in the use phase, each considering the correction factor. Option 2 includes option 1, option 3 includes option 1 and 2, and so forth. For each consecutive option the cost increase as a share of the initial machinery cost is added (which neglects the fact, that a combined implementation might be less costly, than only the addition of two measures). Contrary to the costs, the energy savings are not just aggregated, but for

[27] 10 CFR Part 431 - Energy Conservation Program: Energy Conservation Standards for Small Electric Motors, Federal Register / Vol. 75, No. 45 / Tuesday, March 9, 2010, p. 10919; stated for the small business customer subgroup (conditions applicable to the US).

each option the point of reference for further savings is the energy consumption level achieved with the option before. Those options, which are not relevant for this machine tools archetype, are left blank in the graph.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 6 is depicted in **Figure 6-9**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-14**, but these run largely in parallel with the indicator Total Energy.

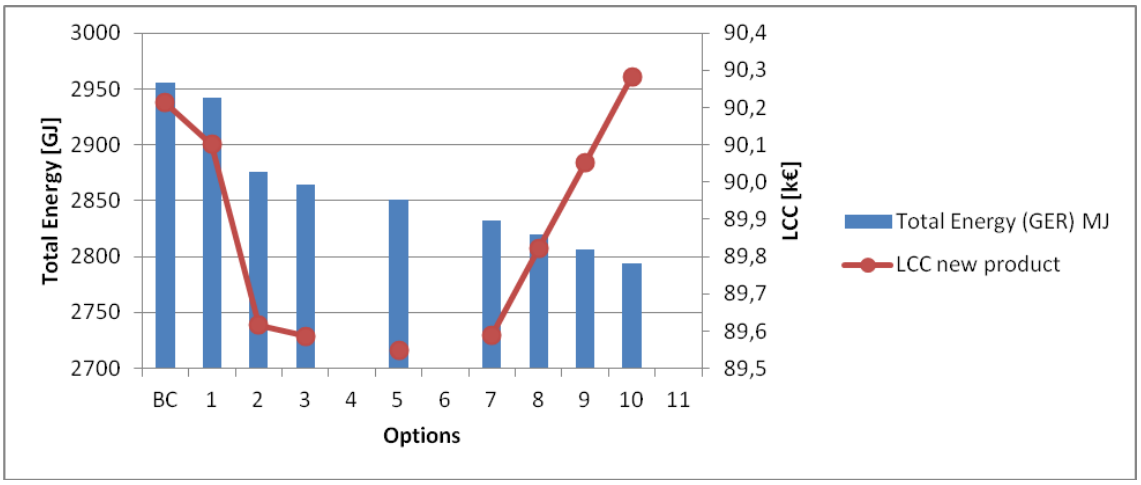


Figure 6-9: Base Case 6 – Total Energy and LCC per Option

Table 6-14: Improvements for Base Case 6 (one product, full life cycle, life cycle costs)

				Option										
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11
8	Total Energy (GER) MJ	MJ	2955871	2942483	2875880	2864127		2851329		2832098	2819359	2806587	2793815	
9	of which, electricity (in primary MJ)	MJ	2780003	2766616	2700013	2688259		2675461		2656230	2643492	2630720	2617948	
10	Water (process)	ltr	189775	188883	184442	183659		182806		181524	180674	179823	178971	
11	Water (cooling)	ltr	7347343	7311643	7134035	7102693		7068564		7017282	6983313	6949254	6915195	
12	Waste, non-haz./ landfill	g	10782517	10766995	10689772	10676145		10661306		10639009	10624240	10609431	10594623	
13	Waste, hazardous/ incinerated	g	149181	148872	147337	147067		146772		146329	146035	145741	145446	
	Emissions (Air)													
14	Greenhouse Gases in GWP100	kg CO2 eq.	135176	134592	131686	131173		130614		129775	129219	128662	128104	
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0		0		0	0	0	0	
16	Acidification, emissions	g SO2 eq.	769243	765796	748645	745619		742323		737371	734091	730802	727514	
17	Volatile Organic Compounds (VOC)	g	2040	2035	2010	2005		2001		1993	1989	1984	1979	
18	Persistent Organic Pollutants (POP)	ng i-Teq	111194	111106	110670	110593		110509		110383	110299	110216	110132	
19	Heavy Metals	mg Ni eq.	75395	75165	74023	73821		73602		73272	73053	72834	72615	
	PAHs	mg Ni eq.	7443	7417	7286	7262		7237		7199	7174	7149	7124	
20	Particulate Matter (PM, dust)	g	106266	106193	105826	105762		105691		105586	105516	105445	105375	
	Emissions (Water)													
21	Heavy Metals	mg Hg/20	32344	32257	31828	31752		31670		31546	31464	31381	31299	
22	Eutrophication	g PO4	1446	1445	1443	1443		1442		1442	1441	1441	1441	
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0		0		0	0	0	0	
	LCC new product	Euro	90213	90102	89616	89586		89547		89590	89821	90052	90284	

The point of Least Life Cycle Costs is option 5 (including consecutive implementation of options 1-3), but Life Cycle Costs changes throughout these options are marginal and reach a cost savings potential of 0,7%, at 3,5% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. The implementation of option 9 still represents a reduction (0,2%) of Life Cycle Costs compared to the status quo at Total Energy savings of 5%.

It should be borne in mind that these figures apply to a highly abstract case. For specific machine tools or market segments there might be significant savings potentials at low or moderate costs, but this has to be assessed carefully on a case-by-case basis and cannot be stated as a general finding.

6.2.7 Base Case 7: Wood working machine tools: Throughfeed edge banding machine

Improvement options listed in **Table 6-8**, p. 22, are analysed as follows: The base case assessment from task 4 is adjusted now by the investment cost changes and energy savings in the use phase, each considering the correction factor. For each consecutive option the cost increase as a share of the initial machinery cost is added. Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before. Those options, which are not relevant for this machine tools archetype are left blank in the graph.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 7 is depicted in **Figure 6-10**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-15**, but these run largely in parallel with the indicator Total Energy.

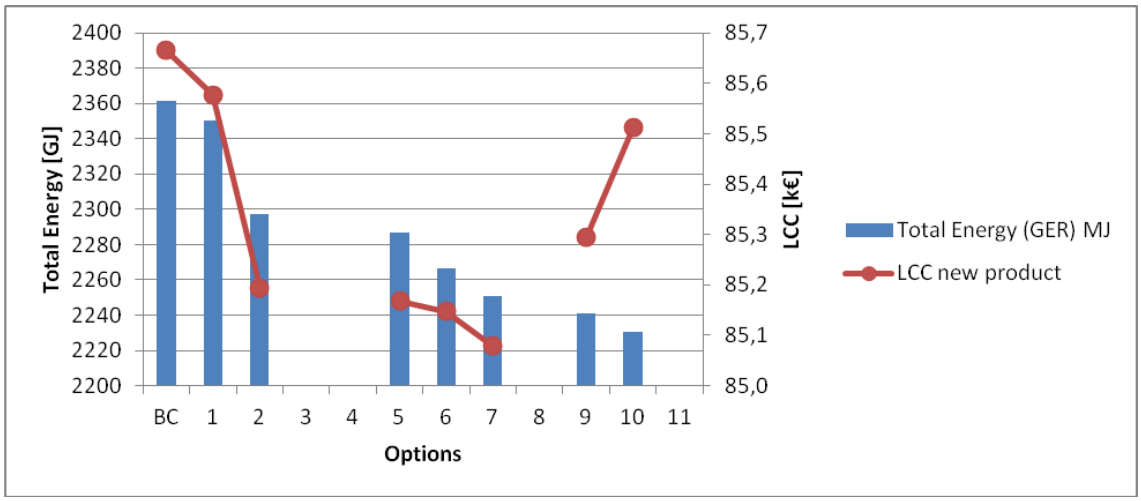


Figure 6-10: Base Case 7 – Total Energy and LCC per Option

The point of Least Life Cycle Costs is option 7 (including consecutive implementation of options 1, 2, 5, and 6), but Life Cycle Costs changes throughout these options are marginal and reach a cost savings potential of 0,7% at 4,7% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. The implementation of option 10 still represents a reduction (0,2%) of Life Cycle Costs compared to the status quo at Total Energy savings of 5,5%.

These results basically confirm the trends identified for the panel saw (Base Case 6), although process and technology is different.

Table 6-15: Improvements for Base Case 7 (one product, full life cycle, life cycle costs)

				Option										
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11
8	Total Energy (GER) MJ	MJ	2361192	2350482	2297200			2286883	2266238	2250867		2240705	2230728	
9	of which, electricity (in primary MJ)	MJ	2214047	2203337	2150055			2139738	2119093	2103722		2093560	2083583	
10	Water (process)	ltr	152300	151586	148034			147346	145970	144945		144268	143603	
11	Water (cooling)	ltr	5849575	5821015	5678929			5651417	5596364	5555374		5528276	5501670	
12	Waste, non-haz./ landfill	g	8255549	8243132	8181354			8169392	8145455	8127633		8115851	8104283	
13	Waste, hazardous/ incinerated	g	70783	70536	69308			69070	68595	68241		68006	67776	
	Emissions (Air)													
14	Greenhouse Gases in GWP100	kg CO2 eq.	107168	106701	104376			103926	103025	102354		101910	101475	
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0			0	0	0		0	0	
16	Acidification, emissions	g SO2 eq.	630343	627585	613865			611209	605893	601935		599318	596749	
17	Volatile Organic Compounds (VOC)	g	1601	1597	1577			1573	1565	1560		1556	1552	
18	Persistent Organic Pollutants (POP)	ng i-Teq	68471	68401	68052			67984	67849	67748		67682	67616	
19	Heavy Metals	mg Ni eq.	67701	67517	66603			66426	66072	65808		65634	65463	
	PAHs	mg Ni eq.	21205	21184	21079			21059	21018	20988		20968	20948	
20	Particulate Matter (PM, dust)	g	105120	105061	104768			104711	104597	104513		104457	104402	
	Emissions (Water)													
21	Heavy Metals	mg Hg/20	30248	30179	29835			29769	29636	29537		29471	29407	
22	Eutrophication	g PO4	313	313	311			311	310	310		310	309	
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0			0	0	0		0	0	
	LCC new product	Euro	85666	85577	85194			85169	85147	85079		85295	85512	

6.2.8 Base Case 8: Wood working machine tools: CNC machining center

Improvement options listed in **Table 6-8**, p. 22, are analysed as follows: The base case assessment from task 4 is adjusted now by the investment cost changes and energy savings in the use phase, each considering the correction factor. For each consecutive option the cost increase as a share of the initial machinery cost is added. Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before. Those options, which are not relevant for this machine tools archetype, are left blank in the graph.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 8 is depicted in **Figure 6-11**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-16**, but these run largely in parallel with the indicator Total Energy.

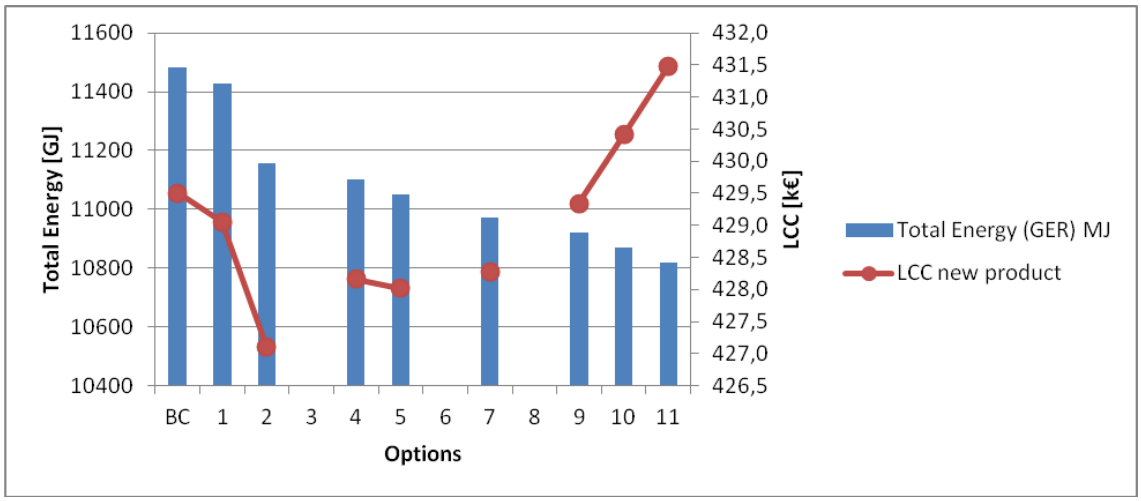


Figure 6-11: Base Case 8 – Total Energy and LCC per Option

Table 6-16: Improvements for Base Case 8 (one product, full life cycle, life cycle costs)

				Option										
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11
8	Total Energy (GER) MJ	MJ	11481681	11427081	11155609		11102790	11049968		10972593		10920586	10868766	10816947
9	of which, electricity (in primary MJ)	MJ	11163960	11109360	10837889		10785069	10732247		10654872		10602865	10551045	10499226
10	Water (process)	ltr	933327	929687	911589		908068	904546		899388		895921	892466	889012
11	Water (cooling)	ltr	29636677	29491077	28767154		28626303	28485443		28279109		28140424	28002239	27864053
12	Waste, non-haz./ landfill	g	20876237	20812931	20498176		20436935	20375690		20285979		20225680	20165598	20105516
13	Waste, hazardous/ incinerated	g	372183	370924	364669		363452	362235		360452		359253	358059	356865
	Emissions (Air)													
14	Greenhouse Gases in GWP100	kg CO2 eq.	515216	512833	500987		498682	496376		493000		490730	488469	486208
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0		0	0		0		0	0	0
16	Acidification, emissions	g SO2 eq.	3101152	3087092	3017188		3003587	2989985		2970061		2956670	2943326	2929983
17	Volatile Organic Compounds (VOC)	g	5956	5936	5834		5814	5794		5765		5745	5726	5706
18	Persistent Organic Pollutants (POP)	ng i-Teq	131844	131486	129707		129361	129015		128507		128167	127827	127487
19	Heavy Metals	mg Ni eq.	530969	530032	525374		524468	523562		522235		521342	520453	519564
	PAHs	mg Ni eq.	56454	56347	55812		55708	55604		55452		55349	55247	55145
20	Particulate Matter (PM, dust)	g	206138	205837	204344		204054	203763		203338		203052	202767	202482
	Emissions (Water)													
21	Heavy Metals	mg Hg/20	285438	285086	283335		282995	282654		282155		281820	281486	281152
22	Eutrophication	g PO4	5815	5814	5805		5804	5802		5800		5798	5797	5795
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0		0	0		0		0	0	0
	LCC new product	Euro	429507	429054	427098		428159	428021		428278		429346	430415	431485

The point of Least Life Cycle Costs is option 2 (including implementation of option 1). Life Cycle Costs changes throughout these are marginal and reach a cost savings potential of 0,6% at 2,8% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. The implementation of option 9 still represents a reduction (<0,1%) of Life Cycle Costs compared to the status quo at Total Energy savings of nearly 5%.

6.2.9 Base Case 9: Welding equipment

Improvement options mentioned in 6.1.3 are analysed as follows: The base case assessment from task 4 is adjusted now by the investment cost changes and energy and gas savings in the use phase. For each consecutive option the cost increase as a share of the initial machinery cost is added. Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before.

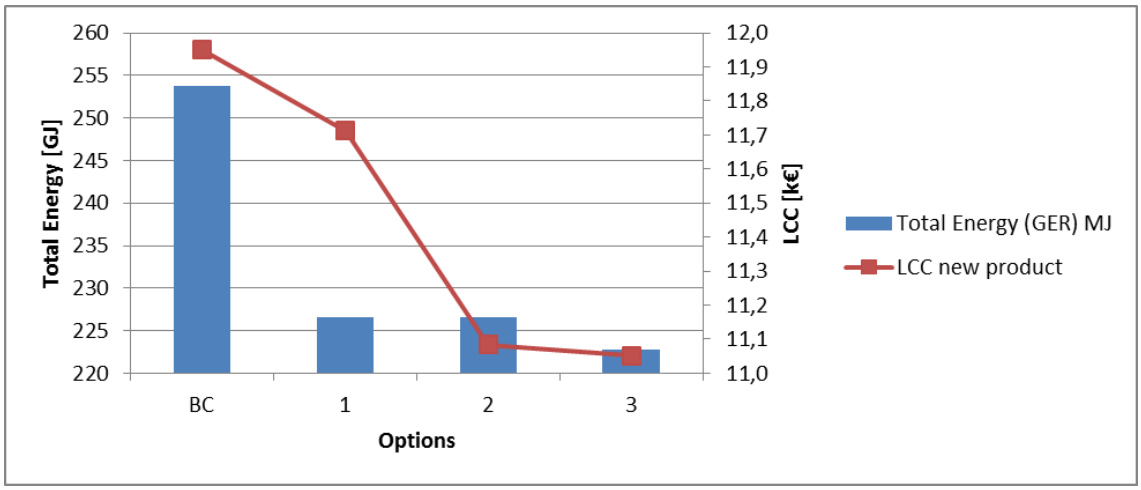


Figure 6-12: Base Case 9 – Total Energy and LCC per Option

The aggregated implementation of options 1-3 turns out to represent the point of LLCC. Realised savings are 12,2% of Total Energy consumption, at 7,5% lower LCC.

