Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 1: Definition

Final report to the European Commission, DG ENER
2 April 2014



European Commission

Developed by:

bio by Deloitte.

ATKINS

Document information

CLIENT	European Commission, DG ENER
CONTRACT NUMBER	ENER/C3/403/2010
REPORT TITLE	ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 1: Definition
PROJECT NAME	Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC
PROJECT CODE	ENER Lot 28
PROJECT TEAM	Bio by Deloitte, Atkins
DATE	2 April 2014
AUTHORS	Mr. Shailendra Mudgal, Bio by Deloitte Mr. Sandeep Pahal, Bio by Deloitte Mr. Benoit Tinetti, Bio by Deloitte Mr. Alvaro De Prado Trigo, Bio by Deloitte Dr. Hugh Falkner, Atkins Mr. Keeran Jugdoyal, Atkins
KEY CONTACTS	Mr. Sandeep Pahal spahal@bio.deloitte.fr Or Mr. Shailendra Mudgal shmudgal@bio.deloitte.fr
DISCLAIMER	This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. The project team does not accept any liability for any direct or indirect damage resulting from the use of this report or its content.

Please cite this publication as:
Bio by Deloitte (2014), Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC, ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 1: Definition prepared for. European Commission, DG ENER

Photo credit: cover @ Per Ola Wiberg

©Bio by Deloitte 2014

Table of Contents

1.1 Introduction 8
1.1.1 Wastewater 8
1.1.2 What are pumps? 10
1.1.3 The principles of pumping 11
1.1.4 Basic pump laws for Newtonian fluids 14
1.1.5 Wider context of pumps covered in ENER Lot 28 study 17
1.1.6 Functionality 17
1.1.7 WW pump characteristics 24
1.1.8 Importance of inlet pressure 27
1.1.9 PRODCOM categories 27
1.1.10 EN-, ISO- and other classifications used by standardisation bodies 28
1.1.11 Labelling categories (EU Energy Label or EcoLabel) 29
1.2 Proposed categorisation scheme for pumps 29
1.2.1 Description of ENER Lot 28 pumps 29
1.2.2 Screening analysis 35
1.2.3 Energy Saving Estimates of pump types 36
1.3 Test Standards 44
1.3.1 Test Procedure 44
1.3.2 Standards at European Union level 45
1.3.3 Standards at Member State level 46
1.3.4 International Standards 47
1.3.5 Summary of test standards 47
1.4 Existing Legislation 48
1.4.1 Legislation and Agreements at European Union Level 48
1.4.2 International Legislation 50
1.5 Product performance assessment 51
1.6 Conclusions 54

List of Tables

Table 1: Pump application-type matrix 19

Table 2: PRODCOM categories 27

Table 3: Annual energy consumption and energy savings potential (both at product level and extended-product level) for the stock of the pumps considered for the screening analysis in 2011 38

Table 4: Contribution (in %) of each of the pumps covered in the screening exercise to the overall environmental impacts due to all of these pumps 40

Table 5: Non energy-related EU standards relevant for pumps for wastewater and fluids with high content 45

Table 6: Water Industry Mechanical and Electrical Specifications (WIMES) specifications (UK) 46

Table 7: International Standards 47

List of Figures

Figure 1-1: Operating principles of positive displacement pumps (pump on left side) and rotodynamic water pumps (pump on the right side) 10

Figure 1-2: How rotodynamic pumps work: flow paths (left) and cutaway of motor coupled pump (right) 11

Figure 1-3: Illustration of an open pumping network 13

Figure 1-4: Example of a pump system curve showing the difference between the best efficiency point and the actual efficiency point 14

Figure 1-5: Duty points of pumps of different sizes but same specific speed 15

Figure 1-6: Principle impeller designs for typical pump sizes and specific speed 16

Figure 1-7: Preliminary classification for pumps 18

Figure 1-8: Pumps for the Paper and Pulp industry (copyright Sulzer pumps) 21

Figure 1-9: Detail of 185 kW system showing drive belt gearbox and bearings 22

Figure 1-10: Screw removed for maintenance at a WWT plant 22

Figure 1-11: Share of annual energy consumption of positive displacement pumps by their application types (Source: Final report of 2nd Ecodesign Working plan) 24

Figure 1-12: Cutaway of a Submersible Pump showing the motor integrated with the impeller. 30

Figure 1-13: A selection of impeller types commonly found in wastewater and solid handling pumps 31

Figure 1-14: Dry well pump 31

Figure 1-15: A selection of dewatering pumps 32

Figure 1-16: Examples of different domestic drainage pump configurations 33

Figure 1-17: Commercial grinding pump 34

Figure 1-18: Domestic shredding pump 34

Figure 1-19: Example of a cutting mechanism in a shredding pump 34

Figure 1-20: Slurry Pumps 35

Figure 1-21: Testing and verification of pumps (only relevant to testing of products by an external test house 45

Figure 1-22 Definition of Extended Product Approach – (Source Europump) 51

Figure 1-23 Load profile for a typical variable flow system such as found in HVAC systems (Source Europump) 52

Figure 1-24 Load profile for a typical constant flow system 53

Figure 1-25: Relative significance of each life cycle phase per environmental impact category CS RSP 1 to 10 56

Figure 1-26: Relative significance of each life cycle phase per environmental impact category CS RSP 10 to 25 56

Figure 1-27: Relative significance of each life cycle phase per environmental impact category CS RSP 25 to 1000 57

Figure 1-28: Relative significance of each life cycle phase per environmental impact category CS MFAP 57

Figure 1-29: Relative significance of each life cycle phase per environmental impact category CS1 SG 58

Figure 1-30: Relative significance of each life cycle phase per environmental impact category CS1 RSP 1 to 10 58

Figure 1-31: Relative significance of each life cycle phase per environmental impact category CS1 V 59

Figure 1-32: Relative significance of each life cycle phase per environmental impact category CDWP RSP 1 to 10 59

Figure 1-33: Relative significance of each life cycle phase per environmental impact category CDWP RSP 10 to 25 60

Figure 1-34: Relative significance of each life cycle phase per environmental impact category CDWP RSP 25 to 1000 60

Figure 1-35: Relative significance of each life cycle phase per environmental impact category CDWP MFAP 61

Figure 1-36: Relative significance of each life cycle phase per environmental impact category ASP 61

Figure 1-37: Relative significance of each life cycle phase per environmental impact category CSDD 62

Figure 1-38: Relative significance of each life cycle phase per environmental impact category SDP 62

Figure 1-39: Relative significance of each life cycle phase per environmental impact category SP LD 63

Figure 1-40: Relative significance of each life cycle phase per environmental impact category SP HD 63

Task 1: Definition

The scope of the study includes pumps (extended product approach including motors, variable speed drives (VSDs) and controls, where appropriate) for private and public wastewater (WW) and for fluids with high solids content.

Note that clean water pumps are covered by TREN Lot 11 and ENER Lot 29.

The main objective of this document is to set a solid foundation for the ENER Lot 28 preparatory study by defining the product scope for pumps for private and public WW and for fluids with high solids content, and to understand these products from a functional and technical point of view. It also structures appropriate product groups while providing a first screening on the basis of their sales volumes and energy savings potential.

This report provides stakeholders an opportunity to review and comment on the information collected and conclusions.

The report is structured as follows:

- Section 1.1 provides a technical introduction to WW definition, pumping characteristics, functionality, existing product categorisation and some basic concepts.
- Section 1.2 sets out proposed product categorisations for ENER Lot 28 pumps and provides brief product introductions. It also presents the preliminary environmental analysis of these pumps through a screening exercise.
- Section 1.3 lists existing test standards at the EU, Member State and international levels.
- Section 1.4 lists existing legislation at the EU and international levels.
- Section 1.5 discusses extended product approach and system boundaries of the "playing field" for ecodesign. This is important for a realistic definition of design options and improvement potential and it is also relevant in the context of technically defending any implementing legislation or voluntary measures that may arise following the study. It then goes on to discuss a proposed methodology for the analysis of WW pumps.
- Section 1.6 lists the main conclusions of Task 1.

1.1 Introduction

1.1.1 Wastewater

WW is any contaminated water resulting from human activities, which may consists of soluble and/or insoluble substances and can be characterised by its aesthetic, chemical and biological quality. The Urban Wastewater Treatment Directive (UWTD)[1] classifies WW into urban, domestic and industrial types.

- **Urban WW**

Is the domestic WW or a blend of WW from the domestic sector with industrial WW and/or run-off rainwater.

The flow and concentration of WW under this classification can fluctuate drastically as it is highly dependent on unpredictable influences such as seasons. These uncertainties increase the difficulty in designing a robust and reliable treatment system. Toxic compounds from industries further complicate the biological process in treatment plants.

- **Domestic WW**

Is the WW discharged from residential settlements and services; mainly originating from daily household activities and human metabolism.

The main parameter that is considered in the design of a sewage treatment system include Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Dissolved Oxygen (DO), pH and temperature. These days, domestic WW also consists of emerging pollutants such as phthalates and Bisphenol.

- **Industrial WW**

Is defined as any WW effluent from premises that are used for business activities, trading or industry productions but not included in domestic WW classification and are not from run-off rainwater.

Industrial WW can range widely as its physical properties and chemical contents differ from one pollutants source to another. WW from manufacturing processes such as plating has high toxicity and extremely high pH. On the other hand, WW from paper production industries has high solid content and tends to form an emulsion. Lubricant and hydraulic oil manufacturing industries produce organic WW while food production industries normally generate biologically treatable WW.

- **WW treatment**

There are three fundamental steps for treatment of WW.

- ***Pre-treatment***: is based on the use of mechanical processes, screening, settlement or flotation for the removal of stones, sand and fat/grease.

[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1991:135:0040:0052:EN:PDF

- ***Primary treatment***: is carried out in settlement or flotation tanks and used to remove any suspended solid materials in the WW.
- ***Secondary biological treatment***: is the process of converting any remaining pollution in the WW into sewage sludge by using certain microorganisms.

More advanced treatment process steps can be used for:

- Nutrient removal (nutrients such as nitrates or phosphates, can be removed by biological processes and by adding chemicals).
- Disinfection (by using techniques such as UV radiation or ozone treatment).

The need for a scientific definition of WW

The above concerns only descriptors of the typical WW arising from different applications. Current practice is that specifiers and suppliers understand what type of pump will work in different applications, but we found no evidence of detailed quantitative specifications. This is a critical issue in terms of the ERP Directive, as without precise scientific descriptors of WW content, it will be impossible to regulate WW pumps under real life operating conditions.

If this classification scheme gave numerical values for the proportion of these properties in a WW body, then it would give a formal technical basis for pump selection. This would give manufacturers and specifiers alike a common basis for pump definition.

Maximal functionality in wastewater pumping is a mix of efficiency and reliability. This should not be judged as a compromise but the key parameter. Efficiency in wastewater transport should not solely be focused on energy-efficiency. Cost will only be diverted from energy to maintenance.

By way of illustration, a scientific definition of WW that can be used as a basis for the selection of the appropriate pump technology for a particular type of WW should classify the following key properties of WW:

- Viscosity
- Rag
- Grit
- Chemical properties

The European Commission has already given a horizontal mandate to CEN[2] in this context to start such a standardisation process. However, this is not trivial, indicatively at least 5 years are necessary for an acceptable standard to be developed and accepted.

As a pragmatic alternative to a non-existant quantitative definition of WW types[3], it is suggested to instead follow current commercial practices and simply define pump categories by their type.

[2] European Committee for Standardization. www.cen.eu/cen/pages/default.aspx

[3] No scientific definition of WW in EU is currently reported in any existing standards or legislation. The ENER Lot 28 project team has verified this with Europump (European Pump Manufacturers Association), the Chartered Institution

This approach is justified by Table 1, which shows that all applications can be served by more than one pump type, and that each pump type can serve more than one application. Each type of pump has particular applications for which it is best suited, with the many different selection parameters included in section 1.1.7, illustrating the many trade-offs that specifiers are faced with. In particular, the trade-off between efficiency and reliability is of central importance. It is therefore thought at this stage to be important to maintain separate base cases for each type with a view to regulating each type individually.

EUROPUMP has offered to produce a standard, defining artificial wastewater to enable comparable testing of wastewater pumps. Results shall be available in 2014.

1.1.2 What are pumps?

Pumping can be defined as the addition of energy to a fluid to move it from one point to another. Because energy is capacity to do work, adding it to a fluid causes the fluid to do work, normally through a pipe or rising to a higher level.[4]



Figure 1-1: Operating principles of positive displacement pumps (pump on left side) and rotodynamic water pumps (pump on the right side)

Figure 1-1 shows the basic differences between a Rotodynamic and a Positive Displacement pump. A Positive Displacement pump in its simplest (and oldest) form is typified by a bucket lifting water from a well or river. It shows the principle of all pumps of this type; enclosed volumes of liquid are collected at the pump inlet and discharged at the outlet at increased head. The basic principle of a Rotodynamic pump is illustrated by the stirring of a cup of tea to the point where the rotating liquid is given sufficient energy to spill into a (rather deep) saucer, where the level (head) is higher than the mean level in the cup. In a Rotodynamic pump, a continuous flow of liquid passes through a rotating impeller which imparts energy, is collected (usually by a volute or guide vanes) and discharged against an increased head.

of Water and Environmental Management (CIWEM), some manufacturers of WW pumps and operators of WW treatment plants.

[4] Abridged from Karassik and Maguire, Centrifugal Pumps, Chapman and Hall, 1998.

Water is pushed into the pump inlet branch by the pressure acting on the water surface (usually atmospheric pressure) and, where applicable, the height of the water level above the pump. The water flow then passes from the inlet branch of the pump to the inlet of the impeller. It then has to change direction from axial to (near) radial as it enters the passage between the impeller vanes. In a well-designed impeller, at best efficiency flow the water will pass smoothly over the vane inlets with little disturbance. The vanes will then start to work on the water as it flows through the impeller, creating an increase in pressure and velocity. At best efficiency flow, the water will spiral out of the impeller in a free vortex of constant angle to the tangential direction. As the diameter of the volute increases, the flow velocity reduces and pressure is recovered. The volute cutwater angle should be a close match to the spiral angle and will peel off the water to guide it to the outlet branch. The water then leaves the pump with a much-increased pressure.

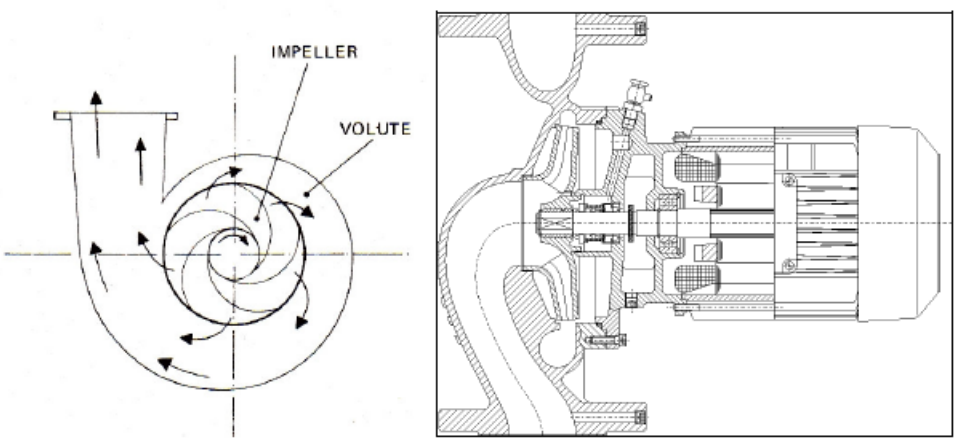


Figure 1-2: How rotodynamic pumps work: flow paths (left) and cutaway of motor coupled pump (right)

Rotodynamic types are generally cheaper and more robust, and so account for the bulk (>90%) of sales. Positive Displacement types are more sophisticated and highly engineered, and despite their usually better efficiency, are just not currently cost effective for the different types of water applications.

WW pumps are distinguished from clean water pumps by their ability to handle fluid that is not adequately clean to meet the definition of clean water.

1.1.3 The principles of pumping

A pump will be described in a catalogue in terms of head (H), flow (Q) and, usually, power. In order to include a power curve, a specific gravity of unity (g) is used (i.e. a density of 1000 kg/m³), in other words the catalogue shows the power absorbed when pumping clean cold water. The actual mechanical power consumption is calculated as $P_{mech} = Q \times H \times density \times g / pump\ efficiency$. This means that it is not possible to give standard curves of power consumption against duty for all Newtonian liquids, as generally the power consumption varies with fluid properties. In addition, the same pump can be used with different motor speeds and impeller sizes, which adds additional variation.

Because a pump will spend on average most of its life operating below its Best Efficiency Flow, part flow operation is usually more critical from an energy perspective. Furthermore, pumps can be designed to have different trade-offs between full and part flow efficiency. It is therefore important that performance at part flow is taken account of in the analysis.

There is no "standard" flow distribution pattern for the types of pumps that are being considered in this study, and so an assumed pattern has been used in the analysis of energy consumption.

The concept of head is very useful and fairly easy to understand in a system such as that shown in Figure 1-3 below. The pump has to produce a head to overcome the static difference in water levels plus the equivalent head of the friction losses in the pipework. The advantage of using head is that the pump will deliver the same flow in the system shown no matter what liquid is being pumped (assuming its viscosity is low, clearly a centrifugal pump would not generate much head if trying to pump treacle). Confusion arises when the significance of head is not understood. Put simply, head is the effective work done on, or energy received by, the liquid per unit of mass, divided by g (the gravitational constant). This can be shown dimensionally:

A column of liquid of height (or head) H exerts a force F on its base of area A equal to its weight, i.e.

$$F = mass \times g = H \times A \times density \times g$$

Equation 1

Thus,

$$H = \frac{F}{A \times density \times g} = N / \frac{m^2 \times kg}{m^3 \times g} = Nm/(kg \times ms^{-2})$$

Equation 2

Irrespective of the liquid pumped, a given pump at a given flow and speed does the same amount of effective work on each unit mass of liquid (and therefore generates the same head). This assumes that viscosity is low and that g varies very little on earth. (In space, a pump will generate an infinite head.) Pressure and power will vary with liquid density.

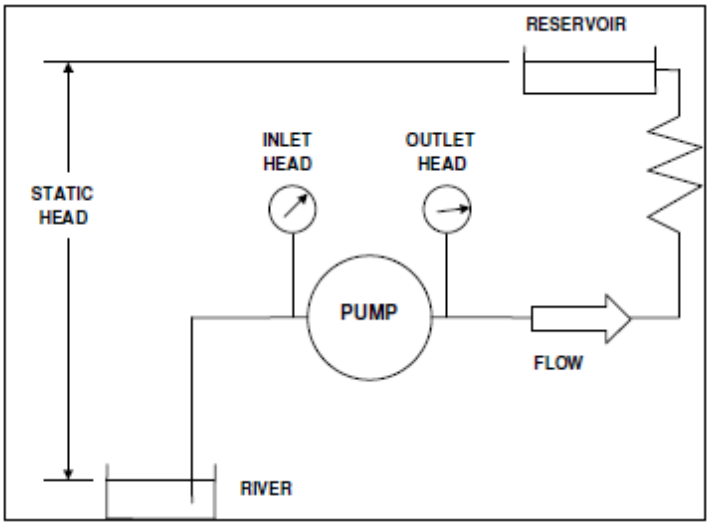


Figure 1-3: Illustration of an open pumping network

In this figure, *Pump head = (outlet head – inlet head) = (static head + friction head).*

Any particular pump when operated at a fixed speed will can output a range of flow rates which is dependent on the head that it is pumping against. This relationship between the head and flow for a given pump is often shown on graphs called 'pump curves'. When pumps are discharging flows into a pipe system, the head that it has to overcome is related to the flow rate – the greater the flow rate the greater the head in the system. Plotting the change in system head on the same chart as a pump curve shows what the duty point, i.e. the head and flow that would result from operating the pump. An example a pump system curve is shown in Figure 1-4.

These pump and system curves are often shown with details of how the pump efficiency changes with flow rate. The flow rate where the efficiency is known as the "best efficiency point".

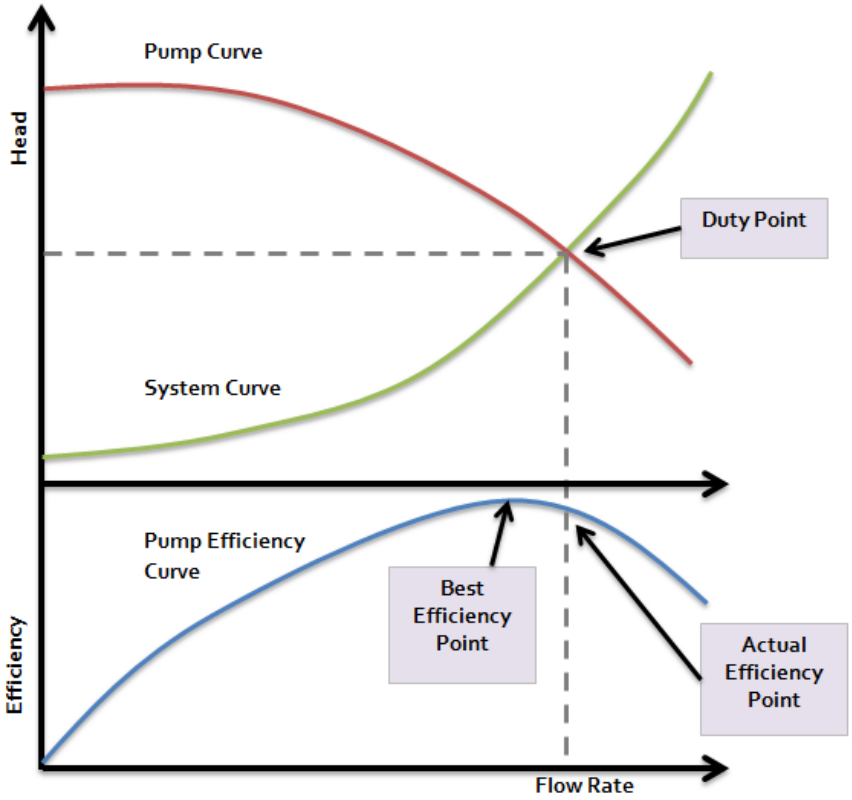


Figure 1-4: Example of a pump system curve showing the difference between the best efficiency point and the actual efficiency point

1.1.4 Basic pump laws for Newtonian fluids

The fundamental similarity (scaling) laws applying to rotodynamic pumps pumping Newtonian fluids are shown in the following equations. These equations do not apply to positive displacement pumps as they use a different mechanism to transfer fluids:

$$\frac{Y_{P2}}{Y_{P1}} = \frac{H_{P2}}{H_{P1}} = \left(\frac{n_{P2}}{n_{P1}}\right)^2 \cdot \left(\frac{D_{P2}}{D_{P1}}\right)^2$$

Equation 3

where: Y= Specific hydraulic work (i.e. work done per unit of mass), D= Impeller diameter (in mm), n =Pump speed and H= Head (in m)

$$\frac{Q_{P2}}{Q_{P1}} = \frac{n_{P2}}{n_{P1}} \cdot \left(\frac{D_{P2}}{D_{P1}}\right)^3$$

Equation 4

where Q = flow rate (in m^3/h)

This shows, for example, that for two pumps which are exact scaled models, the power consumption (proportional to *Q x H*) is proportional to the impeller diameter to the fifth power at constant speed, or to speed cubed at constant diameter.

Resolving equation 1 and 2 results in

$$n_{P1} = n_{P2} \cdot \frac{(Q_{P2}/Q_{P1})^{1/2}}{(H_{P2}/H_{P1})^{3/4}}$$

Equation 5

With a Q_{P1} = 1m³/s, H_{P1} = 1m and Pump 2 at best efficiency point equation 3 leads to the specific speed n_s (usually used in literature for n_{P1})

Specific speed:

$$n_s = n \cdot \frac{(Q_{opt})^{1/2}}{(H_{opt})^{3/4}}$$

Equation 6

where n is speed in rotations per minute (rpm), Q_{opt} is flowrate in m³/s, and H_{opt} is total head across pump in m, all at best efficiency point. It is conventional to refer to n_s in units of rpm, although this is not strictly correct.

The specific speed is the most important similarity parameter in hydrodynamic pump technology. It has central focus throughout pump literature. It characterises the impeller shape, is suited to compare different impeller types and consequently pump types on a common basis.

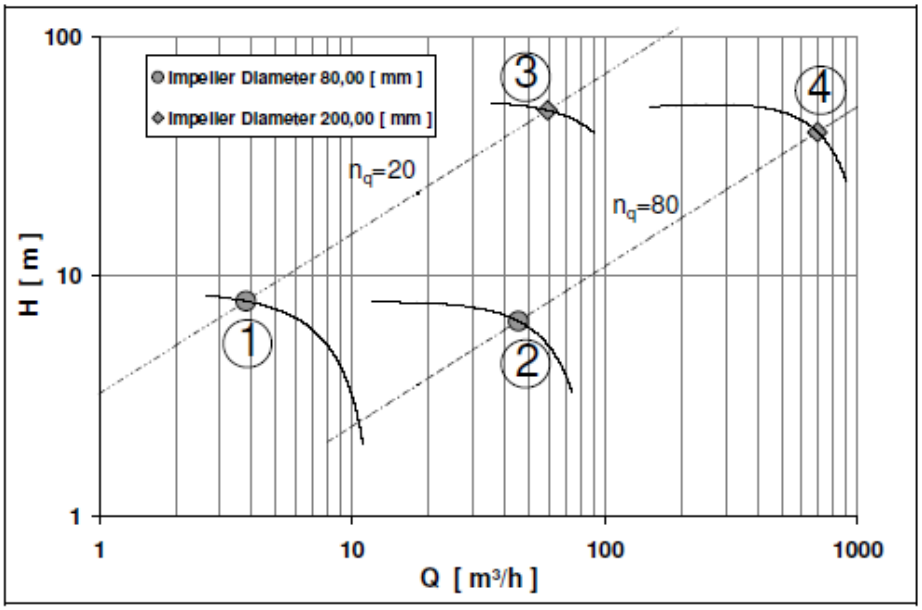


Figure 1-5: Duty points of pumps of different sizes but same specific speed

Figure 1-5 illustrates four different pump cases of two different pump types in a H-Q-Diagram. The two pump types are characterised by the specific speed. Though the pump sizes of for

example No.1 and No.3 are completely different (more than a magnitude difference in flow) their geometrical ratio is similar and therefore they have also the same specific speed.

The same four cases are shown in Figure 1-6 in more detail. The impeller diameters of pumps with the same specific speed are different and hence their flow rate at best efficiency point also. The pump is designed for a system in which it has to be implemented (heating / cooling systems, open pump systems etc.). All these different systems mean different requirements to the pump itself and subsequently the hydraulic design. Hence, there is a requirement within industry for a large variety of pump sizes to service the European market. This allows pump manufacturers to optimize pump efficiency for each design. For example, usually a bigger sized impeller with the same specific speed has a better efficiency than the geometrically similar smaller version. To say "the bigger the better" is however not necessarily correct because of the large amount of energy dissipated by operating points which may not match to the system. The choice of a pump for a specific application is also dependent on the Net Positive Suction Head (NPSH[5]), noise, dirt etc.

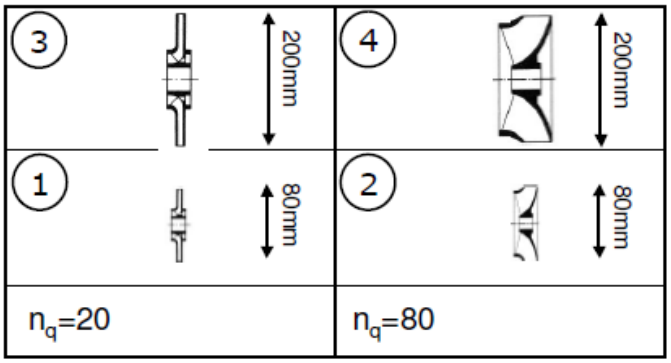


Figure 1-6: Principle impeller designs for typical pump sizes and specific speed

Trimming the impeller is a cheaper alternative to VSDs, and is a common way to adjust the output of a pump to suit a particular application. The User therefore has an almost infinite range of pump options, which makes analysis difficult. However, because the pump will be designed for best efficiency at full impeller, it is most appropriate to only consider performance at full impeller, as this is indicative of performance at all impeller diameters. As the Ecodesign Directive aims at improving pump design, this was seen as being the most appropriate impeller diameter to consider. Because of the special geometries used in many WW pumps, impeller trimming is less common in these types than with clean water pumps. *PREN 16480 Pumps - Minimum required efficiency of rotodynamic water pumps* is based on the measurement of pumps with full impeller, and is therefore the method considered for use in this ENER Lot 28 study.

The use of Variable Speed Drives on WW pumps is also much less common than with clean water pumps. In addition to the possible energy savings, it has the benefit of offering rapid but controlled reversals of direction in order to help free blocked impellers. Product categorisation and performance assessment

[5] A measure of the pump inlet position in relation to the wet well water level. It is used to prevent the pumped liquid from vaporising inside the pump body causing premature wearing.

1.1.5 Wider context of pumps covered in ENER Lot 28 study

The following factors are to be considered in defining the exact specifications of types of pumps within each category:

- Standard types - the Directive is aimed at commodity types of products, not those designed especially for specialist or niche applications where there are only very low sales or where custom / semi-custom designs are the norm.
- When collecting data, manufacturers should not offer their "nearest equivalent" type of pump from a different family of non-solids handling pump that satisfies the required duty, as this would lead to distortions in the results.
- As pumps are characterised by hydraulic values rather than power (kW) ratings, it is not possible to link them directly to the ranges in the motor study[6]. Where pumps are analysed without the motor, an IE3 motor will be assumed in the conversion from shaft to electrical power. The reasoning behind this decision is that Regulation 640/2009[7] requires all fixed speed motors between 7.5 kW and 375 kW to be rated IE3 by 1 January 2015. This requirement is extend to motors between 0.75 and 375 kW on 1 January 2017.
- As with many products, sales of those at the extreme of sizes will be very low compared to those in the "centre ground", and in many cases can be considered to be low volume products that are engineered rather than series produced commodity types. We do not have firm data on the proportion of the market excluded from the study in this way, and it will vary with the different types considered, but our best estimate is that it is less than 5% of the total sales of each type, which types are low volume and often for "specialist" applications.

In each case, care must be taken to check that these considerations will not inadvertently allow excluded products from benefiting by being excluded from any policy options.

1.1.6 Functionality

Pumps come in a variety of generic types as shown in Figure 1-7.

[6] ENER Lot 11 preparatory study on ecodesign of motors

[7] COMMISSION REGULATION (EC) No 640/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors

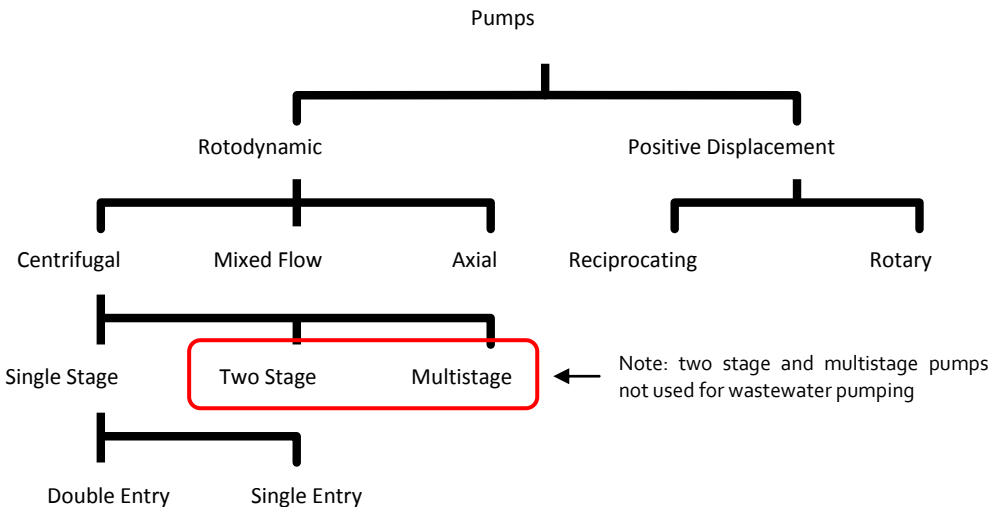


Figure 1-7: Preliminary classification for pumps

Wastewater pumps are required to operate in challenging environments and a key part of any regulations should be to ensure that they are designed to operate reliably as well as efficiently over their expected lifetime. The primary function of a ENER Lot 28 water pump is to move both solid and liquid waste (three main types of WW as defined earlier in section 1.1.1) through a system; in many cases the water is merely a convenient medium for conveying the waste material. The solids not only have the potential to clog the pumps, but their abrasive nature can cause significant wearing which can reduce their operational performance over time and be very costly for the end users.

Table 1: Pump application-type matrix

	Application		Wastewater					High Solids fluids			Sludge							
			Rainwater	Domestic wastewater	Industrial wastewater	Commercial wastewater	Municipal wastewater	Sand water	Grit water	Slurry	Raw sludge	Primary sludge	Secondary sludge	Activated sludge	Tertiary sludge	Trickling filter sludge	Stabilized sludge	Dewatered sludge
Centrifugal	Centrifugal submersible pump	Radial sewage pump 1 to 1000kW			x	x	x											
		Mixed flow & axial pumps	x											x				
	Centrifugal submersible pump – once a day operation	Shredding, grinding pumps		x	x	x	x											
		Radial sewage pumps 1 to 10kW	x	x	x	x	x											
		Where volute is part of a tank	x	x	x	x												
	Centrifugal dry well pump	Radial sewage pumps 1 to 1000kW	x	x	x	x	x	x	x		x	x	x	x	x			
		Mixed flow & axial pumps	x											x				
	Centrifugal submersible domestic drainage pump < 40 mm		x	x														
	Submersible dewatering pumps							x	x									
	Slurry Pumps									x								
Positive displacement	Archimedean screw pump		x		x	x	x											
	Progressing cavity pump										x	x	x	x	x	x	x	x
	Peristaltic pump										x	x	x	x	x	x	x	x
	Plunger and piston pumps										x	x	x	x	x	x	x	x
	Diaphragm pump										x	x	x	x	x	x	x	x
	Rotary lobe pumps										x	x	x	x	x	x	x	x
	Tank mixers																	
	Turbo blowers																	
	Rotary vane pump																	
	Gear pump																	

There is a large variety of pump types on the market to service the many different applications in scope of the primary functionality of ENER Lot 28 pumps. It is important that the analysis is first based on application, and then type. To support this approach, Table 1 shows a matrix that identifies which of the pump types are suitable for the different applications shown.

This shows that:

- For each pump type, there is more than one possible application,
- For each application, there is more than one possible pump type.

Setting identical Minimum Energy Performance Standards (MEPS) on all pump types would thus allow the indication of the most appropriate technology for a given application. This justifies continuing to study each pump separately, and hence in Task 5 creating a basecase for each type. This gives maximum flexibility at subsequent stages of the study should any new information come to light regarding the "pump type – application" mapping.

Certain pumps are capable of pumping either solids or highly viscose fluid, but were found to be outside the scope of this study. These pumps are detailed as follows: **Paper and Pulp pumps** are not a specific type of pump, but rather the term describes a large and diverse range of pumps used in the paper manufacturing process. These are specifically designed to handle various stages of the paper making process (Figure 1-8), and will need to be able to handle hot fluids with varying solids content. These are excluded on the basis that the properties of often hot paper and pulp fluids are very different from those of wastewater or other high solids content fluids.

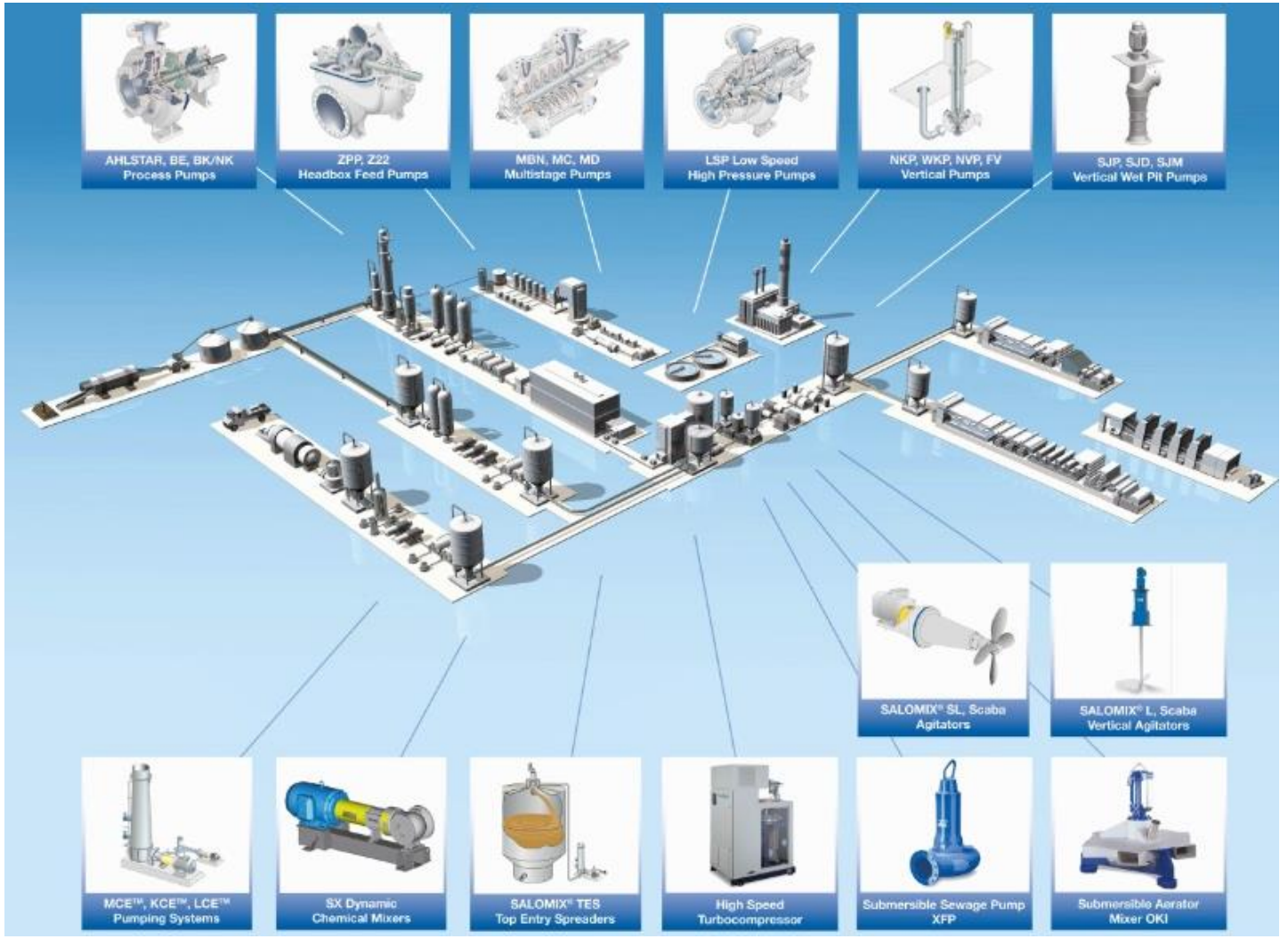


Figure 1-8: Pumps for the Paper and Pulp industry (copyright Sulzer pumps)

Archimedean screw pumps are engineered products. These pumps have to be designed case by case for each wastewater plant individually. Typically, for these pumps, the screw is welded to sheet metal and the trough is individually formed from concrete in situ. Examples of these pump types are shown in Figure 1-9 and Figure 1-10 Efficiencies are typically 75%, fairly independent from flow. They have a high resistance to blockages and ragging, this makes them very attractive where there is space for them to be installed. The devices are custom manufactured for each application. Their design has to take into account desired flow and given static head. In many cases space availability at the installation site is a critical factor and determines slope, screw diameter, helix angle and speed. There is no standard product offering for these pumps, not even some kind of a modular system. These pumps will therefore not be considered for the analysis performed in this study.

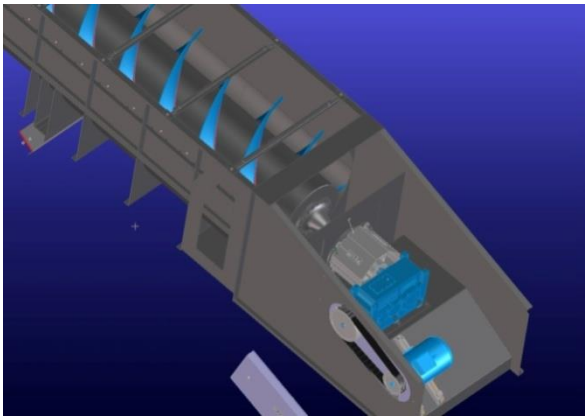


Figure 1-9: Detail of 185 kW system showing drive belt gearbox and bearings



Figure 1-10: Screw removed for maintenance at a WWT plant

As earlier shown in Table 1, following are some products types that are related to the secondary functionality of ENER Lot 28 pump applications:

- **Progressive Cavity Pumps** are basically not designed for wastewater, but for heavy sludge. On this basis they are excluded from scope.
- **Peristaltic pumps** are only used for sludge applications and very rarely in small number in engineered wastewater applications. These pumps are basically not designed for wastewater, but for heavy sludge and therefore are excluded from this study. These pumps are for wastewater applications even more exotic than progressing cavity pumps. There is a small application overlap with Progressive Cavity pumps.
- **Rotary Lobe pumps** are used for pumping very delicate high viscosity products such as many foodstuffs, and again have design features for different types of product that would make setting a benchmark hard. Other similar positive displacement pumps which are not used for solids handling include **rotary vane pumps** and **gear pumps**. As they are primarily used to pump viscose liquids rather than solids they are excluded from this study.
- **Plunger and Piston pumps** are used for moving high viscosity product and are therefore excluded from this study. The output of the pumps is not linear as there is nothing being pumped when the plunger/piston is retracting. These

pumps are not typically used in the wastewater industry, as progressing cavity pumps provide the same solids handling capability but have a linear (non-pulsating) output.

- **Diaphragm pumps** are either compressed air driven or driven by electric motors, pumping slurries by alternately inflating two membranes. These are inherently inefficient, but are popular for example in the ceramics industry for clay pumping. These are excluded on the basis that they are used predominantly in highly viscous slurry applications, very different from the defined scope of the study.
- In addition, wastewater treatment (WWT) aeration plants have **turbo-blowers** and **surface mixers**, which are not strictly pumps, and so they are excluded from the scope of the study.
- **Tank mixers** are really a form of stirrer, and are used to prevent solids from settling in WWT tanks

Figure 1-11 shows the share of annual energy consumption of positive displacement pumps by their application types. It is evident from Figure 1-11 that these pumps are mostly used for applications other than wastewater. Therefore, as the types of pumps mentioned above do not serve the primary function of ENER Lot 28 pumps, they will not be considered for the analysis performed in this study. At this point, it is worthwhile noting that the positive displacement pumps are included as a category in the conditional list of the second Ecodesign Working Plan covering the three years period from 2012 to 2014[8]. An important point is that some types of pumps could theoretically be used in many different application categories, but this rarely happens in practice for reasons of cost or detailed design features. If product categories are too broad, then they do not mean much to the user, and any suggested design options would be likely to miss design / application subtleties and so be flawed.

[8] http://ec.europa.eu/enterprise/policies/sustainable-business/documents/eco-design/working-plan/files/comm-swd-2012-434-ecodesign_en.pdf

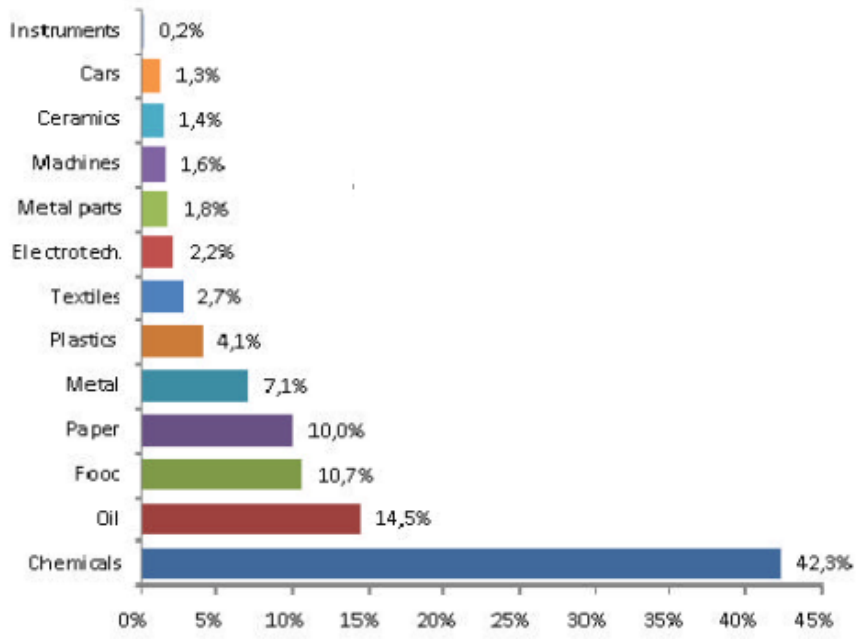


Figure 1-11: Share of annual energy consumption of positive displacement pumps by their application types (Source: Final report of 2nd Ecodesign Working plan)

While there will always be overlaps between different pump types and their suggested range of applications, the pragmatic way forward is to use the basic classification proposed in this section to split the continuum of pump types into manageable groups. Without this, it would be impossible to have a single implementing measure that could sensibly apply to all types.

1.1.7 WW pump characteristics

It appears that the lack of consumer information around more efficient wastewater pumps hinders their market penetration. Pump manufacturers do have a good understanding of how to design reliable and efficient wastewater pumps, however users have to rely on experience to determine what a good pump is. This can often result in users being resistant to innovation as they do not want to compromise reliability. Good regulation is the key to putting information regarding a pump's lifetime reliability and performance into the hands of the users, which would help to overcome this existing problem in the market.

The importance of technical factors is that they are often instrumental in guiding the specification of a pump, and so these must be considered for any future possible policy options. These include:

- **Pump speed.** The rotational speed of the shaft is the most important pump operating variable. Pumps tend to be purchased to operate at the highest speed that the suction conditions (NPSH) will allow, since this usually results in the lowest first cost. (Since most pumps are driven by fixed speed induction motors, the speed options tend to be limited.) This can be false economy for many reasons, e.g. a two pole motor (2900rpm) can be cheaper than a four pole motor (1450rpm); but more maintenance will be required since the life of wearing parts (such as impeller/casing wear rings, seals, bearings, couplings) will be reduced.

Of the highest importance is the fact that the fastest pump may not be the most efficient option, so that the initial price advantage can be lost in a short time by increased energy costs.

- **Solids handling capability.** The pumps considered in this study all need to be able to pump solid materials suspended within the liquid. The ability to handle fibrous components in the wastewater is also of importance. In order to achieve this, the impeller should be suitably sized to allow solids to pass between the gaps between the vanes. Some pumps will have the ability to cut larger solids into smaller pieces, which can fit through the impeller.
- **Net Positive Suction Head (NPSH).** This is the total head at the pump inlet above vapour pressure (corrected to the level of the first stage impeller inlet, if different). Two important values of NPSH are the NPSH required by the pump ($NPSH_R$) and the NPSH available to the pump ($NPSH_A$). The $NPSH_R$ is usually that at which the pump (or the first stage impeller if a multistage pump) loses 3% of its generated head due to cavitation. The $NPSH_A$ must exceed the $NPSH_R$ by a safety margin. This would rarely be less than 1m but will usually be greater because of many factors such as pump speed, size and operating range. The $NPSH_R$ reduces between pump best efficiency flow (BEQ) and about half flow, but increases rapidly above BEQ.
- **Minimum clearances required.** The radial running clearance between the impeller(s) and the casing is critical, since the leakage through this clearance has an adverse effect on efficiency. In a cold water pump this clearance can be as low as 0.25 mm on diameter. However, if the pump operates away from its best efficiency point there is likely to be contact, wear, and a resulting increase in clearance. In addition, abrasives in the water can erode clearances quite quickly. This can be a particular problem with sand in boreholes, slurry and wastewater pumps.
- **Expected lifetime of the pump.** The lifetime of a wastewater/solids handling pump will rarely be dictated by obsolescence. The lifespan of wastewater and solid handling pumps will often be related to the solids they are required to pump.
- **Seal arrangements.** The pump shaft must be sealed to minimise leakage between the pump and atmosphere. Many wastewater pumps will have mechanical seals consisting of axial faces **held together by a** spring. The faces will usually be silicon carbide or tungsten carbide. These seals are 'leak free', although actually passing a very small flow of water vapour. They do not require cooling or sealing water unless they have to operate below atmospheric pressure.
- **Efficiency over operating range/duty point.** This is a major determinant in lifetime operating costs. It is therefore important that a pump should be chosen which has maximal efficiency over the range of duties it is expected to pump. Also that its best efficiency point (BEP) is as close as possible to the principal

duty on site. The efficiency of a pump depends on its basic geometry, fine running clearances and a good surface finish. Unfortunately, most pumps lose efficiency due to wear in their wear rings, due to operation at part flow, and/or roughening of their cast iron volutes by corrosion products.