Table 6-17: Improvements for Base Case 9 (one product, full life cycle, life cycle costs)

				Option		
	Other Resources & Waste		BC	1	2	3
8	Total Energy (GER) MJ	MJ	253721	226576	226576	222778
9	of which, electricity (in primary MJ)	MJ	233968	206528	206528	202731
10	Water (process)	ltr	16004	14174	14174	13921
11	Water (cooling)	ltr	625535	552362	552362	542235
12	Waste, non-haz./ landfill	g	597337	606125	606125	601722
13	Waste, hazardous/ incinerated	g	22291	21661	21661	21573
	Emissions (Air)					
14	Greenhouse Gases in GWP100	kg CO2 eq.	11465	10282	10282	10117
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0
16	Acidification, emissions	g SO2 eq.	67741	61290	61290	60312
17	Volatile Organic Compounds (VOC)	g	187	177	177	175
18	Persistent Organic Pollutants (POP)	ng i-Teq	4480	4309	4309	4284
19	Heavy Metals	mg Ni eq.	5883	5529	5529	5463
	PAHs	mg Ni eq.	5940	5897	5896	5889
20	Particulate Matter (PM, dust)	g	6072	5936	5936	5915
	Emissions (Water)					
21	Heavy Metals	mg Hg/20	3856	3693	3693	3669
22	Eutrophication	g PO4	36	35	35	35
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0
	LCC new product	Euro	11950	11712	11084	11052

6.3 BNAT and long-term systems analysis

In Task 5, a multitude of BNATs with broad technological and sectorial coverage were introduced. It has been highlighted that great efforts are currently invested in research activities concerning resource-efficient and sustainable production plants.

Due to the strong dynamism of the machine tool markets, the quantification of these activities in terms of energy and cost saving potential is a highly difficult task, and depends on numerous factors, many of which may not be foreseeable. This comprises the successful outcome of research activities, with regard to the market maturity and competitiveness derived, in terms of the price of the products, and the applicability of these solutions to different machine tools, and their related machinery. The other factors include the development of novel production technologies, and machines which replace other machineries in the long term, and set standards in energy consumption and efficiency. From this perspective, a long-term observation would necessitate the

development of a multitude of different scenarios, of which the probability of occurrence is unfeasible to predict.

At the time of writing, BNATs are developed firstly on a components level, i.e. optimisation of individual components and sub-systems, which does not allow one to later estimate effects at the machinery level (and which itself is highly dependent on how these components are actually implemented within the system). Secondly, research tends to conceptualise the “energy-efficient machine tool”, which is a promising approach, but does not allow a credible extrapolation to the whole machine tools market for 2020 or 2025.

6.4 Sensitivity analysis of the main parameters

The intention of the sensitivity analysis is to verify the robustness of the results, particularly the identified environmental impacts and improvement trends, including the identification of the point of Least Life Cycle Costs, if major parameters of the assessment model are analysed. A sensitivity analysis tries to identify which sources of uncertainty might have the most weight, regarding the robustness of the study's conclusions.

In the course of the study the following relevant aspects have been identified:

(1) use pattern assumptions, i.e. shift models, times spent in individual modes

(2) lifetime assumptions

(3) energy costs, which vary widely among countries and company sizes

(4) choice of Base Cases as suitable “abstraction of reality”

(5) stock model and market forecast

Aspects (1) – (3) will be analysed for selected Base Cases and scenarios below on the basis of “per unit machine tool”. For these analyses we pick out those Base Cases for which there is the highest likelihood, that such an alternative scenario is applicable.

The choice of the Base Cases as such cannot be verified, as no calculation of alternative archetypal machine tools can be undertaken, due to time constraints – hence this uncertainty remains. As the analysis in Task 6 was undertaken only on a “per unit machine tool” basis, the uncertainty of the stock model and market forecast has to be discussed in Task 7, where total market impacts are quantified.

6.4.1 Shift model

Typical shift models have been chosen for the various Base Cases, but frequently machine tools intended to be covered by a given Base Case are used in a different production environment. For CNC machining centers (and other machine tools represented by BC1) a sensitivity analysis is undertaken with the following parameter changes:

- 1 shift instead of 2 shifts: on-mode 6 hours x 5 days x 50 weeks = 1.500 h/a; standby 2 hours x 5 days x 50 weeks = 500 h/a; off 6760 h/a

With these settings, the results for Base Case 1 change as depicted in **Figure 6-13**: The graph shows both the initial Base Case scenario with improvement options implemented consecutively (i.e., the same as in 6.2.1), and LCC and Total Energy consumption with the adapted shift model. Not surprisingly, Total Energy consumption and Life Cycle Costs, both being closely related to the use phase, decrease. Whereas the point of Least Life Cycle costs in the initial scenario is option 4, this point is now reached already with option 3, but with an even more marginal change compared to the status-quo. The Total Energy savings potential is logically lower as well for the 1-shift-scenario. However, the overall trend is confirmed for the 1-shift-scenario:

- Implementation of several options leads to moderate energy savings
- A couple of options can be implemented for a nearly cost-neutral investment
- Some options with a somewhat higher savings potential are correlated also with higher LCC

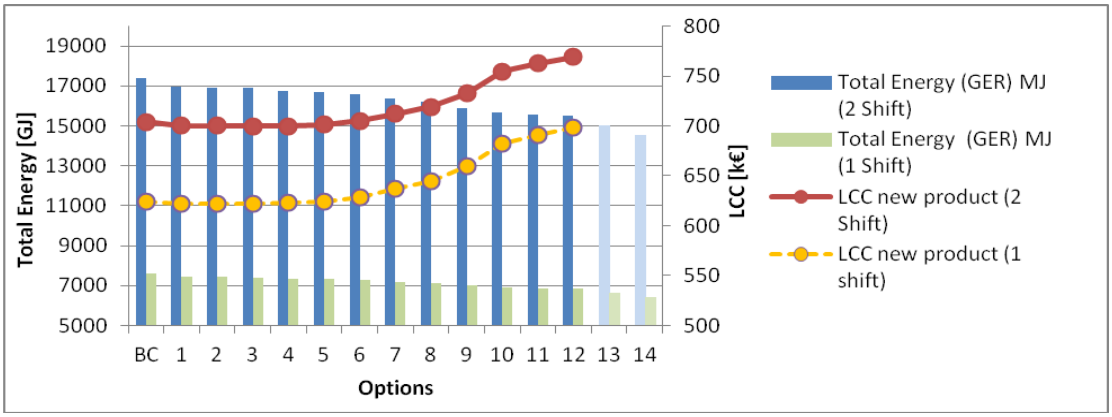


Figure 6-13: Base Case 1 – Sensitivity analysis – shift model change

Wood working is dominated by small businesses / crafts businesses. Consequently, wood working machine tools have been modelled with one shift. In the furniture industry and similar market segments, a two-shift production pattern might be more common. Exemplarily for horizontal panel saws (and other machine tools represented by BC6) a sensitivity analysis is undertaken with the following parameter changes:

- 2 shifts instead of 1 shift: on-mode 1 hour x 6 days x 50 weeks = 300 h/a; idle 15 hours x 6 days x 50 weeks = 4500 h; standby = 3 hours x 6 days x 50 weeks = 900 h, remaining time off-mode

With these settings, the results for Base Case 6 change as depicted in **Figure 6-14**: The graph shows both the initial Base Case scenario with improvement options implemented consecutively (i.e., the same as in 6.2.6), and LCC and Total Energy consumption with the adapted shift model. The Total Energy consumption and Life Cycle Costs, both being closely related to the use phase, increase for the 2-shifts-model compared to the 1-shift-model. Whereas the point of Least Life Cycle costs in the initial scenario is option 5, this point is now reached with option 7, and even with option 10 the LCC is still below the status quo.

This analysis leads to the conclusion that for an industrial 2-shift scenario, the positive effect of implementing consecutively a multitude of options leads to greater relevant savings in terms of Total Energy consumption and moderate cost savings.

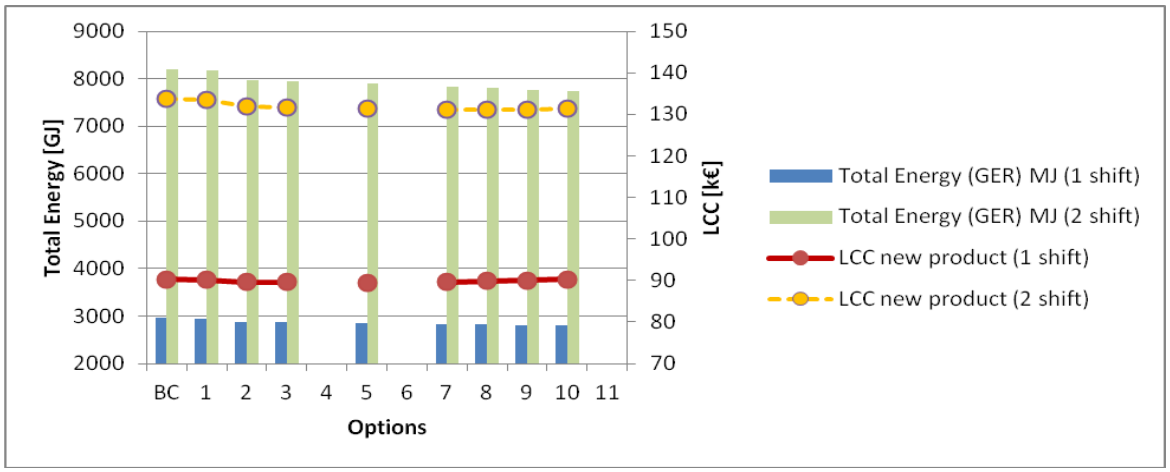


Figure 6-14: Base Case 6 – Sensitivity analysis – shift model change

6.4.2 Electricity price

Once we assume a rather industrial production scenario for wood working machine tools as calculated above, a more appropriate electricity price is that of larger companies. In this sensitivity analysis instead of 0,14 Euro/kWh as the identified proxy for the wood working sector, a lower electricity price of 0,11 Euro/kWh (similar to that for the metal working sector, see Task 2) is anticipated. The aggregated result of changing to a 2-shifts-model and the lower electricity price is depicted in **Figure 6-15**. The point of LLCC remains at option 7, although at roughly 13.350 Euro lower total LCC.

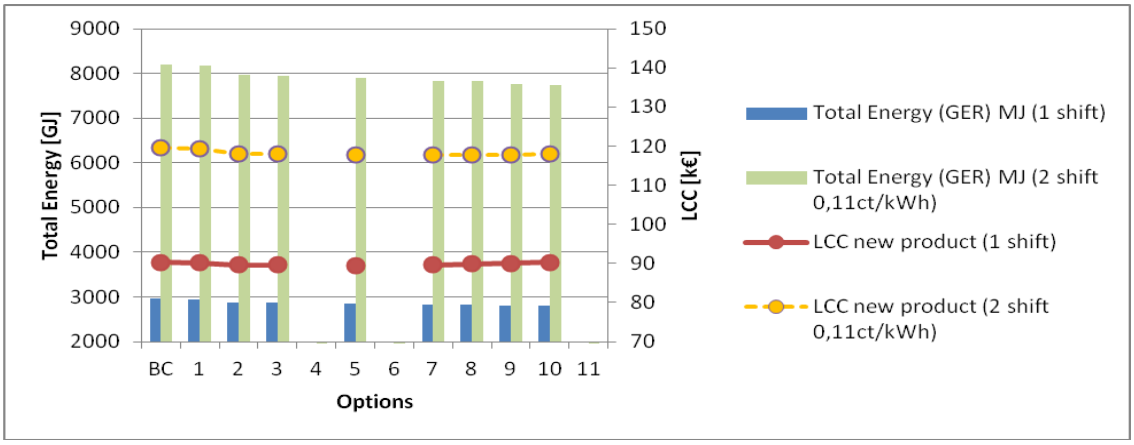


Figure 6-15: Base Case 6 – Sensitivity analysis – shift model change and electricity price change

The changed electricity prices do not have an impact on the overall trends and conclusions.

6.4.3 Lifetime

The lifetime of machine tools is highly uncertain. Despite the survey data and experts' estimations presented in task 2 it must be noted that machinery lifetime is not a constant figure, but subject to economic impacts, introduction of disruptive technologies (and related replacement of conventional ones), and the huge refurbishment and reuse business including exports outside of the EU-27. Furthermore, the expected lifetime differs for different types of machine tools.

For small-stationary wood working tools (BC5) an average lifetime of 20 years has been stated in Task 2, which is likely to hold true for machinery used stationary in workshops, etc. However, machinery used at changing locations, i.e. at construction sites, is much more subject to mechanical stress and wear and tear, and might be used

only for 10 years or less. Hence, the scenario for the sensitivity analysis is a lifetime of 10 years, instead of 20 years for the saw in Base Case 5 Table saw. Both cases are depicted in **Figure 6-16Fehler! Verweisquelle konnte nicht gefunden werden.**. As expected, the Total Energy consumption and LCC per unit go down[28], if used only for 10 years, but trends remain the same:

- The additional costs for more efficient motors do not payback over the anticipated lifetime (option 2)
- The incremental reduction of Total Energy consumption could be achieved by material changes (option 1; however, note that one disadvantage is that this would mean a higher weight)

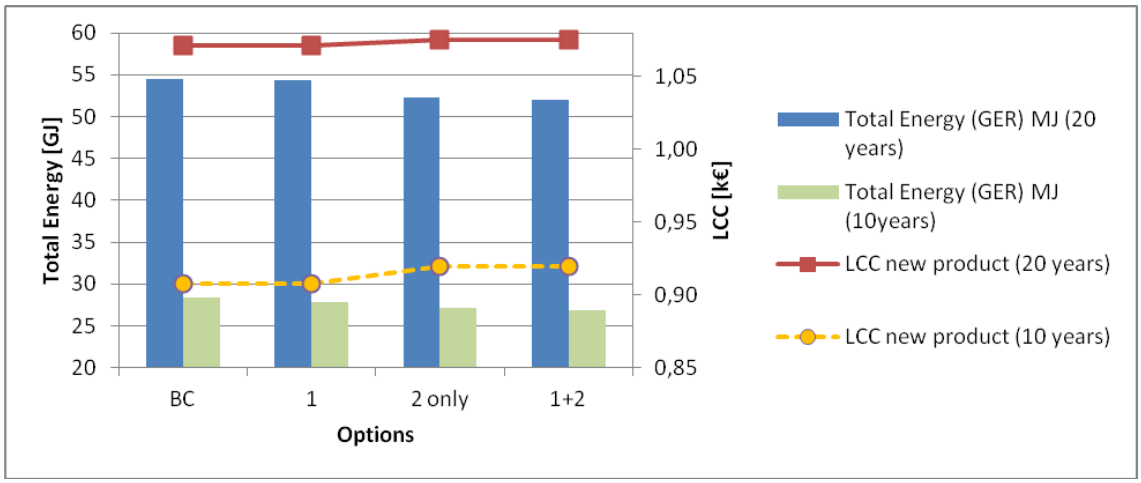


Figure 6-16: Base Case 5 – Sensitivity analysis – shorter lifetime

6.4.4 Use patterns

There is no comprehensive data available on use patterns of machine tools. Although some machine tools manufacturers, via remote maintenance, are aware of the usage of the machines they sell, there is no overview accessible for the machine tools usage at large.

[28] But notice, that with half the lifetime actually 2 machine tools will be required where before only one is needed to achieve the same output. This aspect is not taken into account in the above calculation.