- **Material.** There are very different materials used for volutes and impellers, depending on the application:
  - Volutes may be from cast iron for standard sewage pumps, stainless steel for sewage containing high amount of sulphides or chlorides. They can also be from aluminium for e.g. contractor pumps.
  - Impellers are made from cast iron for standard sewage pumps, but may also be stainless steel, hard metal (for very abrasive water), bronze for water with high chloride content or ever special plastic materials (e.g. for vortex type of pumps)
- **Maintenance needs.** Ease of maintenance varies with pump type. Larger dry well pump can be easier to maintain as they are generally mounted in more accessible areas than submersible pumps. However, maintenance of small submersible pumps, is much easier than of small dry mounted pumps plus dry well mounted pumps can have long shafts associated with them and are more likely to suffer from NPSH availability issues. With End Suction Close Coupled pumps it is possible to access the impeller by removing one set of nuts or screws and removing the full rotating element including the motor without disturbing the pipework. Access to the seal is then possible by removing the impeller. With End Suction Own Bearings pumps, the coupling spacer is removed and the pump rotating element can then be withdrawn without disturbing the motor or the pipework. With progressing cavity pumps the rotor can be withdrawn from the stator without disturbing the pipework.
- **Variable speed drives.** The implications of using variable speed drives with wastewater pumps need to be explored, as there are issues surrounding their use, which are not present in clean water pumping. In clean water pumps, it is good practice in terms of energy efficiency to match the pump output to the system demand. Doing this with wastewater pumps can potentially result in a reduction the reliability of the pump and the solids handling effectiveness. Wastewater pumps are usually specified to provide a minimum velocity in the pipe to prevent solids from settling within the rising main. It is important that any use of variable speed drives to improve energy efficiency does not compromise the transport of solids. Also, operating a pump at a lower speed may reduce the cutting ability of an impeller and therefore increase the chance of ragging.

1.1.8 Importance of inlet pressure

Unlike a fan, a pump requires a minimum pressure at its inlet branch if it is to produce any flow at all. This is because at low pressures, the water vaporises at the impeller inlet and the impeller is then unable to produce the pressure rise necessary to overcome the system resistance it is intended to work against.

The net positive suction head (NPSH) required ($_R$) by the pump ($NPSH_R$) is defined above. NPSH values have to be considered for the specific operating point or operating range. To operate normally the pump will usually be arranged in the system such that the NPSH available at the pump inlet ($NPSH_A$) is at least 0.5m greater than the $NPSH_R$ throughout the intended flow range.

If the $NPSH_A$ is close to or less than the $NPSH_R$, the head produced by the pump and the pump efficiency will both fall. It is therefore essential to provide adequate suction pressure to the pump if its optimum performance is to be achieved.

If the pressure at the pump suction is below atmospheric pressure, the pump performance can also deteriorate if air leaks into the pipework or through the pump seal. Even a very small leakage of air can reduce the pump head and efficiency significantly, so close attention to sealing is essential[9]. In the case of Submersible pumps, if the water level in the well is too low air can be drawn into the pump through a vortex and again the performance will be adversely affected.

1.1.9 PRODCOM categories

PRODCOM is the official source of EU statistics on EU industrial production, and so is the primary reference used for classification of pumps. PRODCOM lists many subcategories considered suitable for ENER Lot 28 pumps for wastewater and fluids with high solid content. They are presented in Table 2.

Table 2: PRODCOM categories

PRODCOM Code	Label
28131280	Positive displacement reciprocating pumps, diaphragm
28131320	Positive displacement pumps, rotary, gear
28131340	Positive displacement pumps, rotary, vane
28131360	Positive displacement pumps, rotary, screw
28131380	Positive displacement pumps, rotary (including peristaltic, rotary lobe and helical rotor pumps) (excluding hydraulic units, gear pumps, vane pumps, screw pumps)

[9] Grundfos Industry (2004) Pump Handbook

PRODCOM Code	Label
28131413	Submersible motor, single-stage rotodynamic drainage and sewage pumps
28131415	Submersible motor, multi-stage rotodynamic pumps
28131430	Centrifugal pumps with a discharge outlet diameter > 15 mm, channel impeller pumps, side channel pumps, peripheral pumps and regenerative pumps
28131451	Centrifugal pumps with a discharge outlet diameter > 15 mm, single-stage with a single entry impeller, close coupled
28131453	Centrifugal pumps with a discharge outlet diameter > 15 mm, single stage with a single entry impeller, long coupled
28131455	Centrifugal pumps with a discharge outlet diameter > 15 mm, single-stage with double entry impeller
28131460	Centrifugal pumps with a discharge outlet diameter > 15 mm, multi-stage (including self-priming)
28131471	Rotodynamic single-stage mixed flow or axial pumps
28131475	Rotodynamic multi-stage mixed flow or axial pumps
28131480	Other liquid pumps, liquid elevators

PRODCOM statistics have the advantage of covering a wide range of pump products but there are weaknesses with this data, as it does not adequately distinguish between applications covered by each category (e.g. clean water or wastewater applications for the centrifugal pump series). For the aforementioned reasons, the aim of Task 2 will be to gather more detailed market data relying mostly on information provided directly by the industry for wastewater pumps covered in ENER Lot 28.

1.1.10 EN-, ISO- and other classifications used by standardisation bodies

Within the norm EN 12050 "Wastewater lifting plants for buildings and sites – principles of construction and testing" the related minimum free solid passages is listed as well as the minimum discharge requirements in relation to the application/use in fluids containing faecal matters or being faecal-free. BS EN 12056-2:2000 "Gravity drainage systems inside buildings" covers wastewater drainage systems that operate under gravity. It is applicable for drainage

systems inside dwellings, commercial, institutional and industrial buildings. This standard sets out principles to be followed for both layout and calculation. It makes limited provision for drainage systems conveying trade effluent and makes limited provision for fluids removed by pumps.

1.1.11 Labelling categories (EU Energy Label or EcoLabel)

There are currently no EU ecolabels that can be used as a basis for pump categorisation. The voluntary circulator scheme is a useful reference (Commission Regulation EC No 641/2009), in particular in the way that it takes account of operation at reduced flow. However, the flow-weighting scheme on which it is based is only feasible because the flow distribution is similar in most systems – which is not the case with most of the pumps considered in this study because they are used primarly at or close to maximum flow.

1.2 Proposed categorisation scheme for pumps

This section provides preliminary definitions of the products that could be included within the scope of the ENER Lot 28 study.

The high solids content of the fluids handled by of all the pumps covered in this study means that there are demanding operational constraints on the pump design, which could lead to lower operating efficiencies. For some pumps, at this stage the categories have been split into individual power ranges to make analysis easier to understand. Pumps may also have additional features through being customised for either mass market (small pumps) or designed for individual applications (large pumps).

1.2.1 Description of ENER Lot 28 pumps

- **Centrifugal submersible pumps**



Figure 1-12: Cutaway of a Submersible Pump showing the motor integrated with the impeller.

A submersible pump consists of an electric motor and pump, which is sealed into a single unit and submersed in the media being pumped, as shown in Figure 1-12. The advantages of the submersible concept are low investment costs and favourable duty conditions. A compact product allows a simple installation and the submersed installation means good conditions for cooling and prevents noise and cavitation up to a high extent.

These pumps are typically found in wastewater networks, as the submersed concept has a small visual impact and allows a narrow and simplified pumping station design. Standard submersible wastewater pumps are commonly available from very small sizes up to 600-1000 kW and are designed for flow rates from about 4 l/s up to over 2000 l/s. Sizes on the upper end of this type, (typically 160 kW or above) are usually designed as per customer's specifications ("engineered products").

Most pump manufacturers offer several different installation configurations of which the stationary wet well is the most common in wastewater pumping. Guided on vertical bars or rails, the pump is immersed to a discharge connection on the bottom of the tank where it seals to the pipe system by a levering motion using its own weight. It is a pull out type of system, which enables removal of the pump for maintenance purposes without needing to touch the pipe work or base mounting.

The electric motor is fitted in the stator casing to ensure excellent heat exchange with the surrounding water. If the stator is equipped with an external jacket and an internal circulation system for cooling the basic submersed concept can be adapted to dry installation conditions.

Most pumps have simple monitoring features to prevent product failure like sensors to detect seal leakage and high winding temperatures in the motor. Other common sensors can provide moisture levels in the motor, bearing temperatures or vibration levels. Some manufactures offer customized alarm systems that track parameters and allow remote monitoring of the pump duty conditions.

There are different types of impellers that can be used depending on the type of wastewater and solids being pumped. For wastewater containing soft and hard solids there are various designs of open or closed single or multi-vane impellers on the market. In case of raw wastewater containing large solids impeller types with large passages are traditionally used in order to

prevent clogging. While for larger pumps multi-channel impellers can provide the desired passages, typical impeller types providing large passages even for small sizes are vortex impellers or open or closed single vane impellers. For small pumps or especially fluids with high contents of soft but large solids, a cutting or grinding device might be used to break down the solids to sizes more suitable for pumping. For abrasive solids chromium iron versions of the above or vortex, impellers are often used. Some manufacturers offer special material options suitable in chemically demanding environments. A selection of impellers is shown Figure 1-13.



Figure 1-13: A selection of impeller types commonly found in wastewater and solid handling pumps

It is important to note that the use of vortex impellers will have an efficiency penalty when compared to other impeller types; however, they do offer the prospect of greater reliability and reduced wearing.

- **Centrifugal dry well pumps**



Figure 1-14: Dry well pump

A dry well pump, as shown in Figure 1-14, comprises an electric motor and a pump coupled together where the pump and motor are located outside the pumped liquid. The pump is connected to the piping system through flanges on suction and discharge side. For this type of pumps usually standard motors are used. Pump and motor are installed on a base frame with a shaft coupling between them. Executions where motor and pump are closed coupled are common too. Horizontal installations are possible as well as vertical installations. In some vertical installations the motor is installed separately on the second floor and connected to the pump through a cardanic drive.

The founding of the dry well concept is easier service and maintenance compared to submersible pump sets. Further the speed can get adjusted without using a VSD by use of belt drives.

Disadvantages are comparatively high investment cost and more space required for the installation.

Standard dry well wastewater pumps are commonly available from up to 600-800 kW and are designed for flow rates from about 4 l/s up to over 1600 l/s. Sizes on the upper end of this type (typically 160 kW[10]) or above are usually designed as per customer's specifications ("engineered products").

As discussed with regards to submersible pumps there are various impeller types that are selected depending on the size of the pump and on the type of wastewater and solids being handled.

Similar to centrifugal sumbersible pumps, the use of vortex impellers in case of cenrifugal dry well pumps will also have an efficiency penalty when compared to other impeller types, however, they do offer the prospect of greater reliability and reduced wearing.

- **Centrifugal submersible dewatering pumps**



Figure 1-15: A selection of dewatering pumps

Dewatering pumps are normally used to empty liquids holding abrasive solids in mines, quarries and construction sites. They are designed to be portable, to include a built in lifting handle to facilitate movement by hand or with a forklift, and to be able to stand alone on the ground with a hose or pipe connected to its discharge. Portability is also reflected in the material selection where aluminium often is used to reduce the weight and rubber coatings selected to prevent wear on critical parts.

In mines, dewatering pumps up to 6 kW are used at rock faces and in stopes to keep the water from the ground. Pumps up to approximately 20 kW are used for stage pumping which is a simple form of sump pumping. Above 20-30 kW the installation is normally more permanent and pumps with powers up to 100 kW are used for feeder pumping between intermediate levels. To keep the water at minimum level the smaller pumps, below 20 kW, often operate in a snoring condition were not enough water is fed to the hydraulic inlet. This can cause wear on the pumps as heavier solids cannot be transported away and thus accumulate inside the pump.

[10] This capacity limit value of 160 kW was proposed by Europump and still needs wider stakeholder agreement. Therefore stakeholders are encouraged to share their feedback on it.

Pumps for dewatering in mines and construction sites are designed for duty towards a high head, which makes 2-pole electric motors favourable. Many manufacturers also provide 2-stage solutions to duplicate the total output head for a certain pump diameter. Similar to the submersible pumps the pumped media is used to cool the stator. To allow lower water levels the liquid passes in between the stator and an external jacket before it reaches the outlet which can be either on the side or on the top of the pump.

The flow rates typically range from 4 to 80 l/s with heads typically up to 60m, although larger pumps, single or multi-stage, can have flows up to 200 l/s or heads up to 150m and a power rating of up to 100 kW.

Semi-open or closed multi vane impellers are used and the hydraulic clearances can be axially adjustable or stationary and fitted with radial wear rings. A strainer typically surrounds the hydraulics to prevent that rocks and grit larger than the pump free passage enter the inlet.

Some manufacturers provide complete pumps in stainless steel, cast iron or high chromium iron to allow operation in special applications.

- **Centrifugal domestic drainage pump**

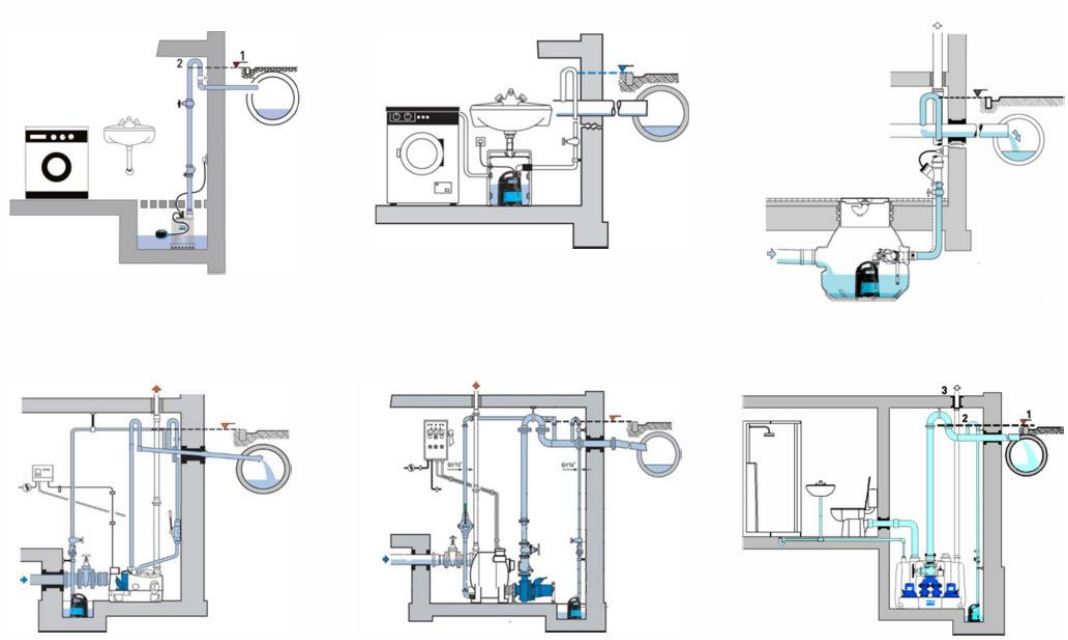


Figure 1-16: Examples of different domestic drainage pump configurations

In domestic situations, small drainage pumps are required to lift wastewater and drainage into the local sewerage collection network. These pumps are designed for domestic and commercial building flow rates and power supplies, therefore they are typically sized for flows between 1 and 40 l/s at 3 to 15 m head, and power ratings between 0.4 and 7.5 kW. Figure 1-16 shows the type of configurations for domestic drainage pumps.

Typically, the pump and motor section form a pressure-tight encapsulated unit, fully flood-proof, with motor housing constructed from corrosion resistant material, and the outer jacket and impeller of durable plastics. The pumps have integral level controls that control their operation.

Many of the pumps have a check valve built into the outlet to prevent the wastewater from flowing back into the sump.

- **Centrifugal commercial grinding/shredding pumps (full building dewatering)**

These pumps (Figure 1-17) are required in situations where the sizes of the solids in the wastewater are too large for downstream pump or pipework. They effectively grind/shred the solids into small pieces suitable for pumping. They are typically used in domestic, remote locations mostly inside pump sumps / shafts or where the topography or distances make it difficult to use gravity

The pump body is typically formed by a water pressure-tight encapsulated fully flood-proof motor and the pump section forms a compact, robust, unit construction. These hydraulic constructions may vary in different technologies. Each single construction has its own technical benefit in relation of reliability and operational lifetime, pressure, flow, and motor power. The grinding/shredding system is formed with a stationary cutting device in the inlet and a rotating cutting device that is typically placed at the end of the pump/rotor shaft.

Flow rates are available up to 8 l/s and power ratings up to 11 kW at the larger end of these pumps, although small commercial/domestic are typically rated at around 2 kW.



Figure 1-17: Commercial grinding pump

- **Centrifugal domestic shredding/grinding pumps**

These pumps (Figure 1-18 and Figure 1-19) are mainly used in combination with a toilet inside a building where gravity pipes cannot be used for removing the wastewater. This could be a toilet in the basement of a house. They cut solids into small parts that enable the wastewater to be removed in small pipe diameters.



Figure 1-18: Domestic shredding pump

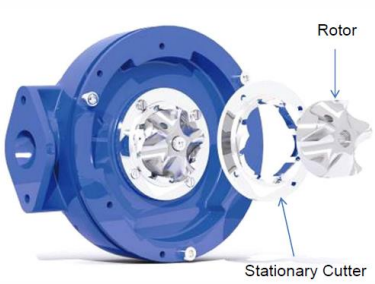


Figure 1-19: Example of a cutting mechanism in a shredding pump

- **Slurry Pumps**

Slurry pumps (Figure 1-20) are designed to pump heavy slurries, primarily in mining applications. These pumps are therefore designed to handle high concentrations of fine solids that are often very abrasive. The overwhelming slurry pump design goal is to minimise wear. Slurry pumps are usually designed with replaceable liners and other wear components. These pumps are engineered products tailored for individual applications, for example, the materials for impeller and volute/volute cladding have to be chosen individually, matching to the medium to be pumped. In some difficult applications, such as mill service, total pump life before refurbishment is required may well be under 1000 hours. As a general statement, in true slurry applications the pumps do not clog because they operate with relatively fine solids. Efficiency is not the top priority in most applications because from the start, the hydraulic components will wear and the initial efficiency cannot be maintained. Material selection is generally a compromise between wear and impact considerations.



Figure 1-20: Slurry Pumps

1.2.2 Screening analysis

A screening analysis was carried out in Task 1 to do a preliminary analysis of the overall environmental impacts, particularly energy consumption and savings potential of the pumps under consideration. The following types of pump were scrutinised in the screening analysis:

- Centrifugal pumps
  - Submersible pump
  - Dry well pump
  - Domestic drainage pump
  - Construction dewatering pump
  - Shredding/ grinding pump
- Slurry pumps
  - Light duty
  - Heavy duty

Note that the above types are subsequently split into further subtypes to reflect actual pumps available in the EU market.

In this study real life product, usage needs to be reflected[11]. Therefore, current norms guide the way in which consideration is given to the products for each application.

The key criteria considered in the screening analysis include:

- Estimated total energy saving potential – this is largely a pragmatic consideration, as it will be better to focus on developing a robust case for the big energy saving targets than to attempt to regulate everything conceivably in scope.
- Different products available to fulfil the application duty – regulations under the Ecodesign Directive are based on functionality requirements. From the product type- application matrix, it is clear both that all pumps can be used in more than one application, and that all applications can be served by more than one type of pumps. This means that in theory each pump type could be phased out if technologies that are more efficient can fulfil the same function, especially given the very deep conservatism of this market in which previous advances in more efficient technologies did not lead to significant changes in selection behaviour.
- Size of custom / specials market –Where products are usually built to custom specifications, often referred to as "Engineered" products, the detailed variations in design and the increased likelihood of attention being given to energy saving means that attempting to regulate this type of product will be extremely hard.

The screening analysis was an iterative process conducted with collaboration with the stakeholders.

1.2.3 Energy Saving Estimates of pump types

The table below shows the annual energy consumption and energy savings potential (at both product level and extended-product level) for the stock of the pumps considered for the screening analysis[12].

At the time of writing Task 1, there are only initial estimates of the technical energy saving potential of the pumps considered. These are the result of a survey of pump manufacturers and users, which has in turn been challenged by the study team in light of final report of ENER Lot 11 study and other information. This saving potential is based on the difference between the industry norm (which can also be considered as being the basecase design), and what is technically achievable using current technologies. These estimates may likely be different from those later in the study, as these later estimates will also be considering the impact of removing from the market those with efficiencies less than the basecase average. A key factor will be the

[11] Information on usage patterns of pumps can be found in Task 3, Section 3.2.1

[12] Source: Europump

spread of efficiencies of pumps of a particular type, the wider it is the greater the potential that there is for energy saving. Larger pumps will have higher efficiencies and hence a smaller spread, and so the energy saving potential will be less. The relationship between the energy savings estimated in Task 1 and the actual energy savings achievable by setting MEPS at different values is complex and explained in length in the final report of ENER Lot 11 preparatory study.

In addition to the energy consumption and energy savings potential, the contribution of each of the pumps covered in the screening exercise to the overall environmental impacts (over the life cycle) due to all of these pumps is estimated and presented in Table 4.

Table 3: Annual energy consumption and energy savings potential (both at product level and extended-product level) for the stock of the pumps considered for the screening analysis in 2011[13]

Pump Type	Annual energy consumption (in GWh)	Product level savings (in GWh)	Share of annual energy consumption (in %)	Share of annual product level savings (in %)	Unit level savings from EPA %	Existing market penetration of EPA%	Potential energy savings to overall market from EPA Regulation %
Centrifugal submersible pump							
Radial sewage pumps 1 to 10 kW	3 808	114	12%	16%	20%	5%	13%
Radial sewage pumps >10 to 25 kW	2 295	69	7%	10%	20%	7%	11%
Radial sewage pumps >25 to 160 kW	8 925	179	29%	25%	20%	20%	8%
Mixed flow & axial pumps	858	17	3%	2%	40%	24%	12%
Centrifugal submersible pump – once a day operation							
Shredding, grinding pumps	13	0.3	0.04%	0.04%	0%	0%	8%
Radial sewage pumps 1 to 10 kW	44	2	0.14%	0.28%	0%	0%	12%
Where volute is part of a tank	14	0.7	0.05%	0.10%	0%	0%	12%
Centrifugal submersible domestic drainage pump < 40 mm passage	88	9	0.28%	1.27%	0%	0%	15%

[13] Following further analysis on the radial sewage pump market, it is proposed to make the top category for both types 25 – 160kW.

Pump Type	Annual energy consumption (in GWh)	Product level savings (in GWh)	Share of annual energy consumption (in %)	Share of annual product level savings (in %)	Unit level savings from EPA %	Existing market penetration of EPA%	Potential energy savings to overall market from EPA Regulation %
Submersible dewatering pumps	2 940	147	19%	19.25%	0%	0%	10%
Centrifugal dry well pump							
Radial sewage pumps 1 to 10 kW	765	23	2%	3%	20%	5%	7%
Radial sewage pumps >10 to 25 kW	717	22	2%	3%	20%	7%	7%
Radial sewage pumps >25 to 160 kW	1 785	36	6%	5%	20%	20%	5%
Mixed flow & axial pumps	64	0.6	0.21%	0.08%	0%	0%	1%
Slurry Pumps							
Light duty	7800	78	25%	11%	0%	3%	1%
Heavy duty	888	8.9	3%	1%	0%	3%	1%
Total	31004	706					

Table 4: Contribution (in %) of each of the pumps covered in the screening exercise to the overall environmental impacts due to all of these pumps[14]

Environmental impact category	Units	CS RSP 1 to 10	CS RSP 10 to 25	CS RSP 25 to 1000	CS MFAP	CS1 SG	CS1 RSP 1 to 10	CS1 V	CDWP RSP 1 to 10	CDWP RSP 10 to 25	CDWP RSP 25 to 1000	CDWP MFAP	SP LD	SP HD	Total
Total Energy (GER)	PJ	14%	8%	32%	3%	0,1%	0,2%	0,1%	3%	3%	6%	0,2%	27,8%	3,2%	100%
of which, electricity (in primary PJ)	PJ	14%	8%	32%	3%	0,0%	0,2%	0,1%	3%	3%	6%	0,2%	27,9%	3,2%	100%
Water (process)	mln. m3	14%	8%	32%	3%	0,1%	0,2%	0,1%	3%	3%	6%	0,2%	27,9%	3,2%	100%
Water (cooling)	mln. m3	14%	8%	32%	3%	0,0%	0,2%	0,1%	3%	3%	6%	0,2%	27,9%	3,2%	100%
Waste, non-haz./ landfill	kt	17%	8%	30%	3%	1,2%	2,8%	1,0%	3%	2%	5%	0,2%	23,8%	2,9%	100%

[14] The methodology is the same one that was used in task 5 to calculate for environmental impact of the bases cases

Environmental impact category	Units	CS RSP 1 to 10	CS RSP 10 to 25	CS RSP 25 to 1000	CS MFAP	CS1 SG	CS1 RSP 1 to 10	CS1 V	CDWP RSP 1 to 10	CDWP RSP 10 to 25	CDWP RSP 25 to 1000	CDWP MFAP	SP LD	SP HD	Total
Waste, hazardous/ incinerated	kt	14%	8%	32%	3%	0,1%	0,2%	1,0%	3%	3%	6%	0,2%	27,5%	3,1%	100%
Greenhouse Gases in GWP100	mt CO_2 eq.	14%	8%	32%	3%	0,1%	0,3%	0,1%	3%	3%	6%	0,2%	27,7%	3,2%	100%
Acidification, emissions	kt SO_2 eq.	14%	8%	32%	3%	0,1%	0,3%	0,1%	3%	3%	6%	0,2%	27,6%	3,2%	100%
Volatile Organic Compounds (VOC)	kt	15%	8%	31%	3%	0,4%	1,0%	0,4%	3%	3%	6%	0,2%	26,7%	3,2%	100%
Persistent Organic Pollutants (POP)	g i-Teq	18%	8%	29%	3%	1,4%	3,2%	0,9%	3%	2%	5%	0,2%	23,2%	3,1%	100%

Environmental impact category	Units	CS RSP 1 to 10	CS RSP 10 to 25	CS RSP 25 to 1000	CS MFAP	CS1 SG	CS1 RSP 1 to 10	CS1 V	CDWP RSP 1 to 10	CDWP RSP 10 to 25	CDWP RSP 25 to 1000	CDWP MFAP	SP LD	SP HD	Total
Heavy Metals	ton Ni eq.	15%	8%	31%	3%	0.4%	1.1%	0.4%	3%	2%	6%	0.2%	26.5%	3.1%	100%
PAHs	ton Ni eq.	15%	8%	31%	3%	0.5%	1.3%	0.5%	3%	2%	6%	0.2%	26.1%	3.0%	100%
Particulate Matter (PM, dust)	kt	21%	7%	25%	2%	2.4%	5.7%	2.8%	3%	2%	5%	0.3%	19.6%	3.6%	100%
Heavy Metals	ton Hg/ 20	15%	8%	31%	3%	0.4%	1.0%	0.3%	3%	2%	6%	0.2%	26.6%	3.1%	100%
Eutrophication	kt PO_4	19%	8%	27%	2%	1.9%	4.4%	1.5%	3%	2%	5%	0.3%	21.4%	3.2%	100%

The abbreviations used for the pump names in Table 4 *are presented below:*

Centrifugal submersible pump

Radial sewage pumps 1 to 10 kW	*(CS RSP 1 to 10)*
Radial sewage pumps >10 to 25 kW	*(CS RSP 10 to 25)*
Radial sewage pumps >25 to 1000 kW	*(CS RSP 25 to 1000)*
Mixed flow & axial pumps	*(CS MFAP)*

Centrifugal submersible pump – once a day operation

Shredding, grinding pumps	*(CS1 SG)*
Radial sewage pumps 1 to 10 kW	*(CS1 RSP 1 to 10)*
Where volute is part of a tank	*(CS1 V)*

Centrifugal dry well pump

Radial sewage pumps 1 to 10 kW	*(CDWP 1 to 10)*
Radial sewage pumps >10 to 25 kW	*(CDWP 10 to 25)*
Radial sewage pumps >25 to 1000 kW	*(CDWP 25 to 1000)*
Mixed flow & axial pumps	*(CDWP MFAP)*

Slurry Pumps

Light duty	*(SP LD)*
Heavy duty	*(SP HD)*

The following observations can be made from Table 4 concerning the share of environmental impact of each of the following pump types are:

- Centrifugal submersible pump – once a day operation: less than 5% for all the environmental impact indicators other than:
  - Particulate Matter (PM, dust): 10.8%
- Centrifugal dry well pump – mixed flow & axial pumps: less than 1% for all the environmental impact indicators
- Centrifugal submersible domestic drainage pump < 40 mm passage: less than 5% for all the environmental impact indicators other than:
  - Persistent Organic Pollutants (POP): 9.9%
  - PAHs: 7.4%
  - Particulate Matter (PM, dust): 11.5%
  - Eutrophication: 10.5%
- Slurry pumps – Light Duty: More than 20% for all the environmental impact indicators other than:
  - Particulate Matter (PM, dust): 19.6%
- Slurry pumps – Heavy Duty: Around than 3% for all the environmental impact indicators

1.3 Test Standards

This section identifies the relevant test standards and procedures.

In technical use, a standard is a concrete example of an item or a specification against which all others may be measured or tested.

The focus is on the environmental performance and related technical aspects, e.g. energy consumption in relation to functional performance of the product. The issue of particular interest is standardisation methodology and related parameters, e.g. allocation of environmental loads to different life cycle stages, usage scenarios, and data requirements.

1.3.1 Test Procedure

For pumps moving wastewater, they typically operate between 80-105% of rated duty. A key driver of this requirement is that at reduced speed the fluid may not flow satisfactorily. For example solids may fall out of suspension, stringy materials become caught, or sticky materials adhere to surfaces. There is therefore no need to characterise wastewater pumps at anything other than rated duty.

The possible exception is Archimedes screw pumps, which self regulate and so might spend considerable periods of time at lower flows.

1.3.1.1 Verification of efficiency values

It is important that the actual efficiencies of products placed on the market comply with any claimed energy performance class. Manufacturers currently use a statistical approach such that all of their pumps (except for a small statistical proportion) will exceed the declared efficiency value after allowing for the permitted test tolerance. Clean water pumps test typically to ISO 9906:2012 Grade 2, which allows for a - 5% tolerance on quoted efficiency. This is also the standard used for testing WWT pumps, although it is obviously not an appropriate indicator of how a pump will wear when subject to real life operating conditions.

(Acceptance) testing is generally done at the manufacturer's own test facility, and may be witnessed by a representative of the purchaser. For larger pumps, a user may request a test of the actual pump to Grade 1, but this costs additional money, and so will not be done unless specifically requested.

Although ISO 9906 does also publish the measurement uncertainties for different measurement techniques, manufacturers will not normally make any specific allowance during acceptance testing for the uncertainties inherent in their test methods, since these uncertainties will usually be less than the permitted tolerance.

Manufacturers will take a statistical risk in how they position the declared and mean production values of efficiency. Those who control production to give a tighter spread may choose either to produce pumps with a lower mean efficiency and reap any cost savings, or quote a higher efficiency.

It is often the case that only the manufacturer will actually test a small percentage of each pump size included in this report, either for customers or for quality control purposes.

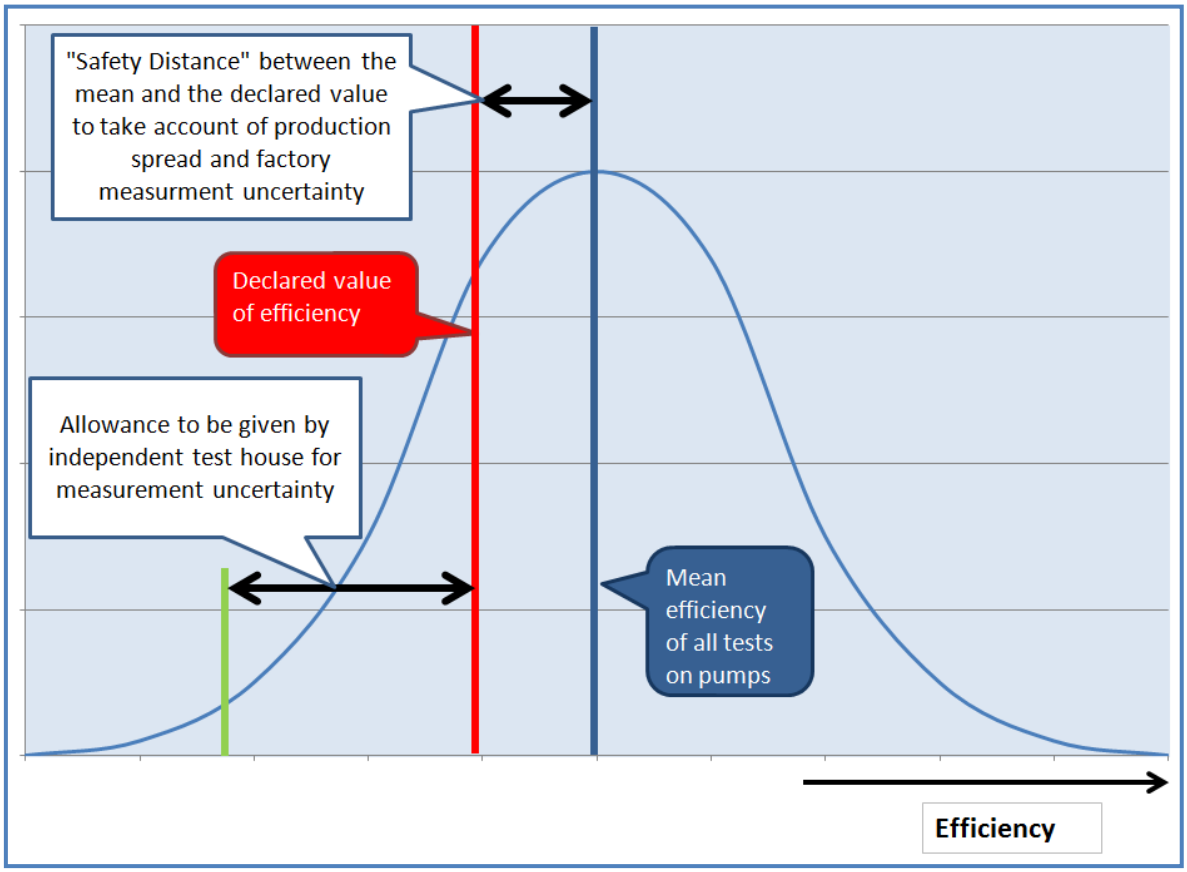


Figure 1-21: Testing and verification of pumps (only relevant to testing of products by an external test house

Care needs to be taken in defining MEPS to take account of allowed tolerances and measurement accuracy. The risk is that the cumulative allowances undermine any regulations.

An efficiency standard will have a tolerance, usually but not always positive and negative. In addition, during compliance testing, the measurement uncertainty must be added on. Therefore, in practice, a manufacturer has to be sure that their product will exceed the published minimum efficiency level, minus the allowed tolerance and minus the measurement uncertainty.

1.3.2 Standards at European Union level

There are no energy related standards that the consortium is aware of for any of the products with ENER Lot 28. However, there are many technical standards governing the construction and design of these pumps, as presented in Table 5.

The CEN TC197 "Pumps" technical committee has been created in 1990 to prepare and publish European standards, establishing the technical safety requirements for liquid pumps and pump units, in conformity with the Machinery Directive 89/392/CE.

Table 5: Non energy-related EU standards relevant for pumps for wastewater and fluids with high content

Reference	Title
EN 1092-2	Flanges and their joints. Circular flanges for pipes, valves, fittings and accessories, PN designated. Cast iron flanges
EN 12483	Liquid pumps. Pump units with frequency inverters. Guarantee and compatibility tests.
EN 12723	Liquid pumps. General terms for pumps and installations. Definitions, quantities, letter symbols and units.
EN 13463-1	Non-electrical equipment for potentially explosive atmospheres. Basic method and requirements.
EN 60034	Rotating electrical machines
EN 733:1995	End-suction centrifugal pumps, rating with 10 bar with bearing bracket. Nominal duty point, main dimensions, designation system
EN 12050	Wastewater lifting plants for buildings and sights – principles of construction and testing
EN 12056	Gravity drainage systems inside buildings
EN 809	Pumps and pump units for liquids
ISO 9908	Technical specifications for centrifugal pumps – Class III

1.3.3 Standards at Member State level

The UK water industry uses the Water Industry Mechanical and Electrical Specifications (WIMES) specifications for the purchase of electrical and mechanical equipment. Standards relevant to ENER Lot 28 products are:

Table 6: Water Industry Mechanical and Electrical Specifications (WIMES) specifications (UK)

Reference	Title
WIMES 10.1	Axial Split Casing Pump Unit
WIMES 10.2	Submersible Pump Unit
WIMES 10.3	Dry Well Sewage Sludge Pump Unit
WIMES 10.4	Progressive Cavity Pump Set

WIMES 10.6	Positive Displacement Pump Set for Sludge Pumping Duties

Also in the UK, WRc Plc[15] publish 'Sewers for Adoption - A Design and Construction Guide for Developers' which, amongst other items, details the requirements for designing wastewater pumping stations that can be connected to the main wastewater collection system. It states the following pump test requirements for all pumps

- The pumpsets shall be tested at the manufacturer's premises to EN ISO 9906 to demonstrate that they are capable of achieving the specified design duty. Type-test curves are acceptable for verification of performance. But it should be noted that this is not an indicator of real life performance when pumping dirty water.
- Characteristic curves of pump-generated head, efficiency and pump and pumpset absorbed power versus flow rate shall be provided before the pumpsets are delivered to Site.
- Hydraulic drop tests shall be carried out by the Developer on-site in the presence of the Undertaker to verify the theoretical performance of each pumpset. The results of these tests shall be recorded and placed in the Pumping Station O & M Manuals.

Many other countries have national standards such as in Germany which has ATV A 115; ATV A 116; ATV A 130;

1.3.4 International Standards

Table 7 presents the international standards relevant for ENER Lot 28 pumps.

Table 7: International Standards

Reference	Title
ISO 1940-1	Mechanical vibration. Balance quality requirements for rotors in a constant (rigid) state. Specification and verification of balance tolerances
EN ISO 9906	Rotodynamic pumps. Hydraulic performance acceptance tests. Grades 1, 2 & 3.

1.3.5 Summary of test standards

In the absence of any standard for testing WW pumps, the current situation is that, these pumps are tested using ISO 9906 standard for clean water applications of pumps. This is not ideal for

[15] www.wrcplc.co.uk/

WW, but is established and gives a fair comparison between different products working for a similar application.

The proposal is that any resulting ErP MEPS regulations are based on this clean water standard. It will though be for the manufacturers to verify that it functions properly under the particular type of application and WW. In practice it means that it will be for them to use, whatever form of proof is going to be convincing, for example field trials or demonstrations.

It is estimated that defining tests to test pumps with different types of WW would involve a lot of time, and the cost of test rigs would be considerable.

1.4 Existing Legislation

1.4.1 Legislation and Agreements at European Union Level

1.4.1.1 Energy related legislation

At this stage, the general approach for the methodology used for clean water pumps (**Regulation 547/2012**[16]) should be applied also for pumps in ENER Lot 28. Some aspects will/may differ as more evidence is collected in later tasks of this study:

- The curves generated for clean water pumps relate to the hydraulic "wet" end only. They will not hold true if a product is regulated with a motor, as motor efficiency will not necessarily vary in sympathy with hydraulic efficiency.
- The performance will be measured at rated flow only. The "House of Efficiency" used for clean water pumps shall not be needed. This is because most WW pumps work at or close to rated duty. They are used for moving WW, which is inherently an on/off operation rather than varying duty.
- The clean water regulations were based on full impeller only. Impeller trimming is far less common with WW pumps, and so this is even less of an issue.
- The pump can be regulated by itself (either as a single component, or a combined or integrated product), irrespective of any additional Extended product regulations.
- Some simpler products may not require the same detailed numerical approach used for clean water pumps. In particular, the smaller types where the usual hydraulic relationships may be spoiled by other size effects becoming important.

In summary, it is suggested for WW pumps, just to regulate their efficiency, leaving it to manufacturers to warrant performance in a particular application. This approach mimics real life product specification.

[16] COMMISSION REGULATION (EU) No 547/2012 of 25 June 2012 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for water pumps. Source: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:165:0028:0036:en:PDF

1.4.1.2 *Environmental legislation*

- **Overview of the WEEE (Waste Electrical and Electronic Equipment) Directive 2012/19/EU**

The WEEE Directive is one of a small number of European Directives that implement the principle of "extended producer responsibility". Under this principle, producers are expected to take responsibility for the environmental impact of their products, especially when they become waste. The WEEE Directive applies this in relation to electrical and electronic equipment (EEE).

The broad aims of the WEEE Directive are to address the environmental impacts of electrical and electronic equipment and to encourage its separate collection, and subsequent treatment, reuse, recovery, recycling and environmentally sound disposal.

The WEEE Directive seeks to improve the environmental performance of all operators involved in the life cycle of EEE, especially those dealing with the end of life of EEE. Accordingly, it sets certain requirements relating to the separate collection of waste of EEE, standards for its treatment at permitted facilities, and requires its recycling and recovery to target levels. It makes producers responsible for financing the majority of these activities. Distributors have responsibilities in terms of the provision of facilities to enable the free take-back of waste of EEE by consumers and also the provision of certain information to consumers of EEE.

Options for Ecodesign measures might include those that contribute to the WEEE implementation in contributing to waste prevention in reducing materials use, when possible, and in introducing e.g. easier disassembly, which will make reuse and recycling of energy using products easier.

The product must meet the following three criteria under the WEEE legislation:

- Main power source is electricity (including batteries)
- Less than 1,000v AC or 1,500v DC
- Electricity is needed for primary function

Even if a pump is sold without a motor, it will usually be powered by an electric motor. For the pumps in the power range considered in this study, this will be less than 1,000v AC. The pump would therefore pass the first three criteria. Given the maximum size of the motor stated, the only types of pumps in the study that are covered by the WEEE Directive are Centrifugal Submersible Domestic Drainage Pumps. These types of pumps are freely available to households from most DIY stores. The other pumps in this study are typically sent to scrap at the end of life due to the high value of the recyclable materials. Therefore they are likely to be disposed of in a manner compliant with the requirements of the WEEE directive

.

- **RoHS (Restriction of Hazardous Substance Directive) 2011/65/EU**

The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2006 ("the RoHS Regulations") implement the provisions of the European Parliament and Council Directive on the Restrictions of the use of certain Hazardous Substances in electrical and electronic equipment ("the RoHS Directive"), as amended. The RoHS

2 directive (2011/65/EU) is an evolution of the original directive and became law on 21 July 2011 and took effect 2 January 2013. It addresses the same substances as the original directive while improving regulatory conditions and legal clarity. It requires periodic reevaluations that facilitate gradual broadening of its requirements to cover additional electronic and electrical equipment, cables and spare parts.

The RoHS 2 Regulations ban the putting on the EU market of new Electrical and Electronic Equipment (EEE) containing more than the permitted levels of certain materials[17].

In order to put products on the market in the EU, manufacturers need to ensure that their products and product components comply with the requirements of the Regulations.

It is not felt that any of the pumps in scope fall within the RoSH2 regulations.

In addition, the MEEUP modelling and analysis will show if any products do contain any of the substances listed in the footnote, in which case a discussion to justify the continued use or phasing out of these substances will be developed

1.4.2 International Legislation

There is no legislation that the consortium is aware of, that imposes significant additional technical constraints on the design or construction of pumps in ENER Lot 28 beyond the factors already mentioned.

The American Petroleum Institute (API) imposes standards for pumps used in the oil industry. These are driven by safety requirements, which often result in reduced efficiency through demanding for instance larger clearances. It is understood that these standards do not impact on the design of water pumps for the European market.

[17] Lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) or polybrominated diphenyl ethers (PBDEs).

1.5 Product performance assessment

Definition of the Extended Product Approach

It is important to distinguish between the Extended Product Approach (EPA) and the Extended Product (EP).

Extended Product Approach (EPA): is a methodology to calculate the energy efficiency Index (EEI) of an Extended Product (EP), which incorporates load profiles and control method. The Energy Efficiency Index (EEI) is a dimensionless figure used to define the energy efficient performance of pumps. Unlike the Minimum Efficiency Index (MEI)[18] it also takes into consideration efficiency related factors from load profiles and control methods.

Extended Products (EP): consists of physical components

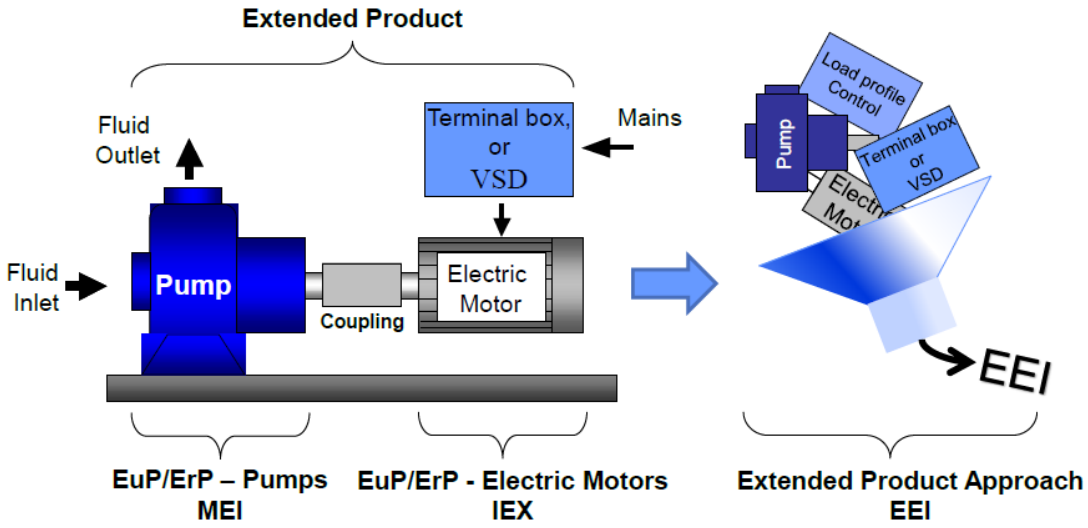


Figure 1-22 Definition of Extended Product Approach – (Source Europump)

The EPA thus extends the boundary of the product to include not just the pump itself, but also the motor and any controls within the defined system. By doing this, the much larger energy savings that are possible from the optimum selection and control of components under real life operating conditions can be achieved.

While the focus of the EPA is on the system, actually it will only regulate the pump, motor, and controls– it will not consider any pipework (hydraulic) or indeed cabling (electrical) losses that are within the system. This approach is in line with that used in the ENER Lot 11 Circulator regulation[19].

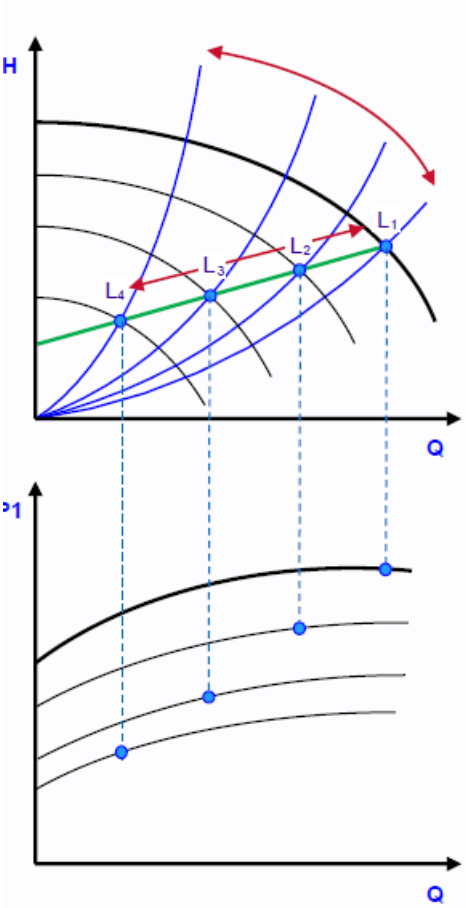
Extended Product Approach System Types

[18] The Minimum Efficiency Index (MEI) is a dimensionless figure that is derived from a complex calculation based on a pump's efficiencies at the best efficiency point (BEP), 75% BEP and 110% BEP and the specific speed. The range is used so that manufacturers do not take an easy option of providing good efficiency at one point.

[19] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0035:0041:EN:PDF

The EPA can be used with both closed loop systems, such as circulator pump systems, and open loop systems, such as wastewater collection systems. It can also be used in for constant flow systems and variable flow system. The result of this is that the EPA can be applied to all the pump types considered in this study.