As there is an indication that for welding equipment the electricity use is over-estimated[29], Base Case 9 is chosen to calculate an alternative scenario, as follows:

- Drastically reduced use time of 15 minutes per day, i.e. on-mode 62,5 h/a, standby 200 h/a, remaining time disconnected, use of gas reduced accordingly

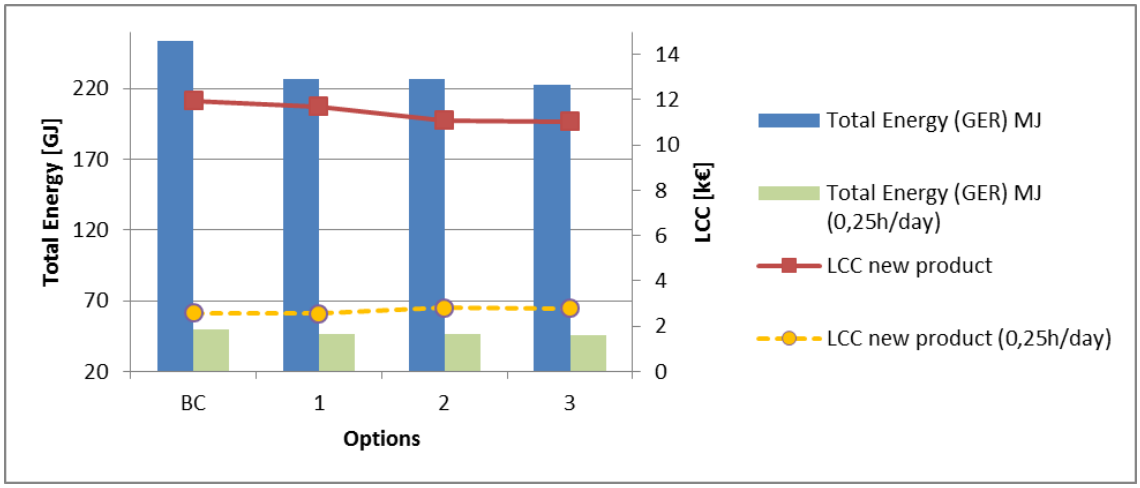


Figure 6-17: Base Case 9 – Sensitivity analysis – use pattern

Both the initial scenario and the reduced use time scenario, are depicted in **Figure 6-17**: Where there was an LCC reduction with the consecutive implementation of improvement options for the baseline scenario, this tendency now is nearly reversed with the alternative scenario. Whereas the increased power source efficiency (option 1) still results in (marginal) LCC savings, all following options result in higher LCC, not a continuous downward trend, which leads to the conclusion that the findings are indeed sensitive to the use pattern assumption in the case of welding equipment.

6.5 Conclusion

The analyses of Least Life Cycle Costs and Best Available Technologies in this task report shows a moderate general savings potential throughout the various Base Cases. The overall results are summarised in **Table 6-18**. The savings potentials at point of Least Life Cycle Costs range from zero to 12,2%. For the arguably most important Base Case 1 group of technologies, representing metal working machine tools, the

[29] In task 4 annual EU-27 electricity costs for welding were calculated at 444 million Euros, whereas US sources (which could not be verified further) state global welding electricity costs of 99 million US-$ only.

savings potential at LLCC is calculated at 4% Total Energy. Similar savings would also be realised with regard to the other environmental indicators.

Most options refer to energy in use, but also material choice and optimising gas consumption for welding have been addressed, and can contribute to environmental savings, although with some limitations.

Table 6-18: Summary improvement potentials per Base Case

	(1) CNC machining centres (and similar)	(2) CNC Laser cutting machine tools	(3) CNC Bending machine tools (and similar)	(4) Non-NC metal working machine tools (and similar)	(5) Table saw (and similar)	(6) Horizontal panel saw (and similar)	(7) Throughfeed edge banding machine (and similar)	(8) CNC machining center (and similar)	(9) Welding equipment
LLCC	-0,6%	- 1,6%	-0,1%	-0,8%	= BC	-0,7%	-0,7%	-0,6%	-7,5%
Total Energy at LLCC	-4,0%	- 4,8%	-1,5%	-2,1%	= BC	-3,5%	-4,7%	-2,8%	-12,2%
Total Energy at LCC break-even	-4,8%	n.a.	-2,2%	n.a.	= BC	-5,0%	-5,5%	-5,0%	n.a.

In general there is no single option with a huge environmental improvement potential. Moderate savings as stated can be realised only with the implementation of several individual options, and what should be called “good machinery design”. As this analysis was meant to address certain archetypal machine tools on a very generic level, it should not be ignored that there might be much larger savings potentials for some machine tools under specific conditions, e.g. for certain applications. This potential can be realised only if the machinery developer has the flexibility to choose from a set of design options those which are most suitable for the target application.



Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 7 Report – Policy and Impact Analysis

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary – Task 7

For the various market segments covered by this study several targeted policy options apply. For less complex machine tools specific requirements can be defined, but for more complex machine tools policy measures need to reflect the multitude of identified improvement options, the systems aspect, and productivity considerations. The analysis of improvement options has shown that a moderate improvement potential can be achieved solely by implementing what can be termed “good design practice”. Therefore, one proposed requirement is the mandatory usage of Good-design-practice Checklists, making it obligatory to assess the feasibility of improvement options. The final judgement regarding whether an option is suitable for a given application would remain with the machinery developer.

Besides such a checklist approach (and closely related to it), power management and information/ declaration requirements can also be defined. Whereas power management addresses the aspect of reducing power consumption in non-productive times without hampering productivity, standardised information/ declaration requirements create a transparency and comparability regarding environmental performance and life cycle costs. In particular the latter is assumed to have an influence on purchase decisions.

Such measures could be introduced either through an ecodesign implementing measure or through one or several Voluntary Agreements/ Self-Regulatory Initiatives (SRIs). No such Voluntary Agreement is currently in place, and some standards are lacking; these issues potentially impede the unambiguous implementation of a potentially feasible Voluntary Agreement.

Minimum environmental performance criteria are assessed as being unfeasible at the machine tools level, due to the broad spectrum of products, missing statistical data on current performance, and application-specific performance. However, such criteria might be feasible to set at the component level, if clearly defined as a performance indicator (e.g. energy efficiency of power transformation). Power management requirements are feasible at both levels, i.e., for the machine tool as such, and at the module / component level, but they would need to be formulated in a rather generic way. Good-design-practice checklists could similarly apply to both machine tools as such, and individual sub-modules. In addition, information and declaration requirements are applicable at the level of both machine tools per se, and at the level of sub-modules.

At a sectoral level, the following policy options might apply:

All machine tools

- Overarching Implementing Measure
    - Generic checklist approach
    - Power management requirements
    - Information/ declaration requirements

Metal working machine tools

- Exemption from the overarching implementing measure, if an SRI can be effectively implemented in the metal working machine tools sector

Wood working machine tools

- Covered by overarching implementing measure
- Product Carbon Footprint (PCF) declaration for light-stationary tools; this option is favoured, because the checklist and power management basically is not useful / applicable for these machine tools

Welding equipment

- Covered by overarching implementing measure
- Specific power consumption requirements

Other machine tools

- Covered by overarching implementing measure, unless any specific SRI is implemented by any sub-sector (e.g. semiconductor equipment)

Related machinery

- For all machinery covered by the machinery directive: Implementing measure tackling selected components with the generic checklist approach

Three policy options, assumed to yield a change in the market from 2014 onwards, are assessed against a Business-as-usual (BAU) scenario regarding their savings potential:

- **LLCC (Least Life Cycle Costs)**: Implementation of a good-design-practice-checklist, accompanied by power management requirements and declaration obligations, leading to machinery improvements which correspond to the point

of Least Life Cycle Costs. This scenario yields a moderate saving estimate of a minimum 31 PJ per year in 2025, or nearly 4% compared to BAU.

- **LCC-BEP (Life Cycle Costs – Break-even Point)**: This can be considered an "optimistic scenario", where good-design-practice yields higher savings. Fiscal incentives furthermore are assumed to pay off for part of the additional machinery costs for implementing even more improvement options than in the LLCC scenario. This option results in savings estimated as slightly higher, of a minimum 38 PJ per year in 2025, compared to BAU.

- **10% VA**: A Voluntary Agreement is implemented hypothetically, setting a target that all machine tools sold in 2014 and thereafter should be, on average, 10% less energy-consuming than in 2010. **PCF (Product Carbon Footprint) label**: For light-stationary machine tools an effective PCF label scenario is calculated.

  A combination of both a Voluntary Agreement with 10% reduction target, and an effective (regardless of whether mandatory or voluntary) PCF label for small units, yields an estimated total saving of 74 PJ per year in 2025, or 9% compared to BAU.

Given the typically long lifetime of the machinery considered (six out of nine Base Cases have an estimated lifetime of 17-20 years), any implemented measure is projected to yield significant overall savings results only over the mid- to long-term.

7 Task 7 – Policy and Impact Analysis

Product groups regulated under the ecodesign directive 2009/125/EC have to meet three criteria (Art. 15):

(a) the product shall represent a **significant volume of sales and trade**, indicatively more than 200 000 units a year (…)

(b) the product shall (…) have a **significant environmental impact** within the Community

(c) the product shall present **significant potential for improvement** in terms of its environmental impact without entailing excessive costs, (…)

Criterion (a) is met for the products falling under the definition of “machine tools” in task 1 as a whole (see Task 2).

Regarding criterion (b), Task 4 provided the relevant calculations: Total environmental impact in terms of total energy consumption is 646 PJ The total energy consumption of all Base Cases is 646 PJ per year, of which 59,9 kWh is electricity. Aggregated Greenhouse Gas emissions total 28 million tonnes CO2-equivalents per year (Base Cases do not fully cover the total stock of machine tools).

Criterion (c) is addressed in Task 6: The analyses performed showed that the combination of options assessed leads to moderate Total Energy savings potentials at the point of Least Life Cycle Costs, which are in the range of 3-5% for the most relevant Base Cases. There are some indications that for individual machine tools significantly higher savings can be realised. It has to be noted that such a savings potential will be realised only slowly, as replacement rates are low, and older equipment will represent a significant share of the stock for the mid-term future (see 7.2).

As no further guidance is provided in the directive regarding the meaning of significant impact and savings potential no definite legalistic conclusion is possible, regarding whether this product group qualifies for policy measures at all. Having said this, the annual energy consumption EU-wide of the product group as a whole is considerable, and this energy use is embedded, in turn, in the products made for many sectors, in many industries, by the machine tools being addressed here. Therefore, the following policy analysis discusses the feasibility of which policy measures should be adopted, how and when.

7.1 Policy Analysis

This Subtask aims at introducing and discussing the range of policy options which could be subject to later regulation on the part of the policy-maker. A critical review of each option takes into account evidence provided by all previous tasks. Aside from possible implementing measures, it should be pointed out that in some part of the machine tool industry energy efficiency measures are already promoted voluntarily.

Policy options for machine tools and related machinery have to consider multiple aspects:

- Nature of measure
- Reference for specific requirements
- Type of implementation
- Product definition
- Sectoral scope

Any policy option has to be assessed against the following criteria:

- Market coverage
- Significant impact in terms of reduced environmental impacts
- Measurable criteria
- Availability of test protocols / standards

7.1.1 Nature of measure

Measures, first of all regardless of the policy tool used, can comprise:

- Minimum environmental performance criteria
- Power management requirements
- Information/ declaration requirements
- Good-design-practice Checklists.

Measures can be combined: A good-design-practice checklist could cover minimum environmental performance criteria and power management requirements. Information / declaration requirements could cover any of the other measures.

Minimum environmental performance criteria as a possible implementation measure impose clear and uniform rules to the manufacturer. Previous tasks demonstrated that generalization and thus making general assumptions and statements is difficult, considering the pronounced heterogeneity of the product scope, as identified in Task 1. However, it should be investigated if certain measures are useful in terms of appropriateness and effectiveness (with regard to the policy option criteria). As reasons for energy inefficiency in machine tools can be manifold, the preceding analysis has revealed that especially highly automated machines can have significant losses during non-productive periods, due to a substantial base load demand. These effects occur where the machine does not have appropriate operating power modes, or where they are not configured appropriately, such as automated stand-by after a defined period. According to the analysis in Tasks 1-6, following **minimum environmental performance criteria** are of priority relevance:

- *Electricity consumption*

For some applications further media are relevant, such as

- *Pressurized air / vacuum consumption*
- *Cooling lubricant consumption*
- *Welding gas consumption*

Table 7-1 lists the consumption of relevant media and utilities. Most machine tools consume only a selection of these. Examples are provided, which utility is relevant for which type of machinery / equipment.

The multitude of machine tools applications and the specifics of these applications, as analysed in the preceding Tasks 1-6, does not permit the definition of general minimum environmental performance criteria for these types of utilities and media consumption.

Measurement procedures for electricity and fluids consumption are described in SEMI S23 Application Guide and Total Equivalent Energy (TEE) CalcII User's Guide as Recommended Practices for Utility Measurement[1].

Table 7-1: Utility and media consumption metrics

Utility or Material	Basic Use Rate Metrics and Units[2]	Remarks
Electricity	Real Power (Watts)	Most relevant parameter for all types of machine tools
Exhaust	Pressure (Pa); Flow (m^3/h); Inlet Temp (°C); Outlet Temp (°C)	Relevant for several types of machine tools, in particular also for wood working machinery, but exhaust system typically is not an integrated part of the machine tool and therefore out of scope; relevant e.g. for semiconductor manufacturing equipment
Vacuum	Pressure (Pa); Flow (m^3/h)	Relevant for numerous machine tools
Dry Air / Nitrogen (N_2)	Pressure (Pa); Flow (m^3/h)	Relevant as pressurized air for numerous machine tools, nitrogen being relevant as shielding gas for thermal processes e.g. in semiconductor manufacturing
Cooling Water	Supply Pressure (kPa); Return Pressure (kPa); Flow (l/h); Inlet Temp (°C); Outlet Temp (°C)	Relevant for e.g. tool cooling, laser source cooling and thermal processes in semiconductor manufacturing
Ultrapure Water (UPW)	Purity Requirements; Inlet Temp (°C); Flow (l/h)	Relevant for some semiconductor manufacturing equipment
Cooling lubricant consumption	Flow (l/h)	Relevant for working of metal and other hard materials
Welding gas consumption	Type; Flow (l/h)	Typically depending on user settings

Electricity consumption requirements need to be defined on a thorough modes definition. ISO 14955-1 (Draft) defines the operating states for metal working machine tools and Table 7-2 provides an abridged version of these in comparison with the modes defined for arc welding equipment in IEC 60974-1 ed.4 (FDIS), and SEMI S23 for semiconductor equipment.

1 referencing SEMI E6-0303 Guide for Semiconductor Equipment Installation, SEMI S23-0708, Guide for Conservation of Energy, Utilities, and Materials Used by Semiconductor Manufacturing Equipment, and Semiconductor Equipment Association of Japan (SEAJ) E-002E, Guideline for Energy Quantification

2 Corresponds with the metrics defined in SEMI S23 for semiconductor manufacturing equipment where these are affected

Table 7-2: Comparison of modes and states of operation

SEMI S23	ISO 14955-1 (draft)		IEC 60974-1 ed.4 (FDIS)
	metal-cutting machine tools	metal-forming machine tools	
process mode - equipment is energized and performing its intended function on target materials	**processing** - mains ON, machine control ON, peripheral units ON, machine processing unit ON and MACHINING, machine motion unit ON and axes MOVING	**cycling** - mains ON, control voltage ON, peripherals ON, all drives ON and axes MOVING	Not defined
idle - equipment is energized and readied for process mode (all systems ready and temperatures controlled) but is not actually performing any active function such as materials movement or processing	**warm up** - mains ON, machine control ON, peripheral units ON, machine processing unit ON but no machining takes place, machine motion unit ON and axes MOVING	**ready for operation** - mains ON, machine control ON, peripherals ON, all drives ON	**idle -** operating state in which the power is switched on and the welding circuit is not energized
	ready for operation - mains ON, machine control ON, peripheral units ON, machine processing unit ON HOLD, machine motion unit ON HOLD (ON HOLD describes the situation where the unit is ON but not operating, i.e. no processing takes place, no movements are carried out)		
sleep - equipment is energized but it is using less energy than in idle mode; initiated by a specific single command signal, either from an equipment actuator, an equipment electronic interface, or a message received through factory control software	**extended standby** - Mains ON, machine control ON, peripheral units ON, machine processing unit OFF, machine motion unit OFF	**extended standby** - mains ON, machine control ON, peripheral units ON, auxiliary drive(s) ON, main drive(s) OFF This state is an intermediate state and the machine tool is remaining in it until enabled for main drives – e.g. until oil temperature is in an admissible range	
	standby - Mains ON, machine control ON, peripheral units OFF, machine processing unit OFF, machine motion unit OFF	**standby** - mains ON, machine control ON, peripheral units ON, all drives OFF	
Not defined	**off** - Mains OFF	**off** - Mains OFF	**standby** - non operating state in which the supply circuit on/off switching device is off

The *provision of an interface to an external or internal energy monitoring and control system* could be a mandatory requirement for CNC machine tools. Such an interface optionally should enable any of the following:

- Stand-alone solutions are designed in such a way that they can be applied for a broad variety of machines; hence, that there is a very low need of specialized machine interfaces.
- Module-based systems are functions usually integrated into the CNC-control software by the control unit manufacturer, in which energy consumption-related PLC commands are addressed.
- As far as external and factory integrated systems are concerned, PROFIenergy is a widely-used protocol in the mechanical engineering industry. Its implementation, however, requires the existence of a communication infrastructure based on the open industrial Ethernet standard PROFINET.