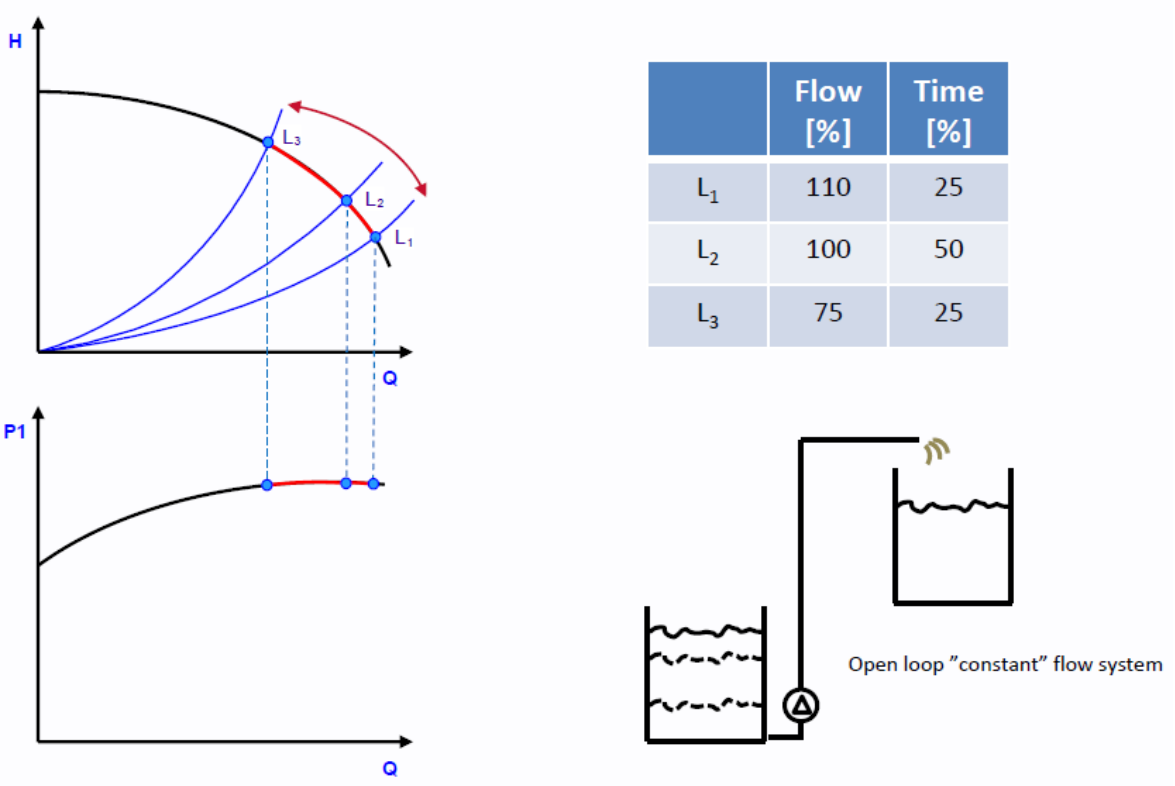
In order to apply the EPA to a particular pump application a load profile first needs to be derived. A load profile describes the proportion of time a pump typically spends pumping a particular flow rate. In variable flow systems this change is flow rate can achieve through the use of variable speed drives, or through throttling valves in the system. An example of a load profile in variable flow systems is shown in the figure below.



	Flow [%]	Time [%]
L_1	100	6
L_2	75	15
L_3	50	35
L_4	25	44

Figure 1-23 Load profile for a typical variable flow system such as found in HVAC systems (Source Europump)

In constant flow system the change of flow can be due to a change in the static head, such as occurs when a wet well empties. An example of load profile for a constant flow system is shown in Figure 1-24



	Flow [%]	Time [%]
L_1	110	25
L_2	100	50
L_3	75	25

Figure 1-24 Load profile for a typical constant flow system

The pumps considered within the scope of this study are typically used in constant flow applications and as such there are likely to have load profiles similar to that shown in Figure 1-24. Each individual pump type requires its own load profile.

1.6 Conclusions

Task 1 presents an overview of the pumps commonly used to handle wastewater and solids.

The primary function of ENER Lot 28 pumps is to pump the three main types of WW (as defined in section 1.1.1). The WW properties are important as the pumps within scope are required to pump fluids with a range of per cent dry solids content, solids sizes, fibre length, hardness of solid, temperature, corrosive chemical content and viscosity.

After initial screening processes, those pumps which are not used for the primary functionality of ENER Lot 28 pumps (such as pumps mainly used to pump very viscous liquids and corresponding to the secondary functionality of ENER Lot 28 pumps) and engineered pumps were eliminated. This means that the pumps excluded from the scope are:

- Positive displacement pumps as they are used for pumping viscous liquids.
- Archimedean screw pumps as they are considered to be engineered products
- Pumps with a capacity over 160 kW as they are considered to be engineered products

The following types of remaining pumps are proposed to be included within the scope of the ENER Lot 28 study (with an upper capacity limit of 160 kW):

- Centrifugal Submersible pumps (radial sewage, mixed flow and axial flow)
- Centrifugal Submersible - once a day operation pumps (shredding, grinding, radial sewage and where volute is part of tank)
- Centrifugal submersible domestic drainage pumps < 40 mm passage
- Centrifugal submersible Dewatering pump
- Centrifugal drywell pumps (radial sewage, mixed flow and axial pumps)
- Slurry pumps (both light duty and heavy duty)

In common with clean water pumps, WW and solids handling pumps are currently tested to ISO 9906:2012 Grade 2. They are tested using clean water, which does not provide an appropriate indication of how the pump will wear when subject to real life operating conditions, but no alternative to it is currently available or foreseeable in near future, at time of drafting this report. It is therefore proposed to use the ISO 9906:2012 Grade 2 standard as basis for the environmental and economic analysis to be performed in ENER Lot 28 study.

At this stage, it is perceived that the general approach for the methodology used for clean water pumps (**Regulation 547/2012**) should be applied also for pumps in ENER Lot 28, regulate according to their relative efficiency pumping clean water, and placing emphasis on manufacturers to warrant performance in a particular WW application. This approach is in line with real life product selection and specification.

The Extended Product Approach considers the energy consumption of the entire pump + motor + controls system, based on assumed duty profiles. In this way it is similar to the existing

regulations governing Circulators. Within this study, it will be necessary to reflect the performance of both the individual pump "wet end" (MEI) and the Extended Product (EEI)[20].

[20] This will need to be done in coordination with Europump. An agreement has already been reached with Europump in this context. Hence, the successful reflection of MEI and EEI values in this study is based on the assumption of timely inputs from Europump.

Annex A

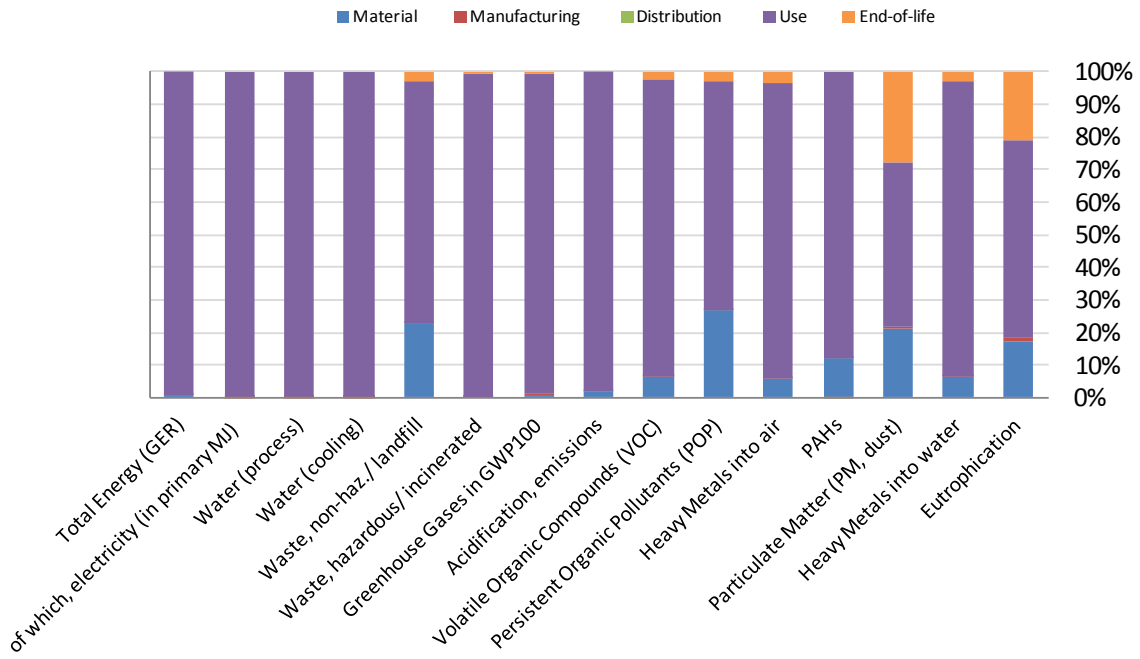


Figure 1-25: Relative significance of each life cycle phase per environmental impact category CS RSP 1 to 10

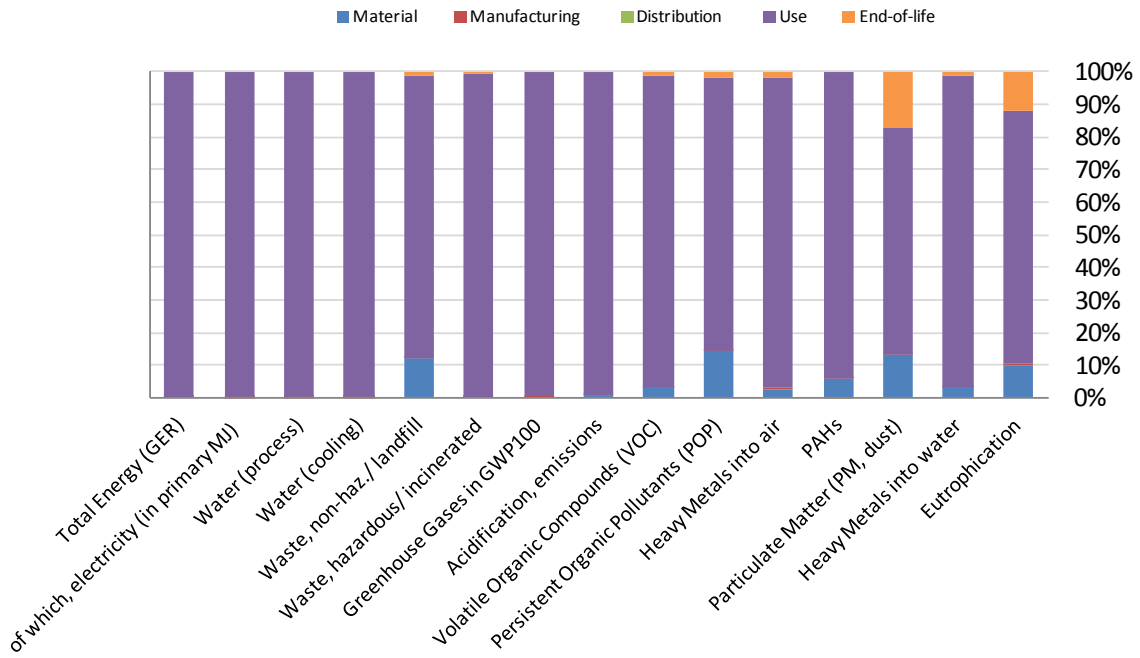


Figure 1-26: Relative significance of each life cycle phase per environmental impact category CS RSP 10 to 25

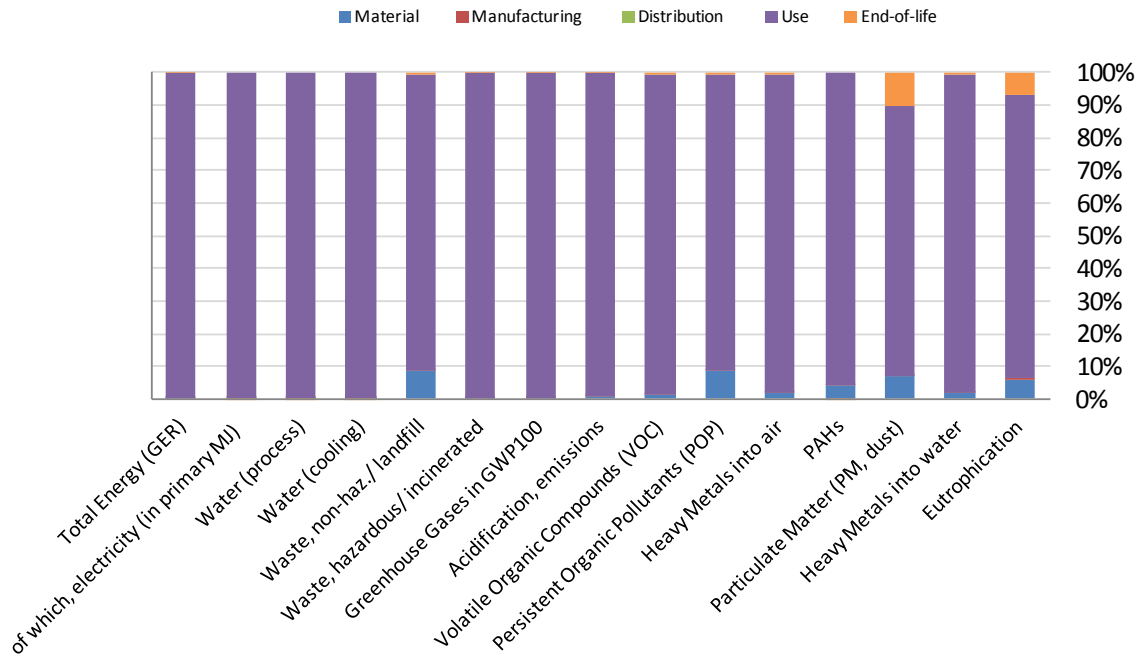


Figure 1-27: Relative significance of each life cycle phase per environmental impact category CS RSP 25 to 1000

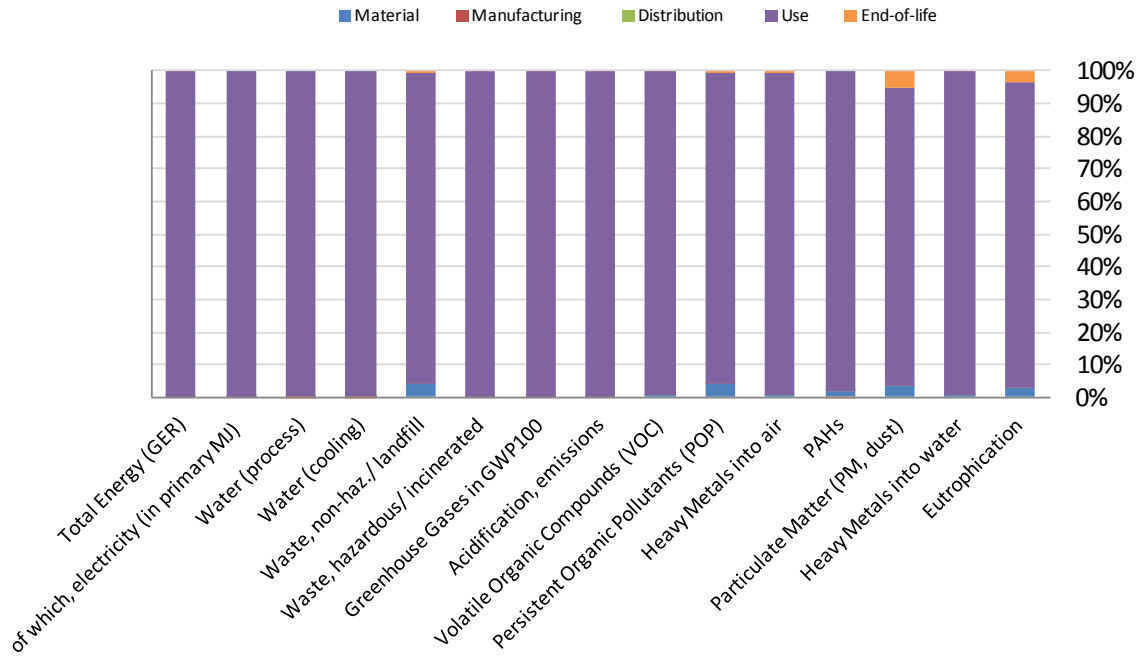


Figure 1-28: Relative significance of each life cycle phase per environmental impact category CS MFAP

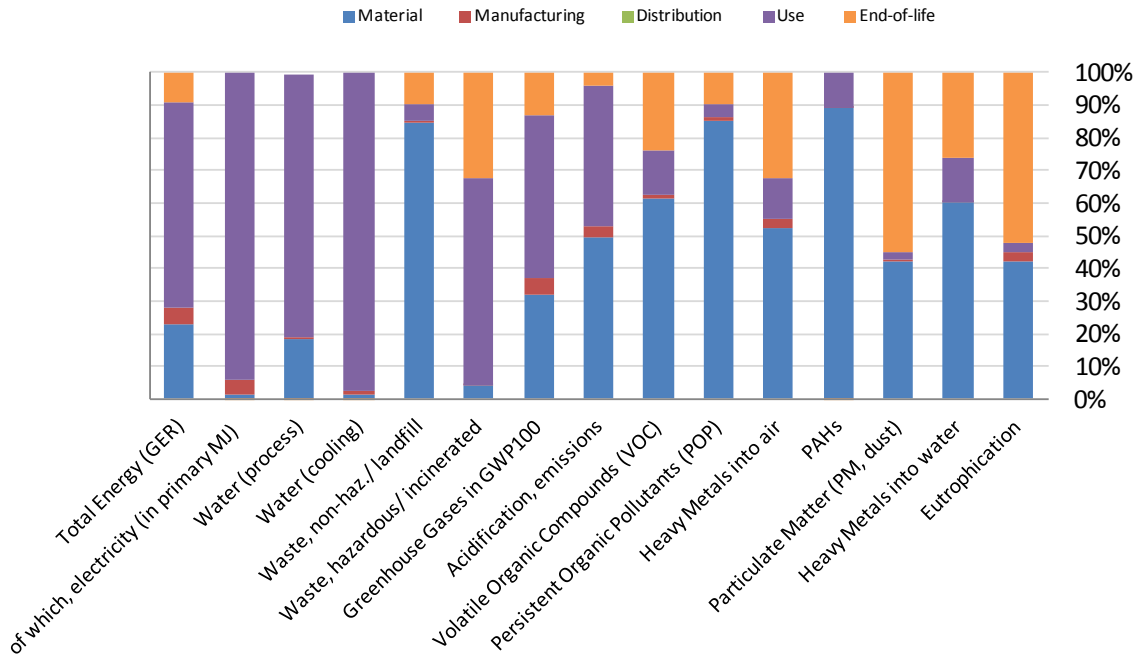


Figure 1-29: Relative significance of each life cycle phase per environmental impact category CS1 SG

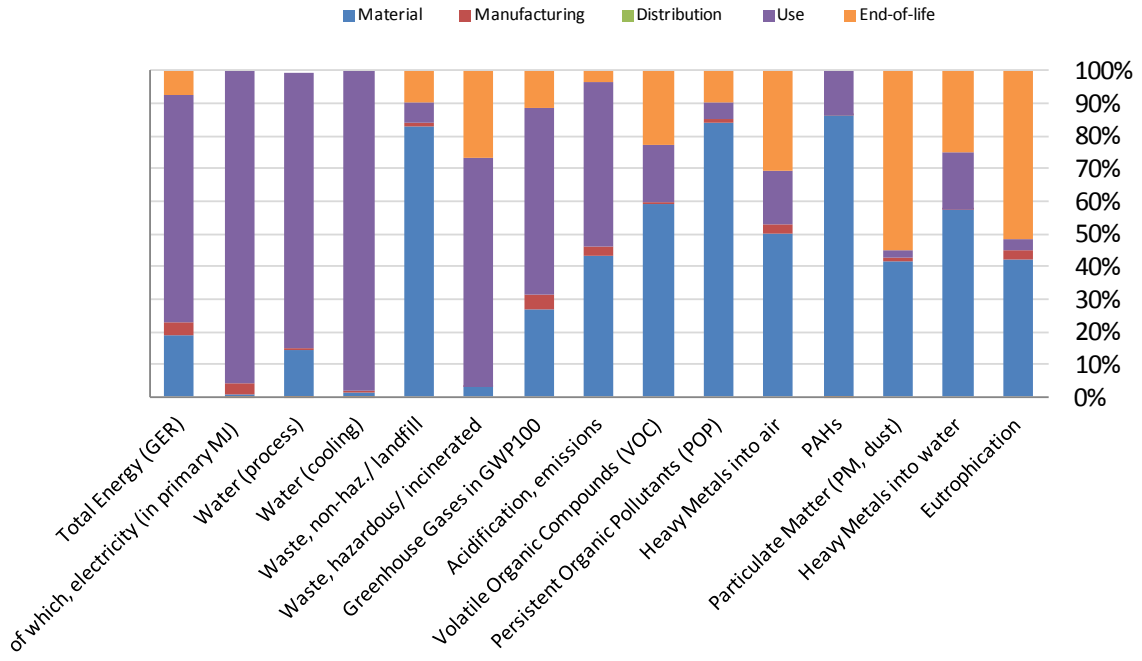


Figure 1-30: Relative significance of each life cycle phase per environmental impact category CS1 RSP 1 to 10

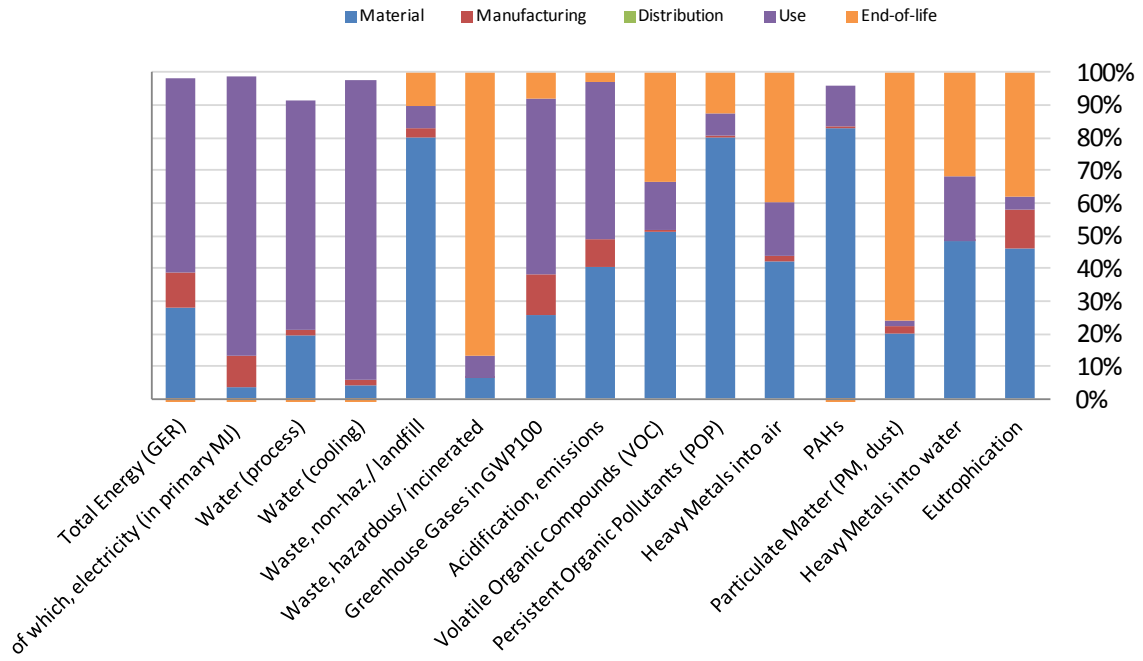


Figure 1-31: Relative significance of each life cycle phase per environmental impact category CS1 V

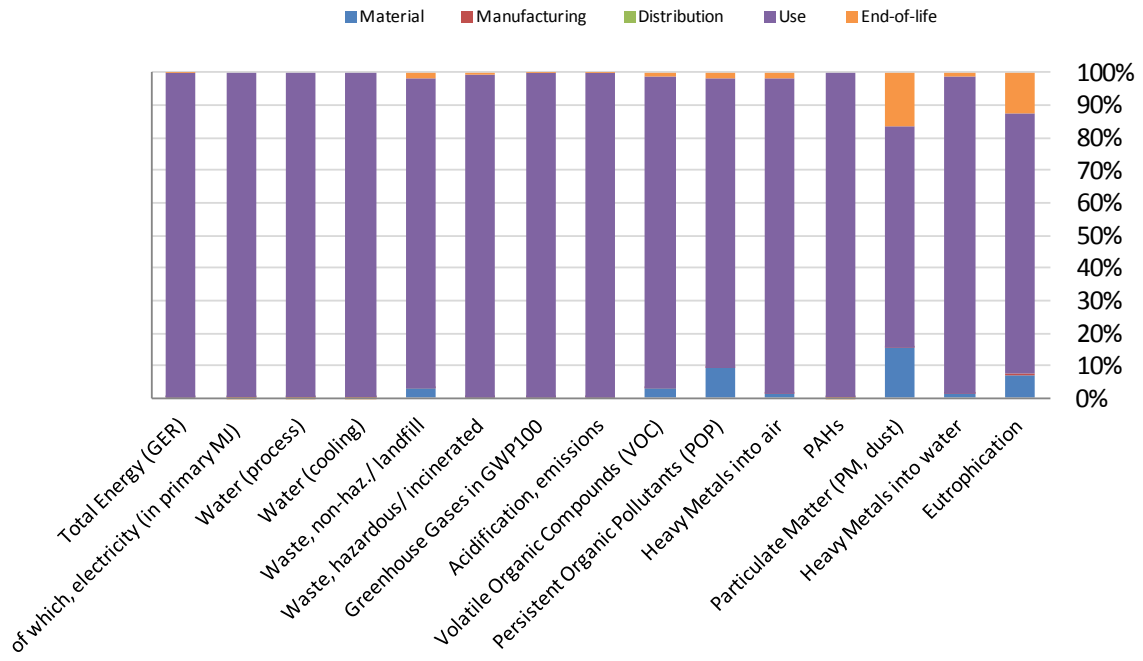


Figure 1-32: Relative significance of each life cycle phase per environmental impact category CDWP RSP 1 to 10

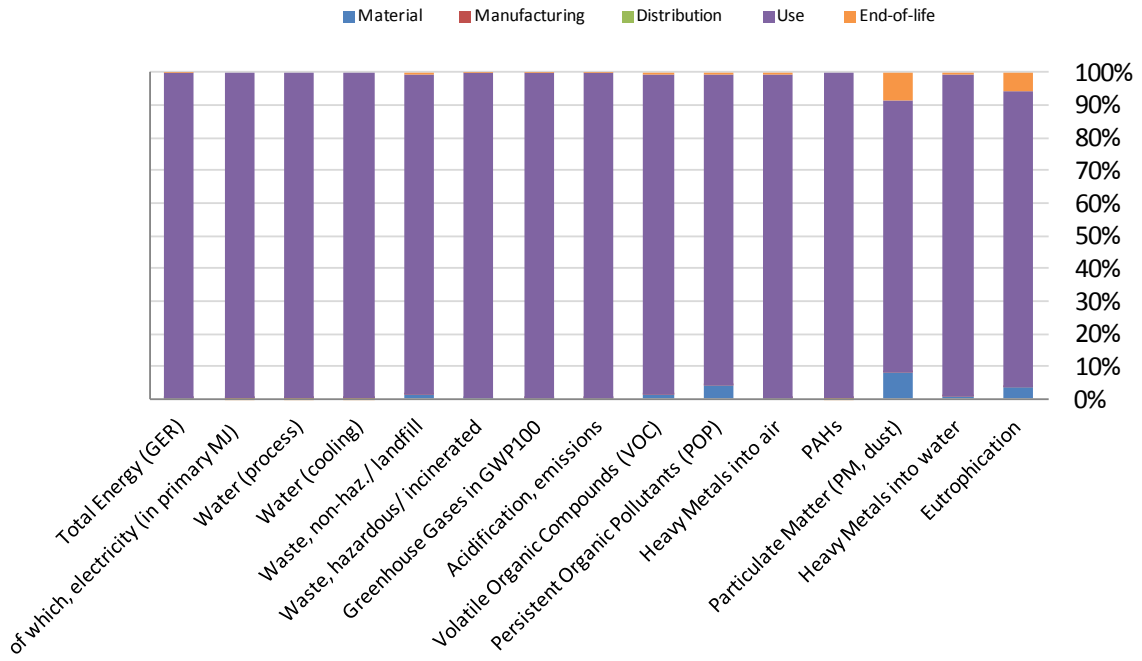


Figure 1-33: Relative significance of each life cycle phase per environmental impact category CDWP RSP 10 to 25

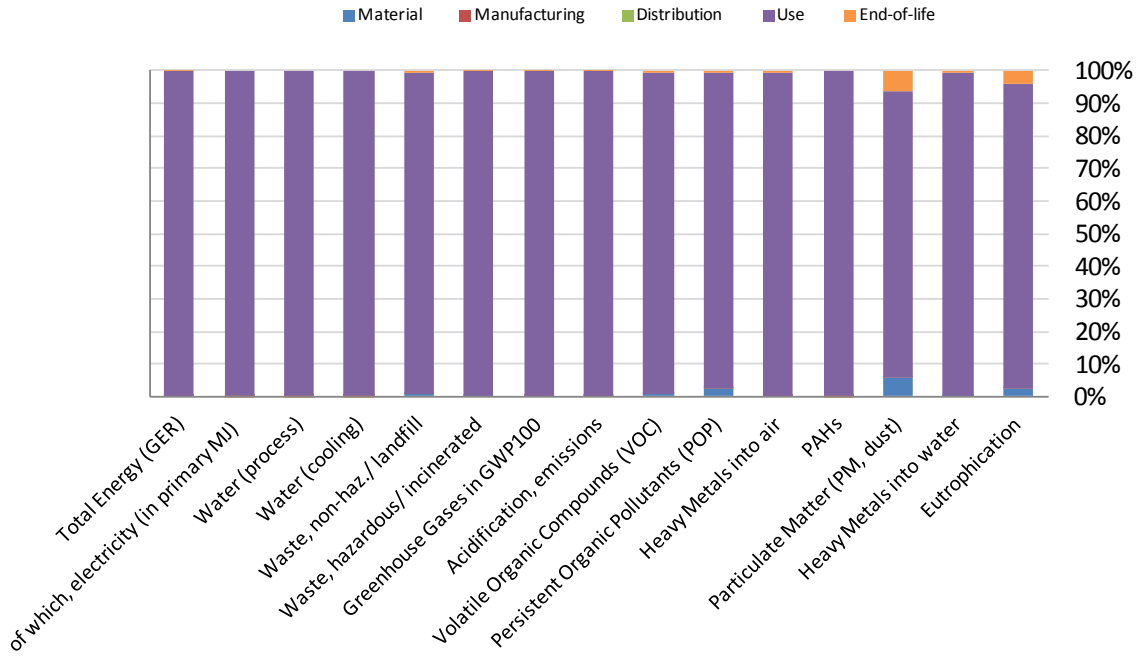


Figure 1-34: Relative significance of each life cycle phase per environmental impact category CDWP RSP 25 to 1000

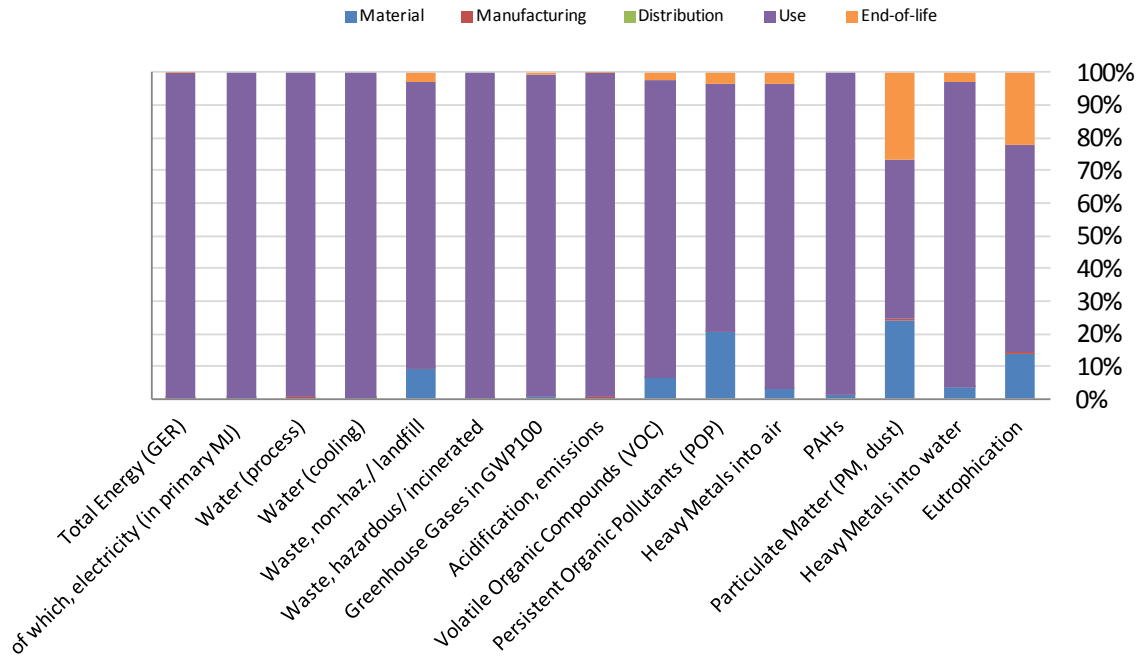


Figure 1-35: Relative significance of each life cycle phase per environmental impact category CDWP MFAP

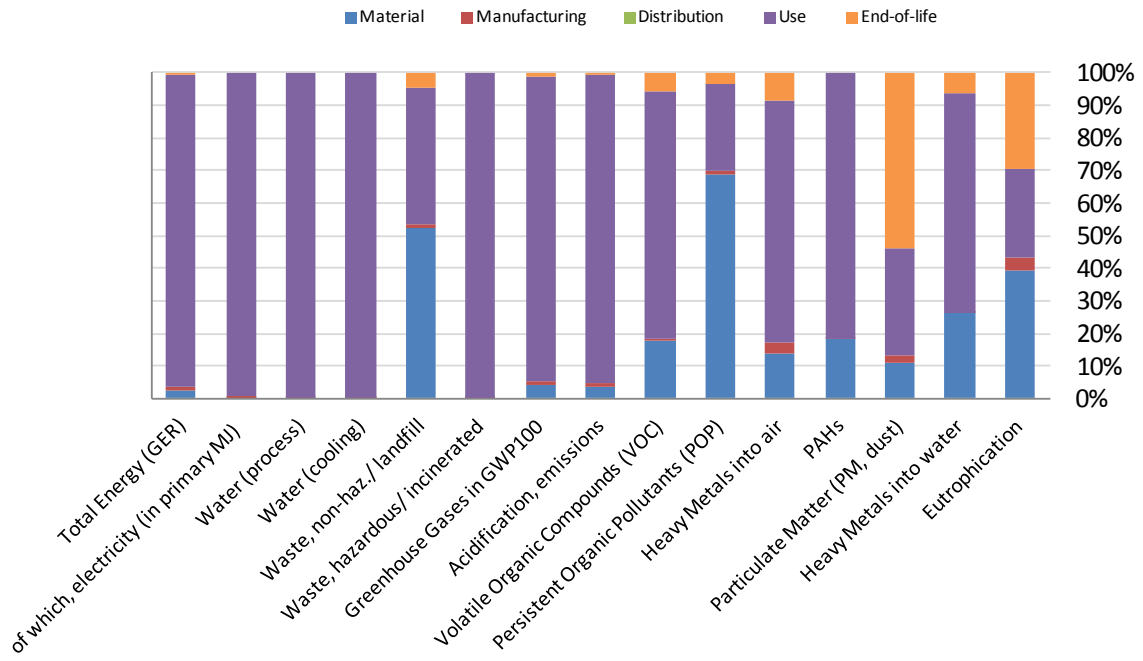


Figure 1-36: Relative significance of each life cycle phase per environmental impact category ASP

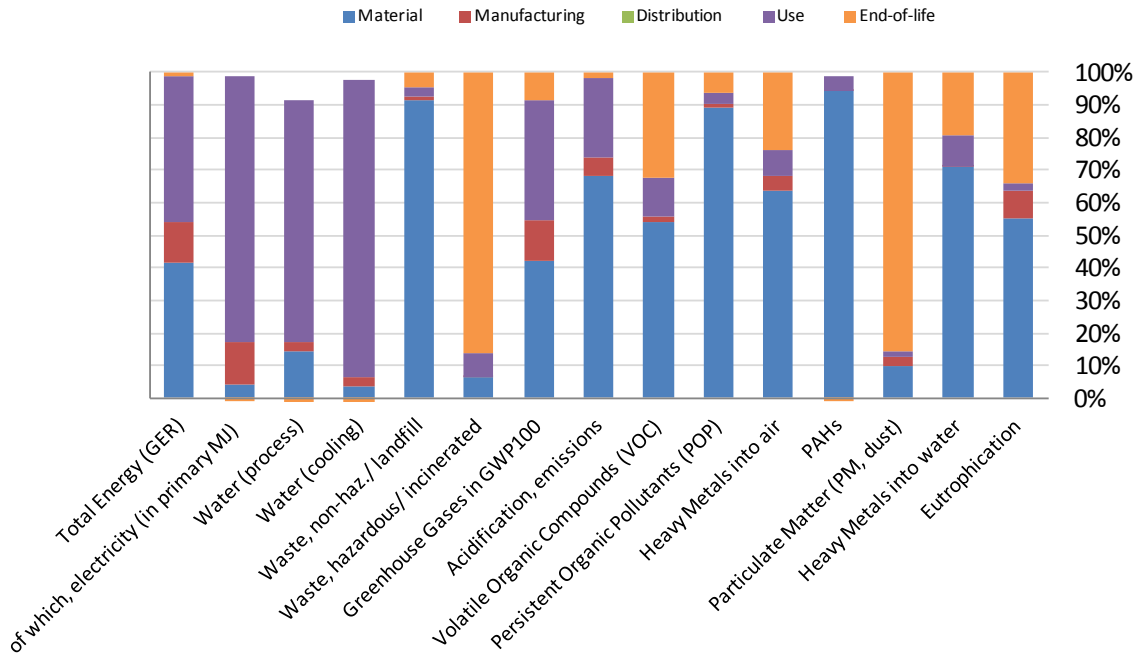


Figure 1-37: Relative significance of each life cycle phase per environmental impact category CSDD

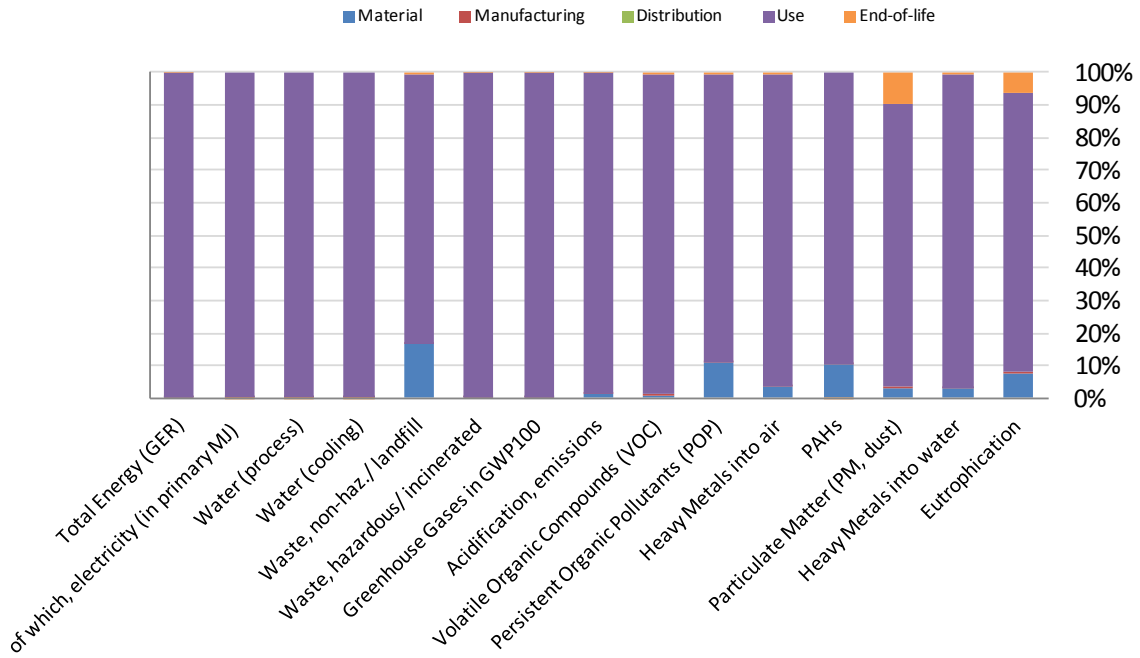


Figure 1-38: Relative significance of each life cycle phase per environmental impact category SDP

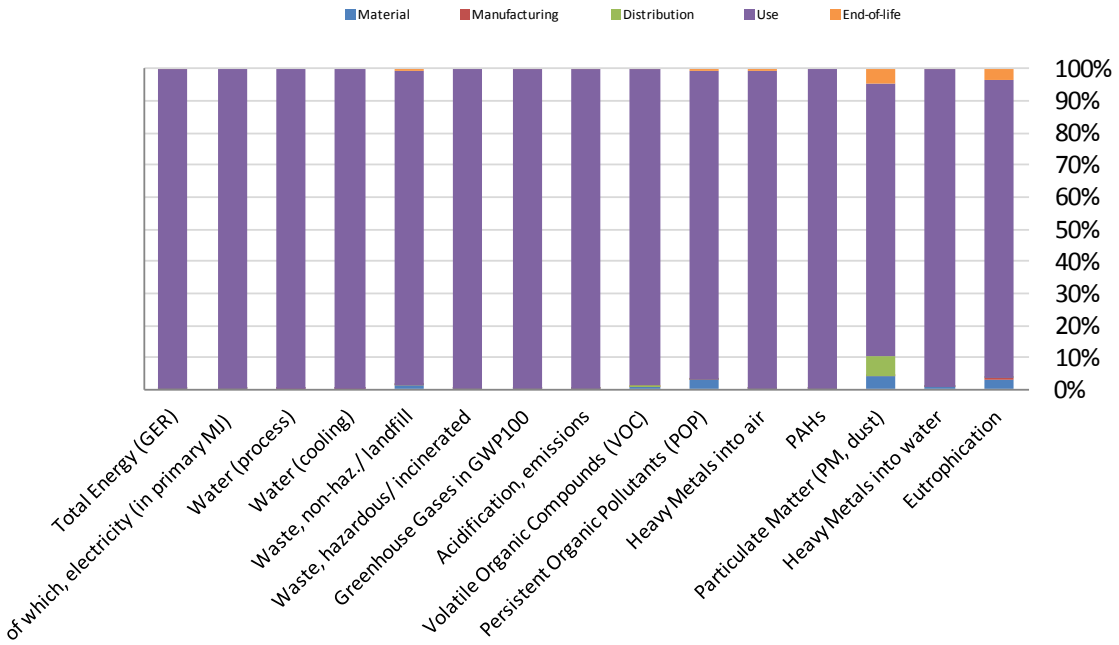


Figure 1-39: Relative significance of each life cycle phase per environmental impact category SP LD

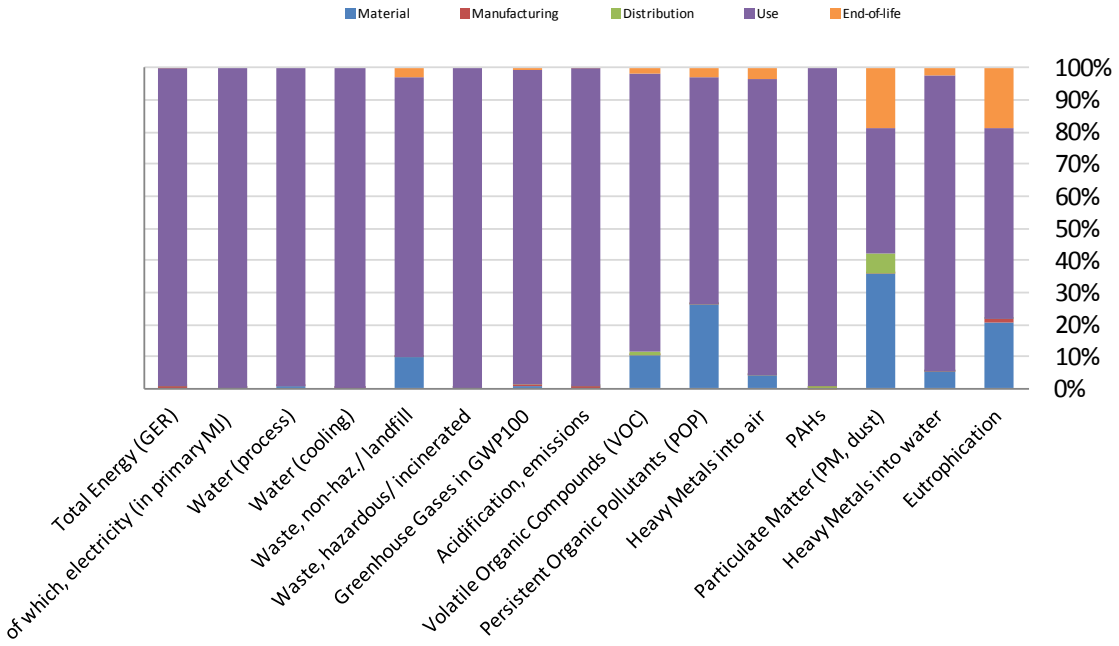


Figure 1-40: Relative significance of each life cycle phase per environmental impact category SP HD



02 April 2014

185 Avenue Charles de Gaulle
92200 Neuilly-sur-Seine
France
+33 (0)1 5561 6755
www.bio.deloitte.fr

Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 2: Economic and Market Analysis Working Document

Final report to the European Commission, DG ENER
02 April 2014



European Commission

Developed by:

bio by Deloitte.

ATKINS

Document information

CLIENT	European Commission, DG ENER
CONTRACT NUMBER	ENER/C3/403/2010
REPORT TITLE	ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 2: Economic and Market Analysis Working Document
PROJECT NAME	Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC
PROJECT CODE	ENER Lot 28
PROJECT TEAM	Bio by Deloitte, Atkins
DATE	02 April 2014
AUTHORS	Mr. Shailendra Mudgal, Bio by Deloitte Mr. Sandeep Pahal, Bio by Deloitte Mr. Benoit Tinetti, Bio by Deloitte Mr. Alvaro De Prado Trigo, Bio by Deloitte Dr. Hugh Falkner, Atkins Mr. Keeran Jugdoyal, Atkins
KEY CONTACTS	Mr. Sandeep Pahal spahal@bio.deloitte.fr Or Mr. Shailendra Mudgal shmudgal@bio.deloitte.fr
DISCLAIMER	This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. The project team does not accept any liability for any direct or indirect damage resulting from the use of this report or its content.

Please cite this publication as:
Bio by Deloitte (2014), Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC, ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 2: Economic and Market Analysis Working Document. Prepared for European Commission, DG ENER

Photo credit: cover @ Per Ola Wiberg

© Bio by Deloitte 2014

Table of Contents

2.1 Generic economic data 8

2.2 Market and stock data 14

2.2.1 Sales data at EU level 14

2.2.2 Stock data at EU level 17

2.2.3 Sales growth rate 19

2.2.4 Product lifetime 20

2.2.5 Replacement sales and new sales 21

2.3 Market trends 22

2.3.1 Market production structures 22

2.3.2 Trends in product design and features 23

2.3.3 Re-design cycle of wastewater pumps 23

2.4 Consumer expenditure base data 23

2.4.1 Purchase cost 23

2.4.2 Installation cost 24

2.4.3 Energy and water costs 25

2.4.4 Maintenance and repair cost 26

2.4.5 Disposal cost 27

2.4.6 Interest and inflation rates 28

2.5 Conclusions 29

List of Tables

Table 1: Market data from PRODCOM for Wastewater treatment pumps in 2010 9

Table 2: Total pump sales in EU by number of units sold 14

Table 3: Estimated installed stock of pumps in the EU-27 17

Table 4: Product technical life and average economical lifetime of pumps in the EU-27 20

Table 5: Purchase price (including VAT) of the average wastewater pumps in Euros/unit 24

Table 6: Average installation cost (including VAT) for wastewater pumps in Euros/unit 25

Table 7: Generic electricity and water prices in the EU-27 26

Table 8: Average annual maintenance and repair cost wastewater pumps (in Euros/year) 27

Table 9: Generic interest and inflation rates in the EU-27 28

Table 10: EU installed stock of pumps 29

Table 11: Market data from PRODCOM for positive displacement reciprocating pumps, diaphragm (PRODCOM code: 28131280) 31

Table 12: Market data from PRODCOM for Positive displacement pumps, rotary, gear (PRODCOM code: 28131320) 31

Table 13: Market Data from PRODCOM for Positive displacement pumps, rotary, vane (PRODCOM code: 28131340) 32

Table 14: Market data from PRODCOM for Positive displacement pumps, rotary, screw (PRODCOM code: 28131360) 33

Table 15: Market data from PRODCOM for Positive displacement pumps, rotary (including peristaltic, rotary lobe and helical rotor pumps) (excluding hydraulic units, gear pumps, vane pumps, screw pumps) (PRODCOM code: 28131380) 34

Table 16: Market data from PRODCOM for Submersible motor, single-stage rotodynamic drainage and sewage pumps (PRODCOM code: 28131413) 34

Table 17: Market data from PRODCOM for Positive displacement pumps, rotary, vane Submersible motor, mutli-stage rotodynamic pumps (PRODCOM code: 28131415) 35

Table 18: Market data from PRODCOM for Centrifugal pumps with discharge outlet diameter > 15 mm, channel impeller pumps, side channel pumps, peripheral pumps and regenerative pumps (PRODCOM code: 28131430) 36

Table 19: Market data from PRODCOM for Centrifugal pumps with a discharge outlet diameter >15 mm, single-stage with a single entry impeller, close coupled (PRODCOM code: 28131451) 36

Table 20: Market data from PRODCOM for Centrifugal pumps with a discharge outlet diameter > 15 mm, single-stage with a single entry impeller, long coupled (PRODCOM code: 28131453) 37

Table 21: Market data from PRODCOM for Centrifugal pumps with a discharge outlet diameter >15 mm, single-stage with double entry impeller (PRODCOM code: 28131455) 38

Table 22: Market data from PRODCOM for Centrifugal pumps with a discharge outlet diameter >15 mm, multi-stage (including self-priming) (PRODCOM code: 28131460) 38

Table 23: Market data from PRODCOM for Rotodynamic single-stage mixed flow or axial pumps (PRODCOM code: 28131471) 39

Table 24: Market data from PRODCOM for Rotodynamic multi-stage mixed flow or axial pumps (PRODCOM code: 28131475) 40

Table 25: Market data from PRODCOM for Other liquid pumps, liquid elevators (PRODCOM code: 28131480) 40

Table 26: Pump sales in EU by number of units sold 43

Table 27: Estimated installed stock of pumps in the EU-27 43

Table 28: Product technical life and average economical lifetime of pumps in the EU-27 44

Table 29: Purchase price (including VAT) of the average wastewater pumps in Euros/unit 44

Table 30: Average installation cost (including VAT) for wastewater pumps in Euros/unit 44

Table 31: Average annual maintenance and repair cost wastewater pumps (in Euros/year) 44

List of Figures

Figure 1: Market size of possible positive displacement pump products in the EU in 2010, PRODCOM (in number of units) 10

Figure 2: Market size of possible submersible, centrifugal, and rotodynamic pump products in the EU in 2010, PRODCOM (in number of units) 11

Figure 3: Market value of possible positive displacement pump products in the EU in 2010, PRODCOM (in market value) 12

Figure 4: Market value of possible submersible, centrifugal, and rotodynamic pump products in the EU in 2010, PRODCOM (in market value) 13

Figure 5: Sales distribution of ENER Lot 28 pumps in EU in 2011. 17

Figure 6: Sales distribution of ENER Lot 28 pumps in EU in 2011 (excluding "Centrifugal submersible domestic drainage < 40 mm passage pumps ") 17

Figure 7: Stock distribution of ENER Lot 28 pumps in EU in 2011 19

Figure 8: Stock distribution of ENER Lot 28 pumps in EU in 2011 (excluding "Centrifugal submersible domestic drainage < 40 mm passage pumps") 19

Task 2: Economic and market analysis

This chapter presents the economic and market analysis of the products covered in the scope of ENER Lot 28 preparatory study on pumps for private and public wastewater (all stages including buildings, networks and treatment facilities) and for fluids with high solids content. There are four main objectives of this chapter, which include:

1. To place the ENER Lot 28 product groups within the overall context of EU industry and trade.
2. To provide market (sales and installed stock) for the assessment of EU-wide environmental impacts of the ENER Lot 28 products.
3. To provide insights into the latest market trends to indicate the market structures and ongoing trends in product design. This will serve as an input for the subsequent tasks such as improvement potentials.
4. To provide the data on consumer prices and rates that will be used later in the study for Life Cycle Cost (LCC) calculations.

From Task 1 of this study it could be seen that wastewater pumps cover a broad range of applications and power capacities.

This report sets out the structure for gathering further information for the products considered in the scope of this study based on the screening exercise, as well as providing stakeholders an opportunity to review and comment on the data collected so far.

2.1 Generic economic data

The PRODCOM[1] statistics (published by EUROSTAT) have the advantage of being the official European Union (EU) source. PRODCOM data is based on manufactured goods whose definitions are standardised across the EU thus guaranteeing comparability between Member States. Although it is used and referenced in other EU policy documents regarding trade and economic policy, it does have its limitations. Many data points are unknown, estimated, confidential and therefore not available.

PRODCOM classifies numerous wastewater pump products in the category NACE 28.13 "manufacture of other pumps and compressors". The pumps covered under this category (relevant for this study) are presented below:

- 28.13.12.80 Positive displacement reciprocating pumps, diaphragm
- 28.13.13.20 Positive displacement pumps, rotary, gear
- 28.13.13.40 Positive displacement pumps, rotary, vane
- 28.13.13.60 Positive displacement pumps, rotary, screw
- 28.13.13.80 Positive displacement pumps, rotary including peristaltic, rotary lobe and helical rotor pumps and excluding hydraulic units, gear pumps, vane pumps, and screw pumps
- 28.13.14.13 Submersible motor, single-stage rotodynamic drainage and sewage pumps
- 28.13.14.15 Submersible motor, multi-stage rotodynamic pumps
- 28.13.14.30 Centrifugal pumps with a discharge outlet diameter > 15 mm, channel impeller pumps, side channel pumps, peripheral pumps, and regenerative pumps
- 28.13.14.51 Centrifugal pumps with a discharge outlet diameter > 15 mm, single-stage with a single entry impeller, close coupled
- 28.13.14.53 Centrifugal pumps with a discharge outlet diameter > 15 mm, single-stage with a single entry impeller, long coupled
- 28.13.14.55 Centrifugal pumps with a discharge outlet diameter > 15 mm, single-stage with double entry impeller
- 28.13.14.60 Centrifugal pumps with a discharge outlet diameter > 15 mm, multi-stage including self-priming
- 28.13.14.71 Rotodynamic single-stage mixed flow or axial pumps
- 28.13.14.75 Rotodynamic multi-stage mixed flow or axial pumps
- 28.13.14.80 Other liquid pumps, liquid elevators

[1] Available at: epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database

These categories include a wide range of pump products, but it is not clear which applications each category covers, e.g. clean water or wastewater applications, power capacities, etc. Hence, PRODCOM can only serve as a broad overview of the market size. The table below shows the summary of import, export, production and apparent EU consumption for pumps, derived from the PRODCOM data[2].

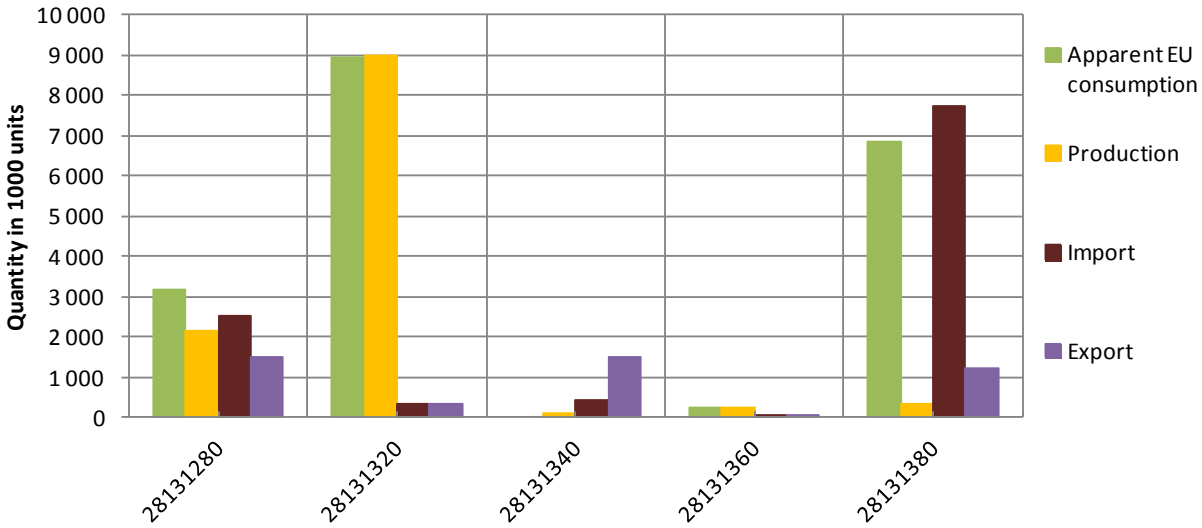
Please Note: The reliability and usability of PRODCOM statistics was questioned by Europump, as they provide no differentiation of pump types by application. **The PRODCOM data presented only serve informational purposes and will not be considered in the environmental and life cycle cost analyses during this study**.

Table 1: Market data from PRODCOM for Wastewater treatment pumps in 2010

PRODCOM Nace code	Quantity in 1000 units				Value in million €			
	Production	Import	Export	Apparent EU consumption	Production	Import	Export	Apparent EU consumption
28131280	2 141	2 544	1 516	3 169	238	69	140	167
28131320	9 000	313	351	8 962	370	33	72	332
28131340	120	420	1 499	-	26	15	69	-
28131360	262	21	48	235	246	7	112	142
28131380	313	7 734	1 200	6 847	422	46	151	316
28131413	1 515	3 629	891	4 253	632	80	361	351
28131415	1 830	554	477	1 906	552	33	157	428
28131430	364	414	151	627	385	6	40	350
28131451	544	368	1 143	-	397	13	134	277
28131453	1 809	616	1 076	1 350	950	11	230	730
28131455	5	7	21	-	120	1	62	59
28131460	1 500	11	298	1 213	863	5	221	647
28131471	3 187	3 769	2 678	4 279	530	68	378	220
28131475	703	459	2 500	-	549	44	1	221
28131480	27 892	30 144	45 342	12 693	991	362	2	400
TOTAL	**51 185**	**51 003**	**59 191**	**45 534**	**7 271**	**793**	**2 130**	**4 640**

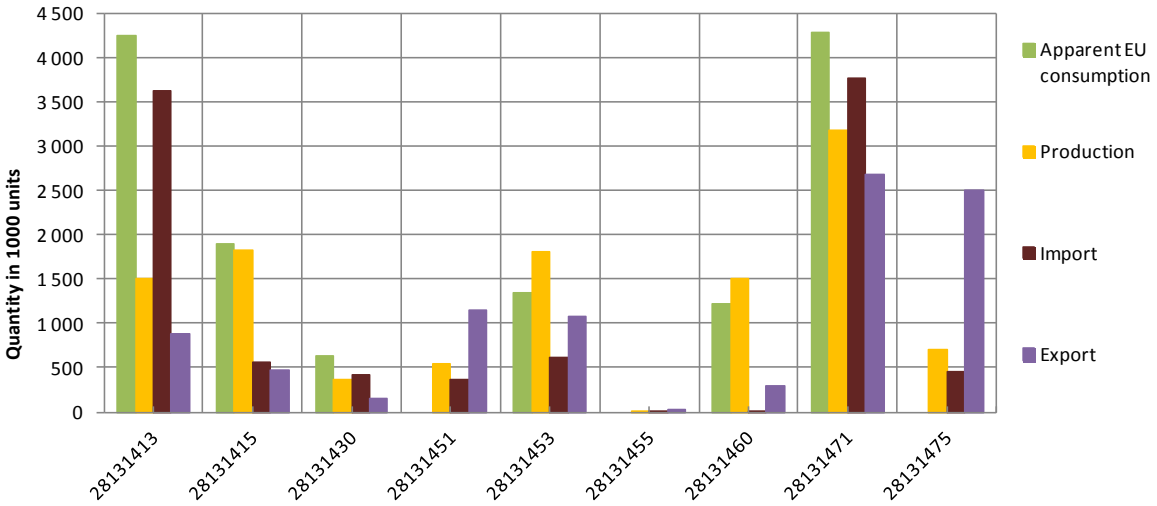
[2] The detailed data for import, export, production and apparent EU consumption for each of the PRODCOM NACE Codes is provided in Annex to this report.

Figure 1 and Figure 2 present the share of different positive displacement and possible submersible, centrifugal, and rotodynamic pump products respectively in the overall EU production, trade, and apparent consumption in 2010 according to PRODCOM categories.



PRODCOM CODE	DESCRIPTION
28131280	Reciprocating pumps, diaphragm
28131320	Rotary, gear
28131340	Rotary, vane
28131360	Rotary, screw
28131380	Rotary including peristaltic, rotary lobe and helical rotor pumps and excluding hydraulic units, gear pumps, vane pumps, and screw pumps

Figure 1: Market size of possible positive displacement pump products in the EU in 2010, PRODCOM (in number of units)

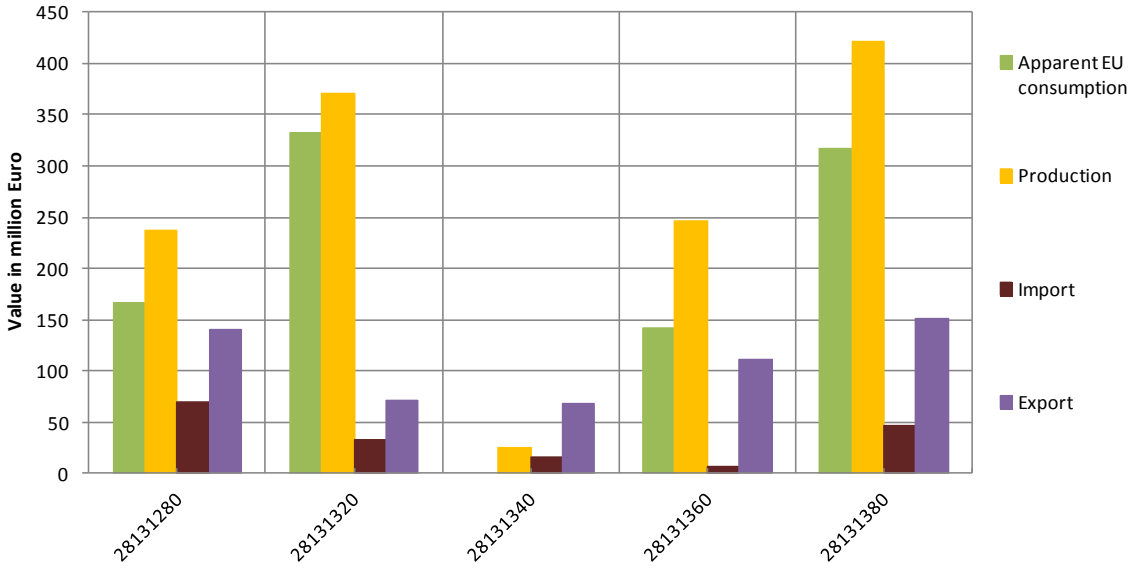


PRODCOM CODE	DESCRIPTION
28131413	Submersible motor, single-stage rotodynamic drainage and sewage pumps
28131415	Submersible motor, multistage rotodynamic pumps
28131430	Centrifugal pumps with a discharge outlet diameter >15mm, channel impeller pumps, side channel pumps, peripheral pumps, and regenerative pumps
28131451	Centrifugal pumps with a discharge outlet diameter >15mm, single-stage with a single entry impeller, close coupled
28131453	Centrifugal pumps with a discharge outlet diameter >15mm, single-stage with a single entry impeller, long coupled
28131455	Centrifugal pumps with a discharge outlet diameter >15mm, single-stage with double entry impeller
28131460	Centrifugal pumps with a discharge outlet diameter >15mm, multi-stage including self-priming
28131471	Rotodynamic single-stage mixed flow or axial pumps
28131475	Rotodynamic multi-stage mixed flow or axial pumps

Figure 2: Market size of possible submersible, centrifugal, and rotodynamic pump products in the EU in 2010, PRODCOM (in number of units)

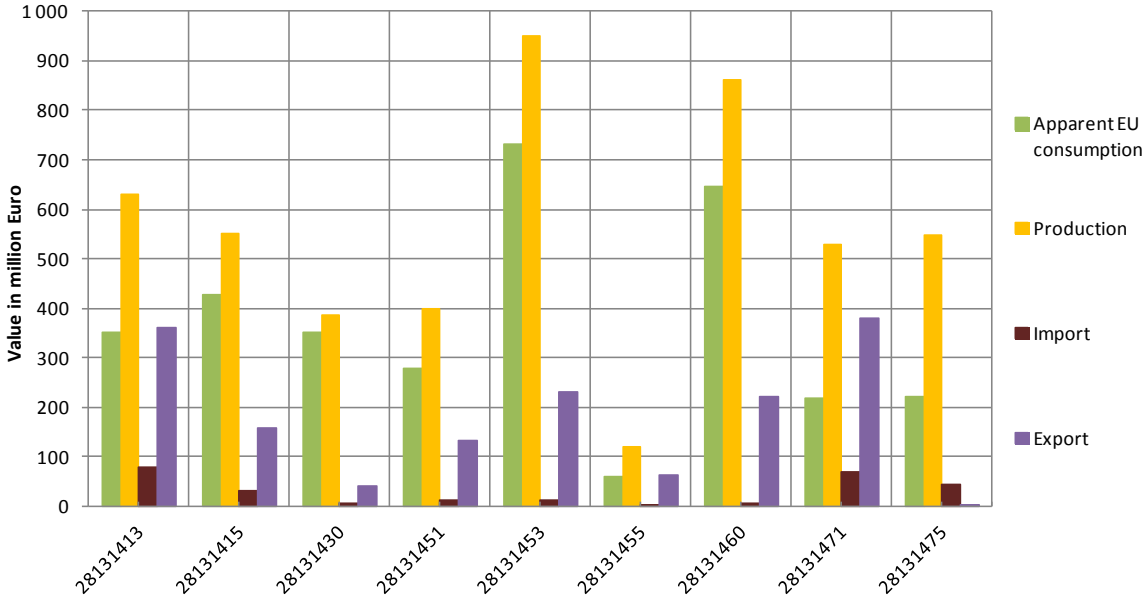
From Figure 1 and Figure 2, it would seem that of the wastewater treatment pumps, rotary gear positive displacement pumps form the majority of apparent consumption of pumps in the EU. Submersible motor single-stage rotodynamic drainage and sewage pumps, rotodynamic single-stage mixed flow or axial pumps, and rotary pumps (including peristaltic, rotary lobe and helical rotor pumps and excluding hydraulic units, gear pumps, vane pumps, and screw pumps) also represent a large share of apparent consumption of pumps in the EU. However, the apparent consumption of centrifugal pumps with a discharge outlet diameter >15mm (channel impeller pumps, side channel pumps, peripheral pumps, and regenerative pumps) and rotary screw positive displacement pumps is relatively small.

Figure 3 and Figure 4 show the market value of different positive displacement and possible submersible, centrifugal, and rotodynamic pump products respectively in the in the EU in 2010 for each PRODCOM category.



PRODCOM CODE	DESCRIPTION
28131280	Reciprocating pumps, diaphragm
28131320	Rotary, gear
28131340	Rotary, vane
28131360	Rotary, screw
28131380	Rotary including peristaltic, rotary lobe and helical rotor pumps and excluding hydraulic units, gear

Figure 3: Market value of possible positive displacement pump products in the EU in 2010, PRODCOM (in market value)



PRODCOM CODE	DESCRIPTION
28131413	Submersible motor, single-stage rotodynamic drainage and sewage pumps
28131415	Submersible motor, multistage rotodynamic pumps
28131430	Centrifugal pumps with a discharge outlet diameter >15mm, channel impeller pumps, side channel pumps, peripheral pumps, and regenerative pumps
28131451	Centrifugal pumps with a discharge outlet diameter >15mm, single-stage with a single entry impeller, close coupled
28131453	Centrifugal pumps with a discharge outlet diameter >15mm, single-stage with a single entry impeller, long coupled
28131455	Centrifugal pumps with a discharge outlet diameter >15mm, single-stage with double entry impeller
28131460	Centrifugal pumps with a discharge outlet diameter >15mm, multi-stage including self-priming
28131471	Rotodynamic single-stage mixed flow or axial pumps
28131475	Rotodynamic multi-stage mixed flow or axial pumps

Figure 4: Market value of possible submersible, centrifugal, and rotodynamic pump products in the EU in 2010, PRODCOM (in market value)

From Figure 3 and Figure 4, it is evident that rotary screw positive displacement pumps have relatively low apparent consumption but have a high value indicating that rotary screw positive displacement pump are expensive to manufacture. The apparent consumption/market value ratio of centrifugal pumps with a discharge outlet diameter >15mm, single-stage with a single entry impeller, long-coupled and centrifugal pumps with a discharge outlet diameter >15mm, multi-stage including self-priming is high reflecting high manufacturing costs for these wastewater pumps. Reciprocally, high apparent consumption of submersible motor, single-stage rotodynamic drainage and sewage pumps and rotodynamic single-stage mixed flow or axial pumps translate in low market value.

2.2 Market and stock data

The aim of this subtask is to provide market and stock data (i.e. number of units sold and installed in the EU) for wastewater pumps covered in ENER Lot 28 study. The market of products within this lot is in general characterised by its diversity. As seen in Task 1, the classification of product groups proposed does not match with the official NACE codes used in PRODCOM. Therefore, the data presented in this section relies mostly on information provided directly by the stakeholders (primarily the manufacturers and users of ENER Lot 28 pumps) and literature review.

2.2.1 Sales data at EU level

Table 2 provides market data for the ENER Lot 28 pumps sold in 2005 and 2011.

Table 2: Total pump sales in EU by number of units sold

Pump Type		Estimate of sales in (units)		Source
		2005[3]	2011[4]	
Centrifugal submersible pump				
	Radial sewage pumps 1 to 10 kW	129 206	160 000	Europump
	Radial sewage pumps >10 to 25 kW	9 690	12 000	Europump
	Radial sewage pumps >25 to 160 kW	4 038	5 000	Europump
	Mixed flow & axial pumps	565	700	Europump
Centrifugal submersible pump – once a day operation				
	Shredding, grinding pumps	40 377	50 000	Europump
	Radial sewage pumps 1 to 10 kW	104 980	130 000	Europump

[3] The values for 2005 pump sales in EU are provided by Europump based on an average annual growth in sales of 3.5% per year between 2005 and 2011.

Europump is the European Association of Pump Manufacturers. It represents 18 National Associations in 15 EU Member States, Turkey, Russia & Switzerland. Europump members represent more than 450 companies with a collective production worth more than €10 billion and employing 100 000 people in Europe. Website: www.europump.org/

[4] These sales figures are provided by Europump based on their best estimates without counteracting any law or Directive.

Please Note: The figures (particularly the market data in Task 2 report) provided by Europump for this preparatory study can be considered representative of the EU market as Europump represents the majority of pump manufacturers as well as the pump market within Europe. The population outside the Europump membership countries in EU is about 21 %. However, the countries represent only approximately 7.6 % of the pump market in EU. When Europump preformed the data collection for providing inputs to this preparatory study, their member companies had the total European market in view and reported accordingly.

Pump Type		Estimate of sales in (units)		Source
		2005[3]	2011[4]	
	Where volute is part of a tank	44 415	55 000	Europump
Centrifugal submersible domestic drainage pump < 40 mm passage		1 211 310	1 500 000	Europump
Submersible dewatering pumps		32 302	40 000	Europump
Centrifugal dry well pump				
	Radial sewage pumps 1 to 10 kW	16 151	20 000	Europump
	Radial sewage pumps >10 to 25 kW	4 038	5 000	Europump
	Radial sewage pumps >25 to 160 kW	808	1 000	Europump
	Mixed flow & axial pumps	81	100	Europump
Slurry Pumps				Europump
	Light Duty	1211	1500	Europump
	Heavy Duty	242	300	Europump
TOTAL		**1 599 413**	**1 980 600**	Europump

From Table 1 and Table 2, it is apparent that there is a large discrepancy between pump sales, or apparent EU consumption in 2010 from PRODCOM statistics and 2011 sales of ENER Lot 28 pumps in EU from Europump data.

The sales of the following pumps (presented in the table above) can be further split based on the type of impeller used:

- **Centrifugal submersible and dry well pumps[5]:**
  - Radial sewage pumps 1 to 10 kW: Vortex and Channel impellers, each represent 50% share of the total sales;
  - Radial sewage pumps >10 to 25 kW: Vortex and Channel impellers, have 20% and 80% share of the total sales, respectively;
- **Submersible dewatering pumps**
  - Radial sewage pumps 1 to 10 kW: Vortex and Channel impellers, each represent 50% share of the total sales;
  - Radial sewage pumps >10 to 25 kW: Vortex and Channel impellers, have 20% and 80% share of the total sales, respectively;

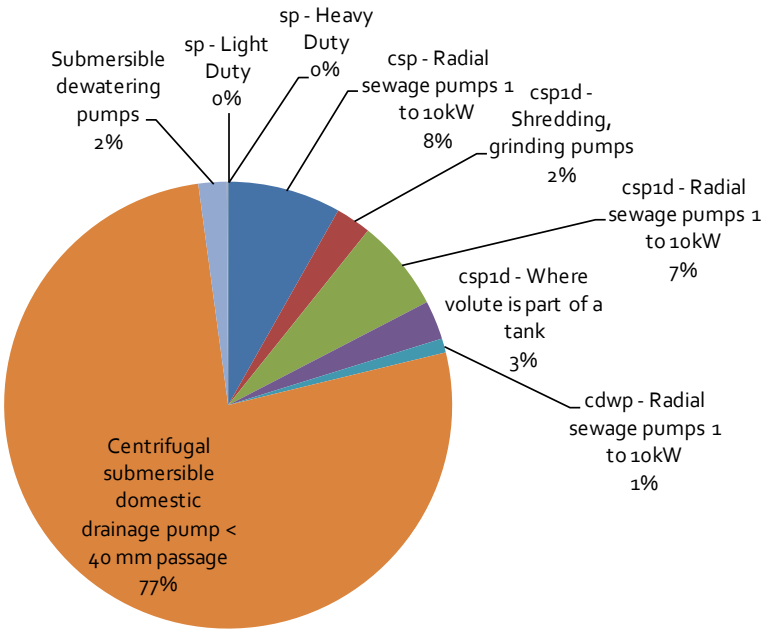
Centrifugal submersibles mixed flow & axial pumps used for storm-water, effluent and recirculation purposes. The sales of these pumps can be split based on these applications,

[5] The percentage split is reflecting the Installed base, however there may be a trend in the future to use more channel type hydraulics

60% for activated sludge recirculation and remaining 40% for storm water and effluent pumping[6].

Figure 5 to Figure 6 presents the share of different pump types in the overall EU sales of ENER Lot 28 pumps in 2011:

- "Centrifugal submersible domestic drainage pump < 40 mm passage pumps" dominates the pump market (market share of 75%), then;
- "Centrifugal submersible pumps – radial sewage pumps 1 to 10 kW" (market share of 8%);
- "Centrifugal submersible pumps – once a day operation – radial sewage pumps 1 to 10 kW" (market share of 6.5%);
- "Centrifugal submersible pumps – once a day operation – where volute is part of a tank " (market share of 3%) respectively; and
- "Centrifugal submersible pumps – once a day operation – shredding, grinding pumps" (market share of 2.5%).
- "Slurry Pumps – Light and Heavy duty" (market share of 0.1%)



[6] The percentage split is reflecting the actual status of installed base and annual sales in 2011, however there may be a future trend for a higher annual sales in activated sludge recirculation, as still more sewage treatment works are refurbished in comparison to newly built or refurbished storm-water pumping stations

Figure 5: Sales distribution of ENER Lot 28 pumps in EU in 2011.

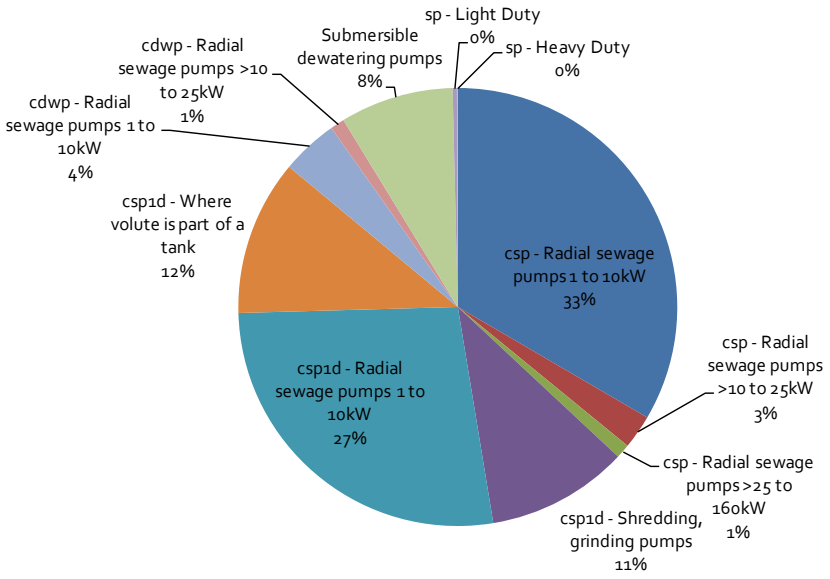


Figure 6: Sales distribution of ENER Lot 28 pumps in EU in 2011 (excluding "Centrifugal submersible domestic drainage < 40 mm passage pumps ")

2.2.2 Stock data at EU level

Stock is the installed base of existing appliances, i.e. the number of units in operation in EU-27. However, the shortage of data availability on pump systems in the EU poses a challenge as it makes the market evaluation of these products difficult. For the purpose of this preparatory study, the stock data has been gathered directly from the industry and is based upon previous work done on the methodology of stock models (see e.g. VHK 2005[7], Lane 2000[8]).

Table 3 presents the installed stock (in 2005 and 2011) of ENER Lot 28 pumps.

Table 3: Estimated installed stock of pumps in the EU-27[9]

Pump Type	Estimate of installed stock in (units)		Source
	2005[10]	20114	
Centrifugal submersible pump			

[7] Kemna, R., van Elburg, M., Li, W., van Holsteijn, R. Ecodesign of Energy-using Products. A methodology study, final-report. Appendix 2: Product Cases. P. 7.1-7.30. 2005

[8] Lane, K. Appendix O: Modelling Approach. In: Fawcett, T.; Lane, K.; Boardman, B. et al. Lower Carbon Futures. Environmental Change Institute, University of Oxford, UK. 2000

[9] The forecasts of installed stock used for scenario development in Task 8 will be based on the installed stock in 2011 and taking into account the population growth rates and/or building growth rates.

[10] The pump installed stock in 2005 in EU are estimated by Europump based on an average annual growth in stock of 1.75% per year between 2005 and 2011. Thereby the figures for 2005 can be calculated backwards from figures 2011 by multiplying by 0.9825^7 = 0.884

Pump Type		Estimate of installed stock in (units)		Source
		2005[10]	20114	
	Radial sewage pumps 1 to 10 kW	1 007 427	1 120 000	Europump
	Radial sewage pumps >10 to 25 kW	107 939	120 000	Europump
	Radial sewage pumps >25 to 160 kW	62 964	70 000	Europump
	Mixed flow & axial pumps	4 407	4900	Europump
Centrifugal submersible pump – once a day operation				
	Shredding, grinding pumps	251 857	280 000	Europump
	Radial sewage pumps 1 to 10 kW	818 534	910 000	Europump
	Where volute is part of a tank	346 303	385 000	Europump
Centrifugal submersible domestic drainage pump < 40 mm passage		11 018 728	12 250 000	Europump
Submersible dewatering pumps		251 857	280 000	Europump
Centrifugal dry well pump				
	Radial sewage pumps 1 to 10 kW	134 923	150 000	Europump
	Radial sewage pumps >10 to 25 kW	33 731	37 500	Europump
	Radial sewage pumps >25 to 160 kW	12 593	14 000	Europump
	Mixed flow & axial pumps	1 799	2000	Europump
Slurry Pumps				
	Light Duty	53 969	60 000	Europump
	Heavy Duty	13 492	15000	Europump
Total		14 120 522	15 698 400	

The stock, similar to the sales of the pumps (presented in the table above) can be further split based on the type of impeller used. The percentage split of share of installed stocks of pump by impeller type is same as the split for sales.

Figure 7 to Figure 8 present the share of different pump types in the overall EU installed stock of ENER Lot 28 pumps in 2011:

- "Centrifugal submersible domestic drainage pump < 40 mm passage pumps" dominates (market share of around 78%), followed by;
- "Centrifugal submersible pumps – radial sewage pumps 1 to 10 kW" (market share of 7%);
- "Centrifugal submersible pumps – once a day operation – radial sewage pumps 1 to 10 kW" (market share of 6%); and
- "Centrifugal submersible pumps – once a day operation – where volute is part of a tank " (market share of 2.5%) respectively; and

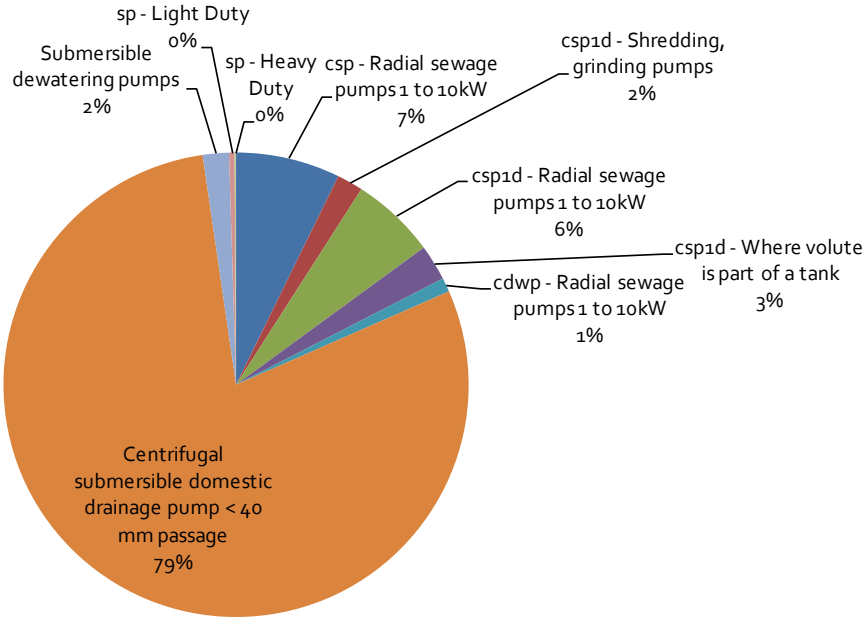


Figure 7: Stock distribution of ENER Lot 28 pumps in EU in 2011

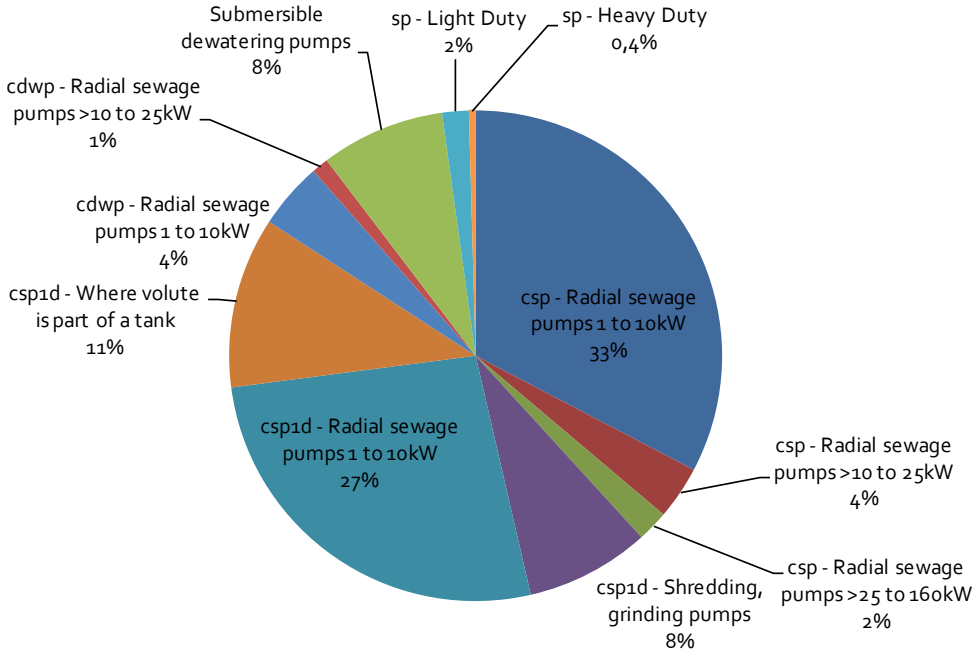


Figure 8: Stock distribution of ENER Lot 28 pumps in EU in 2011 (excluding "Centrifugal submersible domestic drainage < 40 mm passage pumps")

2.2.3 Sales growth rate

In terms of recent market trends in the 'old' Member States, the conversion of a large number of basements to living areas or for laundry rooms has led to increased use of small submersible pumps to pump water back up to drain level. There is little knowledge on the market for small (domestic) sewage pumps in 'new' Member States, although there is anecdotal evidence that it is in some cases significant.

In general, the market trend is estimated with smaller than the average growth in the last years due to the influences of all uncertainties as a result of the current European economic crisis. For year 2012 to 2015, the growth rate of pump sales is estimated to be 2 to 3%. The growth for the following years, from 2015 to 2017, is expected to improve slightly with the growth rate of 4 to 5%[11]. The insights into long term market trends of ENER Lot 28 pumps are not available as it depends on many factors, thus an estimation of the growth rate beyond 2017 is difficult.

2.2.4 Product lifetime

The lifetime of the appliances is of interest in this study as a key parameter in assessing the Life Cycle Costs of the appliances in the later stages of the study (Tasks 5 and 7). The focus is on 'average time to disposal or economic lifetime', i.e. the time in service. Parameters that have the greatest influence on the lifetime of pumps are quality of material, frequency of use, and maintenance. Average economical product life of the ENER Lot 28 pumps is estimated to be the same as technical life (time until which a pump functions sustaining minimum acceptable performance criteria). Pump economic life may vary across products and Member States and is highly depending on how the appliance was used, so should be seen with caution. However, some preliminary estimates on average economic product life are presented in Table 4. The lifetime of the appliances is of interest as a key parameter in assessing the following parameters during the later stages of the study:

- Life Cycle Costs of the Base-Case (BC) and improvement options
- Life cycle environmental impacts of the BC and improvement options
- To compare the impacts of a BC and the improvement options, if some options extend only the lifetime without enhancing the energy efficiency

Table 4: Product technical life and average economical lifetime of pumps in the EU-27[12]

Pump Type	Technical life (in years)	Average time to disposal (economical lifetime in years)	Source
Centrifugal submersible pump			
Radial sewage pumps 1 to 10 kW	10	10	Europump
Radial sewage pumps >10 to 25 kW	10	10	Europump
Radial sewage pumps >25 to 160 kW	15	15	Europump
Mixed flow & axial pumps	10	10	Europump
Centrifugal submersible pump – once a day operation			
Shredding, grinding pumps	7	7	Europump

[11] The growth rate figures for 2012-2017 are provided by Europump

[12] The "Range of Economical Lifetime" depends massively on operational conditions, pumped liquid, maintenance and surrounding conditions thus reliable estimate cannot be given and is excluded in the table.

Pump Type	Technical life (in years)	Average time to disposal (economical lifetime in years)	Source
Radial sewage pumps 1 to 10 kW	8	8	Europump
Where volute is part of a tank	10	10	Europump
Centrifugal submersible domestic drainage pump < 40 mm passage	7	7	Europump
Submersible dewatering pumps	10	10	Europump
Centrifugal dry well pump			
Radial sewage pumps 1 to 10 kW	15	15	Europump
Radial sewage pumps >10 to 25 kW	15	15	Europump
Radial sewage pumps >25 to 160 kW	15	15	Europump
Mixed flow & axial pumps	20	20	Europump
Slurry Pumps			
Light Duty	25	25	Europump
Heavy Duty	25	25	Europump

2.2.5 Replacement sales and new sales

In order to estimate the future installed stock of pumps covered in ENER Lot 28 study, a distinction between replacement and new (non-replacement) sales is needed. Overall sales of products are combinations of new sales, which increase the installed stock, and replacement sales.

The pumps sales in the EU-27 market are mainly for the replacement of old units. On average, 30% of the sales in EU market are for new installations and 70% are for the replacement. In those EU countries which have a mature wastewater infrastructure, the sales for new installation and replacement are 10% and 90% respectively. The wastewater pump market for new installation is higher in those EU countries that have high need for improvement in their wastewater systems. In such countries, the share of sales is 50% for new sales and the other half constitutes replacement sales.

2.3 Market trends

2.3.1 Market production structures

The ENER Lot 28 pumps market in EU is mainly comprised of few large manufacturers. These manufacturers are well represented by industry associations at Member State and EU level. These mainly include Europump[13]. Some of the main manufacturers of ENER Lot 28 pumps are listed by alphabetical order:

- Andritz Ritz
- Ebara
- Grundfos
- Hidrostal
- KSB
- Tsurumi
- Sulzer (ABS)
- Wilo
- Xylem

Very large pumps tend to be engineered and mostly produced in the EU. These pumps are mainly sold overseas in locations of mining activity (Africa, China, Australia, etc). Small/low cost pumps (such as centrifugal submersible domestic drainage pump < 40 mm passage) situated outside the building are used in southern Europe as a 'cheap' option for domestic drainage.

Sewage pumps are supplied through 3 main channels:

- Direct to users
- To framework contract operators
- Through external designers and contractors.

Depending on their final application, the WW pumps are sold to the end user through variety of channels such as directly from manufacturers, via wholesalers, via distributors or via installer. The product distribution channels of non-domestic applications of ENER Lot 28 pumps are mostly business-to-business, as these products usually require experience and engineering knowledge for proper mounting of the pump, and therefore need professional installation. Pump manufacturers develop the business strategies with well managed supply chains to ensure customer satisfaction. Majority of the pumps for non-domestic applications such as centrifugal submersible pumps, dry well pumps and positive displacement pumps are likely to be installed by

[13] Europump is the European Association of Pump Manufacturers. It represents 18 National Associations in 15 EU Member States, Turkey, Russia & Switzerland. Europump members represent more than 450 companies with a collective production worth more than €10 billion and employing 100 000 people in Europe. Website: www.europump.org/

a contractor or installer accompanied by manufacturers supervision, if required. Smaller domestic drainage pumps, < 40 mm passage, that do not require installation might be directly purchased from the retailers.

2.3.2 Trends in product design and features

The main developments in this area concern advances in impeller design. Additional developments concern the use of VSD (Variable Speed Drive) controls for both flow regulation, where this is possible, and de-ragging initiated by a sequence of forward and counter rotations.

Sewage varies hugely in terms of its solid content, particularly when comparing domestic to industrial discharges. The greater number of products (that do not disintegrate adequately in water) flushed into the sewage system is also requiring the use of pumps with a higher solid handling capacity. Higher effluent charges are also encouraging more companies to undertake initial screening and de-watering themselves, so discharging a lower volume but with higher solid content.

2.3.3 Re-design cycle of wastewater pumps

Many of the worst performing pumps may need to be re-designed in order to meet any potential implementing measures proposed later in Task 8. It is therefore of interest to know the typical duration of the re-design cycle of pumps covered in ENER Lot 28 study.

Manufacturers of low-efficient pumps will therefore have to re-design their pump models and make necessary adaptation to the established production lines. Since the current technology used in ENER Lot 28 pumps has already been on the market for many years, and as many pump manufacturers already produce high efficient pumps, a consideration of around 2 – 4 years timeframe for the manufacturers is considered to be enough[14].

The duration of the re-design cycle will be taken into account in the potential implementing measures in Task 8 in order to give manufacturers adequate time to re-design pumps to replace those that may be non-compliant.

2.4 Consumer expenditure base data

Based on the categories defined in subtask 1.6, average EU consumer prices, incl. VAT (in €), as well as applicable rates for running costs (e.g. electricity, water) and other financial parameters (e.g. taxes, rates of interest, inflation rates) are presented in this section. These data will form an input for subtasks 5.3where both LCC for new products and annual cost will be calculated.

2.4.1 Purchase cost

[14] This timeframe is also in line with the observation made in the Impact Assessment concerning Commissions proposal for a regulation **with regard to Ecodesign requirements for water pumps.**
http://ec.europa.eu/governance/impact/ia_carried_out/docs/ia_2012/swd_2012_178_en.pdf

Table 5 presents the range and average purchase price of wastewater pumps in Euros/unit.

Table 5: Purchase price (including VAT) of the average wastewater pumps in Euros/unit

Pump type	Range of purchase price (€/unit)	Average purchase price (€/unit)	Source
Centrifugal Submersible pump			
Radial sewage pumps 1 to 10 kW	600-5 000	2 500	Estimate
Radial sewage pumps >10 to 25 kW	3 400-7 500	6 000	Estimate
Radial sewage pumps >25 to 160 kW	5 500 – 125 000	25 000	Estimate
Mixed flow & axial pumps	2 500 – 50 000	15000	Estimate
Submersible pump – once a day operation			
Shredding, grinding pumps	1 000-8 000	3 000	Estimate
Radial sewage pumps 1 to 10 kW	300-5 000	1 500	Estimate
Where volute is part of a tank	500-5 000	2 000	Estimate
Centrifugal submersible domestic drainage pump < 40 mm passage	50 – 1 000	300	Estimate
Submersible dewatering pumps	1 400 – 12 750	5 000	Estimate
Centrifugal dry well pump			
Radial sewage pumps 1 to 10 kW	600 – 5 000	2 125	Estimate
Radial sewage pumps >10 to 25 kW	1 400 – 12 750	5 100	Estimate
Radial sewage pumps >25 to 160 kW	5 500 – 125 000	21 250	Estimate
Mixed flow & axial pumps	5 500 – 125 000	25 000	Estimate
Slurry Pumps			
Light Duty	7 650 – 75 000	20 000	Estimate
Heavy Duty	7 650 – 75 000	20 000	Estimate

2.4.2 Installation cost

The installation costs of ENER Lot 28 pumps can vary significantly depending on their technology, size, site and application type. For example, the cost of a dry well installation can be around 2 times that of an equivalent submersible installation (as dry well pumps require the construction of a machine room around it, etc.). In northern Europe, dry wells are sometimes preferred where the low temperatures may cause problems (as these can be heated). The scope of installation costs presented in this section mainly concerns expenses related to:

- Pump base plate
- Controls for system feedback
- Labour expenses (e.g. man-hours related to lifting equipment)
- Commissioning of the pump

According to one of rough estimates from industry, "the installation cost is equal to the purchase cost of the pump."[15] Table 6 presents the range and average installation costs of ENER Lot 28 pumps in Euros/unit.

Table 6: Average installation cost (including VAT) for wastewater pumps in Euros/unit

Pump type	Range of installation cost (€)	Average installation cost (€)	Source
Centrifugal submersible pump			
Radial sewage pumps 1 to 10 kW	375 – 3 750	1 250	Estimate
Radial sewage pumps >10 to 25 kW	625 – 4 500	1875	Estimate
Radial sewage pumps >25 to 160 kW	2 500 – 30 000	6 250	Estimate
Mixed flow & axial pumps	1 250 – 10 000	3 750	Estimate
Centrifugal submersible pump – once a day operation			
Shredding, grinding pumps	500 – 2 000	1 250	Estimate
Radial sewage pumps 1 to 10 kW	625 – 4 500	1 250	Estimate
Where volute is part of a tank	400 – 2 500	750	Estimate
Centrifugal submersible domestic drainage pump < 40 mm passage	75 – 250	150	Estimate
Submersible dewatering pumps	150 – 750	250	Estimate
Centrifugal dry well pump			
Radial sewage pumps 1 to 10 kW	375 – 3 750	1 250	Estimate
Radial sewage pumps >10 to 25 kW	625 – 4 500	1 875	Estimate
Radial sewage pumps >25 to 160 kW	2 500 – 3 000	6 250	Estimate
Mixed flow & axial pumps	1 250 – 10 000	3 750	Estimate
Slurry Pumps			
Light Duty	1 875 – 20 000	5000	Estimate
Heavy Duty	1 875 – 20 000	5000	Estimate

2.4.3 Energy and water costs

Electricity and water prices as listed in the new ErP methodology[16] will be used in this subsection.

Table 7 presents the generic electricity and water prices, the discount rate and VAT values in the EU-27.

[15] AEA Energy & Environment (2008) ENER Lot 11 Pumps: (in commercial buildings, drinking water pumping, food industry, agriculture).

[16] Source: http://www.meerp.eu/downloads/MEErP%20Methodology%20Part%201%20Final.pdf

Table 7: Generic electricity and water prices in the EU-27

	Unit	Domestic incl. VAT	Long term growth per year	Non-domestic excl. VAT
Electricity	€/ kWh	0.18	5%	0.11
Water	€/m^3	3.70	2.5%	
Energy escalation rate	%	4%		
VAT	%	20%		

2.4.4 Maintenance and repair cost

Maintenance and repair costs of ENER Lot 28 pumps can be very significant depending upon the type of impellers used and the composition of wastewater being handled. If the type of selected impeller is not appropriate for the composition of the wastewater handled, then the maintenance and repair costs can be far higher than the cost of energy consumption. A particular challenge in this regards is the changing composition of the wastewater. For example, during 'real-life' use, new types of hygiene products with tear-proof components are causing an issue by clogging impellers[17]. Some basic information concerning the maintenance and repair costs for the ENER Lot 28 pumps is presented below:

- The maintenance and repair costs for centrifugal solids handling pump is usually in the range of 17% of total Life Cycle Cost[18]
- Submersible pumps require maintenance checks every 2-4 years to have them inspected and/or replaced of worn hydraulic parts and shaft seals. This type of pump has a high potential of having its impellers clogged with rags. This clogging potential is also valid for dry well pumps in the same way. A screening system should therefore be installed ahead of the pumps[19].
- Using the distribution of costs over 20 years used in LCC for different pump categories it is possible to estimate the average maintenance cost from the purchase cost.[20]
- Slurry pump: Need annual maintenance that concerns the replacing of bladder, coating on valve balls and seats, and service exchange on water valves. Every 5 years, they also require replacement of water valve actuators and replacement of pressure vessels every 20 years[21].

[17] Rough estimates of efficiencies for different impellers are as follows: vortex type 40-50% (this type rarely requires maintenance), highest achieved is 62%; channel type 70-75% (needs more maintenance – often use chopping in advance to avoid blockage); closed type have highest efficiency, around 85% (but high risk of blockage).