Power management requirements have a high potential for improvement, but quantitative requirements (transition times from one mode to another, or even power consumption thresholds in distinct modes) are difficult to quantify across technologies. Productivity is severely hampered, if too short transition periods from any processing mode to a sleep/ standby mode of the machine tool, or parts thereof are made obligatory. This is because warm-up and bringing back the machine to full operating state delays the processing. However, for a given application scenario (job sequence), it is possible to identify a transition time to low-power modes which do not interfere with the majority of jobs which the machine has to handle, but which still allow significant power savings (see schematic graph below).

Typically, for a given application, a correlation can be established between the time span between individual processing jobs and the number of jobs, which are initiated after the respective time span. Such a correlation allows the identification of a suitable transition time, but essentially requires an analysis per individual use case.

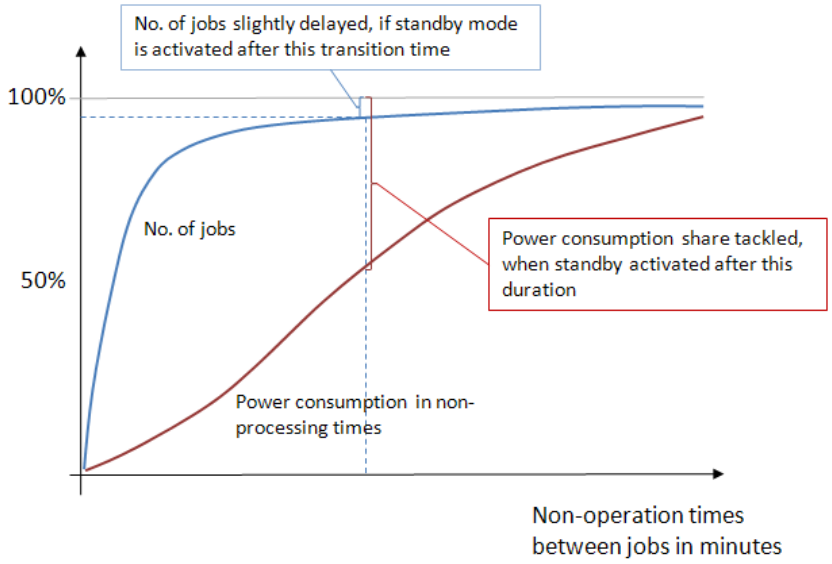


Figure 7-1: Schematic illustration of time between jobs vs. number of jobs

Given the anecdotal evidence provided by a bending machine manufacturer, for bending the vast majority of jobs (>95%) is initiated latest 7 minutes after the preceding job.

Power management requirements need to be based on mode definitions as provided in Table 7-2.

Power management requirements could be formulated as follows:

- *Provision of a manual low power option:* In case the operator wants to interrupt the process on the machine due to a scheduled break or an unexpected event, the machine should be equipped with a stand-by mode which can be triggered manually.
- *Set a transition time to a low-power mode*: At least "x" minutes (e.g. 10 minutes) after the mode idle / ready for operation / warm up is entered and no processing job is initiated, the machine tool should automatically switch into a low-power mode (sleep / extended standby / standby).
    - The operator should be able to change the settings for the transition time to the low power mode
- *Set a minimum reduction target regarding power consumption in low-power compared to idle/ ready for operation:* In low-power mode the machine tool should consume maximum "x" % of the power consumption in idle/ ready for operation (given the evidence provided in Task 5, an appropriate level for "x"

could be 20%). Even if in idle / ready for operation modes certain auxiliary units are powered down, this should count towards the power reduction in low-power mode.

    - The power savings in low-power mode should be stated in %.
    - If power savings on the required level cannot be achieved, a justification must be provided

- Remark (1): Without defining a quantified or at least a relative consumption reduction target, there is the risk that the power management requirement is implemented with only a negligible power consumption difference between modes, thus limiting the potential for greater savings.
- Remark (2): Taking the idle/ ready for operation mode as benchmark bears the risk that this mode is implemented with high power consumption just to achieve the reduction target – therefore power saving features implemented for this mode should already count towards the reduction. Similarly, taking the process mode as a reference would result in the additional effect that power consumption in this mode depends on numerous process parameters and thus could only be determined with difficulty.
- Definition of a low-power mode should follow those provided in Table 7-2:
    - For metal cutting machine tools: Mains ON, machine control ON, peripheral units OFF, machine processing unit OFF, machine motion unit OFF.
    - For metal forming machine tools: Mains ON, machine control ON, peripheral units ON, all drives OFF.
- Remark: This approach requires individual operation state definitions for different types of machine tools, with respect to technological differences

If the machine tools manufacturer does not implement a default transition time to a low-power mode or any other requirements, this must be justified (see also the acceptable justifications provided below, in the paragraph on good-design-practice checklists). Energy management requirements may also be applicable solely for machine tools with an advanced level of automation (also see level of automation classification in Task 1).

Power management at the machine tools level is important, but generic requirements could be set at a broader level, as the power management of a machine tool should

enable not only a “machine-wide” low power mode, but should also enable the powering down of its auxiliary units and parts (e.g. pumps, using variable speed drives), whenever these are not needed, or are run under reduced load. This is a much more complex approach, as it has to reflect the individual configuration and use patterns of machine tools in detail. Therefore, such kind of component-wise power management rather qualifies as a generic design requirement and could be formulated as follows: All [major] power consuming sub-components shall feature the possibility to be switched to a low- or no-power-mode automatically, if no function is provided and if this feature does not entail the following issues: performance losses, conflicts with safety requirements, or if it leads to additional costs which exceed potential energy savings under typical production conditions (to be documented).

It should be noted that compliance with any quantitative requirement (e.g. power consumption in a low-power mode in relation to idle/ ready for operation mode) can only be verified by the machine tools manufacturer once the whole machinery has been constructed and is running for the first time. Given the complexity of machine tools, it is only at this point that reliable measurements are possible. Therefore, where measurement show non-compliant results, a redesign of the machine tool would typically mean excessive costs to implement changes. For custom-made machine tools (which are a major share of the total market) this is even more challenging, as every machine tool has to be subject to such measurements.

Information/ declaration requirements are targeted at

- the machinery purchaser, who should be supported in their purchase decisions
- the machinery operator, to inform and enable him/ her to make use of energy-saving features and other environmental performance settings
- the wider public/ policy-makers/ market surveillance authorities, to review the impact of any policy measure.

For the purchaser, a transparency and comparability of life cycle costs is essential. Therefore a *standardised life cycle costs calculation*, including electricity and media costs, should be provided by the machinery manufacturer, unless the purchaser specifies a life cycle costing scheme of their own. The only standard currently available is *VDMA Einheitsblatt 34160:2006*, for which VDMA also provides a comprehensive suite

of Excel tools for calculations[3]. Although allowing for a very transparent calculation, the consideration of energy consumption in use in various modes requires some additional assumptions, for which VDMA Einheitsblatt 34160:2006 does not provide detailed guidance.

Furthermore, the purchaser should get access to information about the *design features* (design checklist results as outlined above) related to reduction of environmental impacts. This allows for a certain transparency regarding the design measures implemented, and enables the purchaser to specify in detail that certain criteria of the checklist should be met.

The declaration should also include *power (and possibly media) consumption in the various modes* defined above, including a description under which settings consumption was measured[4]. The list of utility and media consumption depicted in Table 7-1 should be provided. Furthermore*, power management default settings* need to be explained in the declaration (the sequence in which the machine tool enters a power saving mode).

For the operator, instructions are required, relating to:

- *how power management settings could be changed*, including information regarding the impact on power and media consumption (information to be provided in the manual and by the CNC system, if applicable)
- *any other instructions*, which enable the operator to operate the machine tool in a manner which reduces environmental impacts

The control panel menu should feature:

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3 Download: http://www.vdma.org/wps/portal/Home/de/VDMAThemen/Management_und_Recht/Management/BW_Download_LCC_Berechnungswerkzeug?WCM_GLOBAL_CONTEXT=/vdma/Home/de/VDMAThemen/Management_und_Recht/Management/BW_Download_LCC_Berechnungswerkzeug

4 The Federal Environmental Agency proposed to require potentially a sensitivity check, or an online tool to calculate energy consumption under specific settings. However, a sensitivity analysis would be even more challenging to provide as this would not only require the definition of one test workpiece / cycle etc. (see 7.1.2), but also alternatives to these and to undertake related measurements. A calculation tool would require the development of parameterized calculation models, i.e. a machinery simulation, which would indeed allow a customized calculation but requires extensive parameter testing for each machine tool individually.

- *power (and media) consumption values* in real time (for the machine tool as a whole) and a historic energy consumption profile (minimum time frame: 24 hours)
- *level of refrigerants* and *status of oils* in the system. in order to identify losses.

The control panel menu could feature:

- *power (and media) consumption values in real time* (at the component / sub-module level) and a historic energy consumption profile,
- *a warning before a low-power mode* is entered automatically.

For market surveillance (under any type of implementation), it is essential that certain data on the environmental performance are provided, which could include:

- power consumption savings compared to a "standard machine tool" (which requires the definition for a comparable standard machine tool, which is problematic, considering the interruptive new technologies and performance levels, which were not achievable with previous machinery designs). The CECIMO SRI proposal (work in progress) is based on this approach.
- power consumption in absolute terms (requires the definition of “typical” use patterns).

Even without setting any performance thresholds, information requirements as stated above could help to close knowledge gaps in terms of the performance of machine tools on the market at large. This could be instrumental for the revision of any policy measure, since it will serve as the basis for setting further requirements reflecting the status of the market and its evolution.

A **screening Life Cycle Assessment** could provide user information in terms of environmental performance throughout the product life cycle. Standards are in place (ISO 14.040), but still lack detail to make them applicable unambiguously. Requiring any LCA data for complex investment goods, such as machine tools, solely on the basis of the ISO standards or similar could risk incentivising the misuse of the concept of LCA In January 2012, product category rules (PCR) were published for CPC Subclass 44214: Machines-tools for drilling, boring or milling metal v1.0, based on CTME’s prac-

tical experience with LCAs for machine tools[5]. Although this PCR is a huge step forward towards unambiguous guidance, regarding how LCA data should be calculated (via its definition of background data for upstream processes, system boundaries and cut-off criteria, functional unit, etc), it still lacks a standardisation of the use scenarios, which hampers a fair comparison of machine tools (see discussion on test workpieces below, which would be required as well as a reference unit for LCA calculations). Consequently, the above-referenced PCR does not qualify as a mandatory requirement; however, it could be a component in voluntary activities to enhance information flow. Only for rather simple equipment is such an LCA approach potentially feasible, via a policy framework. For light-stationary tools/ power tools an EPTA working group drafted a procedure for measuring Product Carbon Footprint of power tools. EPTA is currently evaluating this procedure with several of their members during 2012 and will compare results later in the year[6]. The methodology is not published yet, and was not accessible to Fraunhofer, but given the rather narrow field of equipment covered, it might be specific enough to allow for credible publication of comparable Product Carbon Footprint data.

Good-design-practice checklists are a somewhat “soft” requirement as these outline numerous design aspects, which then have to be checked by the designer regarding suitability for implementation. Designers could be required to state for each design measure how it was addressed, and where it was not addressed, to provide a full explanatory justification. Examples of acceptable justifications are:

- Measure is technologically not applicable for a given machine tool (e.g. requirement for an improved vacuum system where there is none)
- Measure would not result in relevant savings, due to certain specifics of an application (e.g. high-efficiency motors mounted on a movable axis result in increased moved masses, thus higher power consumption), calculation to be provided
- Measure is in conflict with another measure with a higher impact (e.g. implementation of an electrical drive which could simultaneously be replaced by a variable speed drive pump for a hydraulic system, or implementation of an en-

5 Product Category Rules (PCR) for the assessment of the life-cycle environmental performance of UN CPC 44214 "Machine-tools for drilling, boring or milling metal”, http://www.environdec.com/en/Product-Category-Rules/Detail/?Pcr=7945

6 See also: EPTA: Flyer on Product Carbon Footprint, January 12, 2011, http://www.epta.eu/upload/2011-02-01_PCF-FLYER_701.pdf

ergy-efficient axis-drive which simultaneously could be replaced by a counter-weight balance), correlation to be explained

- Measure results in significant negative impacts on productivity and/or yield (e.g. a stable machinery temperature is essential for high precision micro-machining equipment, hence shut-down in production breaks is not tolerable)
- Measure is in conflict with safety requirements
- Measure would not result in a return on investment (ROI) within an acceptable timeline (acceptable timeline to be defined), total-costs-of-ownership calculation to be provided

Existing good-design-practice checklists and similar, which could constitute a basis for any measures, are:

- *Measures listed in Task 4* (basically for all types of machinery covered by the scope of the study, but as yet not formulated as design checklist, covering life cycle aspects beyond energy in use)
- *Informative Annex of ISO 14955-1* (metal working machine tools only, energy in use only)
- *IHOBE: Guías sectoriales de ecodiseño – Máquina herramienta*, February 2010 (metal working machine tools only, description of individual measures, partly company specific solutions, covering life cycle aspects beyond energy in use, in Spanish only)
- *EN 14717:2005: Welding and allied processes — Environmental check list* (for welding equipment only, very generic guidance only: the focus is on proper operation of the equipment, but less on equipment design as such, additional aspects beyond energy consumption covered)
- *SEMI S23-0311: Guide for Conservation of Energy, Utilities and Materials used by Semiconductor Manufacturing Equipment* (for semiconductor manufacturing equipment only)

Regarding SEMI S23, it should be noted that some semiconductor manufacturing equipment is basically covered by the scope of the study as “machine tools” and overlaps also with the metal working machine tools (e.g. wafer saws, laser drilling etc.), but other types of semiconductor manufacturing equipment are covered only as “related

machinery", i.e., at the modular level (e.g. lithography equipment, plasma etching, sputtering).

The good-design-practise checklist approach principally incorporates the peculiarities of the product scope. It considers uncertainties in product properties and provides the greatest possible freedom in implementing individual efficiency measures for the manufacturer. This approach is supported by CECIMO's SRI concept in which it is stated that "the complexity of the individual machine tool types within the given product group is challenging and not obviously definable. Talking about machine tools means describing a product group with about 400 different types/ machines categories and defining a product group with about 2.000 different machine tools." Hence, the "comparability between machine tools is limited" and "a functional unit of a machine tool cannot be defined unambiguously". [7] This appraisal corresponds with evidence provided in Tasks 1-6.To fulfil basic assessment criteria as stated above, and to achieve a wide market coverage, the good-design-practice checklist should either be:

- Generic for all of the ENTR Lot 5 scope, i.e., including all related machinery and components; or
- Specific for technologically-similar machine tools (which requires a distinction of cutting, forming and joining machinery types, differentiating metal, wood and other material processing).

The market coverage can additionally be extended if the checklist is to be used when retrofitting machine tools. The checklist can be combined with standardised process media measurement methods, since a fundamental analysis of the current state of the energy profile of the product is required initially. The checklist and measurement methods should give information about the determination of system boundaries, the definition of existing operating states, functions, modules, and typical use profiles from the customers. It should be clarified at the beginning, if such measurement should allow the comparability of different machine tools (e.g. for a certain machining tasks) or individually (existing methods will be introduced when referencing specific requirements, later in this task).

Thus, besides a basic selection of technological and organizational improvement options, the checklist as a whole needs to subsume further tools and methods, to: (i) ana-

7 CECIMO: *Concept Description for CECIMO's Self-Regulatory Initiative (SRI) for the Sector Specific Implementation of the Directive 2005/32/EC (EuP Directive)*, 2009.

lyze and decipher the current state; (ii) identify energy intensive functions and modules; (iii) develop an overall concept; (iv) assess, select, and implement design features; and (v) monitor and record the process.