[18] Flowserve (2011) MPT. Self-Priming, Solids-Handling Pump

[19] Behnke, P. Bosserman, B. (1998), Selection Criteria for Wastewater Pumps

[20] Pump Center Newsletter (2003) Pump life Cycle Costing: Breaking the barriers to implementation

[21] INTSPS (2012) ISPS Phoenix Slurry Pump Technical Overview

- Progressive cavity pumps – wetted end replacement parts cost around 75 % of the pump's price[22].

Table 8 shows the average maintenance and repair costs of wastewater pumps in the EU-27.

Table 8: Average annual maintenance and repair cost wastewater pumps (in Euros/year)

Pump type	Range of repair cost (€/year)	Average repair cost (€/year)	Range of maintenance cost (€/year)	Average maintenance cost (€/year)	Source
Centrifugal Submersible pump					
Radial sewage pumps 1 to 10 kW	125 – 625	375	250 – 1 000	375	Estimate
Radial sewage pumps >10 to 25 kW	375 – 750	438	313 – 1 125	438	Estimate
Radial sewage pumps >25 to 160 kW	500 – 2 000	750	375 – 2 500	850	Estimate
Mixed flow & axial pumps	375 – 1 125	500	313 – 1 125	450	Estimate
Submersible pump – once a day operation					
Shredding, grinding pumps	58 – 173	86	58 – 575	144	Estimate
Radial sewage pumps 1 to 10 kW	58 – 230	86	29 – 173	46	Estimate
Where volute is part of a tank	58 – 288	115	35 – 173	58	Estimate
Centrifugal submersible domestic drainage pump < 40 mm passage	0	0	0	0	Estimate
Submersible dewatering pumps	125 – 500	312.5	100 – 500	150	Estimate
Centrifugal dry well pump					
Radial sewage pumps 1 to 10 kW	125 - 625	375	250 – 1 000	375	Estimate
Radial sewage pumps >10 to 25 kW	375 – 750	438	313 – 1 125	438	Estimate
Radial sewage pumps >25 to 160 kW	500 – 2 000	750	375 – 2 500	850	Estimate
Mixed flow & axial pumps	375 – 1 125	500	313 – 1 125	450	Estimate
Slurry Pumps					
Light Duty	438 – 1 563	625	344 – 1 813	650	Estimate
Heavy Duty	438 – 1 563	625	344 – 1 813	650	Estimate

2.4.5 Disposal cost

ENER Lot 28 pumps are normally replaced when they fail or when there is a significant irreversible drop in pump performance. As these pumps are mainly constructed of metals, they are likely to be sold for scrap at the end of their life. Cleaning and removal of pathogens is required prior to their delivery to the scrap yard.

[22] Treutel , Chuck (2009) Hose Pumps : Ideal for Abrasive Applications

As pumps have positive scrap value, it is an advantage for the company to send the old pumps for scrap and avoid disposal costs. It is assumed that there is no disposal cost required for the handling of pumps at their end-of-life.

2.4.6 Interest and inflation rates

A default value of 4% is suggested as the EU average discount rate in the new ErP methodology which is proposed to be used in this subsection. Table 9 presents the generic interest and inflation rates in the EU-27.

Table 9: Generic interest and inflation rates in the EU-27[23]

	Unit	Domestic incl. VAT	Long term growth per year	Non-domestic excl. VAT
Interest	%	7.7%		6.5%
Inflation rate	%	2.1%		
Discount rate (EU default)	%	4%		

[23] VHK, MEErP 2011 METHODOLOGY PART 1

2.5 Conclusions

The data presented in Task 2 will form the basis for selecting the most representative products on the European market and eventually formulating the base-case(s) in Task 5. However, estimating sales and establishing the stock of pumps covered by ENER Lot 28 study in sufficient detail to allow base-case selection through existing data sources represents a challenge.

This report represents the best estimates based on a number of individual sources. One of these sources is PRODCOM, however the classification of product groups proposed in Task 1 does not match with the official NACE codes used in PRODCOM. Hence, PRODCOM only serve as a broad overview of the market size and the data presented in this report relies mostly on information provided directly by the industry.

Currently the data suggests that centrifugal submersible domestic drainage pump < 40 mm passage and Centrifugal submersible pump – once a day operation account for the highest sales in EU amongst all the pumps covered in ENER Lot 28 study.

As presented in Table 10, regarding the stock numbers of ENER Lot 28 products when compared to other pumps and motors covered in ENER Lot 29 and ENER Lot 11, it can be said that they represent less than 1/3 of the market (in units), with around 16.0 million units installed in the EU in 2011.

Table 10: EU installed stock of pumps

Study	Stock (million units)	Year	Geographical scope
ENER Lot 11[24]	17.1	2007	EU-25
ENER Lot 28	15.7	2011	EU-27
ENER Lot 29[25]	16.6	2011	EU-27

It is also important to note that it is likely to be differences in market size, production and distribution structures, and product trends between different Member States. As large pumps are mostly engineered for industrial applications, they are likely to be part of smaller-scale markets, and production centred within the EU. On the other hand, smaller pumps are more homogeneous, "mass-produced" in a more global market.

The following tasks of this preparatory study will determine the energy consumption, the environmental impacts and the potential for improvement of this product sector.

[24] Only refers to pumps covered within ENER Lot 11

[25] Swimming pool pumps, pond pumps, aquarium pumps, submersible multistage pumps >6" and vertical multistage pumps >25bar and/or 100m3/hr.

This page is left intentionally blank

Annex 1: PRODCOM data

The tables below present the detailed import, export, production and EU apparent consumption (both number of units and by value in million Euros) for the years 2008-2010 for the Nace Codes concerning pumps covered in ENER lot 28 study as reported by PRODCOM.

Please note: The PRODCOM data presented only serve informational purposes and will not be considered in the environmental and life cycle cost analyses during this study.

Table 11: Market data from PRODCOM for positive displacement reciprocating pumps, diaphragm (PRODCOM code: 28131280)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	6 000	6 000	2 141	*-40.3%*
Import	888	1 092	2 544	*69.2%*
Export	1 521	541	1 516	*-0.2%*
Apparent EU consumption	**5 368**	**6 551**	**3 169**	***-23.2%***
Value in million €				
Production	317	260	238	*-13.3%*
Import	69	61	69	*0.4%*
Export	155	103	140	*-4.7%*
Apparent EU consumption	**231**	**218**	**167**	***-15.0%***
Average price in €				
Production	53	43	111	*45.1%*
Import	77	56	27	*-40.7%*
Export	102	190	93	*-4.6%*
Apparent EU consumption	**43**	**33**	**53**	***10.7%***

The unit sales, EU-27 production, and market value for diaphragm positive displacement reciprocating pumps have been decreasing over the past few years. Sales in 2010 were around 3.1 million units compared to 5.3 million units in 2008.

Table 12: Market data from PRODCOM for Positive displacement pumps, rotary, gear (PRODCOM code: 28131320)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	8 000	7 642	9 000	6.1%

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Import	222	142	313	18.7%
Export	467	291	351	-13.3%
Apparent EU consumption	**7 755**	**7 493**	**8 962**	***7.5%***
Value in million €				
Production	365	299	370	*0.7%*
Import	42	28	33	*-10.8%*
Export	62	56	72	*7.7%*
Apparent EU consumption	**345**	**271**	**332**	***-1.9%***
Average price in €				
Production	46	39	41	*-5.0%*
Import	188	197	106	*-24.9%*
Export	132	193	204	*24.2%*
Apparent EU consumption	**44**	**36**	**37**	***-8.8%***

The market value for rotary gear positive displacement pumps has remained fairly constant since 2008. Sales in 2010 were 8.9 million units, mostly EU-27 produced goods. There has been a slight increase in imported goods from 222,000 units in 2008 to 313,000 units in 2010 as well as a slight decrease in exported goods.

Table 13: Market Data from PRODCOM for Positive displacement pumps, rotary, vane (PRODCOM code: 28131340)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	200	120	120	*-22.5%*
Import	253	106	420	*28.9%*
Export	904	1 129	1 499	*28.8%*
Apparent EU consumption [26]	-	-	-	-
Value in million €				
Production	36	20	26	*-15.0%*
Import	12	8	15	*13.7%*
Export	54	55	69	*12.9%*
Apparent EU consumption	-	-	-	-

[26] No values are listed for sales in units or value in million Euro because there seems to be an issue with estimates for the year.

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Average price in €				
Production	180	167	217	*9.7%*
Import	47	76	37	*-11.7%*
Export	60	48	46	*-12.3%*
Apparent EU consumption	**13**	**29**	**29**	***45.5%***

Since 2008 there has been a steady increase in the quantity of rotary vane positive displacement pumps exported of around 1.5 million units in 2010 compared to 904,000 units in 2008, as well as an increase in quantity imported and decrease in production of 120,000 units in 2010 compared to 200,000 in 2008.

Table 14: Market data from PRODCOM for Positive displacement pumps, rotary, screw (PRODCOM code: 28131360)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	417	250	262	*-20.7%*
Import	21	7	21	*1.0%*
Export	45	94	48	*3.4%*
Apparent EU consumption	**393**	**163**	**235**	***-22.6%***
Value in million €				
Production	309	246	246	*-10.6%*
Import	7	7	7	*0.5%*
Export	106	125	112	*2.5%*
Apparent EU consumption	**210**	**128**	**142**	***-17.7%***
Average price in €				
Production	740	981	941	*12.7%*
Import	355	1069	352	*-0.5%*
Export	2377	1334	2337	*-0.8%*
Apparent EU consumption	**534**	**782**	**604**	***6.4%***

The overall unit sales, domestic production, and market value show have decreased over the past few years for rotary screw positive displacement pumps. Sales in 2010 were 235,000 units, mostly EU-27 produced goods.

Table 15: Market data from PRODCOM for Positive displacement pumps, rotary (including peristaltic, rotary lobe and helical rotor pumps) (excluding hydraulic units, gear pumps, vane pumps, screw pumps) (PRODCOM code: 28131380)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	2 863	857	313	*Chapter 3: -66.9%*
Import	850	3 367	7 734	*Chapter 4: 201.7%*
Export	1 533	1 429	1 200	*Chapter 5: -11.5%*
Apparent EU consumption	**2 179**	**2 795**	**6 847**	***Chapter 6: 77.3%***
Value in million €				
Production	455	436	422	*-3.8%*
Import	51	41	46	*-4.5%*
Export	148	128	151	*1.0%*
Apparent EU consumption	**357**	**349**	**316**	***-5.9%***
Average price in €				
Production	159	509	1345	*190.9%*
Import	59	12	6	*-68.4%*
Export	97	89	126	*14.2%*
Apparent EU consumption	**164**	**125**	**46**	***-46.9%***

The unit sales and import quantity for positive displacement pumps are increasing rapidly whereas EU-27 production is decreasing rapidly for rotary positive displacement pumps (including peristaltic, rotary lobe and helical rotor pumps and excluding hydraulic units, gear pumps, vane pumps, and screw pumps). Annual imports have increased by more than a factor of nine between 2008 and 2010. Sales in 2010 were 6.8 million units, mostly imported goods.

Table 16: Market data from PRODCOM for Submersible motor, single-stage rotodynamic drainage and sewage pumps (PRODCOM code: 28131413)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	1 655	1 353	1 515	*Chapter 7: -4.3%*
Import	2 769	2 742	3 629	*Chapter 8: 14.5%*
Export	993	778	891	*Chapter 9: -5.3%*
Apparent EU consumption	**3 431**	**3 316**	**4 253**	***Chapter 10: 11.3%***
Value in million €				
Production	672	570	632	*-3.0%*
Import	66	65	80	*10.3%*

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Export	405	358	361	*-5.6%*
Apparent EU consumption	**333**	**277**	**351**	***2.7%***
Average price in €				
Production	406	421	417	*1.4%*
Import	24	24	22	*-3.6%*
Export	408	460	405	*-0.3%*
Apparent EU consumption	**97**	**84**	**83**	***-7.7%***

The market value for submersible motor, single-stage rotodynamic drainage and sewage pumps has remained fairly constant. There has been a slight increase in the total number of units sold, with an increase in imports to 3,629,000 units and a slight decrease in EU-27 production compared to 2008.

Table 17: Market data from PRODCOM for Positive displacement pumps, rotary, vane Submersible motor, mutli-stage rotodynamic pumps (PRODCOM code: 28131415)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	1 920	1 500	1 830	*-2.4%*
Import	343	212	554	*27.0%*
Export	265	260	477	*34.1%*
Apparent EU consumption	**1 998**	**1 452**	**1 906**	***-2.3%***
Value in million €				
Production	477	436	552	*7.5%*
Import	27	23	33	*9.3%*
Export	141	132	157	*5.4%*
Apparent EU consumption	**363**	**328**	**428**	***8.5%***
Average price in €				
Production	249	291	302	*10.2%*
Import	80	109	59	*-13.9%*
Export	532	506	329	*-21.4%*
Apparent EU consumption	**182**	**226**	**224**	***11.1%***

The market value and imported quantity for positive displacement pumps (rotary, vane, submersible motor, multi-stage rotodynamic pumps) have slightly increased in 2010 compared to previous years. Additionally, the EU-27 quantity produced has slightly decreased.

Table 18: Market data from PRODCOM for Centrifugal pumps with discharge outlet diameter > 15 mm, channel impeller pumps, side channel pumps, peripheral pumps and regenerative pumps (PRODCOM code: 28131430)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	363	329	364	*Chapter 11: 0.1%*
Import	112	102	414	*Chapter 12: 91.9%*
Export	51	27	151	*Chapter 13: 72.9%*
Apparent EU consumption	**425**	**404**	**627**	***Chapter 14: 21.4%***
Value in million €				
Production	238	300	385	*27.3%*
Import	3	5	6	*28.6%*
Export	36	27	40	*6.3%*
Apparent EU consumption	**205**	**277**	**350**	***30.7%***
Average price in €				
Production	655	912	1059	*27.2%*
Import	31	47	14	*-33.0%*
Export	708	996	267	*-38.5%*
Apparent EU consumption	**483**	**687**	**559**	***7.6%***

The EU-27 production of centrifugal pumps with discharge outlet diameter >15mm (channel impeller pumps, side channel pumps, peripheral pumps, and regenerative pumps) has remained constant whilst the quantity imported, exported, and sold sharply increased in 2010. The market value for rotodynamic single-stage mixed flow or axial pumps has steadily increased.

Table 19: Market data from PRODCOM for Centrifugal pumps with a discharge outlet diameter >15 mm, single-stage with a single entry impeller, close coupled (PRODCOM code: 28131451)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	816	577	544	*Chapter 15: -18.3%*
Import	211	522	368	*Chapter 16: 31.9%*
Export	842	949	1 143	*Chapter 17: 16.5%*
Apparent EU consumption [27]	**185**	**150**	**-**	

[27] No values are listed for sales in units or value in million Euro because there seems to be an issue with estimates for the year.

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Value in million €				
Production	462	386	397	*Chapter 18: -7.3%*
Import	8	15	13	*Chapter 19: 26.9%*
Export	119	114	134	*Chapter 20: 6.1%*
Apparent EU consumption	**352**	**288**	**277**	***Chapter 21: -11.3%***
Average price in €				
Production	567	670	730	*13.5%*
Import	39	29	36	*-3.8%*
Export	141	120	117	*-8.9%*
Apparent EU consumption	**1 904**	**1 917**	**-**	

There has been a decrease in production but increase in imports in centrifugal pumps with a discharge outlet diameter >15mm (single-stage with a single entry impeller, close coupled) in 2010 compared to 2008. The market value for these pumps has steadily decreased across the years.

Table 20: Market data from PRODCOM for Centrifugal pumps with a discharge outlet diameter > 15 mm, single-stage with a single entry impeller, long coupled (PRODCOM code: 28131453)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	1 385	1 058	1 809	*Chapter 22: 14.3%*
Import	166	124	616	*Chapter 23: 92.4%*
Export	787	619	1 076	*Chapter 24: 16.9%*
Apparent EU consumption	**764**	**563**	**1 350**	***Chapter 25: 32.9%***
Value in million €				
Production	938	822	950	*0.6%*
Import	11	17	11	*-1.5%*
Export	242	204	230	*-2.4%*
Apparent EU consumption	**707**	**635**	**730**	***1.6%***
Average price in €				
Production	677	777	525	*-12.0%*
Import	66	135	17	*-48.8%*
Export	307	330	214	*-16.5%*
Apparent EU consumption	**926**	**1 127**	**541**	***-23.6%***

There has been a slight increase in production of these pumps in the EU over the past few years. Additionally, there has been a sharp increase in pumps imported by a factor of six in 2010 of 616,000 units and a double in unit sales for 2010 of 1,350,000 units compared to 2008. The market value for centrifugal pumps with a discharge outlet diameter >15 mm (single-stage with a single entry impeller, long coupled) has remained fairly constant.

Table 21: Market data from PRODCOM for Centrifugal pumps with a discharge outlet diameter >15 mm, single-stage with double entry impeller (PRODCOM code: 28131455)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	4	5	5	*16.0%*
Import	10	6	7	*-16.5%*
Export	51	23	21	*-35.5%*
Apparent EU consumption [28]	-	-	-	-
Value in million €				
Production	145	126	120	*-9.2%*
Import	1,4	1,3	1,2	*-8.3%*
Export	63	100	62	*-1.3%*
Apparent EU consumption	**83**	**27**	**59**	***-15.7%***
Average price in €				
Production	39519	24506	24186	*-21.8%*
Import	147	226	177	*9.8%*
Export	1255	4426	2937	*53.0%*
Apparent EU consumption	-	-	-	-

The market value for centrifugal pumps with a discharge outlet diameter >15mm (single-stage with double entry impeller has decreased by one-fourth from 2008 to 2010. Additionally, the majority of these pumps are imported.

Table 22: Market data from PRODCOM for Centrifugal pumps with a discharge outlet diameter >15 mm, multi-stage (including self-priming) (PRODCOM code: 28131460)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	1 600	1 500	1 500	*Chapter 26: -3.2%*
Import	63	5	11	*Chapter 27: -58.8%*
Export	1 024	903	298	*Chapter 28: -46.1%*

[28] No values are listed for sales in units or value in million Euro because there seems to be an issue with estimates for the year.

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Apparent EU consumption	**639**	**602**	**1 213**	*Chapter 29:* ***37.8%***
Value in million €				
Production	957	879	863	*-5.0%*
Import	5	7	5	*-4.1%*
Export	200	200	221	*5.0%*
Apparent EU consumption	**762**	**685**	**647**	***-7.9%***
Average price in €				
Production	598	586	575	*-1.9%*
Import	87	1347	471	*132.6%*
Export	196	222	742	*94.6%*
Apparent EU consumption	**1 193**	**1 139**	**534**	***-33.1%***

There has been an increase in annual production in the EU for centrifugal pumps with a discharge outlet diameter >15mm (multi-stage including self-priming) to 1,213,000 units in 2010, almost double of that in 2008 with the majority of pumps being produced in the EU. There has also been a slight decrease in the market value as well as a sharp decrease of sales in average price from 2008 to 2010.

Table 23: Market data from PRODCOM for Rotodynamic single-stage mixed flow or axial pumps (PRODCOM code: 28131471)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	2 100	2 718	3 187	*23.2%*
Import	3 875	3 350	3 769	*-1.4%*
Export	1 062	783	2 678	*58.8%*
Apparent EU consumption	**4 913**	**5 284**	**4 279**	***-6.7%***
Value in million €				
Production	639	532	530	*-9.0%*
Import	61	58	68	*6.3%*
Export	407	330	378	*-3.6%*
Apparent EU consumption	**293**	**259**	**220**	***-13.4%***
Average price in €				
Production	304	196	166	*-26.1%*
Import	16	17	18	*7.8%*
Export	383	422	141	*-39.3%*

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Apparent EU consumption	**60**	**49**	**51**	***-7.2%***

The market value for rotodynamic single-stage mixed flow or axial pumps has remained fairly constant.

Table 24: Market data from PRODCOM for Rotodynamic multi-stage mixed flow or axial pumps (PRODCOM code: 28131475)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	720	991	703	*-1.2%*
Import	534	391	459	*-7.3%*
Export	1 714	1 710	2 500	*20.8%*
Apparent EU consumption [29]	-	-	-	-
Value in million €				
Production	568	587	549	*-1.7%*
Import	53	47	44	*-9.2%*
Export	0,8	0,6	0,5	*-18.3%*
Apparent EU consumption	**68**	**121**	**221**	***80.7%***
Average price in €				
Production	789	592	780	*-0.6%*
Import	99	120	95	*-2.1%*
Export	323	300	148	*-32.2%*
Sales	-	-	-	-

For rotodynamic multi-stage mixed flow or axial pumps, the market value has doubled annually with a resulting value of 221 million Euro for 2010.

Table 25: Market data from PRODCOM for Other liquid pumps, liquid elevators (PRODCOM code: 28131480)

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Quantity in 1000 units				
Production	63 516	24 911	27 892	*-33.7%*
Import	31 543	19 097	30 144	*-2.2%*

[29] No values are listed for sales in units or value in million Euro because there seems to be an issue with estimates for the year.

EU-27	2008	2009	2010	Annual average increase or decrease (%)
Export	32 822	39 720	45 342	*17.5%*
Apparent EU consumption	62 237	4 288	12 693	*-54.8%*
Value in million €				
Production	1 221	840	991	*-9.9%*
Import	392	334	362	*-3.8%*
Export	1,4	1,1	1,8	*14.3%*
Apparent EU consumption	**615**	**255**	**400**	***-19.3%***
Average price in €				
Production	19	34	36	*36.0%*
Import	12	17	12	*-1.6%*
Export	30	23	21	*-16.8%*
Apparent EU consumption	**10**	**60**	**32**	***78.6%***

The sales of other liquid pumps and liquid elevators are decreasing rapidly, showing trends towards decreased production and increased imports and exports. Sales in 2010 were around 12.7 million units, which is around one-fifth of sales in 2008.

This page is left intentionally blank

Annex 2: Data of pumps excluded from ENER Lot 28 study

As explained in Task 1, the positive displacement pumps are excluded from the ENER Lot 28 study. Nevertheless, the data collected during the study for positive displacement pumps is compiled in this section for the reference of related work in the future. Table 26 to Table 31 provide the data from the market analysis for positive displacement pumps in wastewater industries. The pumps that had been studied are Archimedean screw pump, progressing cavity pump and Peristaltic pump.

Table 26: Pump sales in EU by number of units sold

Pump Type	Estimate of sales in (units)		Source
	2005[30]	2011[31]	
Archimedean screw pump	390	500	Europump
Progressing cavity pump	19 482	25 000	Europump
Peristaltic pump	3 273	4 200	Europump

Table 27: Estimated installed stock of pumps in the EU-27

Pump Type	Estimate of installed stock in (units)		Source
	2005[32]	20114	
Archimedean screw pump	50 000	12500	Europump
Progressing cavity pump	220 937	250 000	Europump
Peristaltic pump	30 489	34 500	Europump

[30] The values for 2005 pump sales in EU are provided by Europump based on an average annual growth in sales of 3.5% per year between 2005 and 2011.

Europump is the European Association of Pump Manufacturers. It represents 18 National Associations in 15 EU Member States, Turkey, Russia & Switzerland. Europump members represent more than 450 companies with a collective production worth more than €10 billion and employing 100 000 people in Europe. Website: www.europump.org/

[31] These sales figures are provided by Europump based on their best estimates without counteracting any law or Directive.

[32] The pump installed stock in 2005 in EU are estimated by Europump based on an average annual growth in stock of 1.75% per year between 2005 and 2011. Thereby the figures for 2005 can be calculated backwards from figures 2011 by multiplying by 0.9825^7 = 0.884

Table 28: Product technical life and average economical lifetime of pumps in the EU-27[33]

Pump Type	Technical life (in years)	Average time to disposal (economical lifetime in years)	Source
Archimedean screw pump	25	25	Europump
Progressing cavity pump	10	10	Europump
Peristaltic pump	10	10	Europump

Table 29: Purchase price (including VAT) of the average wastewater pumps in Euros/unit

Pump type	Range of purchase price (€/unit)	Average purchase price (€/unit)	Source
Archimedean screw pump	15 000-20 0000	65 000	Estimate
Progressing cavity pump	3 000 – 12 000	6 000	Estimate
Peristaltic pump	100 – 1 000	2 500	Estimate

Table 30: Average installation cost (including VAT) for wastewater pumps in Euros/unit

Pump type	Range of installation cost (€)	Average installation cost (€)	Source
Archimedean screw pump	4 000 – 20 000	15 000	Estimate
Progressing cavity pump	250 – 1 200	800	Estimate
Peristaltic pump	200 – 1 500	800	Estimate

Table 31: Average annual maintenance and repair cost wastewater pumps (in Euros/year)

Pump type	Range of repair cost (€/year)	Average repair cost (€/year)	Range of maintenance cost (€/year)	Average maintenance cost (€/year)	Source
Archimedean screw pump	150 - 500	200	500 - 2000	900	Estimate
Progressing cavity pump	50 - 250	150	100 - 400	200	Estimate
Peristaltic pump	100 - 300	175	100 - 250	175	Estimate

[33] The "Range of Economical Lifetime" depends massively on operational conditions, pumped liquid, maintenance and surrounding conditions thus reliable estimate cannot be given and is excluded in the table.

This page is left intentionally blank



02 April 2014

185 Avenue Charles de Gaulle
92200 Neuilly-sur-Seine
France
+ 33 (0)1 5561 6755
www.bio.deloitte.fr

Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 3 – Consumer Behaviour and Local Infrastructure Working Document

Final Report to the European Commission, DG ENER
02 April 2014



European Commission

Developed by:

bio by Deloitte.

ATKINS

Document information

CLIENT	European Commission, DG ENER
CONTRACT NUMBER	ENER/C3/403/2010
REPORT TITLE	ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 3 – Consumer Behaviour and Local Infrastructure Working Document
PROJECT NAME	Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC
PROJECT CODE	ENER Lot 28
PROJECT TEAM	Bio by Deloitte, Atkins
DATE	02 April 2014
AUTHORS	Mr. Shailendra Mudgal, Bio by Deloitte Mr. Sandeep Pahal, Bio by Deloitte Mr. Benoit Tinetti, Bio by Deloitte Mr. Alvaro De Prado Trigo, Bio by Deloitte Dr. Hugh Falkner, Atkins Mr. Keeran Jugdoyal, Atkins
KEY CONTACTS	Mr. Sandeep Pahal spahal@bio.deloitte.fr Or Mr. Shailendra Mudgal shmudgal@bio.deloitte.fr
DISCLAIMER	This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. The project team does not accept any liability for any direct or indirect damage resulting from the use of this report or its content.

Please cite this publication as:
Bio by Deloitte (2014), Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC, ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 3 – Consumer Behaviour and Local Infrastructure Working Document prepared for. European Commission, DG ENER.

Photo credit: cover @ Per Ola Wiberg

©Bio by Deloitte 2014

Table of Contents

3.1 Real life efficiency 5

3.1.1 Impeller Design for centrifugal pumps 6

3.1.2 Pump applications 8

3.1.3 Frequency of use 12

3.1.4 Product related eco-information 13

3.2 End of life behaviour 19

3.2.1 Present fractions to re-use, recycling and disposal 19

3.2.2 Estimated re-use second hand use, fraction of total and estimated second product life (in practice) 21

3.3 Local infrastructure 21

3.4 Conclusions 22

List of Tables

Table 1: Maximum efficiency of different types of wastewater impeller (source Europump) 8

Table 2: Annual operating hours of the ENER Lot 28 pumps 12

Table 3: Proportion of materials in the pumps considered in the study 20

List of Figures

Figure 3-1: Example of a closed impeller used for clean water applications 6

Figure 3-2: Typical material removed from a conventional 300mm discharge sewage pump 6

Figure 3-3: Passage of a rag through a screw centrifugal impeller (Courtesy of Hidrostal) 7

Figure 3-4: Example of an open impeller 7

Figure 3-5: Vortex impeller 8

Figure 3-6: Example of cutter type impeller 8

Figure 3-7: Typical submersible pumping station arrangement 9

Figure 3-8: Diagram of pumping station network from source to WWT plant 10

Figure 3-9: Refuse collected on wastewater treatment inlet screens 11

Figure 3-10: Example of a prefabricated pumping station 14

Figure 3-11: "Tombstone" curves for the selection of pumps by duty 16

Figure 3-12: Worked example showing the importance of correct selection of a pump 16

Figure 3-13: Centrifugal pump characteristics 17

Figure 3-14: Onset of adverse effects when operating a pump away from its peak efficiency flow 18

Figure 3-15: Illustration of the effect on power and efficiency of operating away from the BEP of a pump 19

Task 3: Consumer Behaviour and Local Infrastructure

Consumer behaviour has a significant direct effect on the use of pumps for wastewater and fluids with high solid content, during the use phase of the product and the End-of-Life phase. To some extent, product-design can be used to influence a consumer's behaviour to improve the environmental impacts and the energy efficiency associated with the product use.

The aim of this task is to investigate the influence of providing product information to the end-users of wastewater and solids handling pumps, and on the influence, they can have on the environmental performance of the equipment. The main aspects covered in this task include: real life efficiency, end of life behaviour, and local infrastructure. Other areas investigated include eco-practices in sustainable product use; and whether it could be useful to consider labelling or provision of other eco-information (e.g. ecological profile of the product). Barriers to the provision of such information and ecodesign measures, due to social, cultural, and infrastructural factors are also investigated. Further, analysing real life use conditions of products in comparison with standard test conditions provides a more accurate picture of the real energy use.

3.1 Real life efficiency

The aim of this subtask is to reflect on how the real life efficiency of pumps for wastewater and fluids with high solid content, differ from those tested in standard conditions and to quantify user defined parameters. Identification of actual user behaviour (average EU) includes:

- Real life efficiency, such as load efficiency (real load vs. nominal capacity), frequency and characteristic of use; power management enabling-rate and other user settings
- Best practice in sustainable product use
- Repair and maintenance practice (frequency, spare parts, transportation and other impact parameters)

While energy efficiency is important, there is a vital trade off with ability to pass solids and resist clogging or ragging. "Rag" is a term used to describe the fibrous solid matter found in wastewater. The ability to resist wear is also crucial so that efficiency is maintained over a pump's lifetime.

By way of comparison, the typical BEP efficiency of a 30 kW wastewater pump is c.30 - 73 %, compared to the typical efficiency of an equivalent duty clean water pump of 65 – 80 %. Users traditionally accept this efficiency penalty in order that the pumps do not regularly block and fail.

3.1.1 Impeller Design for centrifugal pumps

Impellers for clean water pumps have fine clearances to minimise backflow and to maximise hydraulic efficiency. These are typically known as closed impellers, see Figure 3-1. The impellers in centrifugal wastewater treatment pumps are designed to allow solids to pass through the pumps without clogging it up, and so have a very different appearance. They are also considerably less efficient.



Figure 3-1: Example of a closed impeller used for clean water applications

The downtime due to clogging can be significant and costly. Figure 3-2 shows an example of material that can get clogged in a sewage pump.



Figure 3-2: Typical material removed from a conventional 300mm discharge sewage pump

Through careful selection of the impeller, it is possible to achieve the best efficiency with an acceptable (if any) likelihood of blockage from ragging.

Three common impeller types are used in wastewater treatment: *open* which have large spaces between vanes; *vortex* which creates a vortex within the pump bowl which prevents the solids from coming into contact with the impeller; and *grinder impellers which break up the solids which allows them to pass through the pump with greater ease.*.

Open impellers come in a range of types including a screw centrifugal impeller (Figure 3-3)which guide solids through the pump without damaging them. Some designs offer free passage for solids up to 300 mm. This can be of great benefit in some areas of wastewater treatment where a wider passage allows a smooth transfer of activated sludge, but there is an efficiency penalty for this.



Figure 3-3: Passage of a rag through a screw centrifugal impeller (Courtesy of Hidrostal)



Figure 3-4: Example of an open impeller

In medium sized pumps, open single and two channel impellers are common, with the wear disc adjustable to compensate for wear and hence maintain efficiency over pump lifetime. Some larger pumps have closed channels (two sides to the impeller).

In smaller sized pumps besides mostly open single and 2-channel impellers, vortex impellers are very common as they do not make contact with the solids within the pumped liquid and therefore are much less prone to being clogged up by rags. Despite their relatively low efficiencies, their use can be appropriate for applications with low duty and low annual operating hours. Due to their good non-clogging behaviour, they are well suited to remote applications where cal-outs would be expensive. Figure 3-5 shows the operation of a vortex impeller, with the impeller generating a vortex that pulls through the water and any solids without the solids passing through the impeller.

Certain pumps, particularly when used with smaller pipe diameters have the ability to chop the big solid particles into smaller ones. Figure 3-6 shows one such cutting/grinding pump.

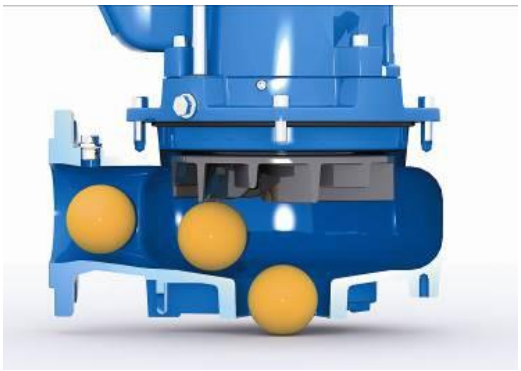


Figure 3-5: Vortex impeller



Figure 3-6: Example of cutter type impeller

The following table is indicative of the relative efficiencies of the different impeller options available for the same basic pump.

Table 1: Maximum efficiency of different types of wastewater impeller (source Europump)

Impeller	Max Efficiency
Open	87%
Vortex	63%
Grinder	42%

3.1.2 Pump applications

The pumps within the definition of scope of ENER Lot 28 study are largely designed for use in specific applications. This means that it will be clear to any user what type is appropriate for a particular application. For some applications, there may be alternative technology options. This is of relevance to the ecodesign process, as it means there is a risk that regulation could inadvertently lead to users selecting a less good pump that has less demanding regulations applied to it. Conversely, risk averse users may not be aware of the more efficiency alternatives

to the types they have used in the past, and so the ecodesign process has a very important role to play in overcoming this critical barrier.

The first step in understanding the use of pumps in scope of ENER Lot 28 is to establish a descriptor of the user requirements of the systems in which they are applied. This section gives an overview of these applications.

The applications considered are:

- Wastewater pumping stations
- Wastewater treatment plants

Pumping stations

Pumping stations are found throughout the wastewater collection network. The collection network starts in the catchment area and brings together the collected wastewater in to progressively larger pumping stations until they are pumped to the wastewater treatment works for processing. Most wastewater pumping stations are used to lift the wastewater into a sewer network where it moves by gravity to the next pumping station in the line. This minimise the pumping power required as most of the work is done by gravity. The size of the collection network is dependent on a number of factors including population density and topography, and can be several kilometres in length.

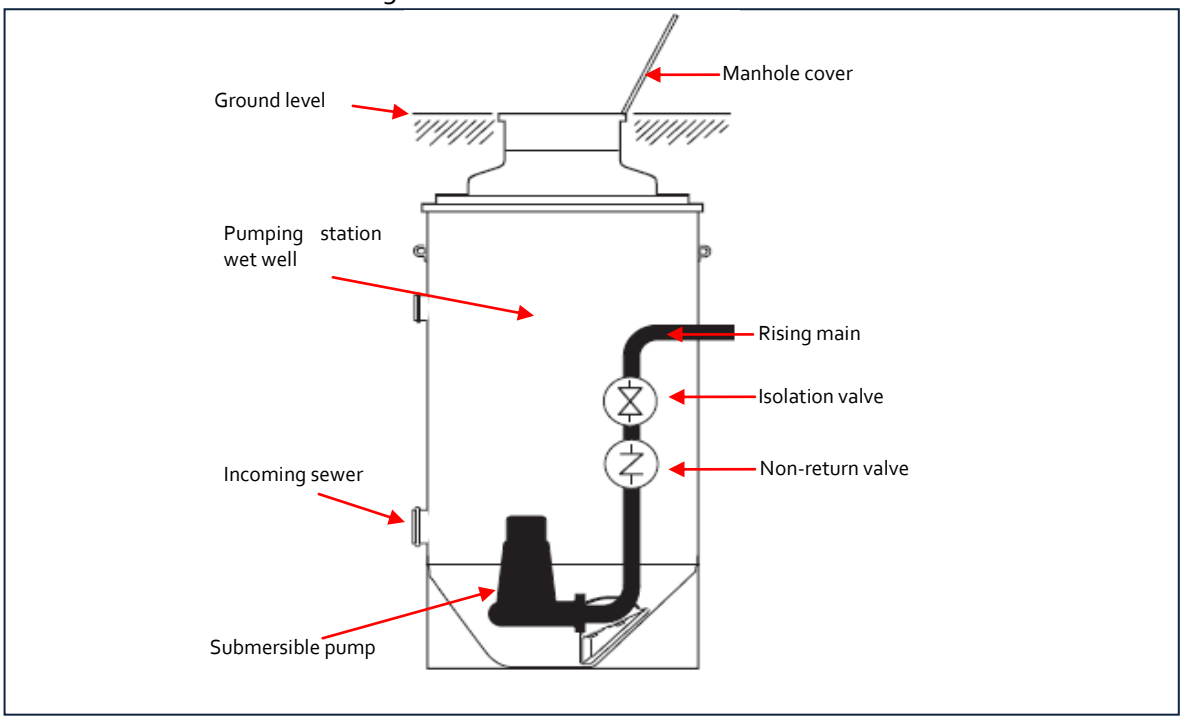


Figure 3-7: Typical submersible pumping station arrangement

Wastewater collection networks can come in two configurations, separate and combined. In a combined system, rainwater collected from road, building drainage is combined with the wastewater, and it is all sent to the wastewater treatment works together. In a separate system, only wastewater is sent to the treatment works and rainwater is discharged directly to the local watercourse.

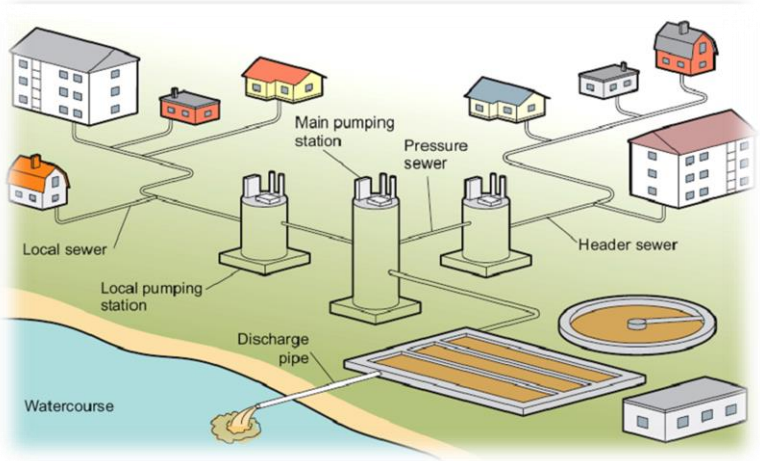


Figure 3-8: Diagram of pumping station network from source to WWT plant

A typical small or medium sized wastewater pumping station consists of two parallel submersible pumps in a wet well. The pumps are operated in a duty / standby or duty / assist configuration. The duty pump is called to run when the water level in the wet well reaches a pre-defined level, and stops when the level approaches a defined stop level, taking into account the minimum submergence needed, given e.g. by NPSHa, motor cooling or prevention of air sucking vortices. The size of pumping station is dependent of the catchment they serve, which can range from a few houses to a large industrial estate. Typical pumps used vary in size from 4 – 200 l/s with a head of 3 – 50 m, and have a rated power of between 3 – 150 kW. The wet wells are sized to ensure that the pumps do not start more than, depending on motor size and design, 6 to 20 times per hour so as to avoid premature motor failure.

The pumps required in a combined collection network are larger than those in a separate system and are subject to much larger variations in flows. A benefit of using a combined system is that the rainwater dilutes the wastewater which, results in principle in less risk of blockages, however combined systems are prone to overloading the pumping stations with accumulated trash from the sewer systems during storm events. As a consequence of this, pumping stations in combined systems are sometimes equipped with a third pump which is scheduled to operate during periods of high rainfall. These larger pumping stations are sometimes fitted with dry well pumps instead of submersible for easier access for repairs and maintenance purposes.

It can sometimes be useful to fit terminal pumping stations, (the final pumping stations before the treatment works) with variable speed drives. This will help to ensure that wastewater reaches the treatment works in a steady stream rather than in batches. This is primarily done to ensure the wastewater treatment process is not overloaded, rather than for reasons of energy efficiency.

- **Wastewater treatment plants**
  - **Preliminary Treatment**

During the preliminary treatment stage, the wastewater is screened to take out the large solids and often there is a grit removal process. Inlet screens are sometimes located higher than the incoming sewer and pumps are required to lift the wastewater to them. Although centrifugal pumps may be used for this purpose, Archimedean screw pumps are often employed due to their excellent solids handling capability and their ability to pump variable flows. In the grit removal

process, vortex pumps are often used due to the abrasive nature of grit. Figure 3-9 shows typical material collected by a primary screen, which may have been pumped a long way along the sewerage network and needs keeping out of the WWT station.



Figure 3-9: Refuse collected on wastewater treatment inlet screens[1]

- **Primary Settlement Treatment (PST)**

Heavy solids are removed in the primary settlement stage with settlement tanks where the sludge is drawn off the bottom of the tank and pumped to a sludge-holding tank. Progressing cavity pumps or centrifugal pumps are used due to the solids content of the liquid. Pump selection can depend on the height of the sludge holding tank, the distance to be pumped and the viscosity of the sludge. Sludge is drawn off and pumped away in batches.

- **Biological (secondary) Treatment**

The two most common biological treatment stages are biological filtration and activated sludge. Biological filtration involves passing the wastewater through a bed of inert media where microorganisms breakdown the dissolved organic matter. The resultant effluent is settled in a settlement tank and humus is drawn off the bottom of the tank. This humus has a low sludge content and so it suitable for pumping with centrifugal pumps. The humus is typically drawn off in batches and pumped by dry well pumps. During periods of low wastewater flow into the treatment works, some of the effluent from the settlement tank can be pumped back to the filter media to stop it from drying out.

In the activated sludge process, the wastewater is mixed with aerobic bacteria and oxygen in a tank. The resulting effluent is passed to a final settlement tank where activated sludge is drawn off the bottom. Unlike primary sludge and humus, activated sludge is drawn off continuously and is returned to the activated sludge plant. Any surplus activated sludge is pumped to the sludge holding tanks. This activity is particularly well suited to the use of variable speed drives as the return rate of the activated sludge can be matched to the mixed liquor suspended solids contents

[1] Thames Water

of the process tank. This reduces the energy use of the process compared to the fixed speed operation.

- **Additional Pumping stations**

Depending on the topography of the site it is possible for the wastewater to pass between the various treatment stages via gravity, however in many sites inter-stage pumping stations are required. These pumping stations generally resemble the pumping stations found in the collection network and a typically fitted with submersible or dry well centrifugal pumps.

The volume of product that can safely pass through a pump is a key criterion in pump design and selection. Larger clearances necessarily mean lower efficiencies, and so this factor will need taking account of in the data collection phase.

3.1.3 Frequency of use

The range of pumps considered in scope has an exceptionally wide range of operating hours. Of particular interest are those used just occasionally to transport wastewater from domestic or small commercial buildings. In these, the low operating hours mean that non-energy considerations become more important, for example materials and reliability. The implication of this is that improvements in energy efficiency can only be made as far as they do not adversely affect these other parameters.

By comparison, pumps at the WWT works will have much longer operating hours, and so here, efficiency considerations become much more important.

A challenge for possible MEPS regulation will be to allow high reliability / low efficiency pumps to be used in low duty applications. Similarly, there is a need to avoid users selecting these less efficient pumps in higher duty applications. Table 2 shows the annual number of operating hours of the ENER Lot 28 pumps.

Table 2: Annual operating hours of the ENER Lot 28 pumps

Pump Type		Annual operating hours	Source
Centrifugal submersible pump			
	Radial sewage pumps 1 to 10kW	1 000	Europump
	Radial sewage pumps >10 to 25kW	1 500	Europump
	Radial sewage pumps >25 to 160kW	2 000	Europump
	Mixed flow & axial pumps	5 000	Europump
Centrifugal submersible pump – once a day operation			
	Shredding, grinding pumps	30	Europump
	Radial sewage pumps 1 to 10kW	30	Europump

Pump Type		Annual operating hours	Source
	Where volute is part of a tank	30	Europump
Centrifugal submersible domestic drainage pump < 40 mm passage		30	Europump
Submersible dewatering pumps		2 000	Europump
Centrifugal dry well pump			
	Radial sewage pumps 1 to 10kW	1 000	Europump
	Radial sewage pumps >10 to 25kW	1 500	Europump
	Radial sewage pumps >25 to 160kW	2 000	Europump
	Mixed flow & axial pumps	250	Europump
Slurry Pumps			
	Light duty	2600	Europump
	Heavy duty	2000	Europump

3.1.4 Product related eco-information

- **Real life efficiency**

Once the pumping station wet well has filled to a set limit, the pump is activated and keeps working until the well has fallen to a lower limit. The total operating hours of a pumping station depends greatly on the flow of water into the wet well. Pumps are generally sized to pump at a flow rate of twice (to 4 times) the average inflow rate, although, due to static head changes, the actual flow rate will vary depending on the level of the water in the well. The routine fitting of standby pumps also halves the average operating time of each pump. On this basis, the maximum duty of any pump is 25% or 42 hours per week, but on average will be much lower.

For isolated premises with their own pumping station, the duty may be extremely small, just a few hours per week. In these applications, extremely reliable but less efficient vortex pumps are popular, with the efficiency trade-off being accepted in order to minimise the risk of blockages.

Reducing pump speed decreases the head drastically ($H \sim n^2$) and so the opportunities for speed reduction in water lifting applications is limited. It also reduces the flow rate, which can cause issues in wastewater pumping, as a minimum flow velocity is required to ensure that the solid particles do not settle out of the water. Reduced pumping speeds also encourages ragging. Variable Speed controls are sometimes used within wastewater treatment works to provide a steady inflow to the process, but minimum speeds are rigorously enforced to maintain flow velocities. In addition, VSDs can be used in reverse in "de-clogging" cycles to attempt to spin off any materials attached to the pump impeller.

- **Repair and maintenance practices**

Larger pumps will require some basic consumables and replacement parts, including lubricant (grease) for bearings, replacement seals, new bearings and new wear rings. Coatings may also be applied to both reduce friction (and hence hydraulic losses) and also reduce corrosion, which can be used both from new and for in service refurbishment. For smaller pumps in sewage pumping stations, it has to be weighed if repair or replacement is economical. For small pumps as e.g. in building and commercial applications, it will not be economic to change these parts, they will instead be replaced by new pumps.

Pumping stations are visited for maintenance on a risk-based approach, with the following factors taken into consideration: historic frequency of breakdown, impact if there is a breakdown (properties impacted, type of wastewater) and Supervisory Control and Data Acquisition (SCADA) equipment to transmit information when there is a problem. Maintenance activity includes condition inspections, security checks, electrical tests and jetting.

Pumps that offer increased wear resistance, less ragging, easier passage of materials and easier to change parts are understandably popular. Wastewater pumps with the ability to pass solids and fibrous materials do have a lower efficiency than conventional pumps, however they are less susceptible to wear. This results in less degradation in performance over time.

Statistically, a wastewater pump in a small pumping station will be replaced 5-6 times over a system's 60-year life, and so the pumping station layout and design will be a key constraint on the type of pump needed. In larger pumping stations pumps are replaced typically 2 to 3 times over a system's design life. Mechanical and hydraulic connections will be a key constraint, with changes in local sewer condition or loading imposing another constraint in terms of flow speeds.

For new pumping stations, for ease of construction, developers will prefer a drop-in pre-fabricated unit.



Figure 3-10: Example of a prefabricated pumping station

Remoteness of pumping stations will dictate more rugged designs with back-up systems and telemetry and monitoring.

Pump run time monitoring is sometimes used to monitor the increase in pump operating time as pump efficiency and flow deteriorate due to wear, offering an economical solution to assessing pump performance.

- **Correct selection of pump**

A critical issue in determining efficiency and lifetime is the correct selection of pump. While specifiers are often at fault for not having an accurate idea of the real duty requirements, the limited number of models in a manufacturers' range may mean that the "nearest" pump is actually a long way from the actual duty point. Supplying pumps with a variety of impeller sizes does help, but at the cost of reduced efficiency. Ideally, a manufacturer would have a very large range of pumps to cater for a range of duties, but the costs make this prohibitive, and so this is a source of energy loss. Theoretically specifiers could often do better by "shopping around", but because they usually order all pumps for a new installation from a single supplier, this does not happen.

It is considered that because pumps are made wholly or almost entirely of easily recyclable metals, and that they are handled by professionals who are aware of their value, they will all be recycled. The market for second hand pumps is only very small.

Given that mainly industry or commerce, rather than consumers use these products, it is hard to identify how social or cultural factors will affect use patterns, however the content of wastewater is affected by cultural factors and this in turn has an effect on pump selection. For example, the type of food cooked will affect the amount of fats, oils and grease in the wastewater. In addition, educational and social factors may affect whether non-organic waste items are flushed down the toilet.

However, although beyond the scope of this report, measures to reduce water consumption would reduce the operating duties of pumps, and ultimately reduce the number of pumps needed, with a consequent reduction of eco-impact. It is becoming increasingly common that industrial premises are looking to reduce water consumption to minimise effluent charges. In domestic properties, grey water use is reducing the effluent generated.

It is clear that the correct selection of pump is at least as important as the selection of pump by highest Best Efficiency Point (BEP). The following text explains how manufacturers design a range of pumps to suit all duties within a range, and the compromises that this means in terms of being able to select a pump for a particular duty.

When selecting a pump, a manufacturer will use "tombstone" curves, which show the ranges of pumps to cover a range of duties, (Figure 3-11: "Tombstone" curves for the selection of pumps by duty). Typically, the duty you want will be roughly 20% below the maximum flow shown on the tombstone, which corresponds to the BEP of the selected pump (each tombstone is built up from individual pumps). However, for economic reasons they have to restrict the number of pumps that they offer. This means that even a manufacturer of particularly efficient pumps may lose out, when quoting efficiencies in competition with less efficient pumps whose BEP just happens to be nearer the requested performance. The worked example following figure makes this clearer.

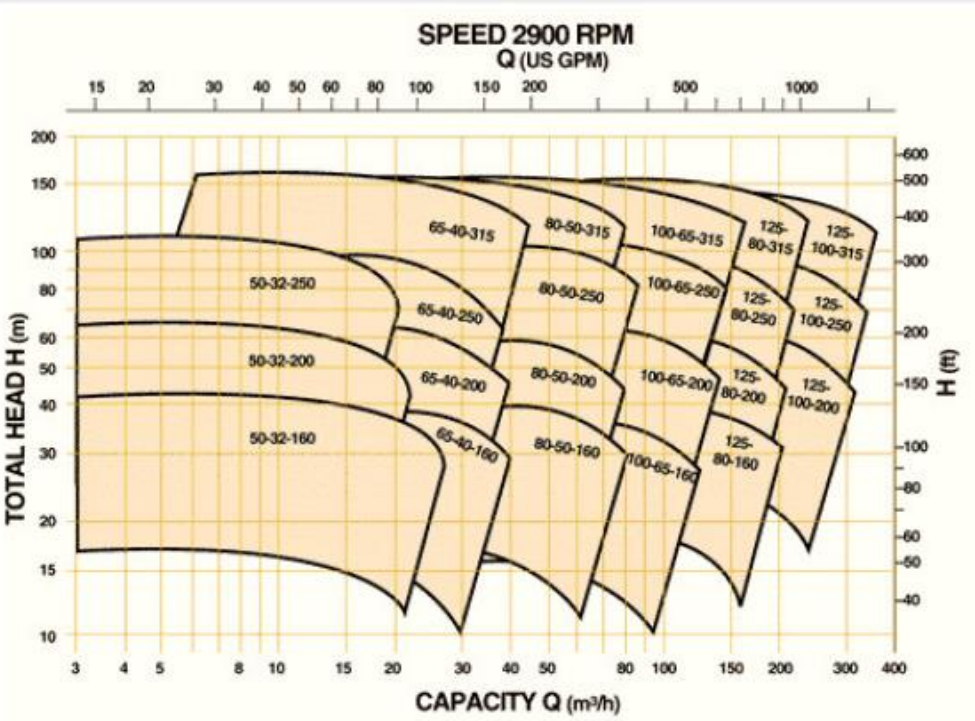
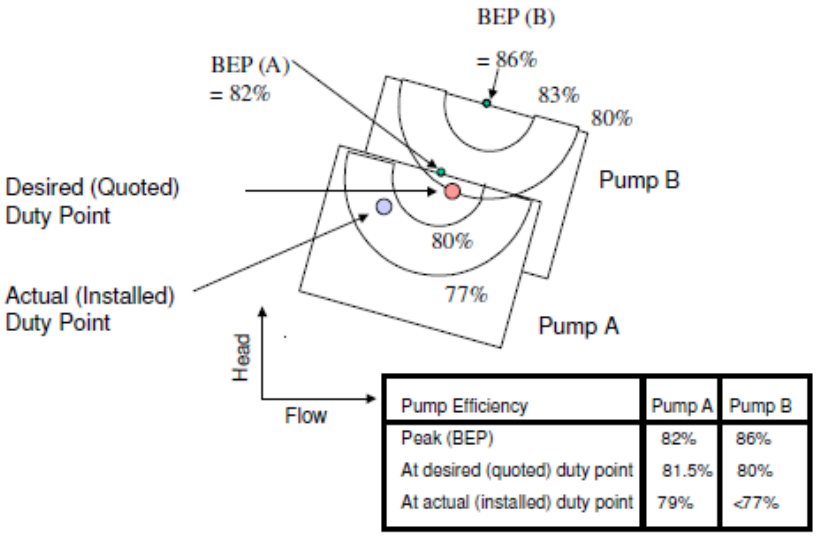


Figure 3-11: "Tombstone" curves for the selection of pumps by duty

A user requests quotes for a pump at a particular desired duty (Figure 3-12). Manufacturers A and B offer the pumps shown, which are the best that they can offer from the ranges that they have.

There are two important points: while pump B has a higher BEP, at the desired duty, pump A actually has a higher efficiency than pump B. Over-specifying the duty means that at the actual installed duty, the efficiency of the pump will be considerably less than quoted. In this particular case, it would be better to use a reduced diameter impeller, or perhaps a quite different pump to either of those quoted for.



Pump Efficiency	Pump A	Pump B
Peak (BEP)	82%	86%
At desired (quoted) duty point	81.5%	80%
At actual (installed) duty point	79%	<77%

Figure 3-12: Worked example showing the importance of correct selection of a pump

- **System Energy Savings**

This report concerns solely the energy savings that can be achieved by using a more efficient pump and extended product – but in terms of the overall savings that can be found in a pumping system these savings represent only a small proportion of the total system loss.

Considering the entire pump system ("electricity to water"), it is found that on average, most significant energy savings come from attention to the way in which the pumping system is designed and controlled. Improving the approach to pump system design would include measures such as optimal pump selection and pipework sizing, minimising velocities and reducing friction losses, optimising operating pressures, and ensuring adequate controls will realise significant energy savings within the complete pumping system. The use of Variable Speed Drives to adjust the flow to match the actual system requirements can make energy savings in some systems. The most efficient control method depends on the specific application needs.

… "In particular, the use of Variable Speed Drives (VSD) to adjust the flow to match the actual system requirements can lead to energy savings of over 50% in some systems, and so is something to be encouraged.

Wastewater pumping applications in general tend to be batch operations, i.e. emptying a wet well once it fills to a certain level. It is therefore not expected to have significant benefit from fitting VSDs to these pumps, but they can be used very effectively in non-batch pumping operations.

- **Part load characteristics of pumps**

Pumps are always defined by their basic characteristics as shown in Figure 3-13: Centrifugal pump characteristics. They show the relationship between head, power and efficiency against flow. It is important to see just how "peaky" the efficiency might be, showing that running at a duty (head and/or flow) below rated duty is likely to lead to a significant reduction in pump efficiency. The Best Efficiency Point (BEP) of a pump is ideally at the rated duty point. The peak power consumption will not necessarily be at the BEP.

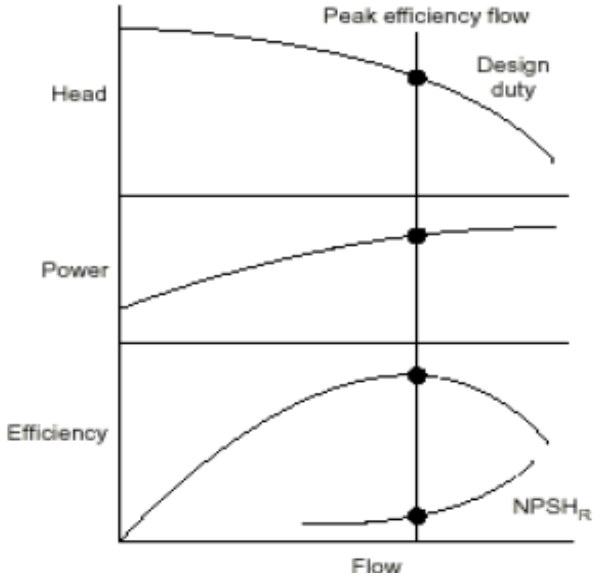


Figure 3-13: Centrifugal pump characteristics

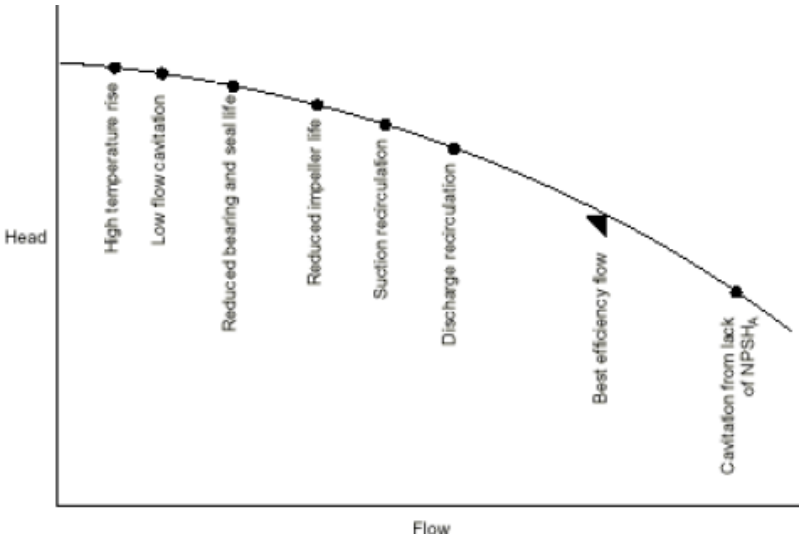


Figure 3-14: Onset of adverse effects when operating a pump away from its peak efficiency flow

The importance of selecting a pump to operate as closely as possible to its BEP cannot be overemphasised. Not only should this save on energy costs, it will have several other benefits:

- The pump should run smoothly with minimum internal disturbing forces, thereby saving on maintenance costs due to premature failure of components such as bearings, wear rings, bushes, couplings and seals
- The risk of damage to pump components due to cavitation would be reduced
- Vibration would be minimised, benefiting other equipment
- Noise would be minimised, improving the environment
- Pressure pulsations would also be minimised, reducing the risk of problems in the pumping system as a whole.

Figure 3-15: Illustration of the effect on power and efficiency of indicates some of the problems, which can result from operating away from BEP. Some of these problems may not be serious in small pumps, but they increase in severity as pump power increases, and should therefore be discussed with the pump supplier.

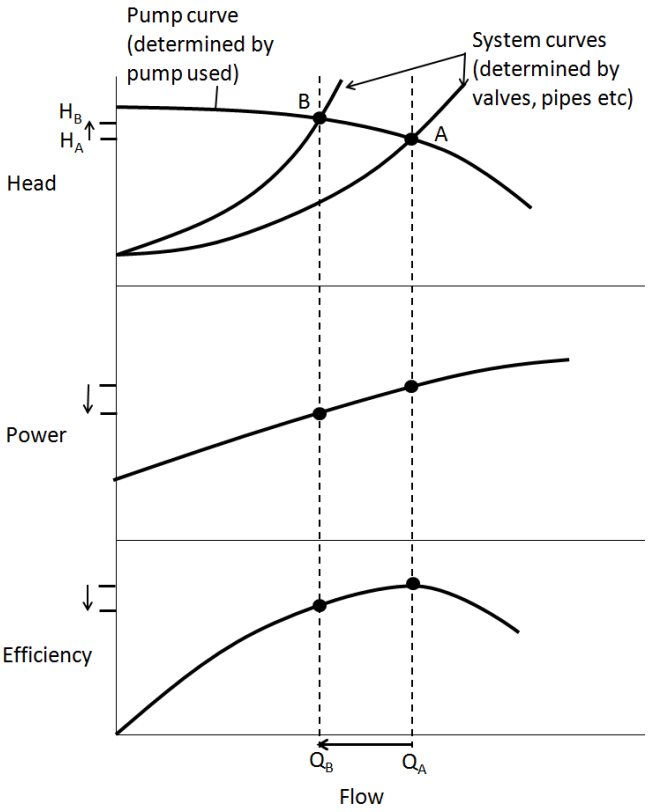


Figure 3-15: Illustration of the effect on power and efficiency of operating away from the BEP of a pump

Taking account of both the wear, and the fact that operation is away from the BEP, stakeholders agreed with the study team's suggestion that the average pump of the types included in this study is operating 10-20% (15% average) below the BEP efficiency.

3.2 End of life behaviour

The high metal content of pumps means that they are likely to be sold for scrap at the end of their lives. However, wastewater pumps may need cleaning to remove pathogens prior to being moved to the scrap yard.

3.2.1 Present fractions to re-use, recycling and disposal

The Bill of Materials (BOMs) for the pumps in the study show the proportion of non-metallic components by weight. Pumps are heavy items, and have both a positive scrap value and an avoided disposal cost, and so it is to a company's advantage to send old pumps for scrap. In practice, it is the norm for pumps to be sent for scrap. To a good approximation, it is assumed that all of the metallic components are recycled. It should be noted, that in real life situations 100% separation of the main metal fractions from the pump is difficult and is often not achieved during scrap treatment, often leading to lower iron recycling quality due to the remaining copper content. The following table shows the weight of pumps split by metallic and non-metallic components:

Table 3: Proportion of materials in the pumps considered in the study

Pump Type		Materials					Total weight
		Steel (%)	Other ferrous-metals (%)	Non-ferrous metals [Al, Cu] (%)	Plastics [PP, PS, ABS, Others] (%)	Others (%)	
Centrifugal submersible pump							
	Radial sewage pumps 1 to 10kW	20	68	10	1	1	80 kg
	Radial sewage pumps >10 to 25kW	20	68	10	1	1	200 kg
	Radial sewage pumps >25 to 160kW	25	58	15	1	1	1 000 kg
	Mixed flow & axial pumps	25	58	15	1	1	400 kg
Centrifugal submersible pump – once a day operation							
	Shredding, grinding pumps	20	68	10	1	1	50 kg
	Radial sewage pumps 1 to 10kW	20	68	10	1	1	45 kg
	Where volute is part of a tank	15	40	10	34	1	40 kg
Centrifugal submersible domestic drainage pump < 40 mm passage		48	0	28	23	1	8 kg
Submersible dewatering pumps		34	14	44	1	7	50 kg
Centrifugal dry well pump							
	Radial sewage pumps 1 to 10kW	5	90	0	1	4	80 kg
	Radial sewage pumps >10 to 25kW	5	90	0	1	4	125 kg
	Radial sewage pumps >25 to 160kW	5	90	0	1	4	550 kg
	Mixed flow & axial pumps	10	85	1	0	4	1 500 kg
Slurry Pumps							
	Light duty	22	70			8%	600 kg
	Heavy duty	19	81				700 kg

Re-use in the context of this study refers to parts that can be removed from a product and re-used in a new product. There are in practical terms no such parts in pumps. Motors on pump sets could however well be re-used.

Unlike products that are used by domestic consumers where most goods end up as landfill, the professional market that is responsible for disposing of old pumps is used to sending metal products for scrap. The 8% landfill figure (same value as that used for pumps in ENER Lot 11 study) set in the EcoReport (the simplified life cycle assessment tool that will be used to assess environmental impacts and life cycle costs in tasks 5 and 7) is therefore thought to be too high. However, as the results of the environmental impact analysis in Task 5 showed that materials are not responsible for much of the total eco-impact, this does not represent a significant error, and so is not investigated any further.

3.2.2 Estimated re-use second hand use, fraction of total and estimated second product life (in practice)

There is some use of second hand pumps, but is not a significant factor in the market. There is no developed second hand pump market as there is with some other consumer or industrial equipment, rather it is as the result of the occasional factory closure or where a pump is incorporated into a larger item of plant that is sold. Therefore, in terms of this study, this second hand life is included in the total lifetime of the product, and so this lack of definitive data does not affect the analysis.

3.3 Local infrastructure

The end user is a central player concerning the environmental impacts of energy–related products. One essential factor is barriers that hinder users from behaving in more environmentally sound ways. It is not only the question of how many and what kind of products are being purchased by end users, but also how these products are being used and for how long they are used are crucial for their overall environmental impacts.

- **Barriers to ecodesign**

In practice, many barriers to ecodesign may come from the supply chain rules. For example, investment-related questions may be directly involved: often the more energy-efficient the product is the more expensive is purchase price. Following are some of the barriers:

- **Preference for stabilised technologies:** technology changes often generate a temporary increase in breakdown rates due to a necessary learning period.
- **Fear of complexity:** e.g. components of complex systems with many connections to the other components and replacing one of these components may necessitate global adaptations of the whole system.
- **Lack of knowledge:** e.g. relevant information is not available to users of pumps for wastewater and fluids with high solid content, etc.

- Other "non technical barriers" (lack of internal incentives e.g. reduced budget next year).

3.4 Conclusions

Task 3 has addressed consumer behaviour and local infrastructure issues associated with ENER Lot 28 pumps. The pumps in this study are specifically designed to pump solids and resist clogging. This in turn has an effect on their real life efficiency. Users have traditionally accepted this efficiency penalty in order to ensure a more reliable operation of these pumps. The biggest factor in the real life efficiency of a pump is the impeller type used. There are a number of impeller options open to users when pumping solids and the most efficient impellers may not be the most appropriate choice when looking for reliable operation. These pumps do require regular maintenance to ensure continued efficient operation over their entire lifetime.

There are certain applications where there is a range of pump types available. For example in wastewater treatment, submersible pumps or dry well pumps could be used for the same application, although they would require different pumping station arrangements. Progressing cavity pumps are typically used for thicker sludge pumping applications, however there are sludges with lower percentage dry solids contents where submersible or dry well pumps could also be used.

The high metal content of the pumps means that they will often be sold for scrap at the end of their working life. There is some use of second hand pumps, but is not a significant factor in the market. There is no developed second hand pump market as there is with some other consumer or industrial equipment; rather it is as the result of the occasional factory closure or where a pump is incorporated into a larger item of plant that is sold.

This page is left intentionally blank



02 April 2014

185 Avenue Charles de Gaulle
92200 Neuilly-sur-Seine
France
+ 33 (0) 1 5561 6755
www.bio.deloitte.fr

Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 4: Technical analysis - Working Document

Final Report to the European Commission, DG ENER
02 April 2014



European Commission

Developed by:

bio by Deloitte.

ATKINS

Document information

CLIENT	Final Report to the European Commission, DG ENER
CONTRACT NUMBER	ENER/C3/403/2010
REPORT TITLE	ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 4: Technical analysis - Working Document
PROJECT NAME	Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC
PROJECT CODE	ENER Lot 28
PROJECT TEAM	Bio by Deloitte, Atkins
DATE	02 April 2014
AUTHORS	Mr. Shailendra Mudgal, Bio by Deloitte Mr. Sandeep Pahal, Bio by Deloitte Mr. Benoit Tinetti, Bio by Deloitte Mr. Alvaro De Prado Trigo, Bio by Deloitte Dr. Hugh Falkner, Atkins Mr. Keeran Jugdoyal, Atkins
KEY CONTACTS	Mr. Sandeep Pahal spahal@bio.deloitte.fr Or Mr. Shailendra Mudgal shmudgal@bio.deloitte.fr
DISCLAIMER	This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. The project team does not accept any liability for any direct or indirect damage resulting from the use of this report or its content.

Please cite this publication as:
Bio by Deloitte (2014), Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC, ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 4: Technical analysis - Working Document prepared for Final Report to the European Commission, DG ENER

Photo credit: cover @ Per Ola Wiberg

© Bio by Deloitte 2014

Table of Contents

4.1 Technical basics 7
4.1.1 Fluid flow concepts 8
4.1.2 Common products and technologies 8
4.2 Production phase 17
4.2.1 Bill of Materials (BoM) 17
4.3 Distribution phase 20
4.4 Use phase (product) 20
4.4.1 Data on Use Phase for Pumps in Scope 20
4.4.2 The Extended Product Approach 21
4.5 End-of-life phase 23
4.6 Recommendations on mandates 24
4.7 Conclusion 24

List of Tables

Table 1: Efficiency spread of impellers with pump types in the study (source – Europump) 12
Table 2: Bill of Material for pumps in study (Source: Europump) 18
Table 3: Bill of Materials for packing materials (Source: Europump) 19
Table 4: Distribution phase input data (Source: Europump) 20
Table 5: Data on use phase for ENER Lot 28 pumps (Source: Europump) 20
Table 6: Load profile for closed loop variable flow systems 37
Table 7: Load profile for open loop variable flow systems 38
Table 8: Load profile for constant flow systems (open and closed loop) 40
Table 9: System type vs. pump type 41

List of Figures

Figure 1 – How rotodynamic pumps work: flow paths (left) and cutaway of motor coupled pump (right) (Source EUP Lot 11 Pumps) 7
Figure 2: Example of the plan and section through a single-vane impeller – (source: Europump) 10
Figure 3: Example of a plan and cross section through a 2-channel impeller (Source Europump) 11
Figure 4 – Example of the operation of a vortex pump 11
Figure 5 – Example of a wet well with float switches 17
Figure 6 – Graphical presentation of the EEI calculation 23
Figure 7 – Loss-causing components of a centrifugal pump. 27
Figure 8 – The influence of rate of flow 27
Figure 9 – Partial losses within a centrifugal pump 28
Figure 10 – The influence of surface roughness 29
Figure 11 – Theorical estimation 30
Figure 12 – The influence of secondary flow through the sealing gaps 31
Figure 13 – Different types of sealing gaps 31
Figure 14 – Europump Ecopump initiative 34
Figure 15 – Difference between a Product Approach and an Extended Product Approach 34
Figure 16 – Road map for energy efficiency regulation on pumps in EU 35

Figure 17 – Definition of Extended Product Approach 36

Figure 18 – Load points and control curve for closed loop variable flow systems 38

Figure 19 – Load points and control curve for open loop variable flow systems 39

Figure 20 – Load points constant flow systems (open and closed loop) 40

Figure 21 – Definition of Powers in an extended pump product. The combined motor and CDM (VSD) is referred to as a Power Drive System (PDS).....42

Figure 22 – Graphical presentation of the EEI calculation 42

Figure 23 – Flow chart for calculating EEI of an Extended Pump Product.....43

Figure 24 – Related losses of a PDS at different part load points 44

Figure 25 – Three points of related losses and shaded area of interest for pump manufacturers when calculating the EEI (Energy Efficiency Index) of a pump unit[8] 44

Figure 26 – Bottom lines for different geometrical pump sizes (defined for nominal flow rate Qn > Q1) within one pump type.....45

Figure 27 – "House of Efficiency" - explanatory representation of the scheme in a η (Q): flow-Plot 46

Task 4: Technical Analysis

This chapter presents the technical analysis of pumps covered in the scope of the ENER Lot 28 study. The technical analysis of product categories described in this chapter uses the product definitions presented earlier in the Task 1 report of this study as its basis. Analysis of the environmental impacts of a product requires the examination of its complete life cycle, starting with the amount of raw materials used during the manufacturing phase and ending with the disposal efforts required at its end-of-life stage. The aim of this task is to examine the technical characteristics of the different product categories covered in this study, which is necessary to form a basis for identifying and defining the base cases that will be further developed in Task 5 of this study.

The first subtask of this report provides insights into the technical basis for the fluid flow and common pump technologies. This is followed by four subtasks concerning the different life-cycle stages of the pumps for private and public wastewater and for fluids with high solids content:

- production phase;
- distribution phase;
- use phase of the product;
- end-of-life phase

The next subtask concerns recommendations for possible mandates to be issued by the European Commission and standardisation organisations for ENER Lot 28 products followed by a final subtask summarising the main conclusions of this task.

4.1 Technical basics

Pumps are available in a wide variety of designs and configurations, which can be split into two distinct categories, positive displacement pumps and rotodynamic pumps. As per the definition stated in Task 1, a positive displacement pump in its simplest (and oldest) form is typified by a bucket lifting water from a well or river. It shows the principle of all pumps of this type; enclosed volumes of liquid are collected at the pump inlet and discharged at the outlet at increased head. In a rotodynamic pump, a continuous flow of liquid passes through a rotating impeller which imparts energy, is collected (usually by a volute or guide vanes) and discharged against an increased head.

Water is pushed into the pump inlet branch by the pressure acting on the water surface (usually atmospheric pressure) and, where applicable, the height of the water level above the pump. The water flow then passes from the inlet branch of the pump to the inlet of the impeller. If the pump is a mixed flow or centrifugal type, the water then has to change direction from axial to (near) radial as it enters the passage between the impeller vanes. In axial flow pumps there is no change in direction of the water flow. In a well-designed impeller, at best efficiency flow the water will pass smoothly over the vane inlets with little disturbance. The vanes will then start to work on the water as it flows through the impeller, creating an increase in pressure and velocity. In mixed flow and centrifugal type pumps, at best efficiency flow, the water will spiral out of the impeller in a free vortex of constant angle to the tangential direction. In axial flow pumps the water is pushed in the pump without any change in the radial location of the fluid particles. As the diameter of the volute increases, the flow velocity reduces and pressure is recovered. The volute cutwater angle should be a close match to the spiral angle and will peel off the water to guide it to the outlet branch. The water then leaves the pump with an increased pressure.

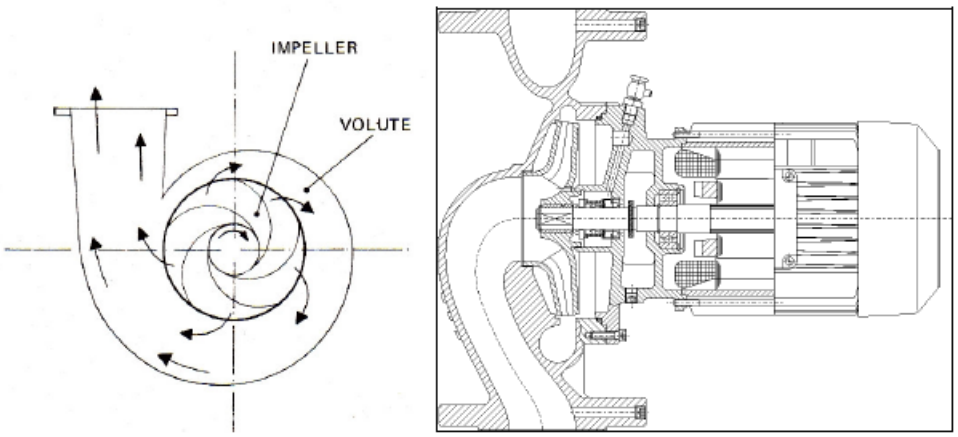


Figure 1 – How rotodynamic pumps work: flow paths (left) and cutaway of motor coupled pump (right) (Source EUP Lot 11 Pumps)

Rotodynamic types are generally cheaper and more robust, and so account for the bulk (>90%) of sales. Positive Displacement types are more sophisticated and highly engineered. They are generally suited to higher pressure pumping applications than are used for rotodynamic pumping applications and for very viscous liquids.

Task 1 Sections 1.0.2 to 1.0.3 contains further details on pump systems and the basic pump laws.

4.1.1 Fluid flow concepts

The flow rate of fluid into a pump is always the same as the flow of fluid out of a pump when measured in terms of mass or weight. The volume of the flow is also the same as long as there are no changes in density. Pressure, velocity and height are the three main forms of energy found within a pump system. The energy in the pump system can change from one form to another.

As liquid flows through a pipe it gives rise to friction. This in turn is a source of energy loss in the liquid as the pump overcomes the friction in the form of pressure losses. The amount of pressure loss depends on the following factors:

- Flow rate
- Pipe length
- Pipe diameter
- Pipe surface roughness
- Piping design
- Viscosity of liquid
- Density of liquid

The flow within a pipe can be either turbulent or laminar depending on the viscosity of the liquid and the design velocity used for the system. The losses associated with laminar flow are dramatically different to those associated with turbulent flow. In laminar flow the layers of liquid slide smoothly over the each other as it travels down the pipe. Laminar flows tend to occur in liquids with a high viscosity when pumped at a low velocity. In turbulent flows the individual particles in the liquid take erratic flow patterns along the pipe, with eddies and local vortices. Most of the flow from rotodynamic pumps is turbulent. The flow within a wastewater pump is predominantly turbulent.

Pump pipework systems are made up of components such as valves, tees, bends and filters in addition to the simple pipes. These components all contribute to the friction in the system and therefore the losses. Wastewater pumping systems do not have filters.

4.1.2 Common products and technologies

The products involved in this study are described in detail in Task 1, section 1.1.7.

There are number of factors that contribute to the overall efficiency of a pump. A detailed discussion of these factors is provided in the 'SAVE Study on Improving the Efficiency of Pumps' was for the European Commission and issued in February 2001. Chapter 5 of this study is provided in its entirety in Annex of this document. It is important to note that the SAVE study was undertaken with clean water pumps and therefore considerable care should be taken when applying its findings to wastewater pumps. The study was produced by Darmstadt University, who emphasise that the main intention of this work was to identify, respectively quantify the various design factors affecting the efficiency of centrifugal pumps in a fundamental and

exemplary manner. The focus of the evaluation was on single stage standard industrial pumps of an overall size, which is typical for this type of pumps.

Regarding an appreciable improvement of the efficiency of centrifugal pumps one has always to consider that the possible gain of efficiency, which can be achieved, e.g. by the reduction of the gap width or additional surface treatments, strongly depends on the initial state of these parts as well as the absolute size of the pump. Other aspects, which also limit the potential of a possible efficiency increase, are requirements arising from operating reliability.

Besides the issue of operating reliability there are many other technical requirements such as production, assembly or system aspects, which determine, respectively dominate the design process of centrifugal pumps. It is therefore not always reasonable or even possible to apply all the design features and recommendations discussed in the SAVE Study.

- **Impellers**

Impellers have a key role in contributing towards the efficiency and performance of waste water pumps. The impellers used in wastewater pumps are different than those used in clean water pumps as they have to allow the free passage of solids through them and also have to be resistant to becoming clogged. There are a number of impeller types available to pump purchasers when looking to pump wastewater.

There are a number of factors to consider when looking to specify an impeller for pumping wastewater. Firstly, the impeller must be suitable for the type of wastewater being pumped. For example, if the wastewater contains large solid particles then it is important to use an impeller that is either going to allow the solid to pass through the pump freely, or one that will cut the solid in smaller more pumpable pieces. A second consideration might be the resistance the impeller has to wearing, as this both decreases the efficiency of an impeller and increases the maintenance cost of the pump. Impellers that have high solids handling ability and an increased resistance to wearing, such as vortex impellers, are often less efficient than other types of impellers, but may have a significantly increased reliability and lifespan. This may result in lower whole life costs and reduced maintenance requirements.

The selection of lower efficient, higher reliability, vortex impellers, rather than higher efficiency single/multi vane impellers, will often be preferable in terms of whole life costs when pumping wastewater with high grit content. This is because grit is very abrasive on impellers and causes rapid wearing. Vortex impellers may also be specified when pumps are located in remote areas and a high level of reliability is required. This is because it can be very costly to repair or unclog pumps that are installed in remote locations.

The three main types of impellers found in wastewater pumps are described as follows:

- Channel impellers
- Vortex impellers
- Grinder impellers

These impeller types are described in further detail below.

  - **Channel impellers**

Channel impellers are available as single vane and multi-vane variants.

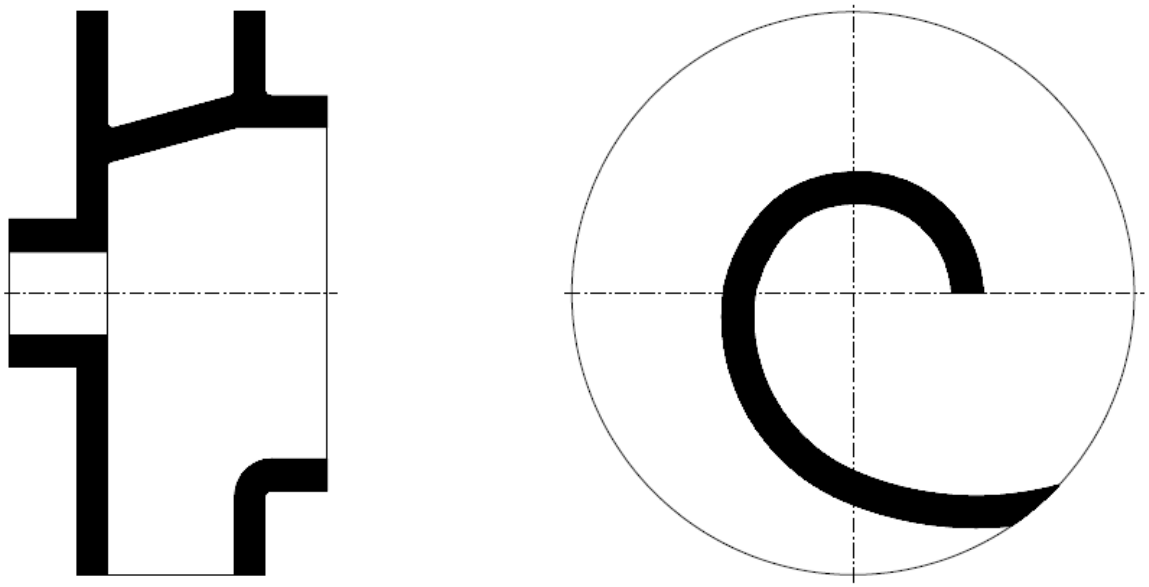


Figure 2: Example of the plan and section through a single-vane impeller – (source: Europump)

Single-vane impellers have a large free passage that allows solids to pass through them. They are less efficient than traditional multiple-vane impellers used in clean water pumping. Single vane pumps typically have an efficiency range between about 40 to 80%. As this efficiency is very much depending on the specific speed it is only possible, to speak roughly about 71% as average. It is important to note that not all hydraulics will reach this value (especially high head hydraulics).

The free passage through the impeller allows balls of solid materials to pass through easily, however there is the potential for longer, fibrous materials to become entangled around it. There is also the potential for solids to collect on the leading edge of the impeller.

Intermittently operated pumps have a natural self-cleaning facility when they stop and fluid is allowed to back flow through the pump, which in turn cleans debris from the leading edge of the impeller. There are also physical modifications, which can be made to the impeller and pump that can decrease the risk of clogging, such as backswept leading edges and adding relief grooves to the pump insert ring, which push solids out of the pump.

An issue with single-vane impellers is they are difficult to dynamically balance and therefore a prone to increased levels of vibration and bearing wear compared to conventional impellers.

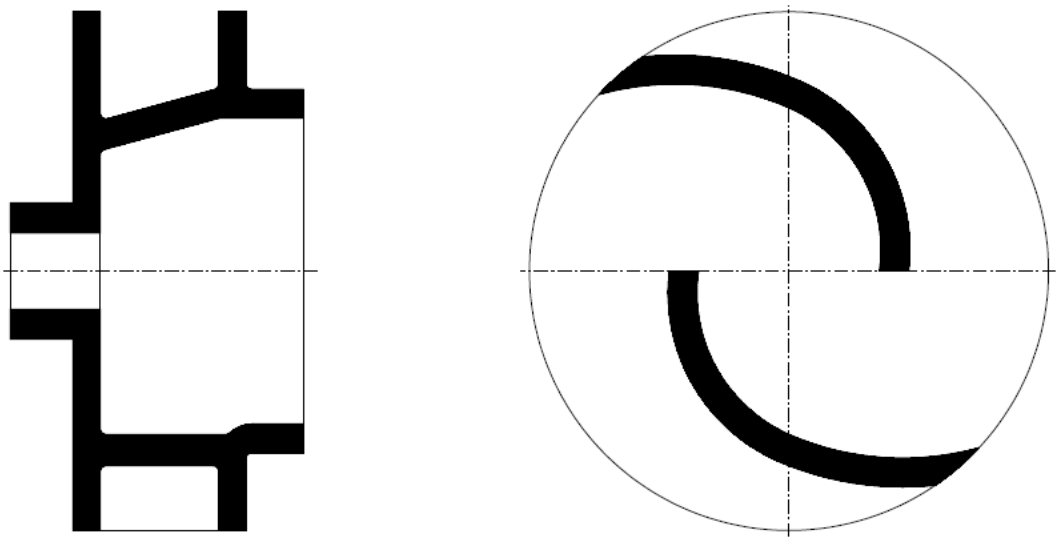


Figure 3: Example of a plan and cross section through a 2-channel impeller (Source Europump)

Multi-vane impellers typically have two or three vanes, and are easier to balance than single-vane impellers. However, they need to be physically larger than to have the same size free passage. They also have two leading edges meaning they have a larger area where debris can collect and have a higher likelihood of clogging.

- **Vortex impellers**

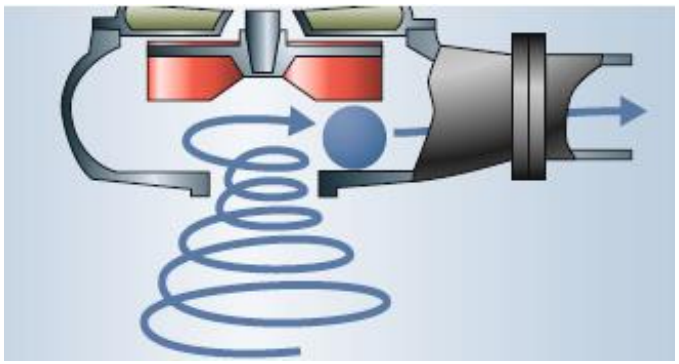


Figure 4 – Example of the operation of a vortex pump[1]

Vortex impellers effectively create a whirling vortex within the pump that can be used to allow some solids to pass through the pump without coming into contact with the impeller.. These are particularly useful when pumping very abrasive solids like grit. These vortex impellers result in a relatively low efficiency compared to most other types, but they do have very good resistance to complete clogging (hard/complete clogging at least end up in tripping the motor protection). Vortex pumps have a hydraulic efficiency range from 26% to 63%.

- **Grinder impellers**

[1] Image courtesy of Xylem Flygt

Grinder impellers are typically fitted on smaller pumps with small-bore pipework, and are used to grind up solid matter in to small, pumpable pieces. The grinder impeller is located on the inlet of the pump and an impeller is used within the pump body.

- Impeller efficiency

The efficiency of these types when used in the applications of the study is shown in Table 1. Note the average efficiency is the mathematical average. Also the hydraulic groups cover a variety in demands, e.g. low and high head applications. Not all hydraulics will be able, to reach the average efficiency.

Table 1: Efficiency spread of impellers with pump types in the study (source – Europump)

Group	Impeller/pump type	ηPmax %	ηPmin %	ηPav %
Radial Sewage Pumps 1 to 10kW submersible & dry installed	Vortex	63	26	43
	Channel	80	39.2	71
Radial Sewage Pumps >10 to 25 kW submersible & dry installed	Vortex	58.5	38.8	45.7
	Channel	87	54	71.5
Radial Sewage Pumps >25 to 160 kW submersible & dry installed	all types average	88.7	55	77.3
Mixed flow & Axial Submersible & dry installed	Activated sludge recirculation Axial (H < 2m)	68.3	35.3	56.5
	Storm water & effluent axial and mixed flow	87.3	68	82.1
Domestic& commercial buildings "once a day operation"	Shredding, grinding pumps	42	22.5	32.3
	Radial sewage pumps 1 to 10kW	78	26	53.5
	Where volute is part of a tank	71	14	27.62
	Centrifugal submersible domestic drainage pump < 40 mm passage	60.8	14.5	35.2
Dewatering pumps, submersible		72	46	64
Slurry pumps	light	82	45	63.5
	heavy	77	35	56

The figures in the table clearly show that the type of impeller used will have an impact on the overall efficiency of the pump. For example, the vortex impellers are on average 25% less

efficient than channel impellers when used for the same radial sewage pump. However, as stated previously, this drop in efficiency may be acceptable if resistance to wear and clogging are increased. It is also important to note from the table that the spread of efficiency for any particular type of pump can be significant. For example, the spread of efficiencies for radial sewage pumps 1 to 10 kW is between 39% to 80%. This spread is partly due to the normal differences in impeller designs found between different manufacturers and partly due to the specific requirements of the different applications.

- **Motors**

All the pumps in the study are likely to be used in conjunction with AC electric induction motors. AC motors are rotating electric machines designed to operate from an AC power source. Like other motors, an AC motor has a fixed portion, called the stator and a rotor that spins with a carefully engineered air gap between the two.

  - **Induction Motors**

In an AC induction motor, a rotating magnetic field is formed in the stator when an AC supply is connected to the stator windings. The rotating magnetic field induces an Electromagnetic Force (EMF) in the rotor as per Lenz's law, thus generating another set of electromagnets; hence the name – induction motor.

Interaction between the rotating magnetic field and the rotor field generates the motor torque. As a result, the motor rotates in the direction of the resultant torque. One way to produce a rotating magnetic field in the stator of an AC motor is to use a three-phase power supply to feed 3 sets of stator coils, which are a distributed e.g. for a 2-pole motor with 2900 rpm at 120 degree intervals.

The speed of the rotating magnetic field (synchronous speed) in an induction motor depends on the frequency of the supply voltage and on the number of poles in the motor.

$$Sychronous\ speed\ (rmp) = \frac{frequency\ of\ the\ applied\ voltage\ (Hz) \times 60}{number\ of\ pole\ pairs}$$

For example, when a 4-pole motor is supplied with 50 Hz supply, the synchronous speed will be 1500 rpm. Motors with 2, 4 and 6 poles represent the vast majority of the motor market. The rotor speed is slightly lower (a few percent at full power) than the synchronous speed and therefore the induction motor is also called asynchronous motor. The rotor slip increases in a linear manner as the load increases, being almost zero at no-load.

The typical motor for wastewater pumps is the so called squirrel cage induction motor. Main characteristics:

- Low construction complexity,
- High reliability (no brush wear), even at very high achievable speeds
- Driven directly by the grid or by multi-phase Inverter controllers
- Low Electromagnetic Interference (EMI)

- Lowest cost per kW among different motor technologies

Induction motors are by far the most widely used motor in the power range under consideration, using over 90% of the electricity consumed by all motors in that range. Induction motors are robust, inexpensive when compared with other technologies and their efficiency ranges from fair (around 70% for small motors) to very high (over 95% for large motors) depending on the power level and on the design. The efficiency class of motors is defined in IEC 60034-30.

General-purpose induction motors are a commodity type of motor constituting a large majority of the market (they represent 80-85% of the 3-phase induction motor market), whose main characteristics are standardised. This standardisation allows motors to be easily exchanged around the world for motors made by different manufacturers meeting the same requirements. There is a huge variety of special purpose induction motors, the most common being submersible motors. In some applications, these motors may have to comply with strict requirements (e.g. explosion proof motors according to ATEX) in which safety is an overriding concern.

▷ Single-Phase Induction motors

As the name suggests, Single-Phase Induction motors operate with a single-phase power supply. In single-phase induction motors, there is a stator main winding and an auxiliary winding for starting and / or operating purposes. The rotor is of the squirrel cage type.

When the motor is connected to a single-phase power supply, the main winding carries an alternating current. This current produces a pulsating magnetic field. Due to induction, the rotor is energised. As the main magnetic field is pulsating, the torque necessary for the motor rotation is not generated. This will cause the rotor to vibrate, but not to rotate. Hence, the single-phase induction motor is required to have a starting mechanism that can provide the starting kick for the motor to rotate. This is accomplished by the auxiliary stator winding, which normally is connected in series with a capacitor. The combination of the two windings creates a rotating field and the motor torque is generated in the rotor like in a 3-phase induction motor. In cases where a starting capacitor is used for starting, a current respectively voltage sensitive relay is typically used to disconnect the auxiliary winding after starting.

Main characteristics:

- Medium construction complexity due to extra capacitor
- Higher cost than 3-phase induction motors (when relating to the same shaft power)
- High reliability (no brushes)
- Lower efficiency than 3-phase induction motors (When relating to the same shaft power)
- Low EMI
- Driven directly from AC line

Single-phase motors are more expensive and less efficient than equivalent 3 phase motors, being mainly used in residential appliances, and rarely exceeding a few kW. The most relevant electric

home appliances are the subject of efficiency assessment regulation in which the efficiency of the whole equipment is regulated. Other integral single-phase motors can be found, mostly in the residential sector, in applications such as submersible pumps and machine tools. In general, terms single-phase motors are used when a three-phase supply is unavailable.

- **Controls**

Pumps are available with a variety of controls to suit a range of pumping operation, such as intermittent batch pumping and variable flow system. The types of controls available are discussed in the following section.

- **Time switches**

As the name suggests time switches are used to control the operation of pumps based on times. These are not commonly used for wastewater pumping as there is a possibility that pumps could operate when there is not any wastewater in the wet well. Conversely, they may not operate in time to empty a wet well that is full.

They can be used to start pumps which have not been operated for a pre-set length of time, in order to stop any wastewater in a wet well from going septic.

They can also be used to control batch processes in wastewater treatment works that require wastewater to be held in a specific process for a specific length of time.

- **Level controls**

Level controls are amongst the most common type of controls used to wastewater pumping. They are used to switch the pumps on when the amount of wastewater in a wet well reaches a pre-set high level, and switch them off once the waste water level reaches a pre-set low level. Level controls can be used to provide variable flow control in pumping stations with more than one pump, by running a single pump during periods of low flow into the station and multiple pumps during high flow periods.

- **Process based controls**

Certain pumps, such as return activated sludge pumps, are controlled based on the process requirements from a wastewater treatment works. The speed of the pumps, as well as the running times, can be managed by process-based controls. For example if there is a high demand for return activated sludge, the pumps will be operated at full speed; however they might be operated at low speed during periods of low demand.

- **Intelligent network controls**

Intelligent network controls are a relatively new technology that is used to balance the flow of wastewater into a treatment works. They work by maintaining control over all the pumping stations in a wastewater network. The intelligent network controls monitor the level of wastewater in each pumping station and can balance the inflow to a treatment works by controlled operation of pumps in the single collection sumps.. The aim is to reduce the volume of wastewater flowing into the treatment works during peak hours by spreading the flow out during the day.

- **Flow controls**

Flow controls are used to vary the speed of pumps in order to maintain a constant or process controlled outlet flow and flow rate in the pumping system. Although they are not commonly used for wastewater transfer operations, flow controls can be found in certain processes in the wastewater treatment, such as return activated sludge processes, where a constant flow rate is required.

- **Sensors**

The sensors used to control wastewater pumps tend to be level sensors. These are available in a number of different types including pressure transmitters, ultrasonic sensor, level probes and float switches. As well as level sensors, pressure sensors are also used in wastewater pump controls.

- **Pressure transmitters**

Pressure transmitters are suspended in the wastewater wet well, in a protective enclosure down close to the bottom of the well. They use the hydrostatic pressure on a membrane as given by the water above, to determine the water level.

- **Ultrasonic sensor**

Ultrasonic sensors are placed in wet wells above the waste water level. They measure the level of the wastewater by emitting ultrasonic sound waves at the wastewater and measuring the time it take for the ultrasound echo to return to the sensor. The longer it takes the echo to return the lower the waste water level in the wet well.

A key benefit of these types of sensor is that they are never in contact with the wastewater and therefore are unlikely to be soiled by the solids in the wastewater.

- **Level probes**

There are 2 different systems of level probes. The principle of the conductive type is that there are 3 or more electrodes placed within the wet well. A low voltage is applied between the electrodes. When the waste water level in the wet well reaches the height of a probe, an electrical connection in made between the electrodes, and this is used as a signal to turn the pumps on or off. A different system of level probes uses capacitive sensors and by this avoiding malfunction given by grease in the wastewater.

- **Float switches**

Float switches are typically made of plastic and are lightweight balls or boxes filled with air and therefore are able to float on water. There is an electrical switch within the float, which turns on and off depending on the orientation of the float. As shown in Figure 5, when the float switch is floating on the wastewater, it turns upside-down, and the switch is turned on and the control system is sent a signal.

Level probes and float switches give only a start-stop signal at a mechanically prefixed level but pressure transmitters and ultrasonic systems transmit the actual level in the sump to the controls. Transmitting the actual level allows variable level setting at the control panel or by a logic embedded in the controls.

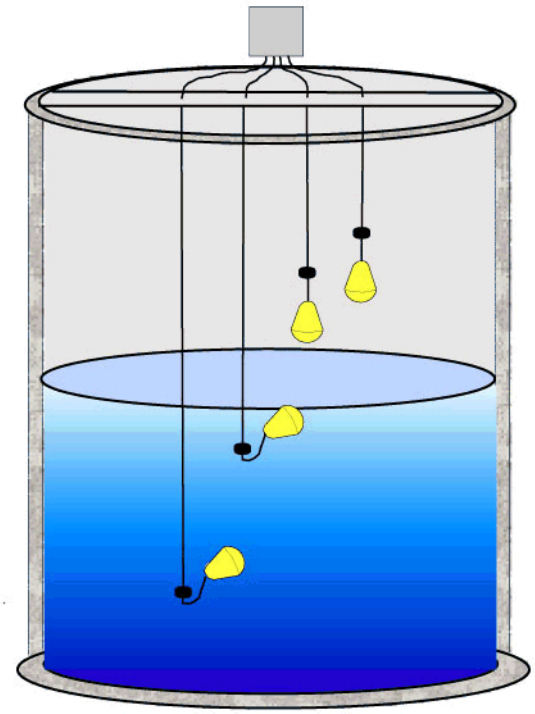


Figure 5 – Example of a wet well with float switches

4.2 Production phase

4.2.1 Bill of Materials (BoM)

The following tables show the BoM for the pumps in the study. The pumps are predominantly made from various metals, as they have to withstand abrasive fluids and relatively high pressures and forces. Ferrous metals tend to be used as the main material in the pumps with steel typically accounting for 5-25% of the pump. The smaller pumps contain plastic elements, but even these are predominantly metal.