7.1.2 Reference for specific requirements

Any specific requirement needs a well-defined reference basis:

- consumption per machine tool/ module (absolute values)
- consumption per machine tool/ module compared to a standard configuration (relative improvement)
- consumption per work piece/ output/ cycle (productivity, efficiency)

A requirement regarding consumption per workpiece/ output/ cycle requires the definition of either

- a test workpiece; or
- a standard test cycle.

Both approaches do not necessarily approximate the real application of the machine tool, and thus they might result - in individual cases - in non-optimal machinery use, for specific use patterns/ cycles.

The **test workpiece** approach allows the definition of an exact product reference for benchmarking, taking into account also productivity. However, this approach is limited, for two reasons:

- *Test workpieces are not (yet) available for all technologies.* There is no all-inclusive “test workpiece” suitable for all types of machine tools. Instead, technology-specific standard work pieces need to be defined, reflecting the processing type (milling, cutting, forming etc.), machine type (number of axes), quality (surface roughness), and certain general performance criteria, if needed (micro machining, high speed processing etc.). Such test workpieces have been defined e.g. by the German NC-Gesellschaft e.V. (NCG) to allow for a performance assessment of various metal working machine tools, used for acceptance testing (see Table 7-3). Typically, test workpieces are also defined by customers to reflect their individual preferences. Standardized (by the NCG or others) test workpieces are not available for all types of machine tools, not

even for the complete range of metal working machine tools[8]. Hence, some form of test workpiece standardisation would be required before this could be made the sole reference point for (energy) consumption.

Table 7-3: List of selected test workpieces

Test workpiece	Reference
Test workpiece for 5-axis micro-milling machines	NCG-2007, Mikroprüfwerkstück für 5-Achsen-Mikrofräsmaschinen (under development), NC-Gesellschaft e.V.
Test workpiece for water-jet cutting	NCG-2006, Prüfwerkstück für Wasserstrahlschneiden, NC-Gesellschaft e.V.
Test workpiece for five-axis simultaneous milling machining	NCG-2005, Prüfwerkstück für die 5-Achs-Simultan-Fräsbearbeitung, NC-Gesellschaft e.V.
Test workpiece for High Speed Cutting	NCG-2004, Prüfrichtlinien und Prüfwerkstücke für hochdynamische Bearbeitungen (HSC), NC-Gesellschaft e.V.

- *Common test workpieces do not reflect the specifics of a distinct application*. By nature, test workpieces are rather intended to test the limits of a machine tool, not to represent a typical, average processing task. Consequently, power consumption values measured for a test workpiece will deviate from the power consumption for the later real application. However, test workpieces should be suitable to benchmark power consumption of different machine tools (which are intended for the same purpose).

- *Definition of suitable common test workpieces affects Intellectual Property of machinery manufacturers.* Knowledge about the distinct operation of machines and typical production tasks is considered valuable know-how and a competitive advantage by (some) machinery manufacturers. Willingness to share such information with the public is low. It might be acceptable, if an intermediate (such as an Independent Inspector under a Voluntary Agreement) were given access to the test workpiece design and was allowed to verify measurements. However, even under such conditions, each manufacturer would develop individual company sample parts, which would then only allow the calculation of (and disclosure of) a kind of "fleet consumption", or "fleet efficiency" (and related year-to-year changes), and would not allow the comparison of machine tools from different manufacturers. Consequently such an approach could work under a Voluntary Agreement, but has limitations with regard to user informa-

[8] JMTBA points out in a stakeholder comment, that "even if each manufacturer in each country collects the machining data by different workpieces, the consumer and industry can be expected to be confused."

tion. Basically, the approach of *individual test workpieces* could work as follows:

- Every machine manufacturer defines a set of sample parts which represent his market, considering materials, geometries (both of the processed input material and the product output), and quality requirements.
- Such a set of sample parts would have to remain unchanged for a longer period of time, to allow for year-to-year comparisons.
- Energy and consumption of other media for processing these sample parts (potentially including also non-operational times, see below) is measured and calculated as efficiency indicator(s) for each type of machine tool in the individual portfolio of a manufacturer.
- Based on efficiencies of each type of machine tool, a use scenario and annual sales figures for an annual "fleet" consumption and efficiency is calculated.

- *Common test workpieces would always disadvantage some manufacturers, because their machines are optimised for another market segment.* In this case manufacturers would then be faced with the choice of either optimizing their machines for the common test workpieces or for their customers (and thus implementing options which lead to real energy savings in production)
- *Quantifying the environmental impacts on a per test workpiece basis does not include the aspect of down time, and other non-operational period of time*. As the analyses in Tasks 4-6 show, the non-productive times are among the most relevant aspects in terms of environmental impacts, and also represent a significant potential for improvement. These aspects can be addressed only if a standard test cycle is referenced.

A **standard test cycle** for metal working machine tools is currently under development by the German NC-Gesellschaft e.V. (NCG)[9]. The first discussion draft of this test cycle is defined as a 15 minutes cycle, 50% thereof tools change time, 25% machining time and the remaining 25% standby time. The tools change cycle is defined in several steps, starting from a status where the main spindle(s), pumps and chip conveyor are

[9] Kaufeld, M.: Energieeffizienz – eine Kennziffer á la NCG für den Anwender, nc transfer, no. 49, September 2011

switched off, covers tool placement in the magazine, rotation of the magazine, tool fitting, movement of all axes back to the working space, cooling lubrication system and chip conveyer activated. This cycle is repeated for 7,5 minutes. The machining time is represented by simultaneous oscillation and rotation of all axes for 3,75 minutes, followed by 3,75 minutes all drives switched off or in stand-by respectively. Based on this cycle a technology independent energy efficiency indicator $EE_{NCG,}$ including electricity and compressed air consumption, is proposed with correction factors for travelling distances of X-, Y-, Z-axes, rotation angles, pressure of the cooling lubricant system, maximum rotational speed, movement speed:

EE_{NCG} [1/(kW/h · m³/h)] = (n · 4) / (E_{electr} · Q_{compr_air})

Such an approach allows the measurement of more realistic power (and compressed air) consumption, although there will be operation scenarios, where much less frequent tool changes are required, or where typically there are much longer standby times.

This test cycle is applicable for machining centres (intended for metal working, but a similar cycle with minor modifications seems to be applicable for woodworking machining centres as well). Similar test cycles are not yet defined for other machine tools and related machinery, such as presses, saws, welding equipment etc.

An alternative approach to **quantify consumption per output** is based on the amount of material processed. This approach is applied for example for plastics injection moulding (see EUROMAP 60, referenced in Task 1), but is not suitable for other than primary shaping processes. Although a machine which is able to remove more material with the same amount of energy is more efficient than another which consumes the same energy, but at a lower material removal rate, this approach is clearly hampered when considering other technical parameters, in addition. Taking the amount of material removed as a basis to assess cutting machine tools would incentivise machine tools with a high removal rate at low accuracy. For bending machine tools, a suitable reference is completely missing. For welding, a typical process/ equipment parameter is the length of the welding seam produced in a given time. However, this parameter depends on numerous other characteristics, such as:

- Welded material(s)
- Weld wire material
- Material thickness
- Welding seam geometrics.

7.1.3 Type of implementation

Any requirements could be implemented through various means:

- Implementing measure
- Voluntary Agreement / Self-Regulatory Initiative
- Energy Efficiency Labelling
- Fiscal instruments.

An **Implementing Measure** actually could be based on the same standards as a Voluntary Agreement, i.e. SEMI S23 for semiconductor equipment or ISO 14955-1 for metalworking machine tools. According to the analysis above, an implementing measure could include:

- Mandatory requirements to apply certain standards for machinery design, or to apply similar design checklists for types of machine tools for which suitable standards are not available (to be developed, provided as an annex to the implementing measure)
- Mandatory power management requirements (as outlined above)
- Mandatory declaration requirements (as outlined above)

Taking the machinery directive as a blueprint for an ecodesign implementing measure could result in an approach, which references the several standards to be applied.

Certain types of machine tools could be exempted, if a Voluntary Agreement is in place for this sector. Alternatively, the only manufacturers exempted from the Implementing Measure might be those which have previously signed a Voluntary Agreement endorsed by the European Commission.

A **Voluntary Agreement** or Self-Regulatory Initiative is under development for the metal working machine tools sector only (CECIMO SRI). For semiconductor equipment, a standard has been developed (SEMI 23), which could serve as the basis for a Voluntary Agreement, in addition. The Annex (Section 7.3) to this Task 7 report lists an abridged extract of criteria which a Voluntary Agreement should meet, in order to be acceptable as an alternative to an implementing measure.

The operational framework of the CECIMO SRI has not yet been developed in detail. A draft of ISO 14955-1, which will define the basic approach for a self-assessment of a machine tool, is available, but besides the initial position papers and later presentations by CECIMO no draft SRI document is available as yet. As it stands today, the SRI is characterised as follows:

- No quantifiable minimum environmental performance criteria are defined
- Good-design-practice Checklist as an informative Annex of ISO 14955-1 (draft)
- Power management requirements covered through the checklist approach
- Information/ declaration requirements are not yet defined, but mandatory publication of the checklists could be a way forward
- Benchmarking with a “standard” machine tool is intended, but the standard machine tool is to be defined by the manufacturer, which is extremely difficult to achieve, unambiguously.

Table 7-4: Assessment of the CECIMO SRI for metal working machine tools

Criteria	CECIMO SRI
Market coverage	• High coverage to be expected, but no signatories confirmed yet; no proposal yet how to cover imported machine tools by non-CECIMO member countries
Significant impact in terms of reduced environmental impacts	• Checklist approach deemed appropriate to realise maximum impact, leaving the machinery developer with high flexibility regarding design decisions • Focus on energy consumption in use phase only
Measurable criteria	• Criteria partly quantifiable (power consumption in various modes), but most are generic criteria
Availability of test protocols / standards	• ISO 14955-1

The "Blue Competence" initiative was recently extended to the European level for metal working machine tools, and is now operated by CECIMO at EU level. At the German level, as initiated by VDMA, this initiative covers many more sectors than purely metal working machine tools, namely also[10]:

- Power transmission
- Lifts and escalators

10 www.bluecompetence.net

- Foundry machines
- Metallurgical Plants and Rolling Mills
- Intralogistics
- Precision tools
- Robotics and automation
- Textile machinery
- Thermo process technology
- Fluid power
- Plastics and rubber machinery.

With this broad scope, several sectors are covered, which comprise also “related machinery”. Machine tools manufacturers joining the Blue Competence initiative “commit to promote sustainable product development and production process design by implementing actions in the following fields: energy, raw materials, emissions, waste and recycling managements, clean production and life cycle cost. The *Blue Competence Machine Tools* initiative is a voluntary initiative which is open to the participation of companies from across Europe. Companies which show convergence with the sustainability principles agreed upon in the Blue Competence charter can apply to become partners of the Blue Competence initiative.”[11] Further details are provided in the press release[12]:

Under the heading “manufacturing in Europe” the nature of companies invited to join the Blue Competence Initiative is explained: *“Only manufacturing companies producing machines or subsystems for working of metal and related materials who carry out at least two of the following three activities "design", "production and assembly" or "sale" in Europe can become a partner of Blue Competence Machine Tools.”* This restriction to European manufacturers might be in conflict with the fact that the ErP directive addresses all products brought on the market in the EU-27, regardless of whether they are manufactured in the European Union or are imported.

11 Invitation to the press conferences on February 17 and 29, 2012

12 CECIMO: The European Machine Tool Industry drives sustainability into the heart of manufacturing under the Blue Competence Initiative, press release, 17 February 2012, Brussels

Requirements to be fulfilled address two levels: the company level, and the product level. Regarding the product level, a criteria catalogue is provided as follows:

"2. Substantive technical preconditions

A Reduction in moving masses

B Use of energy-efficient components and subsystems

C Support for the operator in optimising energy consumption (e.g. monitoring)

D Provision for recovering/re-using energy and/or waste heat

E Avoidance/shortening of start-up and warm-up phases, or energy-saving stand-by concepts based on appropriate design measures or control system features

F Monitoring to detect leaks and losses of gas and fluids and consumables

G The product meets other criteria with an impact on sustainability (please indicate which criteria)

At least three of the technical preconditions shall be met, and none of the technical preconditions shall be infringed by products manufactured by any company that advertises using the Blue Competence trademark. Appropriate documentation shall be drawn up and kept safe in the company concerned, enabling it to be viewed as needed."

This criteria catalogue is an abridged version of a Best-practice-design-Checklist and is thus compatible with the checklist approach outlined above. *"The Blue Competence Machine Tools initiative is based on a self-declaration principle. Partner companies choose which preconditions are fulfilled according to the list of possibilities given in the contract."* With respect to monitoring, the press release states: *"The Blue Competence Machine Tools trademark will not be developed into a product certification (even if a standard would exist). There are also no audits foreseen in this certification context. However, this decision could be reviewed over time."*

The Blue Competence initiative clearly has an impact on the machinery sector, regarding the communication of environmental performance, and features some elements which are essential for a Voluntary Agreement. However, Blue Competence still lacks some components and defined targets to make it a valid alternative to an implementing measure, as explained below.

For example, **Energy efficiency labelling** of machine tools could be developed under the energy efficiency labelling directive, which, since its last revision, covers the same scope as the ErP directive.

Energy efficiency labelling requires the definition of energy efficiency classes and an energy efficiency indicator. Such an indicator has been proposed by the NC-Gesellschaft (see standard test cycle above), which by now is the most advanced approach so far.

As the draft energy efficiency indicator was published only in September 2011, no statistical market data for related indicator results is available, nor does this study provide a statistical survey of the power consumption of a larger number of individual machine tools. Such kind of data is not currently available.

Consequently, the development of an energy efficiency label for machine tools would require the following activities:

(1) Defining an energy efficiency indicator and establishing a testing and calculation method (e.g., based on the indicator under development by the NC-Gesellschaft)

(2) Obtaining statistical data on machine tools performance

(3) Defining suitable classes for the energy efficiency label.

Once step 1 is completed, step 2 could be supported by a mandatory requirement to test every machine tool according to the test cycle defined in step 1, and to disclose related data. Hence, the possible introduction of an energy efficiency label could then be considered in a later stage.

Several stakeholders suggested or at least touched on the possibility of an energy efficiency label for various types of machinery in the past: NC-Gesellschaft e.V., Assembléon[13] (for pick-and-place machines), the project partners of MAXIME[14]. (However, the idea of an energy efficiency label was dismissed in the course of the project), by a

[13] S. Van Gastel: The Environmental Impact of Pick-and-place Machines, SMT, PENN Well, March/April 2009

[14] Industry partners: Alfing Sondermaschinen, Bosch Rexroth, VW, BMW, Daimler, Heller, Siemens, MAG Powertrain, Audi, Studer, Grob

research team[15] at TU Braunschweig, Germany, and the Austrian project "Development of criteria to communicate the energy efficiency of plastics processing machines", which defines an energy efficiency indicator based on the specific energy consumption per kg of polymer processed.

The findings of Task 3 indicate that there is a (moderate) interest in transparent, comparable data regarding energy consumption of machine tools, but there is no clear indication, that an energy efficiency label could provide the required information. Absolute power consumption figures, preferably adapted to individual production patterns, seem to be much more useful information for machinery purchasers, in particular if linked to cost calculations. In a stakeholder comment CECIMO points out the following additional shortcomings of an energy efficiency label for machine tools:

- it is not supported by an ISO standard for measures
- it makes comparisons between machines with different technical characteristics
- it does not take into account specific customization and requirements to satisfy the end users' needs
- it can create confusion and misuse for non-technical stakeholders
- taking into account the customization of the products which leads to meeting the specific requirements given by the end user, labelling is not a suitable tool and does not meet the need of the customer.

For light-stationary tools, an approach for Product Carbon Footprint (PCF) calculations for handheld power tools is under development by EPTA (the European Power Tool Association). Note that handheld power tools is a product segment explicitly ***excluded*** from the scope of this study; however, light-stationary tools (within this study) have a similar level of complexity, and the association working on the PCF methodology is common to both sectors.) In addition, a PCF class label might be feasible, particularly as long as the main energy consuming component (single-phase motors) are not subject to Energy Efficiency classifications. Motor efficiency labelling would be a possible alternative, and it would cover most of the environmental factors of relevancy identified in Tasks 4 and 6 for this type of equipment. If it could be feasibly established, such a mandatory PCF class label would be the first of its kind globally. Although Task 6 iden-

[15] Herrmann, C. et al.: Energy Labels for Production Machines - An Approach to Facilitate Energy Efficiency in Production Systems, Proceedings of the 40th CIRP International Seminar on Manufacturing Systems, May 30 - June 1, 2007, Liverpool, UK

tified a significant improvement potential, the actual impact of such a label is difficult to forecast. An interest in such labelling among the users of light-stationary tools cannot be confirmed based on the findings of Task 3; this is because, basically, large enterprises were the focus of this investigation.

Fiscal instruments are of particular interest, as the analysis in Tasks 3-6 indicates, i.e., that in the machine tools sectors there are some technical measures which generate a return on investment (ROI). However, this ROI occurs over a timeframe that is too long to make the investment attractive for many industry clients. Furthermore, the long use lifetime of machine tools results in a high number of inefficient machine tools (particularly in the non-NC segment) being in operation also for the midterm future[16]. A rapid replacement of these non-state-of-the-art machine tools would result in significant energy savings. Such a scrapping bonus for automobiles, introduced in the economic crisis back in 2008 in several countries yielded significant environmental improvements[17] [18]. A scrapping bonus for industrial machinery was discussed in Germany already in 2010, but was not supported by VDMA at that time[19]. One of the arguments against such a bonus is the risk that manufacturers are incentivised to install overcapacities in times of a generally weak economy.

In order to stimulate the development and implementation of energy-efficient machinery in manufacturing industry sectors, financial measures could be initiated and installed. Financial incentives could focus on two different areas or industry sectors, and may work directly by monetary contribution or indirectly by fiscal bonus:

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16 CECIMO comments that “if a machine can be in use for a long time and taking into account the upgrading tendencies, the environmental footprint of such machines should be considered more energy efficient than any other product which after a short use period of time needs to be replaced.” Although Fraunhofer acknowledges the fact, that long machinery lifetime as such is an important environmental feature, in particular as upgrading is common in industry, but it is rather not possible to achieve an efficiency level comparable to new state-of-the-art machinery solely through retrofitting measures. Given the low impact of machinery manufacturing compared to its use phase in most cases (see task 4), the use phase impacts are most relevant and measures to increase use phase efficiency should have preference, but a thorough analysis of this aspect has not been undertaken yet.

17 Höpfner, U.: Abwrackprämie und Umwelt – eine erste Bilanz, ifeu Institut Heidelberg, 2009

18 Hommel AG offered such a business model back in 2009, when they reduced sales prices of new machine tools by 5-10%, if used machine tools are given to Hommel for scrapping, see http://www.industrieanzeiger.de/home/-/article/12503/26150836/Hommel-converts-%e2%80%9cscrap-iron%e2%80%9d-into-cash/art_co_INSTANCE_0000/maximized/industrieanzeigermarktaktuell

19 See interview with H. Hesse (VDMA): http://www.produktion.de/konjunktur/maschinenbau-will-keine-abwrackpraemie/

(1) The first mechanism is the **financial support of manufacturing industry actors to invest in new, energy-efficient machinery and equipment**. This can reduce the higher investment costs for energy-efficient equipment, or motivate the replacement of existing machinery with inherently higher energy consumption. This measure would have a short time effect in reduction of energy use in industry. Besides incentivising the investment in new, efficient machine tools, this measure could also address upgrading and retrofitting measures (such as installing sensor systems for monitoring fluid systems, energy consumption, and condition monitoring), which increase verifiably the energy efficiency of already existing machine tools. In addition, or alternatively, financial support could be provided for training courses to enhance the energy-efficient operation and maintenance of machine tools. This financial support could also include investment in equipment to improve non-energy related impacts, such as hydraulic oil purifiers.

(2) The second financial support system is directed towards the machine tool industry and to producers of related machinery and equipment, and could **enhance the research and development for energy-efficient machines**. A stimulation instrument could be envisaged as an industry-directed funding of pre-competitive research, accompanying the development of energy-efficient solutions, new technical options, design guidelines or the implementation of best practice in designing products, or using products. This could accelerate ecological developments and generate sustainable concepts and solutions. In the sense of a European initiative, this might be a special action with mixed programme and funding schemes. It could consist on the one hand of European funding (e.g. under Horizon 2020, Intelligent Energy Europe etc.) in order to treat transnational questions, and on the other hand from national funding, which could address purposeful thematically-focused topics. The research measures and topics should be well co-ordinated in Europe in order to gain the active involvement of the main players, to utilise their expertise, and to ensure complementary activities. Such a tightly led and demarcated initiative could accelerate new or ongoing industrial developments, and could speed up industry-wide implementation of best practice, and up-to-date knowledge dissemination.

The BAT analysis undertaken in Task 6 is outlined in **Table 7-5**, including the calculated additional investment at the point of LCC break-even. (Note that an "LCC break-even point" in this context does not really mean a costs break-even from the usual company perspective. This is because the Table 7-5 results are instead calculated over

the *whole anticipated product lifetime*, i.e., it is different from typical commercial return-on-investment [ROI] considerations.). This gives an indication about the financial incentives which might be hypothetically considered, in order to make it attractive for purchasers to choose a more efficient machine tool instead of a less efficient one[20]. It is evident that rather small increases of up to 2% in machinery investment would pay for the additional machinery costs. On the other hand, such a bonus of 2% is much less than the difference between the typical resale value of a used machine tool and the price of a new model. This might hamper the effectiveness of a scrapping bonus in this range.

Table 7-5: Additional machinery investment at LCC break-even per Base Case

	(1) CNC machining centres (and similar)	(2) CNC Laser cutting …	(3) CNC Bending machine tools (and similar)	(4) Non-NC metal working …	(5) Table saw (and similar)	(6) Horizontal panel saw (and similar)	(7) Throughfeed edge banding machine (and similar)	(8) CNC machining centre (and similar)	(9) Welding equipment
Base Case machinery purchase price (kEuro)	480		100			60	60	300	
Additional investment at LCC break-even (kEuro)	7,8		0,09			1	0,9	4,5	
Total Energy at LCC break-even	-4,8%		-2,2%			-5,0%	-5,5%	-5,0%	

The granting of fiscal incentives needs to be based on verifiable criteria, such as cross-checking against the previously-mentioned good-design-practice checklist, with a mandatory minimum number of the mentioned aspects to be implemented, in order to qualify.

7.1.4 Product definition

Any measure might be applied on two levels:

- Machine tool
- (functional or physical) module/ component

[20] Given all other machinery parameters and productivity are exactly the same

Measures defined on the machine tools level would cover the whole unit as such. Given the analysis in this study the definition of “machine tools” as provided in task 1 applies. It is possible that measures could be defined for distinct sub-groups under the overarching “machine tools” definition, e.g. metalworking machine tools, or woodworking machine tools.

On the module/ component level, products beyond “machine tools" could be covered, namely “related machinery”, according to the definition in Task 1.

Minimum environmental performance criteria on the component/ module level could be defined if an environmental performance could be correlated with a distinct technical performance. Hence, sub-assemblies/ components could be regulated. However, “functional modules”, or complex physical modules, do not qualify for setting such minimum performance criteria. Suitable minimum environmental performance criteria are:

- Energy efficiency of arc welding power sources[21][22] (at the rated output at 100 % duty cycle)
    - 70% for single phase power sources and AC welding power source.
    - 75% for three phase power sources

  Such a requirement bans the less efficient and more bulky transformer type power supplies (stage 1).

  As a mid-term target (within the following 4 years), higher efficiencies would be widely achievable (and are justified by the findings of Task 6, stage 2), which would allow the requirements to be tightened (still below the point of LLCC)[23]:

[21] Such efficiency level is only achievable by arc welding power source. Resistance welding power sources are designed by thermal requirement and are not designed for a 100% duty cycle.

[22] The initial proposal in the draft final report was 75% for single phase and 80% for three-phase. This proposal was challenged by EWA with the following comment: “AC arc welding power sources will not achieve the three-phase requirement. The ban of the less efficient and more bulky transformer type power supplies at stage 1 will be achieved with a further allowance of 5% (6% of 2010 market). Change Stage 1 to: 70% for single-phase power sources and AC welding power source; 75% for three phase power sources”

- 75% for single phase power sources and AC welding power source.
- 80% for three phase power sources

As a long-term target (within the next 6 years, stage 3) requirements corresponding to the point of LLCC are feasible[24]:

- 80% for single phase power sources and AC welding power source.
- 85% for three phase power sources

- Idle state power consumption of welding power sources module at cold state
  - 50 W[25] (stage 1), 30 W (stage 2)
- All pump systems designed to operate at 2 working points or more shall be speed controlled

Other minimum environmental performance criteria for the component / module level have not been identified in the course of this study, given the broad system approach followed here.

For functional and physical modules, **sub-chapters of the good-design-practice checklists** are applicable in principle. For all machinery falling under the machinery directive and not being covered by any machine tools specific implementing measure

[23] The initial proposal in the draft final report was 80% for single phase and 85% for three-phase. This proposal was challenged by EWA with the following comment: “AC arc welding power sources will not achieve the three-phase requirement. The ban of the all bulky transformer type power supplies at stage 2 will be achieved with a further allowance of 5% (29% of 2010 market). Change Stage 2 to: 75% for single-phase power sources and AC welding power source. 80% for three-phase power sources”

[24] The initial proposal in the draft final report was 85% for single-phase and 90% for three-phase. This proposal was challenged by EWA with the following comment: “AC arc welding power sources will not achieve the three-phase requirement. The ban of the less efficient inverter type power supplies at stage 3 will be achieved with a further allowance of 5% (80% of 2010 market). This still allows a savings potential larger than 10% as the mean average efficiency is 75% for three-phase power sources. Change Stage to: 80% for single-phase power sources and AC welding power source. 85% for three-phase power sources”

[25] Which takes account of the uncertainty stated in Task 6; 50 W is rather a threshold to ban the least efficient units

or voluntary agreement, the checklist approach can be applied for following components[26]:

- Drive units
- Lubrication system
- Cooling system
- Electric system
- Pneumatic system
- Hydraulic system
- Die cooling / lubrication
- Control unit

As the checklist approach is very generic and does not set quantified targets it is applicable for a rather broad scope.

Table 7-6: Feasibility of measures on machine tools and module level

Nature of measure	Machine tools level	Module / component level
Minimum environmental performance criteria	Not feasible due to • broad spectrum of products, • missing statistical data on current performance • Application specific performance	Feasible, if • clearly defined as a performance indicator (e.g. energy efficiency of power transformation)
Power management requirements	Feasible, if generic, possibly based on relative power consumption	Feasible, if generic
Good-design-practice Checklists	Feasible	Feasible (could be a sub-list of the overarching machine tools related list)
Information / declaration requirements	Feasible	Feasible, but module supplier is required then to provide the information / declaration

[26] List taken from ISO 14955-1 (draft), Annex A and B; component not listed here are “peripheral devices” as this is a “catch-all” category which hardly can be defined unambiguously

7.1.5 Sectoral scope

The discussion above leads to the conclusion, that different approaches are required for the various sub-segments. A distinction has to be made as follows:

- Metal working machine tools
- Wood working machine tools
- Welding equipment
- Other machine tools
- Related machinery.

Table 7-7 summarises a holistic concept, where an overarching implementing measure, similar to the machinery directive, for the scope of machine tools defined in Task 1 integrates segment-specific requirements, and for a broader scope (i.e. scope of the machinery directive) also some checklist components of the machine tools measure apply.

Table 7-7: Policy options on a sectoral level

Sector	Policy options

All machine tools	• Overarching Implementing Measure
	  ○ Generic checklist approach
	  ○ Power management requirements
	  ○ Information / declaration requirements

Metal working machine tools	• Exemption from the overarching implementing measure, if SRI is effective
Wood working machine tools	• Covered by overarching implementing measure • PCF declaration for light-stationary tools, as checklist and power management basically is not useful / applicable for these
Welding equipment	• Covered by overarching implementing measure • Specific power consumption requirements
Other machine tools	• Covered by overarching implementing measure, unless any Voluntary Agreement is implemented by any sub-sector (e.g. semiconductor equipment)
Related machinery	• For all machinery covered by the machinery directive: Implementing measure tackling selected components with the generic checklist approach

Applying the checklist would be done in an internal process, just as with other requirements for CE-marking and under the machinery directive.

It has to be noted, that several standards required to implement this measure are still under development or do not yet exist.

7.1.6 Related machinery

The analysis did not address in detail “related machinery”, given the inevitable specifics of the analysed Base Cases. In the light of the identified suitable measures (rather generic design principles to be considered) it can be stated, that such a design-checklist approach can be applied to numerous other types of machinery, where similar design principle could yield significant savings. An extension of these requirements to “related machinery” requires a thorough definition of the modules addressed in this study. Such an unambiguous definition and in particular a definition of system boundaries (which components/ functionalities are considered to be part of a given module) could not be developed in the course of this study, given the multitude of possible applications. Such a definition is probably best developed via a standardisation process, which would progressively refine the definition of the related design checklists.

Applying the checklist approach only for certain modules of “related machinery”, but not in accordance with the approach for the whole installation, still runs the risk that optimisation would not holistically address the machinery system.

7.1.7 Summary

Table 7-8 summarises the possible requirements for machine tools and related machinery. The scope is related to the definitions provided in Task 1 (1.1.2.2). In the end some exemptions might be needed, but as some major basics are still missing (relevant standards etc.) such exemptions cannot be formulated at this point. In theory the whole stated scope could be covered.

As outlined above, similar improvements could be achieved under Voluntary Agreements (non-existent as yet), which would define ambitious targets.

Besides the requirements listed below, fiscal instruments have been identified as a possible measure to achieve a timely replacement of inefficient machine tools by new ones. However, a detailed concept regarding how to set the right incentives for energy efficient investment goods is still required, but remains to be developed.

Table 7-8: Summary of possible requirements

Requirement	Scope	Evidence for relevance	Comments
Energy Management			
Provision of an interface to an external or internal energy monitoring and control system	CNC machine tools	Monitoring essential for influencing user behaviour (transparency regarding power consumption identified as a gap and as moderate potential for improvement in Task 6) Actual likely impact (behaviour change, and infrastructure adaptation) unknown	Includes also control commands for central systems (e.g. extraction systems in wood working)
Provision of manual stand-by option	All machine tools	Reducing power consumption in non-productive times is of high priority, with a negligible impact on productivity	For small units only off-mode
Transition time to a low-power mode (e.g. 10 min)	CNC machine tools	Reducing power consumption in non-productive times is of high priority, with a negligible impact on productivity (example provided on p. 13)	
Minimum power consumption in low-power compared to idle / ready for operation (maximum 20%)	CNC machine tools	Reducing power consumption in non-productive times is of high priority, negligible impact on productivity, if exemptions are possible	
Good-design-practice checklists			
Tools and methods for	All “machine	Task 5 and 6 findings demonstrate impor-	Only frameworks of

(i) analyzing and decipher the current state **(ii)** Identifying energy intensive functions and modules **(iii)** Developing an overall concept, **(iv)** Assessing, selecting, and implementing **(v)** Monitoring and taking record of the process	tools" (metal working, wood working, welding, other machine tools), module specific checklists could apply also to "related machinery"	tance of implementing several improvement options, but to leave the decision to the machinery developer, which option is useful for a given application	such checklists are now available, design guidance on the module level are partly under consideration (fluids) Exemptions might apply as outlined on p. 18
Information / declaration requirements			
Power (and possibly media) consumption in the various modes	All "machine tools"	Important to allow for a direct comparison of machine tools for an informed purchase decision	Machinery settings (potentially workpiece) to be specified, use scenario will be generic and might not reflect properly the intended use; part of the documentation
Power consumption in absolute terms for a given use scenario			
Standardised life cycle costs calculation	All "machine tools"	Transparency regarding LCC and comparability of LCC (including energy and media) identified as a major barrier in task 3	Further specification of LCC methodology needed
How power management settings could be changed	CNC machine tools	Important to allow an adaptation to specific production conditions	
Any other instructions, which enable the	All "machine	Important for auxiliary consumption (e.g.	No further specifica-

operator to operate the machine tool in a manner, which reduces environmental impacts	tools”	welding gas), and for operation of a machine tool in a larger production environment (e.g. adjustment of a central extraction system for wood working)	tion
Power (and media) consumption values in real time (for the machine tool as a whole)	CNC machine tools	Monitoring essential for influencing user behaviour (transparency regarding power consumption identified as a gap and as moderate potential for improvement in Task 6) Actual likely impact (behaviour change) unknown	Part of the monitoring requirements
power (and media) consumption values in real time (on the component / sub-module level) and a historic energy consumption profile, (optional)	CNC machine tools	Monitoring essential for influencing user behaviour (transparency regarding power consumption identified as a gap and as moderate potential for improvement in task 6) Actual likely impact (behaviour change) unknown	Part of the monitoring requirements
A warning before a low-power mode is entered automatically (optional)	CNC machine tools	Important to avoid productivity constraints	
Power consumption savings compared to a standard machine tool	All “machine tools”	Essential for “bottom-up” mechanism to quantify effectiveness of a measure	Part of the documentation, rather relevant for a VA, approach to define “standard machine tool” missing yet
Product carbon footprint declaration	All “machine	Less frequently used units, material choice is	Coverage of those

	tools", which operate with single-phase motors	relevant for total life cycle impacts, thus production should be included as well (also to account for trade-offs for material for motors of higher efficiency)	smaller units, which do not fall under the ecodesign regulation for motors (and for which no efficiency classes are defined yet)
Minimum environmental performance criteria			
Energy efficiency of welding power sources	Welding equipment	Corresponds with LLCC calculations in Task 6	To be implemented in 3 stages
Idle state power consumption of welding power sources module at cold state			

7.2 Impact Analysis

7.2.1 Scenarios

Scenarios are calculated based on the assumption that any measure takes effect from 2014, and that machine tools placed on the market during that year will be the first ones to deviate from “Business-as-usual”.