The pumps are typically packed in wood however, the small domestic pumps are provided in plastic and cardboard. The weight of the packing materials accounts for a very small percentage (<2%) of the total weight of the pumps.

The BoM does not include any information on VSD. Details of VSD can be found in the Lot 30 study.

Table 2: Bill of Material for pumps in study (Source: Europump)

Pump Type		Steel	Other ferrous metals	Non-ferrous metals	Plastics	Others	Total weight
Centrifugal submersible pump							
	Radial sewage pumps 1 to 10kW	20%	68%	10%	1%	1%	**80 kg**
	Radial sewage pumps >10 to 25kW	20%	68%	10%	1%	1%	200 kg
	Radial sewage pumps >25 to 160kW	25%	58%	15%	1%	1%	1 000 kg
	Mixed flow & axial pumps	25%	58%	15%	1%	1%	400 kg
Centrifugal submersible pump – once a day operation							
	Shredding, grinding pumps	20%	68%	10%	1%	1%	50 kg
	Radial sewage pumps 1 to 10kW	20%	68%	10%	1%	1%	45 kg
	Where volute is part of a tank	15%	40%	10%	34%	1%	40 kg
Centrifugal submersible domestic drainage pump < 40 mm passage		48%	0%	28%	23%	1%	8 kg
Submersible dewatering pumps		34%	14%	44%	1%	7%	50 kg
Centrifugal dry well pump							
	Radial sewage pumps 1 to 10kW	5%	90%	0%	1%	4%	80 kg
	Radial sewage pumps >10 to 25kW	5%	90%	0%	1%	4%	125 kg
	Radial sewage pumps >25 to 160kW	5%	90%	0%	1%	4%	550 kg
	Mixed flow & axial pumps	10%	85%	1%	0%	4%	1 500 kg
Slurry Pumps							
	Light duty	22%	70%			8%	600 kg
	Heavy duty	19%	81%				700 kg

Table 3: Bill of Materials for packing materials (Source: Europump)

Pump Type		Plastic	Cardboard	Paper	Others, Inc wood	Total weight
Centrifugal submersible pump						
	Radial sewage pumps 1 to 10kW	1%	4%	0%	95%	20.8 kg
	Radial sewage pumps >10 to 25kW					
	Radial sewage pumps >25 to 160kW					
	Mixed flow & axial pumps	0%	0%	0%	100%	120 kg
Centrifugal submersible pump – once a day operation						
	Shredding, grinding pumps	4.0%	22.0%	3.0%	71.0%	17.6kg
	Radial sewage pumps 1 to 10kW					
	Where volute is part of a tank					
Centrifugal submersible domestic drainage pump < 40 mm passage		0%	100%	0%	0%	1kg
Submersible dewatering pumps		0%	100%	0%	0%	1kg
Centrifugal dry well pump						
	Radial sewage pumps 1 to 10kW	1%	3%	0%	96%	22.7kg
	Radial sewage pumps >10 to 25kW					
	Radial sewage pumps >25 to 160kW					
	Mixed flow & axial pumps	0%	0%	0%	100%	120 kg
Slurry Pumps						
	Light duty				100%	120kg
	Heavy duty					

4.3 Distribution phase

There can be wide variations in weight and volume of pumps packed for distribution. The Table 4 shows average weights and volumes of pumps that have been derived through consultation with stakeholders.

Table 4: Distribution phase input data (Source: Europump)

Pump Type		Total weight
Centrifugal submersible pump		
	Radial sewage pumps 1 to 10kW	100.8 kg
	Radial sewage pumps >10 to 25kW	220.8 kg
	Radial sewage pumps >25 to 160kW	1 020.8 kg
	Mixed flow & axial pumps	520 kg
Centrifugal submersible pump – once a day operation		
	Shredding, grinding pumps	67.6 kg
	Radial sewage pumps 1 to 10kW	62.6 kg
	Where volute is part of a tank	57.6 kg
Centrifugal submersible domestic drainage pump < 40 mm passage		9 kg
Submersible dewatering pumps		51 kg
Centrifugal dry well pump		
	Radial sewage pumps 1 to 10kW	102.7 kg
	Radial sewage pumps >10 to 25kW	147.7 kg
	Radial sewage pumps >25 to 160kW	572.7 kg
	Mixed flow & axial pumps	1 500 kg
Slurry Pumps		
	Light duty	720 kg
	Heavy duty	820 kg

4.4 Use phase (product)

4.4.1 Data on Use Phase for Pumps in Scope

The data for the use phase energy consumption of the pumps is shown in Table 5

Table 5: Data on use phase for ENER Lot 28 pumps (Source: Europump)

Pump Type		Load factor %	Annual operating hours hours	Annual energy consumption GWh
Centrifugal submersible pump				
	Radial sewage pumps 1 to 10 kW	85	1000	3808
	Radial sewage pumps >10 to 25 kW	85	1500	2295

Pump Type		Load factor %	Annual operating hours hours	Annual energy consumption GWh
	Radial sewage pumps >25 to 160 kW	85	2000	8925
	Mixed flow & axial pumps	70	5000	858
Centrifugal submersible pump – once a day operation				
	Shredding, grinding pumps	75	30	13
	Radial sewage pumps 1 to 10 kW	80	30	44
	Where volute is part of a tank	80	30	14
Centrifugal submersible domestic drainage pump < 40			80	30
Submersible dewatering pumps			75	2000
Centrifugal dry well pump				
	Radial sewage pumps 1 to 10 kW	85	1000	765
	Radial sewage pumps >10 to 25 kW	85	1500	717
	Radial sewage pumps >25 to 160 kW	85	2000	1785
	Mixed flow & axial pumps	85	250	64
Slurry pumps				
	Light duty	100	2600	7800
	Heavy duty	80	2000	888

4.4.2 The Extended Product Approach

The Extended Product Approach is summarised in Task 1, and described in detail in Annex 3 of Task 4 in the description written by Europump. The purpose of this section is to give a more detailed technical review, and then to describe the approach within the context of this study.

- **Why the Extended Product Approach is needed**

The 100% load efficiency figures for the pump and motor could be used to calculate for example the minimum allowable energy consumption for a pump (and pump product), and/or the target energy consumption for "Best in class" pump product. Using this simple method, the regulator could then define the minimum allowable efficiency of a pump+motor combination, assuming that it uses the MEPS applicable to that motor and pump. So simply multiplying the two efficiencies together would give a single combined MEPS for the pump+motor product.

However, this method does not take account of real life operating conditions that will include time at different load points, and so is not adequate for giving an accurate indication of the actual operating costs. This occurs where the more detailed approach of the EPA is of benefit.

- **Deriving values for the EPA**

Existing regulations for the Pump product (only) are based on MEPs for a particular pump size, which are defined with reference to a Minimum Efficiency Index or "MEI" value. The Extended Product Approach energy consumption is distinguished from this by being defined in terms of the Energy Efficiency Index or "EEI" value.

The term EEI comes from the EUP Circulator regulations, where the annual energy consumption is based on the energy used by pump + motor + VSD control over a typical annual operating profile. The advantage of this EEI method is that it considers the real life operating profile of the extended product, and so gives the best representation of the actual costs of using that product.

Creating load profiles that are representative of the different types of application that will be powered by the pumps in scope is critical, but work to date suggests that just three profiles will be adequate:

- Closed loop variable flow.
- Open loop variable flow
- Constant flow[2] (open and closed loop)

The profile just gives the proportion of the time that is spent at each load point, with the actual annual operating time for each application being used to establish energy consumption. The pumps in this lot concern mainly constant flow (open and closed loop).

The following factors are needed for calculating the EEI:

- Pump efficiency at different load points
- Motor efficiency at different load points
- VSD efficiency at different load points in as far as VSD is applicable
- Applicable load profile
- Efficiency of controls (contactors) is neglected, because this is less than 0,1 % of the motor losses

It is very important to note that the majority of the pumps in scope of Lot 28 study are used in constant flow applications and the use of VSDs will only reduce the overall energy efficiency. Therefore, it is not recommended for VSDs to be part of the EPA for most of the pumps in scope of this study.

Unlike existing pump and motor regulations, these values are required at a range of load points. These can either be collected for each load point for each product, or by using a new Semi Analytical Model (SAM) that allows key data to be used to predict product efficiency at part load points.

The need for this information means that in order to devise an EEI value for a pump product, it will be essential to know the efficiency of the pump. Therefore, while the key outcome of this Preparatory study is expected to be EEI values related to the Extended Product Approach, it is still essential for this study to produce efficiency values for the pump alone in order for these EEI values to be calculated.

More specifically, in order that the EEI value can be calculated for every pump size, it is actually important to know what the desirable efficiency is for the selected pump duty. As with the ENER Lot 11 pump regulations, this will vary with head, flow and shaft speed. It is expected that the same type of calculation method as used in existing regulations will again be used for the other types of pump considered in ENER Lot 28 study.

[2] The large majority of waste water pumps follow this profile.

This means that MEPs for pumps of each head, flow and shaft speed will be required in order that corresponding minimum EEI values can be calculated. For the motor, the existing regulated MEPs may be used.

In addition, as with the Circulator regulations, a load profile is required that will state the proportion of time that a pump will operate at a particular load point over a typical operating cycle.

In Tasks 1-4, the work is focussed on the different types of pump in scope. In Task 5, the base case energy consumption of each type of pump is actually based on the first estimates of the Extended Product Approach energy consumption. However, it should be noted that the real life energy consumption of a pump product is the same as that of the EPA it is part of. Where the differences will become more important is in subsequent analysis in Task 6 onwards.

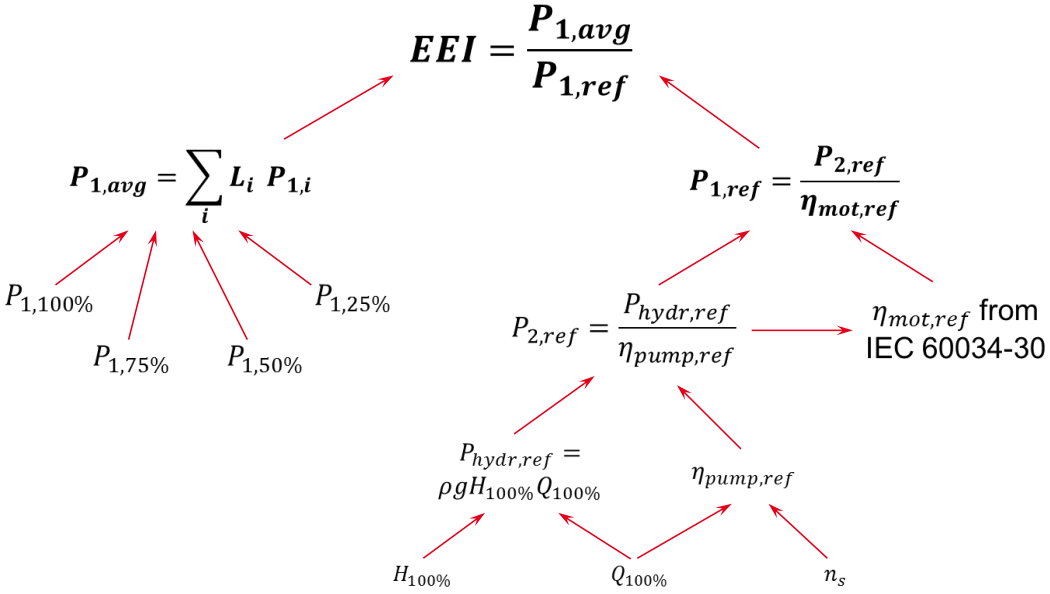


Figure 6 – Graphical presentation of the EEI calculation[3]

In principle, each pump type might be used in more than one EPA load profile, similarly each EPA load profile may be used with more than one pump type, and so there is not a simple relationship between the energy consumption of different pump types and the different load profiles associated with them. However, Annex 2, Table 4 shows that in practice the majority of pump types in this study only have the one load profile, which makes subsequent analysis much simpler

4.5 End-of-life phase

The high metal content of ENER Lot 28 pumps means that they are likely to be sold for scrap at the end of their lives. However, wastewater pumps may need cleaning to remove pathogens prior to being moved to the scrap yard.

The BOMs for the pumps in this study shows that the proportion of non-metallic components by weight is typically less than 1% for larger pumps. Pumps are heavy items, and have both a

[3] Source – Europump Extended Product Approach paper – See Annex 2

positive scrap value and an avoided disposal cost, and so it is to a company's advantage to send old pumps for scrap. In practice, it is the norm for pumps to be sent for scrap. To a good approximation, it is assumed that all of the metallic and none of the non-metallic components are recycled. The percentage (by weight) of the product destined to landfill is estimated to be 8% and is coherent with the value used for pumps in the ENER Lot 11 study.

The lifetime of a wastewater pump will rarely be dictated by obsolescence. The pump will usually be replaced when it fails, due to a broken component or an unacceptable drop in output. The lifespan of ENER Lot 28 pumps will often be related to the solids they are required to pump.

It should be noted that 100% separation of copper, iron and aluminium metal parts is not achieved during scrap treatment, leading to fractions of lower recycling quality due to remaining impurities.

4.6 Recommendations on mandates

It is important that any standards produced for the Lot 28 product group has appropriate mandates to allow meaningful testing to be undertaken. The clean water test standards, ISO 9906:1999 Grade 2 for larger pumps and ISO:9906:1999 Annex A for mass produced pumps, can be used to determine the 'as new' hydraulic efficiency, (this is the hydraulic efficiency of the pump as soon as it is manufactured), however it is not appropriate for testing other key factors associated with efficient wastewater pumping. Therefore, it is recommended that the following issues be addressed by the European standardisation organisations for standards for wastewater pumps through the creation of appropriate tests:

- Ability to handle wastewater of a specified classification
- Ability to resist clogging/blocking shall be tested
- Ability to resist wear to the pump

EUROPUMP has made efforts to prepare such standards.

Measuring the performance of wastewater pumps against these criteria should give a more accurate representation of their overall in use efficiency. However, as discussed, the lack of these standards does not mean that regulations cannot be introduced soon, with refinement to the regulations possible at a time of subsequent revision once these new standards are introduced.

It is also recommended that the hydraulic efficiency test should be made coherent with the present version of ISO9906:2011

4.7 Conclusion

Pumps used to transfer wastewater are available in a variety of sizes and configurations to suit the various pumping applications. The vast majority of waste water pumping is undertaken by centrifugal pumps where a continuous flow of liquid is forced through a rotating impeller. There are a range of impellers available for pumping waste water, including single vane impellers which have large free passages to allow solids through, and vortex impellers which create a powerful swirl within the volute, allowing the solids to pass through the pump without coming into contact with the impeller.

The vast majority of waste water pumps are coupled with an AC induction motor, which provides efficient performance, even at part load. Waste water pumps are typically controlled based on the fluid level in the wet well, but they are also found to be controlled on timers or as required by the waste water treatment controllers. Intelligent network controllers are used to manage many pumping stations at the same time in an attempt to provide a steady flow of water into a waste water treatment works.

Annex 1: Extract from the chapter 5 of the 'SAVE Study on Improving the Efficiency of Pumps'

Introduction

Due to the fact that the majority of the pump manufacturers within the EU have reached a level of knowhow which enables them to carry out hydraulically correct designed centrifugal pumps, the value of the practically attainable overall pump efficiency η of these machines is mainly influenced by factors such as surface roughness of parts which are in contact with the flow as well as the internal leakage flows through the sealing gaps. Especially the surface roughness of hydraulic parts strongly depends on the manufacturing techniques used. Further on the surface quality is a property which can get worse during life time of a pump and thereby causes energy losses during pump operation.

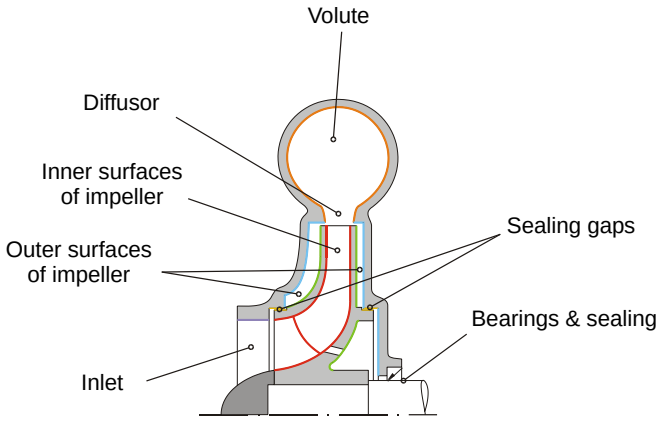
To quantify the effects of these above mentioned factors the following investigations on single-stage centrifugal pumps were carried out at the chair for Turbomachinery and Fluid Power at Darmstadt University of Technology:

- The influence of different values of surface roughness
- The influence of smoothing several parts of pumps
- The influence of different gap clearances on the internal leakage flow rate

The specific speeds of the considered pumps covered the range from ns = 10 min-1 up to ns = 100 min-1 (corresponding to values from 520 min-1 up to 5200 min-1 in US-units) and represents the typical field of application of standard centrifugal pumps. By the aid of the similarity laws it is possible to transfer the results obtained for one pump size to another (respectively from one speed of rotation to another).

To carry out the investigations a special software tool was used, which was developed within the scope of a former research project named "Attainable Efficiencies of Volute Casing Pumps" sponsored by the Research Fund of the German Pump Manufacturer Association.

The main capability of this program is to estimate the maximum theoretically attainable efficiency ηmax,th of volute casing pumps. We explicitly want to point out that this software tool is no CFD code. To determine the friction losses for the parts shown in Figure 5 respectively the leakage flow rates through the sealing gaps the program uses differential equations as well as simplified mathematically loss approaches. All calculations are carried out on the base of a hydraulic design process considering common industrial design standards in respect to the geometrical settings.



Considered Losses

- hydraulic losses:

  friction losses
  deceleration losses
  wake losses
  mixing losses (Volute)

- volumetric losses (gap flow)

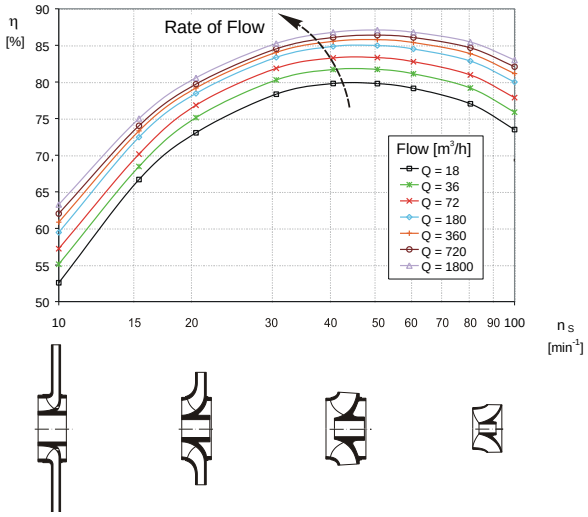
- mechanical losses

Figure 7 – Loss-causing components of a centrifugal pump.

In order to evaluate the efficiency values estimated by the computer program additional experimental investigations were carried out at a centrifugal pump with a specific speed of ns = 12 min-1. This special test pump, designed according to usual industrial standards was equipped with very narrow sealing gaps (radial gap clearance equal to 0.1 mm) as well as hydraulic smooth surfaces. For this optimized pump the value of the inner efficiency ηi was measured at a special high precision test rig and compared to the theoretical value obtained by the computer program. The comparison of both values (for pump operation at the point of best efficiency) results in a very good agreement.

Results of the Theoretical Investigations

For the purpose within this SAVE study the above mentioned software tool was partly modified respectively extended in its capabilities. All the following figures which demonstrate the influence of the parameters surface roughness as well as gap clearance show efficiency values η respectively differences of efficiency values Δη in per cent points that were plotted versus the value of specific speed ns as defined in Figure 5 (where n is the speed of rotation, Q the rate of flow and H the pump head).



Specific speed:

$$n_s = n \cdot \frac{Q^{1/2}}{H^{3/4}}$$

n_s [min^{-1}], n [min^{-1}], Q [$\frac{m^3}{s}$], H [m]

$$n_{s,US-units} = 51.64 \cdot n_s$$

In the following:

$n = 1450\,\text{min}^{-1}$
$Q = 180\,m^3/h$

Figure 8 – The influence of rate of flow

As shown in Figure 5 every specific speed value corresponds to a typical impeller geometry, which means that low specific speeds characterize more radial extended impellers while higher specific speeds correspond to mixed flow respectively more axial types of impellers. Figure 5 exemplarily shows the dependence of the overall efficiency η on the rate of flow respectively pump size at constant speed of rotation (n = 1450 min-1). It can be stated that an increase of the rate of flow leads to higher values of the overall pump efficiency, which is the effect of an increasing Reynolds number Re. The above figure also shows that the efficiency values for very low specific speeds are definitely smaller than for higher ones, which is due to the geometric as well as hydraulic attributes of such types of pumps.

In respect to a better comparability all results of the investigations shown in the following diagrams were generated for operating conditions characterized by a flow rate of 180 m3/h and a speed of rotation n = 1450 min-1.

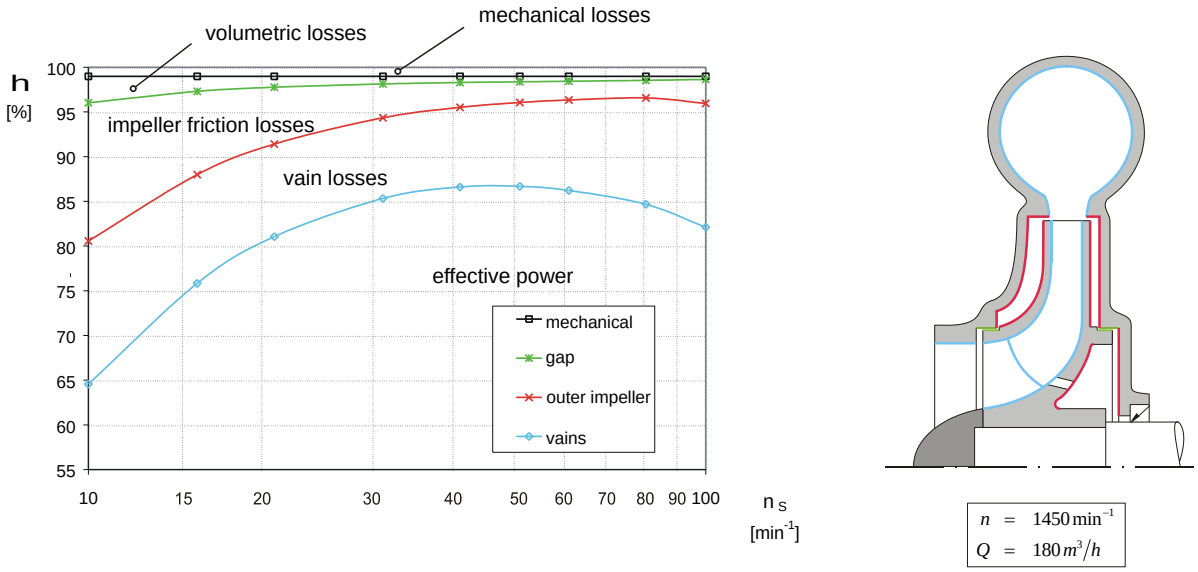


Figure 9 – Partial losses within a centrifugal pump

Depending on the value of specific speed which directly corresponds to the shape of the impeller different influences on the losses caused by several pump components can be mentioned. For pumps with lower specific speeds volumetric losses as well as losses due to disk friction at the back and front shroud of the impeller are very significant. This also applies to the losses within in the volute casing. For higher specific speeds the influence of blade friction losses within the impeller dominates and mainly determines the level of the overall efficiency η. According to former investigations based on statistically evaluated data it is known, that the largest potential regarding an improvement of efficiency does exist at low specific speeds.

Influence of different values of surface roughness

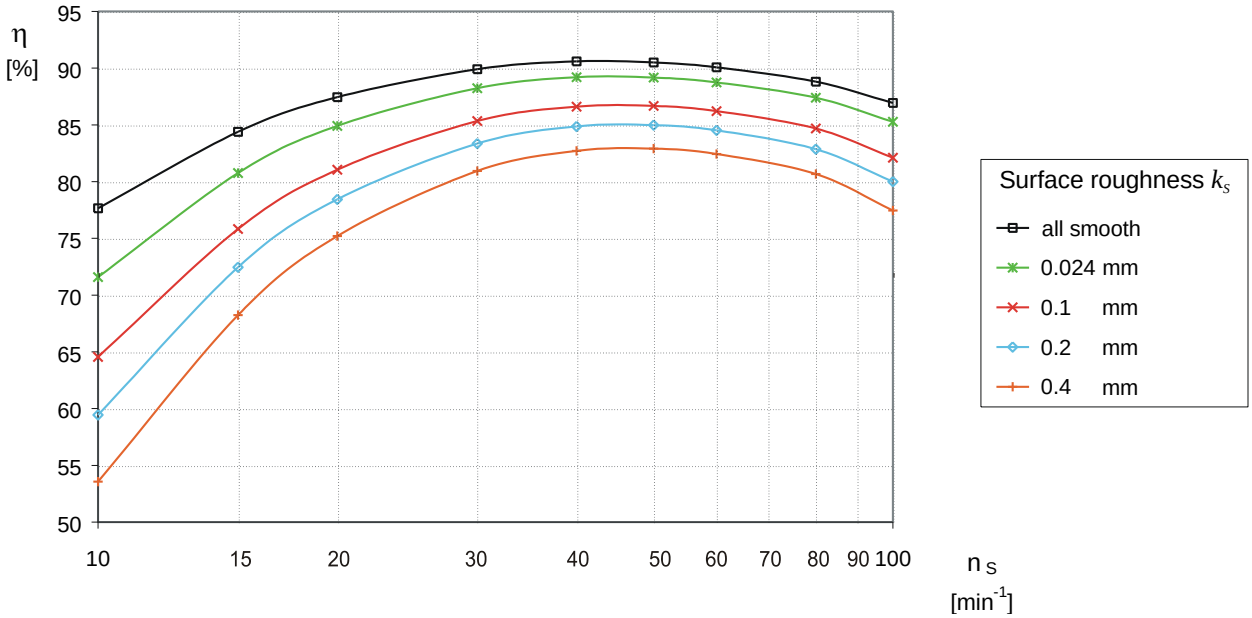


Figure 10 – The influence of surface roughness

Figure 5 demonstrates the general influence of different values of surface roughness whereas all inner surfaces of the pump show identical conditions.

It is remarkable that the gain of efficiency due to smoothing the inner surfaces of a centrifugal pump is estimated more than 5 per cent points compared to pumps showing top quality sand-cast-rough surfaces (surface roughness ks ≈ 0.024 mm). Compared to pumps showing a very low surface quality (e.g. due to low quality of manufacturing, corrosion or incrustation which can result in a value for the surface roughness up to ks = 0.4 mm) a theoretical efficiency improvement of even more than 20 per cent points could be estimated for pumps of very low specific speed (ns = 10 min-1).

The Influence of smoothing several parts of pumps

Since smoothing a whole pump is a very cost intensive manufacturing process (especially for small and medium sized pumps produced by a normal sand cast method) the influence of smoothing only several parts of the pump (i.e. volute, casing, outer surface of impeller, inner surface of impeller) was investigated theoretically by the aid of the described software.

The result of this parameter study shows, that also in case of partial smoothing the maximum efficiency improvement is to be expected for pumps with low specific speeds and can reach values of roughly 6.5 per cent points (e.g. in case of smoothing the outer surfaces of a radial impeller showing a origin surface roughness ks = 0.2 mm). With respect to an overall surface treatment of the impeller the investigations showed also, that a smoothing of the inner surfaces is primarily favourable for pumps with higher specific speeds (ns > 30 min-1), where the hydraulic losses were mainly quantified by the flow velocity within the impeller.

The Influence of Only Partly Smoothing the Outer Surface of the Impeller

Due to the fact that especially for radial pump impellers (ns < 30 min-1) smoothing the outer surfaces of the impeller front and back shroud (by turning) is a very efficient and less costly procedure to reduce the losses, i.e. improvement of pump efficiency, the effect of smoothing the

impeller front and back shroud only partly was also investigated by an appropriate theoretical parameter study.

As a result of this study it could be estimated, that smoothing only 40 % of the outer surface of the back and front shroud (starting the turning process at the impeller outlet diameter D2) an efficiency improvement of roughly 5.5 per cent points still can be estimated. This value decreases to 3.5 per cent points in the case of smoothing only 20 % of the outer surface of the back and front shroud. Du to this fact there is no need to smooth the impeller at smaller diameters where turning gets more difficult because of the more complicated impeller contour.

As a validation of the above mentioned effect for the test pump (ns = 12 min-1) available at the chair of Turbomachinery and Fluid Power at Darmstadt University of Technology an improvement of efficiency of about 2 per cent points could be measured by smoothing 50 per cent of the outer surface of the impeller back and front shroud (whereas the original surface roughness ks before smoothing showed a very low (good) value of roughly 0.03 mm).

Figure 5 summarises the theoretical estimation results obtained by the several parameter studies. The labelled efficiency values roughly quantify the maximum gain of efficiency (in per cent points) that can be expected by smoothing the wetted surfaces of a centrifugal pump showing a surfaces roughness equal to a ks value of 0.2 mm. Depending on the specific speed of a pump the efficiency values can be significantly less.

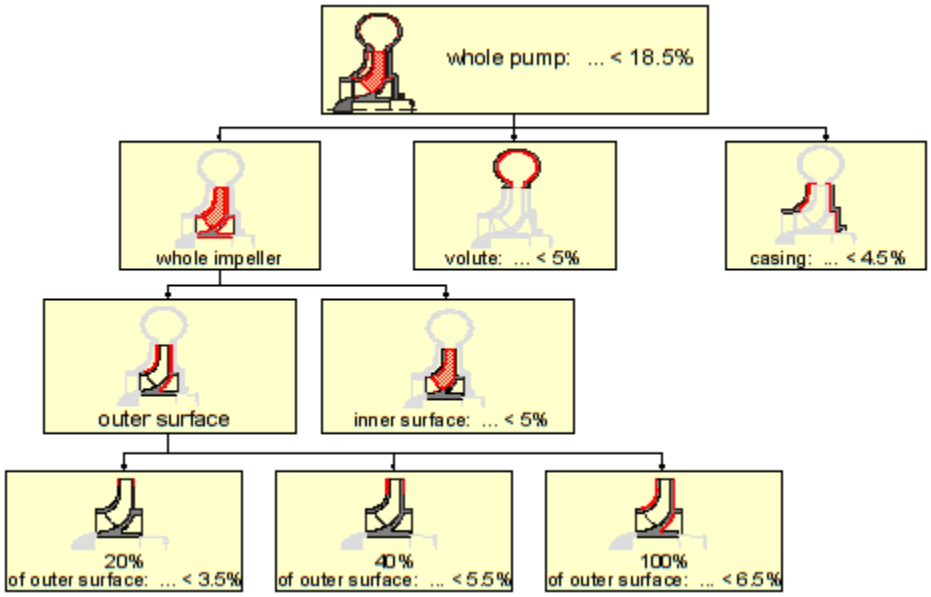


Figure 11 – Theorical estimation

Volumetric losses are mainly caused by the existence of a suction-sided sealing gap which serves as a throttle in order to reduce the secondary flow from the impeller out- to inlet as well as a an additional pressure-sided sealing gap which usually belongs to the axial thrust balancing system of a single-stage centrifugal pump. This internal leakage flows strongly depend on the clearance of the sealing gaps. Figure 5 shows the change in efficiency due to a variation of the gap clearance (the change in efficiency refers to a smooth gap with a radial gap clearance of 0.6 mm).

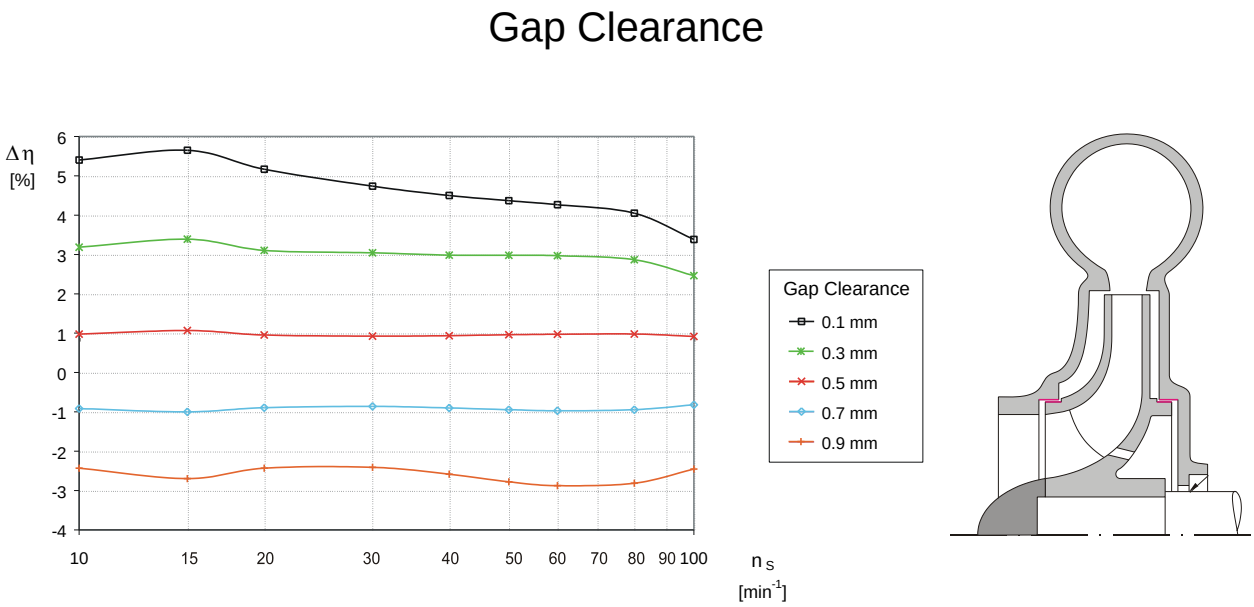


Figure 12 – The influence of secondary flow through the sealing gaps

The above diagrammed estimation results demonstrate that a reduction of gap clearance for instance from 0.6 mm to 0.3 mm can improve the pump efficiency about 3 per cent points. A possible additional treatment to reduce the internal leakage flows is to furnish one or both gap surfaces with circumferential notches (Figure 5).

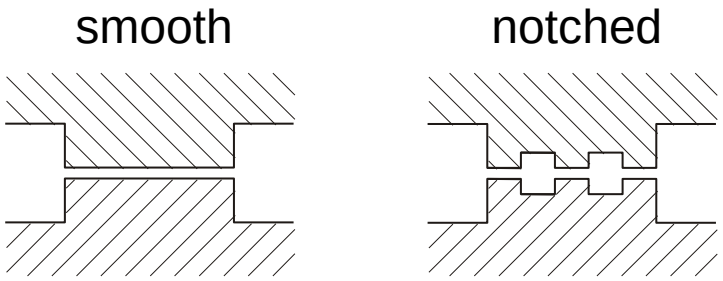


Figure 13 – Different types of sealing gaps

The theoretically carried out parameter study showed, that notching gaps of the type usually used in standard centrifugal pumps (cylindrical gaps with a relatively short gap length), only leads to a slight improvement of the pump efficiency.

Conclusions

The presented results show, that for single-stage standard centrifugal pumps within a range of specific speed n_s = 10 min^{-1} up to n_s = 100 min^{-1} (corresponding to values from 520 min^{-1} up to 5200 min^{-1} in US-Units), the highest potential for an efficiency improvement can generally be found in the region of low specific speeds. All efforts aimed at an improvement of the surface quality of several parts of the pump which are in contact with the flow cause a gain of efficiency. With regard to the manufacturing costs, which result from such additional surface treatments the smoothing of the outer front and back shroud of the impeller can be proposed as a cost-efficient procedure to improve the efficiency. Furthermore, it could be shown that it is recommendable to

reduce the clearance of the sealing gaps to the smallest possible value in order to increase the volumetric efficiency.

It should also to be mentioned, that the conditions of the surfaces as well as the sealing gaps within a centrifugal pump normally depend on the time of operation, which means that there is a strong necessity to check these parameters at reasonable intervals during the lifetime of a pump.

Annex 2: Draft description of the Extended Product Scheme, (Europump)

Foreward

This working document is prepared by a subcommittee of the Europump Standards Commission which consists of the following members:

- Dr. Niels Bidstrup, Grundfos
- Mr. Markus Teepe, WILO
- Mr. Gerhard Berge, KSB
- Dr. Gerhard Ludwig, TU Darmstadt

The working document will serve as a communication tool towards the European Commission during the legal process concerning the ecodesign requirements based on the extended product approach (EPA) for pumps. At a later stage this working document will be elaborated into a Europump guide, as an aid for pump manufacturers and users to ensure compliance with the future regulation on the extended product approach (EPA) for pumps.

This working document for a future Europump guide on the Extended Product Approach is prepared by a subcommittee of the Europump Standards Commission. It has not been presented or discussed in the Europump Standards Commission or the joint working group for EuP/ErP and currently does not reflect the position of Europump.

Europump's answer to the ecodesign directive for pumps is based on three pillars as shown in Figure 5. The Product Approach focuses on the efficiency of the pump alone. The Extended Product Approach is focused on the extended product (pump, PDS, controls) and the System Approach focuses on optimising the pumping system. The purpose of this guide is to describe the methodology for future implementing measures (i.e labelling, legislation etc.) for extended pump products (EPs).

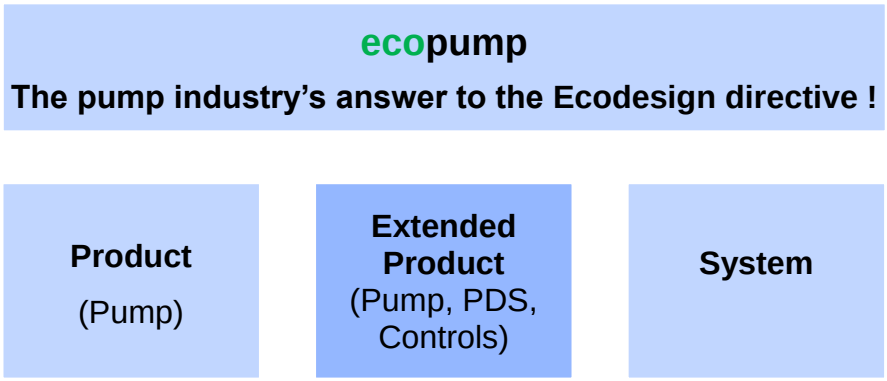


Figure 14 – Europump Ecopump initiative

Figure 5 shows the difference between a Product Approach and an Extended Product Approach. Implementing measures based on a Product Approach take only the efficiency of the product into account, whereas the Extended Product Approach via the load profile and control method curve also takes the reductions in pump head into account.

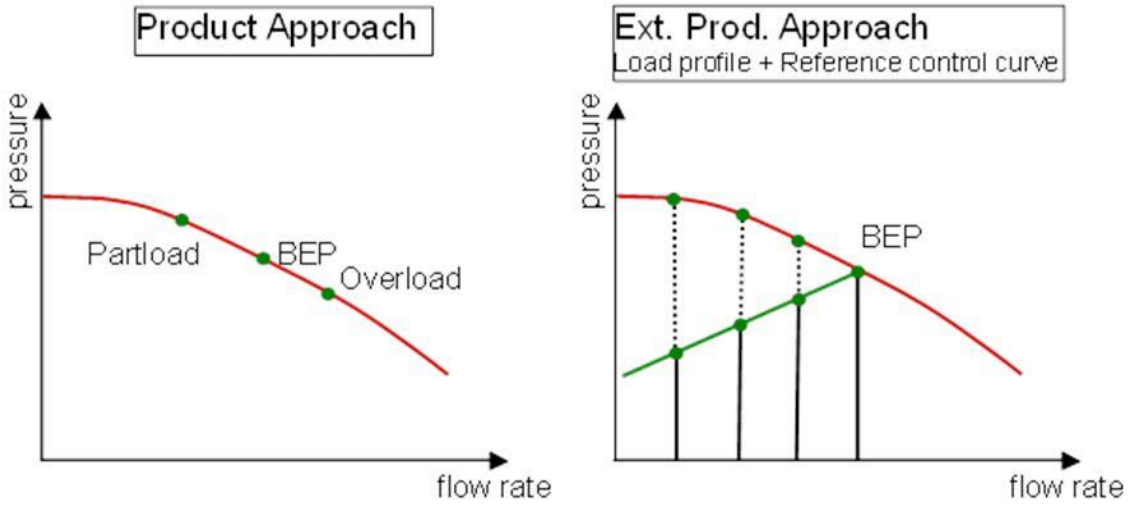


Figure 15 – Difference between a Product Approach and an Extended Product Approach

- **Pumps in scope**

The Extended Product Approach (EPA) has already been applied for circulators and forms the basis for the ecodesign requirement for these products today[4]. Figure 5 shows the road map for ecodesign requirements for pumps.

[4] *Commission Regulation 641/2009 (EC)*, Brussels: European Commission, 2009.

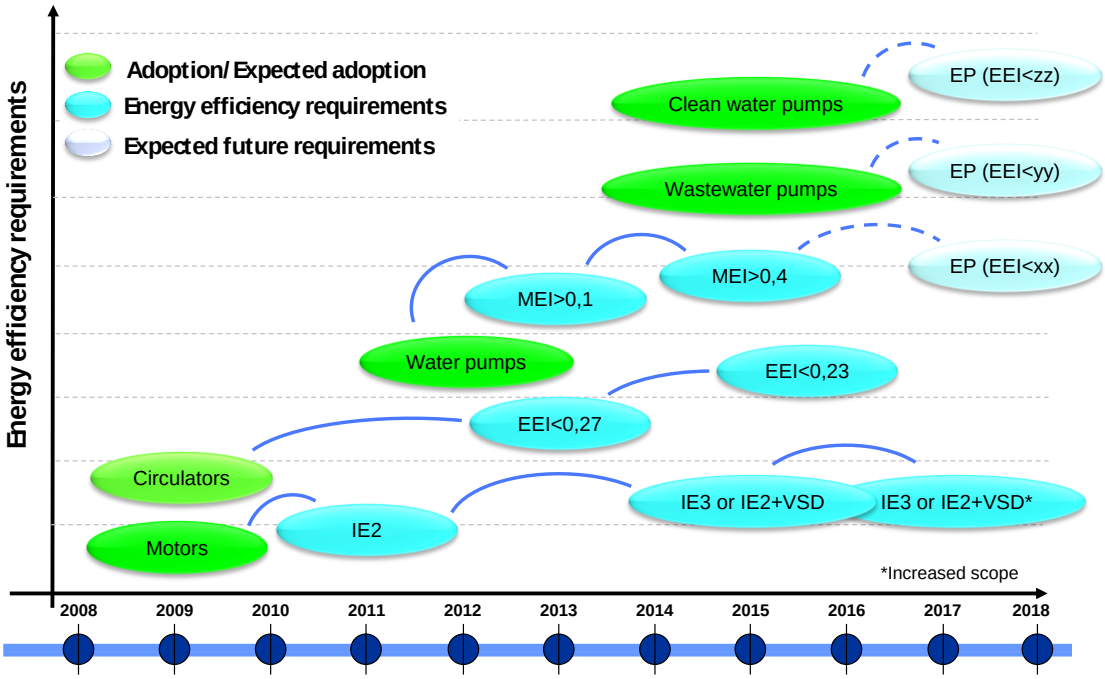


Figure 16 – Road map for energy efficiency regulation on pumps in EU

Ecodesign requirements based on extended products (EPs) are expected to be introduced during the next 5 years and the requirements will be based on an Energy Efficiency Index (EEI) as for circulators. The following pump products are expected to be targeted:

- Water pumps as defined[5]
- Booster systems (directly or indirectly)
- Wastewater pumps as defined in (to be determined)…up to 150 kW?
- Clean water pumps as defined in (to be determined)…up to 150 kW?

Energy savings

The main driver for the Extended Product Approach is the huge energy saving potential. Europump estimates that a marked transformation based on the EPA for water pumps in the scope of Commission Regulation 547/2012 only will lead to energy savings of 35 TWh per year, which is approximately ten times greater than the saving in 2020 achieved by the current regulation for water pumps.

Task 4: Extended Product Approach for pumps

It is important to distinguish between the *Extended Product Approach (EPA)* and the *Extended Product (EP)*.

- Extended Product Approach (EPA): a methodology to calculate the Energy Efficiency Index (EEI) of an Extended Product (EP), which incorporates load profiles and control method.

[5] *Commission Regulation 547/2012 (EU)*, Brussels: European Commission, 2012

- Extended Product (EP): consists of physical components

The EPA is a methodology or procedure which can be used to qualify an extended product for a certain efficiency level, whereas the EP is the actual product. This is shown graphically in Figure 5.

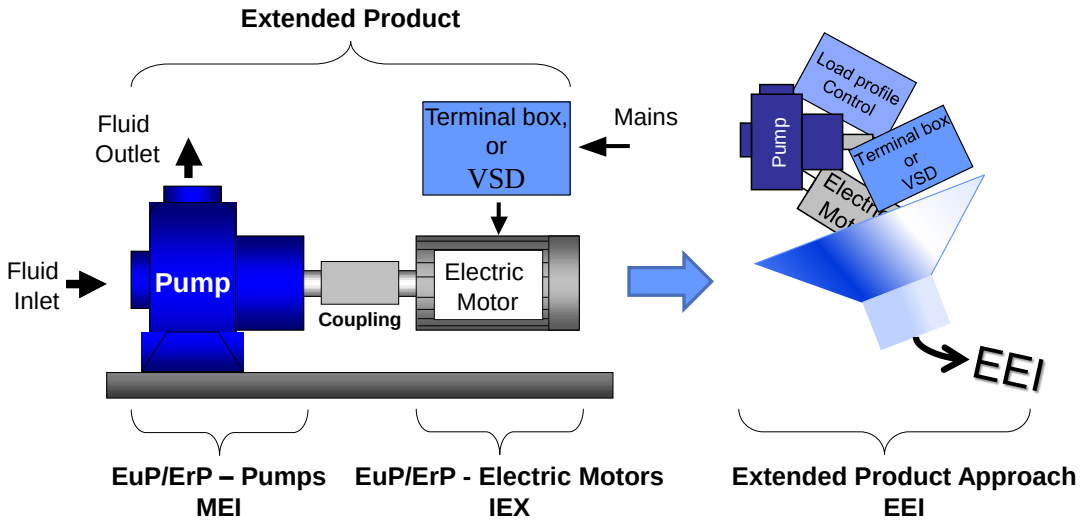


Figure 17 – Definition of Extended Product Approach

Extended pump products are placed on the market as integrated units i.e. a pump, a motor with or without VSD, which is supplied by one manufacturer as a complete unit. They are also placed on the market as separated units i.e. where the pump, motor and VSD are separate products supplied by one or more manufacturers. The EPA must be able to handle both integrated and separated extended pump products.

This leads to the following general definition for an extended pump product

> *Extended pump product means a pump driven by an electric motor with or without a variable speed drive (VSD)*

This definition is valid for all extended pump products in the scope, including circulators. The speed control is based on a system feedback which can come from sensors in the system or in the pump or from sensorless feedback transmitted by the motor.

Load Profiles and reference control curves

Extended pump products are used in a variety of applications with different load profiles and control methods. For the purpose of the EPA methodology, these load profiles and control methods are grouped into the following:

- Closed loop systems or open loop systems
- Constant flow systems or variable flow systems

- Sensorless speed control possible, (although complex to achieve)

When combined they cover all applications in the scope.

- Closed loop variable flow system

In a closed loop system, the purpose of the pumps is to produce enough head to overcome friction losses in the system and satisfy the requirement for actuators (valves etc.). A typical closed system is a hydronic distribution system of a heating and/or air conditioning system (HVAC-system). The purpose of these pumps is to distribute energy from the energy supply (boiler, chiller etc.) to the emission systems (radiator, coils, air handling units etc.) by circulating a pumped media. The load profile for these systems is shown in Table 4.

Table 6: Load profile for closed loop variable flow systems

	Flow (%)	Time (%)
L_1	100	6
L_2	75	15
L_3	50	35
L_4	25	44

At part load, the pump head can be reduced due to reduction in friction losses in the system. The control method must consider those. Figure 5 below shows the load points from and the reference control curve as defined for these systems (green line).

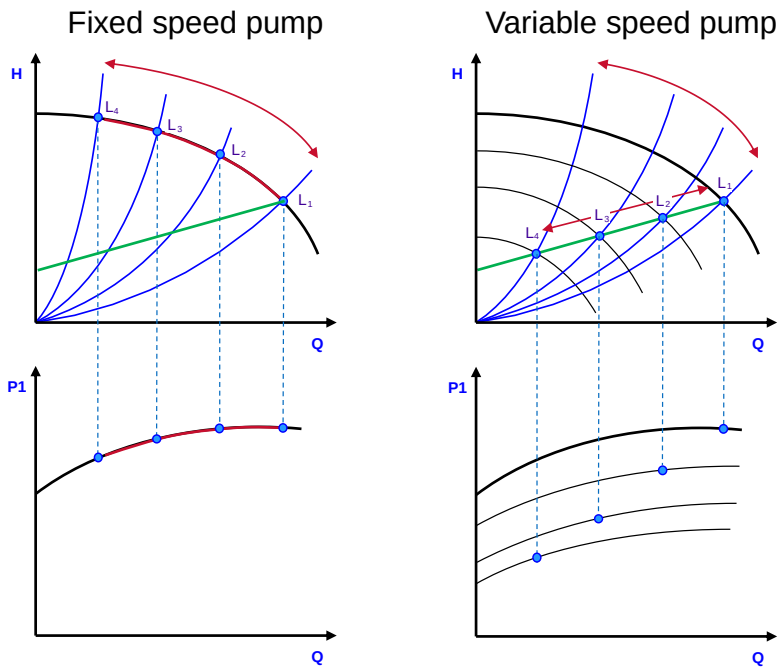


Figure 18 – Load points and control curve for closed loop variable flow systems

The EEI calculation of all pumps (fixed speed or variable speed) used in closed loop variable flow systems will be evaluated according to this reference control curve and load profile.