“Business-as-usual” is calculated with the Base Case results in Task 4 per unit, plotted with the annual stock figures according to the stock model developed in Task 2, for the years up to and including 2025.

For all of the policy scenarios, all stock installed before 2014 is calculated with the Base Case figures of Task 4. All stock implemented in 2014 and thereafter is calculated with the corresponding results of the related improvement option, as in Task 6.

This approach neglects that the stock still consists of numerous older, much less efficient machine tools. Replacing these machine tools by inherently more efficient ones is not considered in this simplified model (as it would not be an effect of policy measures, with the possible exception of a scrapping bonus).

The following policy scenarios are calculated:

- **LLCC**: Implementation of a good-design-practice-checklist, accompanied by power management requirements and declaration obligations, leading to machinery improvements corresponding to the point of Least Life Cycle Costs (LLCC).
- **LCC-BEP**: This can be considered a more “optimistic scenario”, where the analysis of individual machine tools shows in numerous cases a higher individual savings potential than what could have been addressed with the generic archetypal calculations from Task 6. Fiscal incentives furthermore are assumed to pay off for part of the additional machinery costs for implementing even more improvement options than in the LLCC scenario. Calculation basis for all machine tools sold in 2014 and thereafter is the Life-Cycle-Costs-Break-Even-Point identified in Task 6
- **10% VA**: A Voluntary Agreement is implemented, setting a target that all machine tools sold in 2014 and thereafter should, on average, consume 10% less energy than in 2010. Productivity increase is not accounted for in this model

calculation (but could and should be addressed in a VA). If productivity changes were taken into account, only the absolute values would change, not the general trends.

- **PCF label**: For light-stationary machine tools, this scenario is based on the assumption that transparency regarding life cycle impacts guides purchase decisions, and is an incentive for tool manufacturer to develop equipment with a lower carbon footprint, despite the slightly higher Life Cycle Costs. For the calculation of this Product Carbon Footprint label scenario, the implementation of both improvement options as outlined in Task 6 is assumed[27].

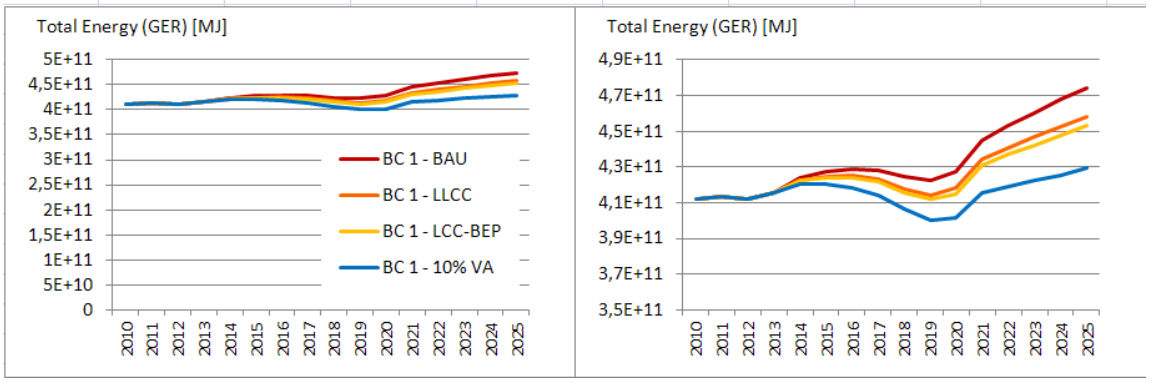
7.2.2 Forecast 2025

The forecast data depicted below refers only to Total Energy consumption. Similar trends can be anticipated for the other environmental impact categories. For each Base Case the results are shown in two graphs, one with the y-axis starting at zero to visualise the correlation of total changes (left), and a zoomed-in graph (right) to show the more minor differences among the scenarios.

Given the slight market growth of CNC machines the BAU scenario for Base Case 1 shows a slightly growing energy consumption trend (Figure 7-2). The LLCC and the LCC-BEP scenarios slightly lower the total energy consumption from 2014 onwards. In 2025, a significant number of CNC machining centres (and similar) installed before 2014 will still be in operation, which means that the gap between BAU and the other scenarios will continue to increase. The scenario with the highest improvement potential is “10% VA”, but still with only a moderate effect in 2025. More ambitious targets via a VA (or much stricter requirements and an implementing measure) could result in higher savings. A 20% target – if reached - would double the effect in 2025 for this and the following Base Cases.

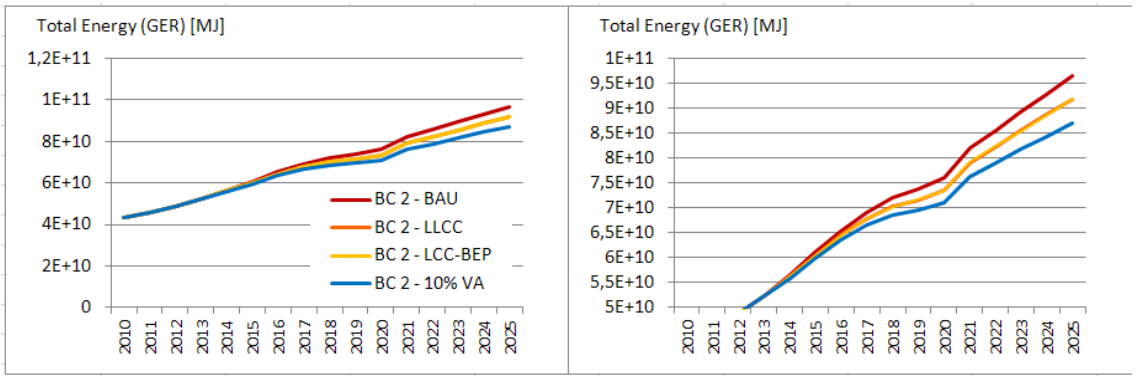
[27] whereas the replacement of aluminium by the more heavy-weight cast iron represents rather a “wildcard” for material changes and reductions as such

Figure 7-2: Base Case 1 - Policy Scenarios - Total Energy 2025 Forecast



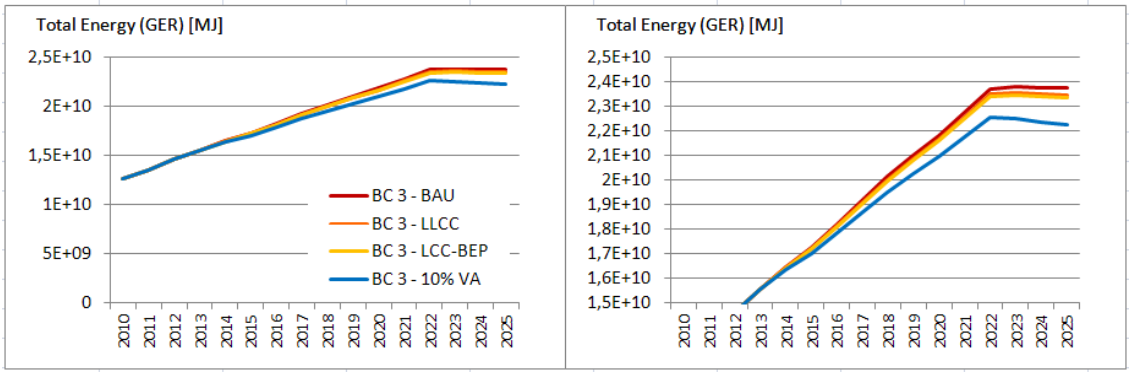
Given the significant market growth of laser cutting machines the BAU scenario for Base Case 2 shows a steadily growing energy consumption trend (Figure 7-3). The LLCC and the LCC-BEP scenario (in this case, both are the same) slightly lower the total energy consumption from 2014 onwards. In 2025 still some laser cutting machine tools (and similar) installed before 2014 will be in operation, which means the gap between BAU and the other scenarios will still increase. The scenario with the highest improvement potential is “10% VA”, but still with only a moderate effect in 2025.

Figure 7-3: Base Case 2 - Policy Scenarios - Total Energy 2025 Forecast



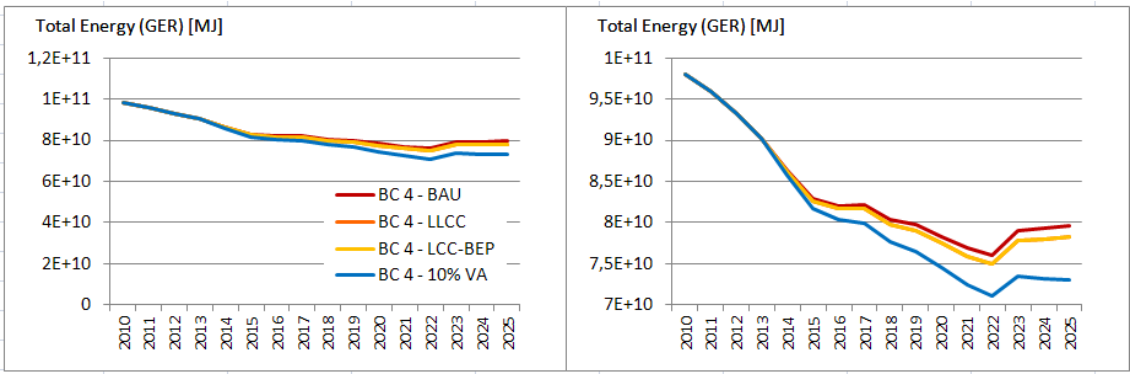
For hydraulic presses (and similar, Base Case 3) the same trend as for the other metal working machine tools is observed (Figure 7-4).

Figure 7-4: Base Case 3 - Policy Scenarios - Total Energy 2025 Forecast



Conventional, non-numerical controlled machine tools see a decreasing number of installed units which results in a slowly decreasing energy consumption trend for the BAU scenario for Base Case 4 (Figure 7-5). The LLCC and the LCC-BEP scenarios slightly lower the total energy consumption from 2014 onwards. In 2025 still a significant number of non-NC machine tools installed before 2014 will be in operation, which means the gap between BAU and the other scenarios will still increase. The scenario with the highest improvement potential is “10% VA”, but still with only a moderate effect in 2025.

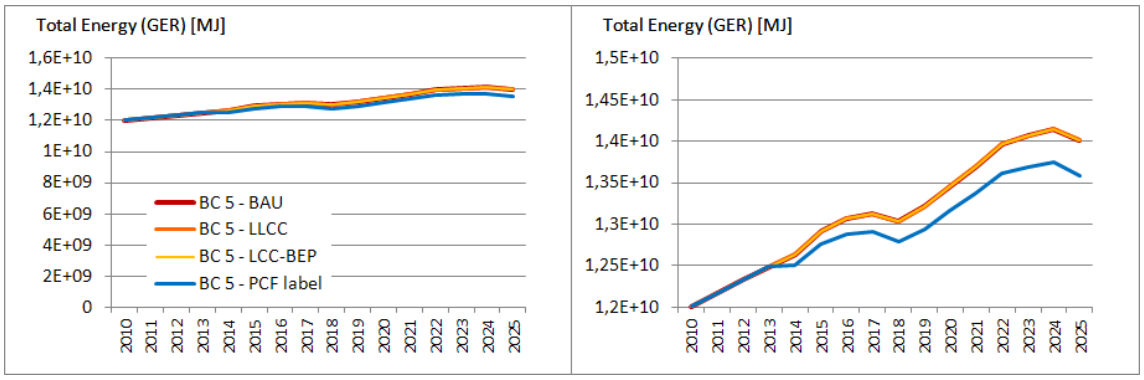
Figure 7-5: Base Case 4 - Policy Scenarios - Total Energy 2025 Forecast



For light-stationary machine tools, a near-stable total energy consumption is to be expected in the BAU scenario (Base Case 5, Figure 7-6). The LLCC and the LCC-BEP scenario actually do not apply for these, as neither LLCC nor a LCC-BEP where identified. Only the PCF label scenario results in savings, although on a very low level, which is basically due to the fact that the scenario in accordance with Task 2 is based on a lifetime of 20 years, which presumably overestimates real lifetime for some of the relevant market segments. In 2025 still numerous light-stationary machine tools installed

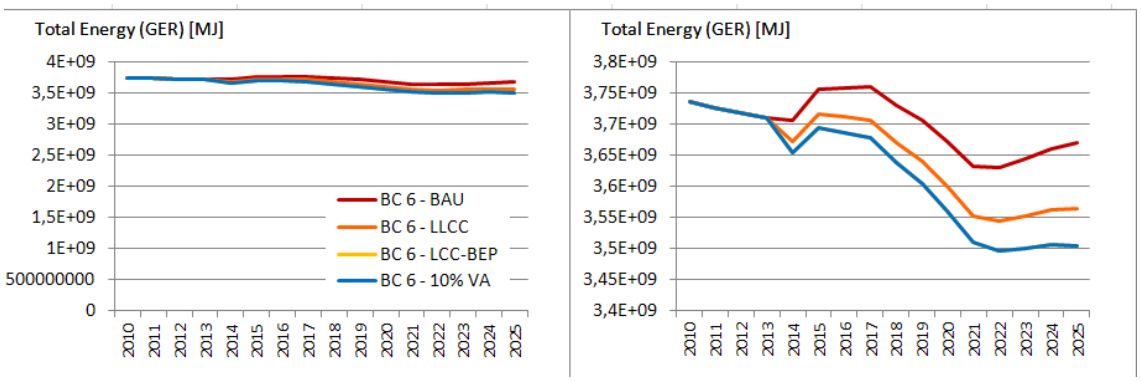
before 2014 will be in operation (actually nearly 50% of the stock), which means the gap between BAU and the PCF label scenarios will still increase.

Figure 7-6: Base Case 5 - Policy Scenarios - Total Energy 2025 Forecast



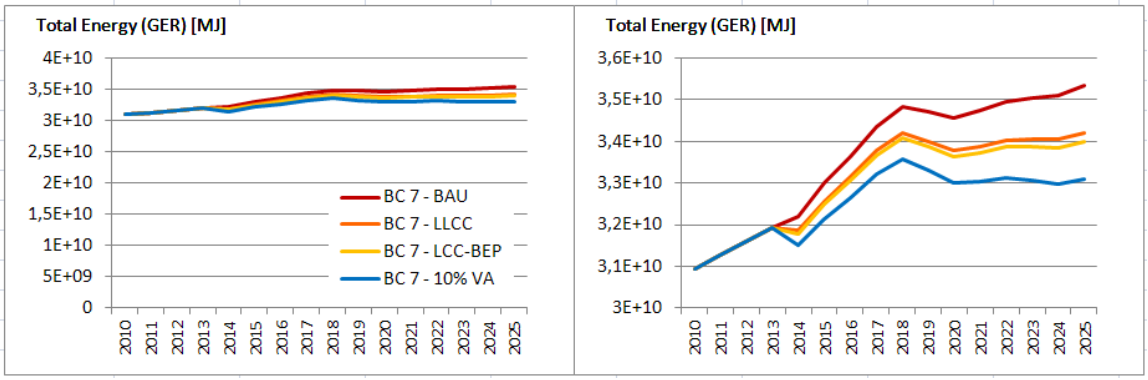
For larger industrial wood working machine tools the anticipated long lifetime results in similarly small short- and mid-term effects of policy options: For panel saws (and similar, Base Case 6) total energy consumption remains on a stable level in the BAU scenario (Figure 7-7). The LLCC scenario results in a small energy consumption reduction. The LCC-BEP scenario is the same as the 10% VA scenario, and although meaning a significant saving per unit, the effect on the stock is very moderate. In 2025 still numerous panel saws installed before 2014 will be in operation, which means the gap between BAU and 10% VA scenarios will increase beyond 2025.

Figure 7-7: Base Case 6 - Policy Scenarios - Total Energy 2025 Forecast



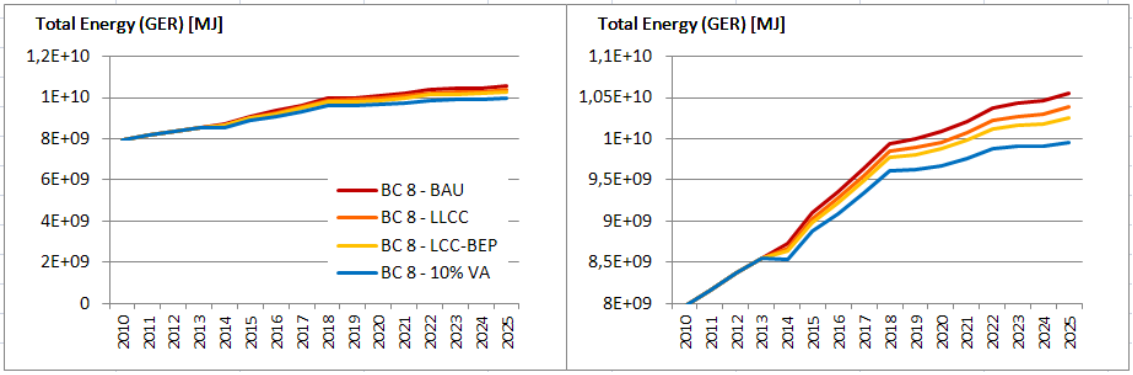
For throughfeed edge banding machine tools (and similar, Base Case 7, Figure 7-8) same statements as for the panel saws above apply.

Figure 7-8: Base Case 7 - Policy Scenarios - Total Energy 2025 Forecast



For CNC wood working machining centres there is a slight energy consumption growth trend (Base Case 8, Figure 7-9), given a market growth in this segment, but otherwise the same statements apply as for the other industrial wood working machine tools, above.

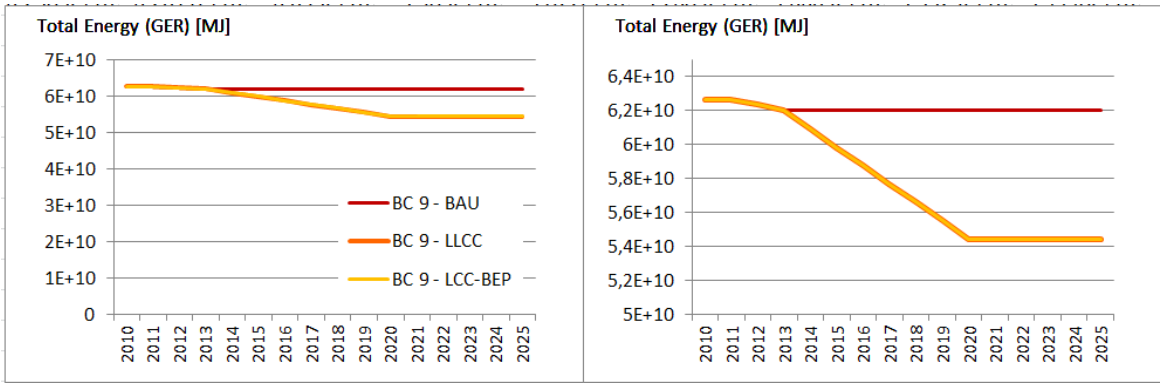
Figure 7-9: Base Case 8 - Policy Scenarios - Total Energy 2025 Forecast



For welding equipment (Base Case 9, Figure 7-10) a stable stock is anticipated in terms of units. Consequently the BAU scenario results in a constant level of energy consumption over time. The LLCC and LCC-BEP scenarios lead to a significant drop in total energy consumption from 2014 onwards. Note that LLCC and LCC-BEP are based on improvement options which result in lower power consumption than proposed in 7.1 with staged implementation. This means that where longer transition times occur (as proposed in Task 7.1), this savings potential will only be realized later. As LLCC and LCC-BEP already constitute a savings potential larger than 10%, no 10% VA scenario is calculated here.

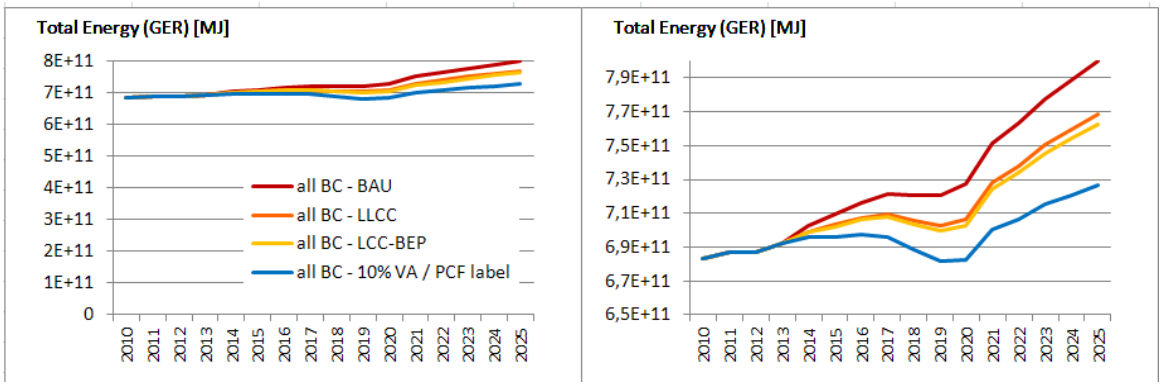
It should be noted that the calculations presented do not include further savings of welding/ shielding gas.

Figure 7-10: Base Case 9 - Policy Scenarios - Total Energy 2025 Forecast



An aggregated graph for all Base Cases and related scenarios is depicted in Figure 7-11: The short- to mid-term effect of any policy measure is hampered by the long life-time, i.e. low exchange rate of investment goods, such as machine tools. Moderate savings can be achieved with the LLCC and LCC-BEP scenarios, and the difference between both is minor. A target-setting of 10% improvement could result in significant total savings. However, even then the absolute total energy consumption level of today is exceeded, and only the power consumption increase is slowed down.

Figure 7-11: All Base Cases - Policy Scenarios - Total Energy 2025 Forecast



Total savings range from 31 PJ in 2025 (LLCC scenario) to 74 PJ (10% VA / PCF label). More ambitious targets under a Voluntary Agreement at high market coverage could yield higher savings.

Table 7-9: All Base Cases - Policy Scenarios - Total Energy 2025 Forecast

Total Energy (GER) [PJ]	2013	2014	2020	2025	Savings
all BC - BAU	692	702	727	800	-
all BC - LLCC	692	699	706	769	31
all BC - LCC-BEP	692	699	703	762	38
all BC - 10% VA / PCF label	692	696	682	726	74

When interpreting these results it is important to remember the shortcomings of this analysis:

- Although the Base Cases cover the most important market segments of machine tools, a gap has to be stated for numerous other types of machine tools, which cannot be represented properly by the chosen Base Cases (see annex of Task 4). Consequently, the total impact and the total savings potential will be higher than stated here; at a best estimate, these figures might be between 10 and 50% higher, but a reliable extrapolation is not feasible.
- The calculations do not reflect the increasing complexity (and productivity) of almost all machine tools types, which will actually lead to an even faster increase of total energy consumption – but presumably also lower energy consumption per product output.
- There is a high level of uncertainty regarding individual stock figures, which means also an uncertainty for the absolute figures, but this does not affect the overall trends observed.

7.2.3 Plausibility

For metal working machine tools the results are confirmed by a top-down calculation provided by VDW. Based on the assumption that a savings potential of 20% for new machine tools vs. old machine tools is feasible[28], Hagemann and Würz calculate a an electricity savings potential of 7,54 TWh for 2020. This calculation is based on the assumption that the more efficient technologies are implemented already from 2010 onwards. The baseline consumption scenario is provided in Task 4, 4.5.10.1. VDW calculations regarding stock effects are documented in Table 7-10.

28 Comparing machine tools in operation currently with those which will be optimized and newly brought on the market, our analysis compares “new, not realizing the optimal savings potential” vs. “new, economically ecodesigned”. Hence, our calculation is based on lower savings potentials.

Table 7-10: Top-down estimate electricity savings potential of metal working machine tools in EU-27 (estimate by VDW, translation Fraunhofer)

	2010	2012	2014	2016	2018	2020
Energy consumption of machine tools replaced in a given year [TWh, electricity]	3,24	3,42	3,44	3,45	3,47	3,48
Aggregated energy consumption of machine tools replaced in a given year (= subject to potential efficiency gains) [TWh, electricity]	3,24	10,08	16,94	23,84	30,76	37,72
Energy consumption "old stock" [TWh, electricity]	65,08	58,52	51,94	45,33	38,69	32,02
Energy efficiency related savings [TWh, electricity]	0,65	2,02	3,39	4,77	6,15	7,54
Aggregated savings [TWh, electricity]	0,65	3,99	10,08	18,93	30,54	44,93
Total energy consumption [TWh, electricity]	67,67	66,58	65,49	64,40	63,30	62,19
CO2 savings [t/a] (0,616kgCO2/kWh)	398.921	2.460.084	6.211.521	11.660.250	18.813.289	27.677.654
Aggregated CO2 savings [kt]	399	4.078	14.413	34.797	68.633	119.342

The power consumption (end-energy) forecasts, based on VDW's estimates are depicted in Figure 7-12 and as aggregated savings from 2010 to any given year until 2020 in Figure 7-13.

Figure 7-12: Top-down estimate electricity savings potential of metal working machine tools in EU-27 (estimate by VDW, translation Fraunhofer)

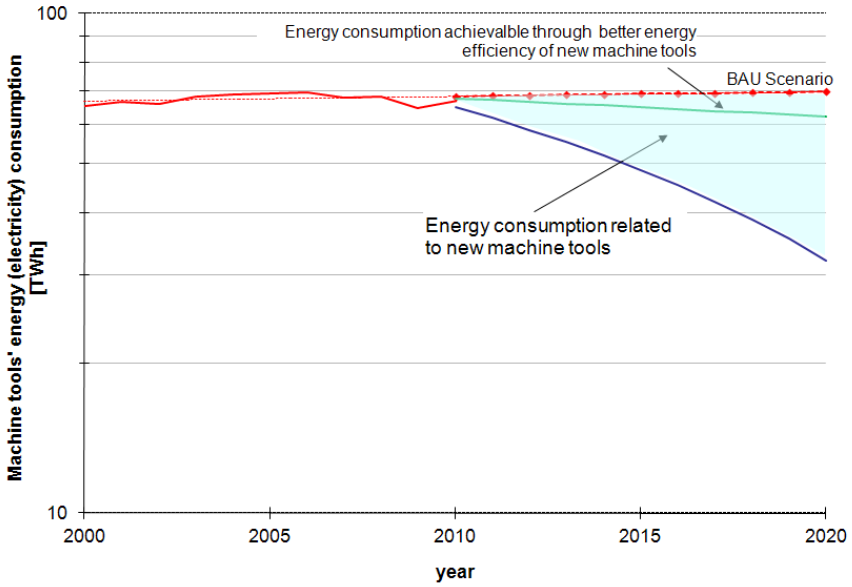
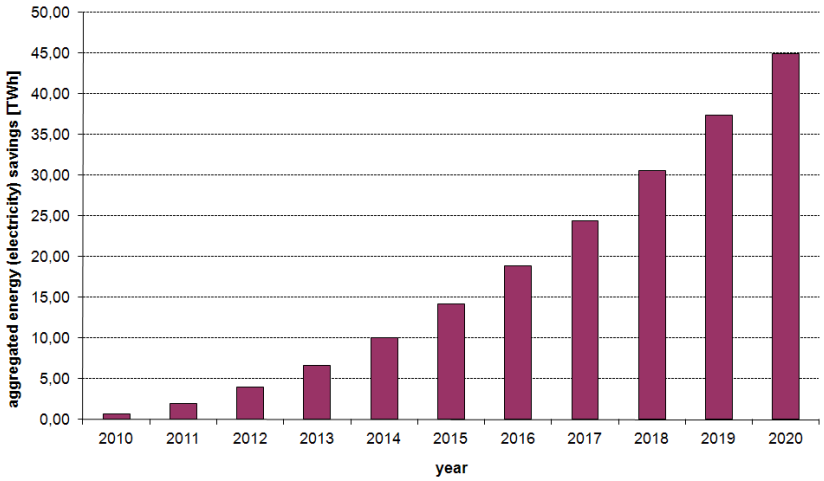


Figure 7-13: Aggregated electricity savings of metal working machine tools in EU-27 according to VDW calculations



7.2.4 Other impact criteria

Besides environmental criteria, there are some more, which are relevant in an impact assessment. Reflecting the findings of all tasks, Table 7-11 provides a qualitative assessment of some of the key indicators for the three policy scenarios.

Table 7-11: Impact Matrix

Impact Indicator	LLCC	LCC-BEP	10% VA / PCF label
	Change in comparison to "Business-as-usual"		
Economic impact indicators:			
- functionality of the product	0	0	-
- affordability of the product	0	-	-
- Implementation costs / administrative costs	-	--	-
- life cycle costs of the product	+	0	0
- competitiveness	0	0	+
Social impact indicators:			
- health	+	+	+
- safety	0	0	0
- number of jobs	0	+	0
Environmental impact indicators:			
- energy use	+	+	++
- greenhouse gas emissions	+	+	++
- end of life	0	0	0
Other criteria:			
- durability of the product	0	0	0
- technical feasibility	++	+	++
- interaction with other Community interventions	++	+	+
- efficiency & effectiveness (value for money)	0	0	0

7.3 ANNEX - Criteria for Voluntary Agreements

Voluntary agreements proposed by industry have to be assessed against the 9 criteria indicated in Annex VIII of the Directive (source: Working Document - Voluntary agreements under the Ecodesign Directive 2009/125/EC, March 12, 2010):

Criterion 1: openness of participation

The self-regulatory initiative shall be open to any new signatory.

Criterion 2: added value

The self-regulatory initiative must deliver added value, i.e. more than 'business as usual', in terms of environmental performance of products in its scope

Criterion 3: representativeness

The self-regulatory initiative must cover a large majority of the relevant market. As an order of magnitude it means that in principle more than 70% of the products placed on the market should be covered by the agreement.

Criterion 4: quantified and staged objectives

The self-regulatory initiative must set quantified and staged objectives, starting from a well-defined baseline and measured through clear and reliable indicators, based on extensive scientific and technological background. These indicators must allow monitoring the compliance with the objectives.

Criterion 5: involvement of civil society

The self-regulatory initiative must be publicised, including through the use of Internet and other electronic means of disseminating information. The same must apply to interim and final monitoring reports. Interested stakeholders, including NGOs and consumer organisations, must be invited to comment on a self-regulatory initiative and have access to the relevant information (e.g. annual reports, meetings of the monitoring/steering body).

Criterion 6: monitoring and reporting

Signatories are responsible for including a well-designed, credible and reliable monitoring and reporting system in the self-regulatory initiative, based on verifiable, objective and detailed data. It is notably expected that the signatories will report annually to the Commission on their progress in meeting the objectives of the self-regulatory initiative. These reports will have the form of aggregated data gathered and submitted to the Commission. Member States wishing to verify the reported values will be granted access to the background data upon request. To enable independent inspection to occur the signatories will have to declare which products are covered by the VA and which are not. (...)

Criterion 7: cost-effectiveness of administering a self-regulatory initiative

The self-regulatory initiative, notably as regards monitoring, must not lead to a disproportionate administrative burden.

Criterion 8: sustainability

The self-regulatory initiative shall be in line with the objectives of the Ecodesign Directive and in particular: free circulation, enhanced environmental performance of products in a lifecycle perspective.

Criterion 9: incentive compatibility

The self-regulatory initiative shall be consistent with existing framework conditions, especially incentives.