- **Open loop variable flow system**

Pumps in open loop variable flow systems must deliver a certain static pressure and, in addition, enough head to overcome friction losses in the system. A typical open loop variable flow system is a water distribution system in cities and buildings. A load profile for these systems is shown in Table 4.

Table 7: Load profile for open loop variable flow systems

	Flow (%)	Time (%)
L_1	100	1
L_2	90	2
L_3	80	3
L_4	70	4
L_5	60	6
L_6	50	12

L_7	40	19
L_8	60	26
L_9	20	21
L_{10}	10	6

At part load, the pump head can also be reduced in these systems due to reduction in friction losses and the control method must take that into account. Figure 5 shows the load points from table above and the reference control curve as defined for these systems (green line).

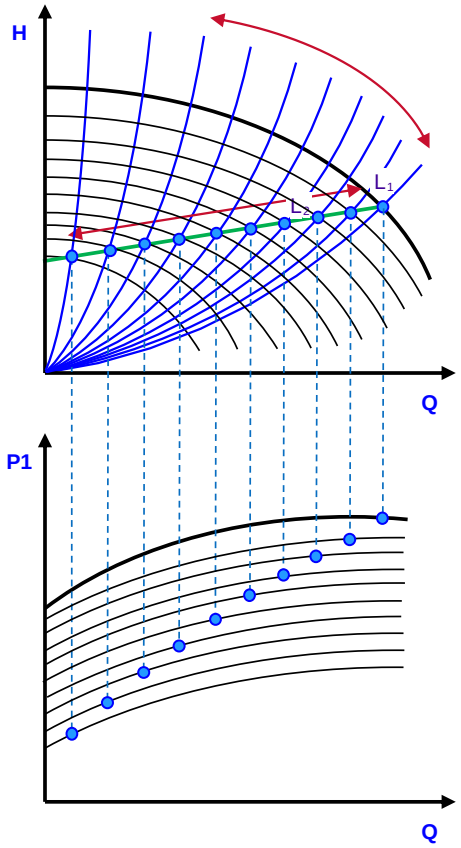


Figure 19 – Load points and control curve for open loop variable flow systems

The EEI calculation of all pumps (fixed speed or variable speed) used in open loop variable flow systems will be evaluated according to this reference control curve and load profile.

- **Constant flow system (open and closed loop)**

In a constant flow system, the pump must overcome a certain static pressure in an open loop system or overcome a certain friction loss in a closed system which is designed to give a certain constant flow. A typical application of an open loop constant flow system is where the purpose of the pump is to move liquid from one reservoir to another. A typical example of a closed loop system could be a boiler feed pump. In a real system, the flow is very seldom constant. For

example, it will vary due to the level of the reservoirs etc. Therefore, it makes sense to define a load profile with a load point around the best efficiency point. Such a load profile is shown in Table 4 below.

Table 8: Load profile for constant flow systems (open and closed loop)

	Flow [%]	Time [%]
L_1	110	25
L_2	100	50
L_3	75	25

These are the same load points as those used for MEI calculation for water pumps, where a time profile has been added.

In these systems, variable speed is not a benefit and no reference control curve is defined.

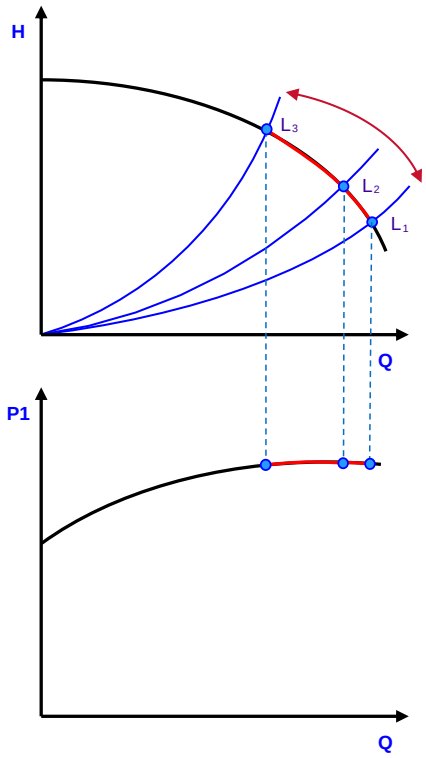


Figure 20 – Load points constant flow systems (open and closed loop)

The EEI calculation of all pumps (fixed speed or variable speed) used in constant flow systems (open loop and closed loop) will be evaluated according to this load profile.

- **Relation between system types and pump types**

There is no one-to-one mapping between system types and pump types. Some pump types are used in different systems. Table 4 shows the relation between system types and pump types.

Table 9: System type vs. pump type

Pump type	Relation to EuP/ErP	System type		
		Variable flow		Constant flow
		Closed loop	Open loop	Closed and open loop
Circulators	Lot 11	X		
ESCCI	Lot 11	X	X	O
ESOB	Lot 11	X	X	X
ESCC	Lot 11	X	X	X
MS	Lot 11	O	X	O
MSS	Lot 11	O	O	X
Wastewater	Lot 28	O	O	X
Clean water pumps	Lot 29 (except Lot 11 pump types)	O	O	X

For pump types used in more than one system type, more than one EEI value will be calculated. The *product information requirements* must ensure that the EEI is calculated and documented for all the entries in the table marked with an 'X'. Calculation and documentation of an EEI are optional for the entries marked with an 'O' in the table.

The *energy efficiency requirements* must specify that when putting an extended product into service, the energy efficiency requirements (in terms of EEI) for a particular pump type used in a particular system type must be met.

- **Task 4: Methodology for calculation of EEI for extended products**

The Energy Efficiency Index (EEI) is based on the same methodology as for circulators. Basically, it consists of an average power input calculated on a load-time profile divided by a reference power input.

Figure 5 shows how the power in an extended product is defined. P_1 is the electrical power input from the grid. P_2 is the mechanical power from the motor shaft. P_{hydr} is the hydraulic power produced by the pump.

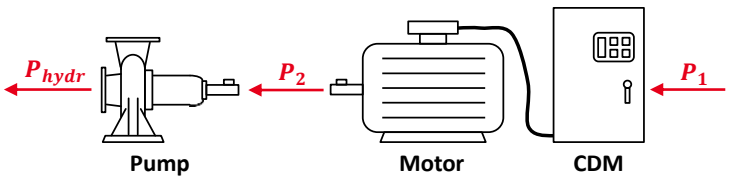


Figure 21 – Definition of Powers in an extended pump product. The combined motor and CDM (VSD) is referred to as a Power Drive System (PDS)

A graphical presentation of the EEI calculation is shown in Figure 5 below. The left side shows the calculation of average power input i.e. the numerator of the EEI index. The right side shows how to calculate the reference power i.e. the denominator of the EEI index.

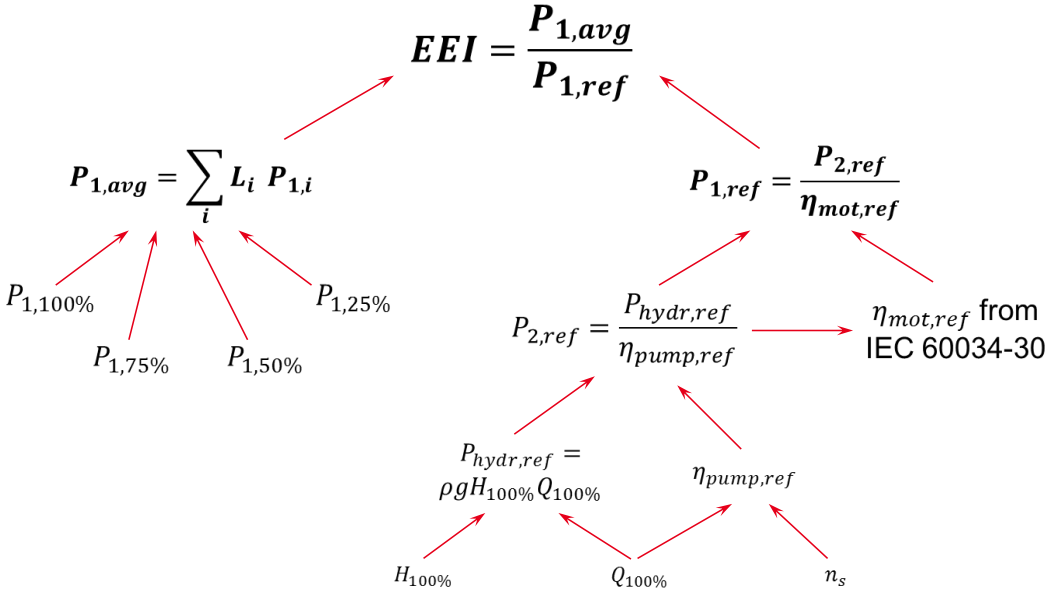


Figure 22 – Graphical presentation of the EEI calculation

The power input values $P_{1,l}$ in Figure 5 above can be measured, but this is not possible in most cases especially not for separated units. The $P_{1,l}$ values will then be calculated from Semi Analytical Models as described in the next section.

The reference power input based on actual efficiency of the pump as defined in the EC regulation for water pumps[6] and later on for the other pump types in the scope in Lot 28 and Lot 29. Based on actual measurements of the pump, the head and the flow, the best efficiency point (H100%, Q100%) is determined and from that the specific speed (ns) is calculated. Based on the hydraulic power and the efficiency, the reference shaft power $P_{2,ref}$ is calculated, which can via the IEC 600034-30 for motors be converted onto a reference power input. The reference efficiency of the VSD is set to 100% by definition. The actual efficiency of the specific VSD is captured by the power input values $P_{1,l}$ as is the case for pump and motor.

- **Semi Analytical Models (SAMs)**

[6] *Commission Regulation 547/2012 (EU)*, Brussels: European Commission, 2012

A methodology for an extended pump product cannot be based on measurement only although this is an option, which can be applied in some cases.

Separated extended pump products are in many cases built on site, which makes a determination of EEI based on measurements of the extended product impossible. Therefore, a methodology based on Semi Analytical Models (SAMs) has been developed to overcome this problem[7].

A SAM is a model which is based on measurement combined with physical and empirical knowledge of the product. Based on SAMs of the pump, motor and VSD it is possible to calculate the EEI of the extended product based on a few measurement points (supporting points) of the individual products (pump, motor and VSD).

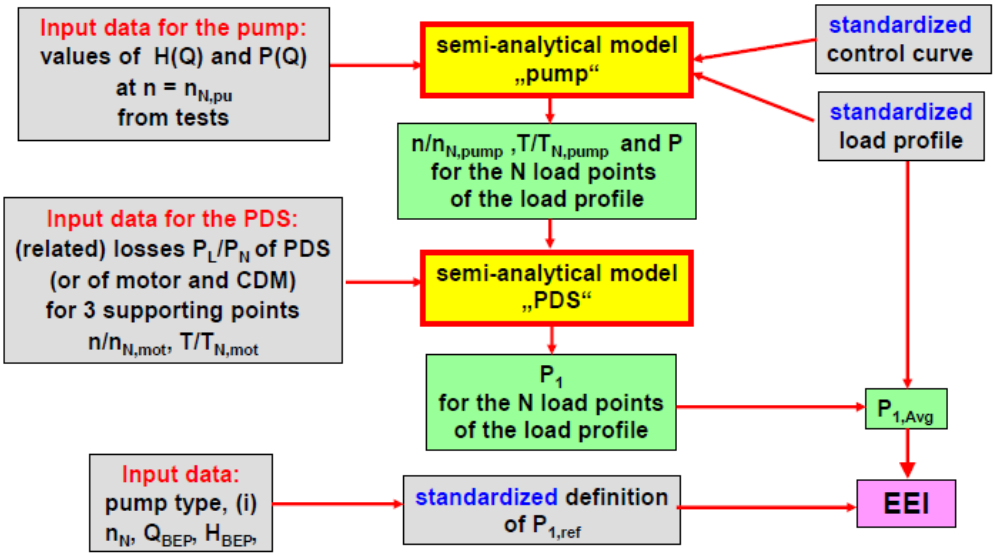


Figure 23 – Flow chart for calculating EEI of an Extended Pump Product

Based on the SAM for the pumps, the torque and rotational speed at the part load point is calculated.

Based on SAMs of the Power Drive System (PDS) the power losses at these part load point can be calculated and used to determine the power input to the extended product.

The SAM for the PDS is decribed in prEN50589-2[8] [4]. Figure 5 shows the eight load points which are defined in this standard. These eight points are chosen to cover all PDS applications.

[7] B. Stoffel, *Semi Analytical Models SAM's for Pumps,* Technical University of Darmstadt, 2013

[8] *prEN 50589-2 Energy efficiency indicators for power drive systems and motor starters,* CENELEC, 20xx.

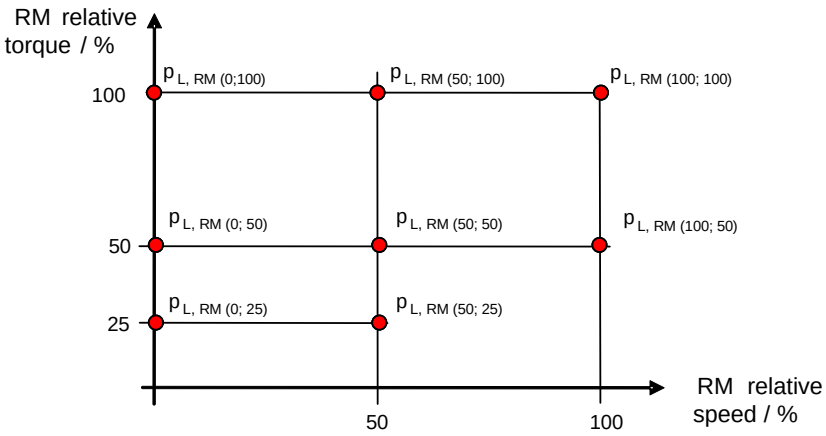


Figure 24 – Related losses of a PDS at different part load points[9]

Figure 5 shows the three supporting points for pump applications. All pump applications in the scope will be within the green shaded area.

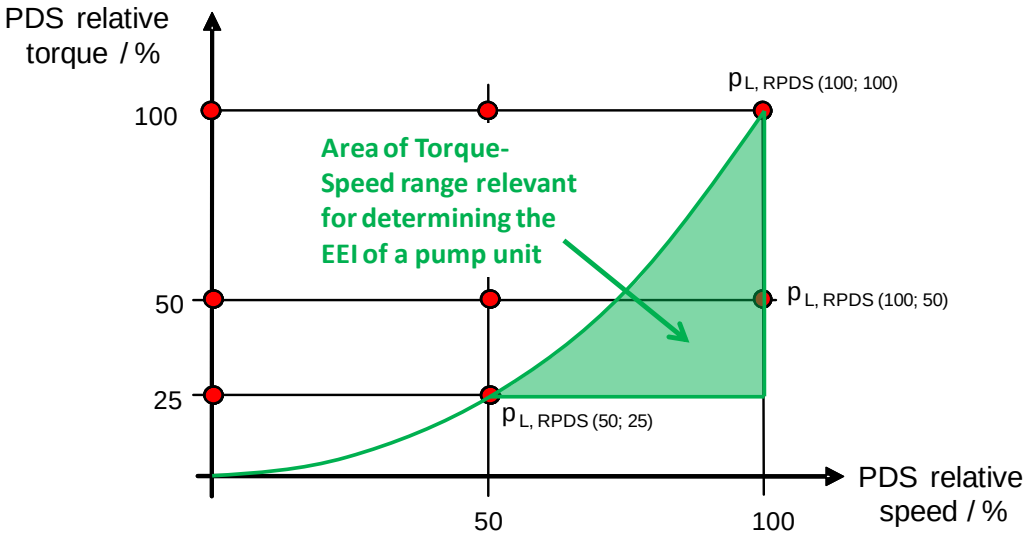


Figure 25 – Three points of related losses and shaded area of interest for pump manufacturers when calculating the EEI (Energy Efficiency Index) of a pump unit[8]

The actual losses will be based on interpolation based on these supporting points. Part One of the PDS standard[10] will cover the generic application of the standard for extended products. A specific measurements standard must be written for all products. A draft standard for pumps is already under development.

[9] *prEN 50589-2 Energy efficiency indicators for power drive systems and motor starters,* CENELEC, 20xx.

[10] *prEN 50589-1 Procedure for determining the energy efficiency indicators or motor driven applications by using the extended product approach and semi analytical model,* CENELEC, 20xx

Annex 3: Extract from the Lot 11 Preparatory study - The "House of Efficiency" scheme[11]

The decision scheme "House of Efficiency" takes into account design and application purposes as well as the pump minimum efficiency dependence on flow. The minimum acceptable efficiency is therefore different for each pump type. The pass-or-fail scheme is based on two criteria A and B.

- Criterion A is the pass-or-fail minimum efficiency requirement at the best efficiency point (b.e.p.) of the pump:
- Criterion B is the pass-or-fail minimum efficiency requirement at part load (PL) and at overload (OL) of the pump:

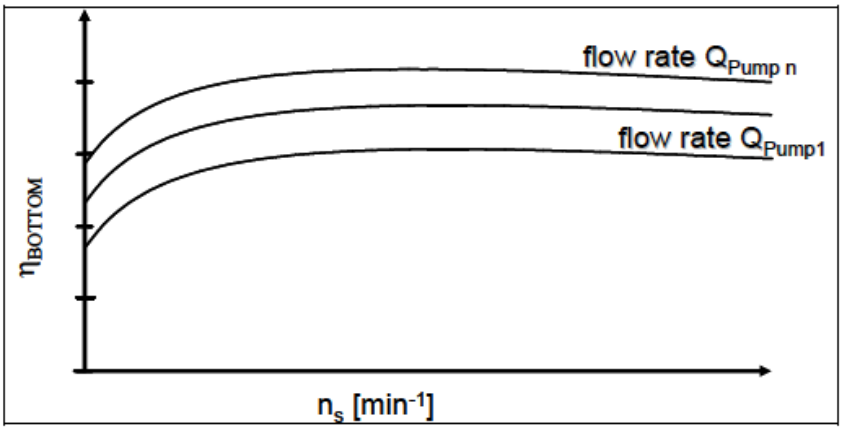


Figure 26 – Bottom lines for different geometrical pump sizes (defined for nominal flow rate Qn > Q1) within one pump type

That leads to bottom lines specific to each pump type at a certain flow (see Figure 5) which have to be defined, based on statistical data.

[11] This section is included for reference, and is an extract from the Lot11 Preparatory report section 8.1.12.3).

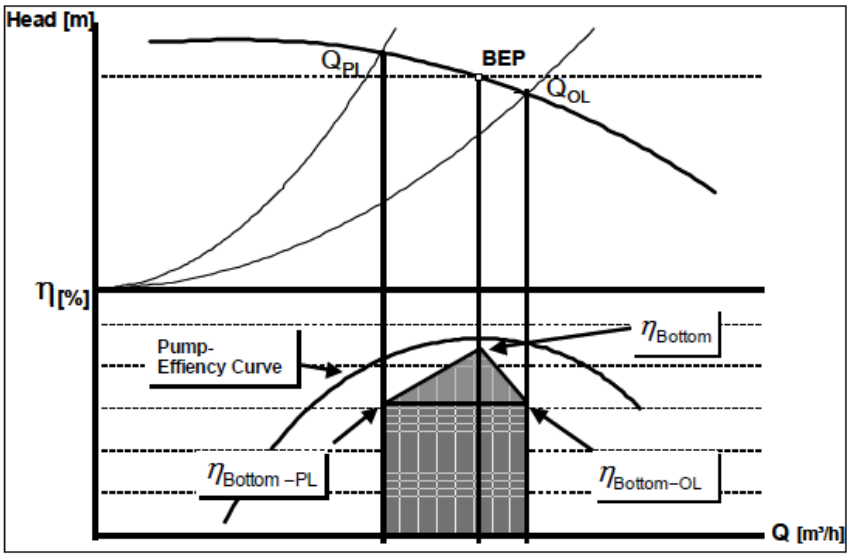


Figure 27 – "House of Efficiency" - explanatory representation of the scheme in a η (Q): flow-Plot

In Figure 5 the representation of the two criteria is shown in an η(Q):flow-plot. The pump efficiency curve with its maximum at the best efficiency point does not cross the "roof of the efficiency house". The part and over load minimum acceptable efficiencies at 0.75·QBEP and 1.10·QBEP build the roof-triangle with the minimum acceptable efficiency at best efficiency point. As a result, the pump efficiency curve has to be broad and high to fulfil the criteria. The shown example is for a pump passing the agreed efficiency criteria (not yet set) and would therefore pass the energy efficiency check. Subsequently it would be eligible for CE-marking in accordance with the applicable Directive. Pumps with robust trade-off criteria like NPSH, noise, application for dirty water or other aspects should separately be considered with their own minimum acceptable efficiency and specific factor "x" to be defined.

The application of this scheme requires the definition of pump specific bottom lines for different flows as well as the factor "x" for part load and overload based on the statistical data provided by the manufacturers.



02 April 2014

185 avenue Charles de Gaulle
92200 Neuilly-sur-Seine
France
+ 33 (0) 1 5561 6755

www.bio.deloitte.fr

Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 28– Pumps for private and public wastewater and for fluids with high solids content – Task 5: Definition of base-case – Working document

Final Report to the European Commission, DG ENER
02 April 2014



European Commission

Developed by:

bio by Deloitte.

ATKINS

Document information

CLIENT	European Commission, DG ENER
CONTRACT NUMBER	ENER/C3/403/2010
REPORT TITLE	ENER Lot 28– Pumps for private and public wastewater and for fluids with high solids content – Task 5: Definition of base-case – Working document
PROJECT NAME	Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC
PROJECT CODE	ENER Lot 28
PROJECT TEAM	Bio by Deloitte, Atkins
DATE	02 April 2014
AUTHORS	Mr. Shailendra Mudgal, Bio by Deloitte Mr. Sandeep Pahal, Bio by Deloitte Mr. Benoit Tinetti, Bio by Deloitte Mr. Alvaro de Prado Trigo, Bio by Deloitte Dr. Hugh Falkner, Atkins Mr. Keeran Jugdoyal, Atkins
KEY CONTACTS	Mr. Sandeep Pahal spahal@bio.deloitte.fr Or Mr. Shailendra Mudgal shmudgal@bio.deloitte.fr
DISCLAIMER	This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. The project team does not accept any liability for any direct or indirect damage resulting from the use of this report or its content.

Please cite this publication as:
Bio by Deloitte (2014), Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC, ENER Lot 28– Pumps for private and public wastewater and for fluids with high solids content – Task 5: Definition of base-case – Working document prepared for. European Commission, DG ENER

Photo credit: cover @ Per Ola Wiberg
© Bio by Deloitte 2014

Table of Contents

5.1.1 Criteria for defining base-cases 7
5.2.1 Centrifugal submersible pumps 10
5.2.2 Centrifugal dry well pumps 12
5.2.3 Slurry pumps 13
5.3.1 BC-1: Centrifugal submersible radial sewage pump 1-160 kW 17
5.3.2 BC-2: Centrifugal submersible mixed flow & axial pump 19
5.3.3 BC-3: Centrifugal submersible once a day operation pump 21
5.3.4 BC-4: Centrifugal submersible domestic drainage pump < 40 mm passage 23
5.3.5 BC-5: Submersible dewatering pump 25
5.3.6 BC-6: Centrifugal dry well pump 28
5.3.7 BC-7A: Slurry pump – Light Duty 31
5.3.8 BC-7B: Slurry pump – Heavy Duty 34
5.5.1 Life-cycle environmental impact at EU-27 level 39
5.5.2 Life-cycle costs at EU-27 level 41
5.5.3 EU-27 total system impact 42

List of Tables

Table 5.1: Overview of ENER Lot 28 pumps product Base-Cases in 2011 8

Table 5.2: Summary of ENER Lot 28 pumps product Base-Cases 9

Table 5.3: Inputs in the End-of-life phase of BC-1 to BC-7 10

Table 5.4: Bill of materials of BC-1 to BC-5 10

Table 5.5: Inputs in the use phase of BC-1 and BC-5 11

Table 5.6: Inputs to economic analysis in EcoReport for BC-1 to BC-5 11

Table 5.7 Bill of materials of BC-6 12

Table 5.8 Inputs in the use phase of BC-6 13

Table 5.9 Inputs to economic analysis in EcoReport for BC-6 13

Table 5.10 Bill of materials of BC-7A and BC-7B 13

Table 5.11 Inputs in the use phase of BC-7A and BC-7B 14

Table 5.12 Inputs to economic analysis in EcoReport for BC-7A and BC-7B 14

Table 5.13: Life cycle impact (per unit) of BC-1: Centrifugal submersible radial sewage pump 1-160 kW 17

Table 5.14: Life cycle impact (per unit) of BC-2: centrifugal submersible mixed flow & axial pump 19

Table 5.15: Life cycle impact (per unit) of BC-3: centrifugal submersible once a day operation pump 21

Table 5.16: Life cycle impact (per unit) of BC-4: centrifugal submersible domestic drainage pump < 40 mm passage 23

Table 5.17: Life cycle impact (per unit) of BC-5: Submersible dewatering pump 25

Table 5.18: Life cycle impact (per unit) of BC-6: Centrifugal Dry Well Pump 28

Table 5.19: Life cycle impact (per unit) of BC-7A: Slurry pump – Light Duty 31

Table 5.20: Life cycle impact (per unit) of BC-7B: Slurry pump – Heavy Duty 34

Table 5.21: EcoReport outcomes of the LCC calculations for all the Base cases 38

Table 5.22: EU-27 total impact of the installed stock (2011) of the Base-Cases 40

Table 5.23: EU-27 total annual consumer expenditure (2011) 41

List of Figures

Figure 5-1: Distribution of the BC-1's environmental impacts by life cycle phase 18
Figure 5-2: Distribution of the BC-2's environmental impacts by life cycle phase 20
Figure 5-3: Distribution of the BC-3's environmental impacts by life cycle phase 22
Figure 5-4: Distribution of the BC-4's environmental impacts by life cycle phase 24
Figure 5-5: Distribution of the BC-5's environmental impacts by life cycle phase 26
Figure 5-6: Distribution of the BC-6's environmental impacts by life cycle phase 29
Figure 5-7: Distribution of the BC-7A's environmental impacts by life cycle phase 32
Figure 5-8: Distribution of the BC-7B's environmental impacts by life cycle phase 35

Task 5: Definition of Base-Case

This task provides an environmental and economic assessment of the average EU pumps for private and public wastewater and for fluids with high solid contents covered in the ENER Lot 28 preparatory study, also known as the "Base-Cases" (BCs). A 'BC' is *"a conscious abstraction of reality"* used to represent the average of a range of similar products on the market. The aim of the assessment is to quantify:

- the environmental impacts of the selected Base-Cases throughout its life
- the economic Life Cycle Costs (LCC)

The assessment includes all stages of the Base-Case's life from the extraction of the materials contained within its components, to the disposal of these materials at the end-of-life. The environmental impacts are determined by a well-established methodology known as Life Cycle Analysis (LCA). In this study a simplified LCA tool is used to calculate the environmental impacts and LCC. The tool, which is called EcoReport, is part of the MEEuP methodology, required by the European Commission for undertaking all preparatory studies under the Ecodesign Directive.[1]

While this study has been completed as comprehensively and accurately as possible, it relies on data which has been extrapolated from literature and information provided by stakeholders. The performance of real-life appliances can vary substantially from the data provided in this report. This is understood and mitigated as much as possible, while handling and calculating the data during the analysis, however rough approximations are ultimately unavoidable. The results of the study nevertheless are valuable as they represent the best indication to date of the environmental impacts of the ENER Lot 28 pumps in the EU.

The description of the Base-Cases is the synthesis of the results of Tasks 1 to 4 of this preparatory study. The environmental and life cycle cost analyses of the selected Base-Cases provide the main results of this study and it serves as the point-of-reference for Task 6 (technical analysis of Best Available Technologies), Task 7 (improvement potential), and Task 8 (policy analysis).

[1] MEEuP – Methodology Study Eco-design of Energy Using Products. Kemna, R. et al. (VHK) for DG ENTR of the European Commission, MEEuP Methodology Final Report, 2005. Accessible at: http://ec.europa.eu/energy/demand/legislation/doc/2005_11_28_finalreport1_en.pdf

5.1 Overview of base-cases

5.1.1 Criteria for defining base-cases

According to the Ecodesign Directive (2009/125/EC), the products subject to future establishment of implementing measures should meet three criteria:

- Significant market share
- Significant environmental impact
- Significant improvement potential

The implementing measures target appliances that are common on the EU market, bear a large environmental burden, and have the potential to improve their environmental performance. An appliance that does not meet any of these three criteria provides little opportunity for policy action, and therefore is not considered as a BC. As previously mentioned, BCs are not necessarily representative of real products. When two products have a similar functionality, bill of materials (BoM), technology and efficiency, they can be represented by a single BC. For further justification of the criteria for selecting Base-Cases, please refer to the MEEuP methodology[2]. It is out of the scope of this study to reflect further upon how and why Base-Cases should be chosen.

Table 5.1 shows the selection of these Base-Cases based on preliminary information gathered from industry stakeholders and technical literature. The total energy consumption of the product stock at EU-27 level is estimated for the year 2011. The specific energy saving potentials estimates have been provided by stakeholders. Seven[3] most appropriate BCs for this study have been selected through discussion with the stakeholders, using the above criteria as guidelines.

Such a high number of BCs is necessary to cover the broad range of ENER Lot 28 water pumps. The main parameters of the selected Base-Cases are presented in Table 5.1 and Table 5.2.

[2] MEEuP – Methodology Study Eco-design of Energy Using Products, Kemna, R. et. al. (VHK) for DG ENTR of the European Commission, MEEuP Methodology Final Report, 2005, accessible at http://ec.europa.eu/energy/demand/legislation/doc/2005_11_28_finalreport1_en.pdf

[3] Please Note that the last three base cases (BC7-BC 9) might be discarded after the 2nd Stakeholder meeting owing to their exclusion from the scope of ENER Lot 28 study, as previously explained in the Task 1 report. This would eventually bring down the total number of base cases to six.

Table 5.1: Overview of ENER Lot 28 pumps product Base-Cases in 2011

Pump Type		Stock in 2011	Sales in 2011	Hydraulic pmu power*	Operating hours	Energy consumption/ unit	Energy consumption of stock	Share of energy consumption	EPA savings for 2011 stock	Share of savings for 2011 stock	Base-case
		Units	Units	kW	Hours/year	kWh/year	GWh/year	%	GWh	%	
Centrifugal submersible pump	Radial sewage pumps 1 to 10 kW	1 120 000	160 000	4	1 000	3 400	3 808	*12.3%*	510	*23.7%*	BC-1
	Radial sewage pumps >10 to 25 kW	120 000	12 000	15	1 500	19 125	2 295	*7.4%*	256	*11.9%*	
	Radial sewage pumps >25 to 160 kW	70 000	5 000	75	2 000	127 500	8 925	*28.8%*	695	*32.4%*	
	Mixed flow & axial pumps	4 900	700	50	5 000	175 000	858	*2.8%*	99	*4.6%*	BC-2
Centrifugal submersible pump – once a day operation	Shredding, grinding pumps	280 000	50 000	2	30	45	13	*0.04%*	1	*0.04%*	BC-3
	Radial sewage pumps 1 to 10 kW	910 000	130 000	2	30	48	44	*0.1%*	5	*0.2%*	
	Where volute is part of a tank	385 000	55 000	2	30	36	14	*0.04%*	2	*0.1%*	
Centrifugal submersible domestic drainage pump < 40 mm passage		12 250 000	1 500 000	0.3	30	7	88	*0.3%*	13	*0.6%*	BC-4
Submersible dewatering pumps		280 000	40 000	7	2 000	10 500	2 940	*9.5%*	287	*13.3%*	BC-5
Centrifugal dry well pump	Radial sewage pumps 1 to 10 kW	150 000	20 000	6	1 000	5 100	765	*2.5%*	53	*2.4%*	BC-6
	Radial sewage pumps >10 to 25 kW	37 500	5 000	15	1 500	19 125	717	*2.3%*	54	*2.5%*	
	Radial sewage pumps >25 to 160 kW	14 000	1 000	75	2 000	127 500	1 785	*5.8%*	88	*4.1%*	
	Mixed flow & axial pumps	2 000	100	150	250	31 900	64	*0.2%*	1	*0.03%*	-
Slurry Pumps	Light Duty	60 000	1 500	50	2 600	130 000	7 800	*25.2%*	78	*3.6%*	BC-7A
	Heavy Duty	15 000	300	37	2 000	59 200	888	*2.8%*	9	*0.4%*	BC-7B
Total		15 698 400	1 980 600				31 004		2 149	*100%*	

* Calculated as ((Hydraulic pump power * Annual operating hours) +20%) * EU Stock in 2011

Table 5.2: Summary of ENER Lot 28 pumps product Base-Cases[4]

		Stock in 2011	Sales in 2011	Hydraulic pmu power	Operating hours	Energy consumption/ unit	Energy consumption of stock	Share of energy consumption	EPA savings for 2011 stock	Share of savings for 2011 stock
		Units	Units	kW	Hours/year	kWh/year	GWh/year	%	GWh	%
Base Case 1	Centrifugal submersible pump: Radial sewage pumps 1 to 160 kW	1 310 000	177 000	7	1 062	7 972	15 028	49%	1 462	68%
Base Case 2	Centrifugal submersible pump: Mixed flow & axial pumps	4 900	700	50	5 000	175 000	858	3%	99	5%
Base Case 3	Centrifugal submersible pump – once a day operation	1 575 000	235 000	2	30	45	70	0.2%	8	0.4%
Base Case 4	Centrifugal submersible domestic drainage pump < 40 mm passage	12 250 000	1 500 000	0.3	30	7	88	0.3%	13	1%
Base Case 5	Submersible dewatering pumps	280 000	40 000	7	2 000	10 500	2 940	10%	287	13%
Base Case 6	Centrifugal dry well pump	201 500	26 000	10	1 135	12 505	3 267	11%	194	9%
Base Case 7A	Slurry Pumps – Light Duty	60 000	1 500	50	2 600	130 000	7 800	25%	78	4%
Base Case 7B	Slurry Pumps – Heavy Duty	15 000	300	37	2 000	59 200	800	3%	9	0.4%
Total		15 696 400	1 980 500				30 939		2 148	100%

[4] Some stakeholders raised concern about merging of a wide range of different products in BC 1 ("Radial sewage pumps" from 1 to 160 kW) and suggested to split it in two Base-Cases: a) 1-25 kW, b) 25 – 160 kW. However, based on our project team's analysis, it was concluded that the current approach for BC 1 (and other BaseCases) is justified and allows to perform a robust policy analysis in Task 8. Some of the main reasons for not splitting the BC 1 are:

- Technical similarities: The pump technologies used for the BC 1, across its power capacity range are quite similar
- No impact on proposed Implementing Measures (IM): the IM proposed in Task 8 are mainly based on Hydraulic efficiency only and as the pump technology (directly related to hydraulic efficiency) for types considered by BC 1 are quite similar, it further justifies to maintain the current classification of Base-Cases. Any slight differences in pump technologies for the BC's (such as impeller type, main application area) should be accounted for in the variation in the C-Values presented as Annex to Task 8 report

5.2 Product specific inputs

In this section a description of the characteristics of the selected Base-Cases and the specific inputs needed for the environmental and economic analysis are presented, as well as the justification of all the assumptions made.

The information used in the environmental and economic analysis of the Base-Cases hereunder is provided by stakeholders and completed with information taken from publicly available literature. Vortex impellers are considered for the Base-Cases presented in this section.

The electricity rates are taken from the MEErP methodology and are a fixed value to be used across all ErP preparatory studies. The discount rate is defined as the interest rate minus the inflation rate. A discount rate of 4% (same for all Base-Cases) was also obtained from MEErP methodology. The discount rate is used for the Life Cycle Cost (LCC) analysis.

For the end of life phase, the same approach as in the ENER Lot 11 is followed. The percentage (by weight) of the product destined to landfill is estimated to be 8%. From the recovered share of plastics, 1% is destined to closed loop recycling, 9% is destined to materials recycling and the rest (90%) to thermal recycling (energy recovery). In order to be used in the EcoReport tool, the reuse, recycling and incineration rates have been recalculated to sum up 100% of the plastic fraction. The recycling rate of the metal and miscellaneous fraction is fixed by the MEEuP at 95%.

Table 5.3: Inputs in the End-of-life phase of BC-1 to BC-7

Disposal: Environmental Costs per kg final product	
Landfill (fraction products not recovered) (%)	*8%*
Re-use, Recycling Benefit	
Plastics: Re-use, Closed Loop Recycling (%)	*1%*
Plastics: Materials Recycling (%)	*9%*
Plastics: Thermal Recycling (%)	*90%*

5.2.1 Centrifugal submersible pumps

5.2.1.1 Inputs in the production and distribution phase

The average quantities of materials used for production and packaging of centrifugal submersible pump base cases are provided in Table 5.4. The biggest share of overall materials used for BC-1 to BC-3 is comprised of "other ferrous metals", while for BC-4 it is "steel" and BC-5 it is "non-ferrous metals".

Table 5.4: Bill of materials of BC-1 to BC-5

	BC-1	BC-2	BC-3	BC-4	BC-5
Hydraulic PMU Power [kW]	6.75	50	2	0.3	7
Product weight [kg]	114	400	45	40	50

	BC-1		BC-2		BC-3		BC-4		BC-5	
Packaging weight [kg]	21		120		17.6		1		1	
Volume of package product [m^3]	0.8		2		0.7		0.5		0.8	
Product Content	**kg**	**%**	**kg**	**%**	**kg**	**%**	**kg**	**%**	**kg**	**%**
Steel	24	20	100	25	9	19	4	15	17	34
Cast Iron	0	0	0	0	0	0	0	0	0	0
Other ferrous metals	75	68	232	58	28	61	0	40	7	14
Non-ferrous metals	13	10	60	15	4	10	2.2	10	22	44
Plastics	1	1	4	1	4	9	1.8	34	1	1
Coatings	0	0	0	0	0	0	0	0	0	0
Electronics	0	0	0	0	0	0	0	0	0	0
Other Materials	1	1	4	1	0.4	1	0.1	1	4	7
Packaging Content	**kg**	**%**	**kg**	**%**	**kg**	**%**	**Kg**	**%**	**kg**	**%**
Plastics	0.2	1	0	0	0.2	4	0	0	0	0
Cardboard	0.6	4	0	0	1.2	22	1.0	100	1.0	100
Paper	0	0	0	0	0	3	0	0	0	0
Other (Wood, etc.)	20	95	120	100	16.2	71	0	0	0	0

5.2.1.2 *Inputs in the use phase*

The annual energy consumption of BC-1 to BC-5 pumps is provided in Table 5.5. On-mode consumption per year refers to the annual energy consumption of different types of pumps corresponding to a base case, weighted per unit of corresponding pump sales in year 2011.

Table 5.5: Inputs in the use phase of BC-1 and BC-5

	BC-1	BC-2	BC-3	BC-4	BC-5
Product life in years	10	10	8	7	10
On-mode: Energy consumption per year (in kWh)	7 972	175 000	45	7	10 500

5.2.1.3 *Economic inputs*

The market data, product price and user expenditure inputs provided in Table 5.6 are based on values collected and already described in the Task 2 report.

Table 5.6: Inputs to economic analysis in EcoReport for BC-1 to BC-5

	BC-1	BC-2	BC-3	BC-4	BC-5
Annual sales 2011	177 000	700	235 000	1 500 000	40 000

	BC-1	BC-2	BC-3	BC-4	BC-5
EU stock 2011	1 310 000	4 900	1 575 000	12 250 000	280 000
Average product purchase price (€)	3 373	15 000	1 617	300	5 000
Installation costs (€)	1 434	3 750	1 130	150	250
Electricity rate (€/kWh)	0.11	0.11	0.11	0.11	0.11
Repair & maintenance costs (incl. VAT) (€/yr)	782	950	162	0	463
Discount rate (incl. VAT)	4%	4%	4%	4%	4%

5.2.2 Centrifugal dry well pumps

5.2.2.1 Inputs in the production and distribution phase

The average quantities of materials used for production and packaging of centrifugal dry well pump base cases are provided in Table 5.7. The biggest share of overall materials used for BC-6 is comprised of "other ferrous metals".

Table 5.7 Bill of materials of BC-6

	BC-6	
Hydraulic PMU Power [kW]	10	
Product weight [kg]	107	
Packaging weight [kg]	22.5	
Volume of package product [m^3]	0.9	
Product Content	**kg**	**%**
Steel	5	5
Cast Iron	0	0
Other ferrous metals	96	90
Non-ferrous metals	0	0
Plastics	1	1
Coatings	0	0
Electronics	0	0
Other Materials	4	4
Packaging Content	**kg**	**%**
Plastics	0.2	1
Cardboard	0.5	3
Paper	0	0
Other (Wood, etc.)	22	96

5.2.2.2 *Inputs in the use phase*

The annual energy consumption of BC-6 pumps is provided in Table 5.8. On-mode consumption per year refers to the annual energy consumption of different types of pumps corresponding to a base case, weighted per unit of corresponding pump sales in year 2011.

Table 5.8 Inputs in the use phase of BC-6

	BC-6
Product life in years	15
On-mode: Consumption per year (in kWh)	12 505

5.2.2.3 *Economic inputs*

The market data, product price and user expenditure inputs provided in Table 5.9 are based on values collected and already described in the Task 2 report.

Table 5.9 Inputs to economic analysis in EcoReport for BC-6

	BC-6
Annual sales 2011	26 000
EU stock 2011	201 500
Average product purchase price (€)	3 433
Installation costs (€)	1 563
Electricity rate (€/kWh)	0.11
Repair & maintenance costs (incl. VAT) (€/yr)	807
Discount rate (incl. VAT)	4%

5.2.3 Slurry pumps

5.2.3.1 *Inputs in the production and distribution phase*

The average quantities of materials used for production and packaging of slurry pump for light and heavy duty base cases are provided in Table 5.10.

Table 5.10 Bill of materials of BC-7A and BC-7B

	BC-7A		BC-7B	
Hydraulic PMU Power [kW]	50		37	
Product weight [kg]	600		700	
Packaging weight [kg]	120		120	
Spare parts weight [kg]	665		5165	
Volume of package product [m^3]	4		4	
Product Content	**kg**	**%**	**kg**	**%**
Steel	135	23	133	19
Cast Iron	0	0	0	0
Other ferrous metals	417	70	567	81
Non-ferrous metals	0	0	0	0

	BC-7A		BC-7B	
Plastics	0	0	0	0
Coatings	0	0	0	0
Electronics	0	0	0	0
Other Materials	48	8	0	0
Spare parts content	**kg**	**%**		
Steel	15.3	2	0	0
Cast Iron	0	0	0	0
Other ferrous metals	200	30	5165	100
Non-ferrous metals	0	0	0	0
Plastics	0	0	0	0
Coatings	0	0	0	0
Electronics	0	0	0	0
Other Materials	450	68	0	0
Packaging Content	**kg**	**%**	**kg**	**%**
Plastics	0	0	0	0
Cardboard	0	0	0	0
Paper	0	0	0	0
Other (Wood, etc.)	120	100	120	100

5.2.3.2 *Inputs in the use phase*

The annual energy consumption of BC-7A and BC-7B pumps is provided in Table 5.11. On-mode consumption per year refers to the annual energy consumption of slurry pumps.

Table 5.11 Inputs in the use phase of BC-7A and BC-7B

	BC-7A	BC-7B
Product life in years	25	25
On-mode: Consumption per year (in kWh)	130 000	59 200

5.2.3.3 *Economic inputs*

The market data, product price and user expenditure inputs provided in Table 5.12 are based on values collected and already described in the Task 2 report.

Table 5.12 Inputs to economic analysis in EcoReport for BC-7A and BC-7B

	BC-7A	BC-7B
Annual sales 2011	1 500	300
EU stock 2011	60 000	15 000
Average product purchase price (€)	20 000	20 000
Installation costs (€)	5 000	5 000
Electricity rate (€/kWh)	0.11	0.11
Repair & maintenance costs (incl. VAT) (€/yr)	1 275	1 275

	BC-7A	BC-7B
Discount rate (incl. VAT)	4%	4%

5.3 Base-case environmental impacts

This section provides the environmental impacts of the Base-Cases throughout all the life cycle stages. These results were calculated using the EcoReport tool of the MEEuP methodology and based on the inputs presented in the previous section. The MEEuP methodology tracks 17 environmental impact categories, classified in three main categories:

- Resources and waste
  - Total energy (GER - gross energy requirement)
  - Electricity (in primary MJ)
  - Water (process)
  - Water (cooling)
  - Waste, non hazardous/landfill
  - Waste, hazardous/incinerated
- Emissions (air)
  - Greenhouse gases in GWP100
  - Ozone depletion, emissions
  - Acidification, emissions
  - Volatile organic compounds (VOC)
  - Persistent organic pollutants (POP)
  - Heavy metals into air
  - Polycyclic aromatic hydrocarbons (PAHs)
  - Particulate matter (PM, dust)
- Emissions (water)
  - Heavy metals into water
  - Eutrophication
  - Persistent organic pollutants (POP)

The analysis presented in sub-sections below allows the most significant environmental impacts to be determined. It will also be used as a reference when analysing the improvement potential of design options in Task 6.

5.3.1 BC-1: Centrifugal submersible radial sewage pump 1-160 kW

The Table 5.13 presents the contribution of each life cycle stage to the overall environmental impacts of centrifugal submersible radial sewage pump 1-160 kW.

Table 5.13: Life cycle impact (per unit) of BC-1: Centrifugal submersible radial sewage pump 1-160 kW

Life Cycle phases -->		Production			Distribution	Use	End of Life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debit	credit		
Total Energy (GER)	MJ	3 531	643	4 174	940	837 076	819	363	456	842 646
of which, electricity (in primary MJ)	MJ	134	384	518	2	837 039	0	1	-1	837 559
Water (process)	ltr	255	6	260	0	55 805	0	0	0	56 065
Water (cooling)	ltr	316	178	494	0	2 232 095	0	3	-3	2 232 587
Waste, non-haz./ landfill	g	199 750	2 187	201 937	414	972 513	13 204	2	13 202	1 188 066
Waste, hazardous/ incinerated	g	14	0	14	8	19 288	1 226	0	1 226	20 536
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	235	36	271	57	36 530	61	27	34	36 893
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	2 504	155	2 659	172	215 563	120	34	87	218 480
Volatile Organic Compounds (VOC)	g	13	0	13	17	315	3	0	3	348
Persistent Organic Pollutants (POP)	ng i-Teq	1 319	13	1 332	2	5 500	91	0	91	6 925
Heavy Metals	mg Ni eq.	603	31	633	21	14 367	238	0	238	15 259
PAHs	mg Ni eq.	152	0	152	38	1 650	0	0	0	1 840
Particulate Matter (PM, dust)	g	1 159	24	1 183	2 735	4 616	1 066	1	1 065	9 599
Emissions (Water)										
Heavy Metals	mg Hg/20	237	0	237	1	5 399	68	0	68	5 705
Eutrophication	g PO_4	6	0	7	0	26	4	0	4	36
Persistent Organic Pollutants (POP)	ng i-Teq	Negligible								

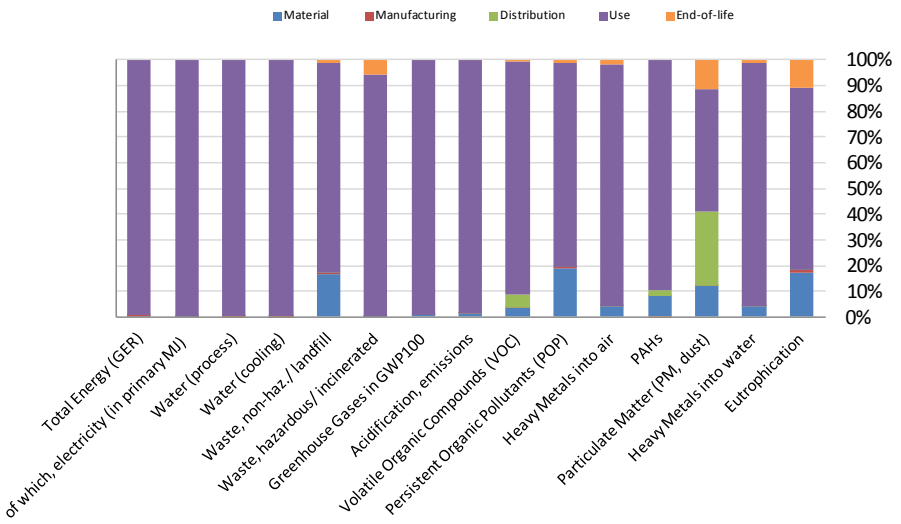


Figure 5-1: Distribution of the BC-1's environmental impacts by life cycle phase

The use phase is clearly the main predominant phase contributing to the environmental impacts of a centrifugal submersible radial sewage pump 1-160 kW. The following 15 out of the 17 impacts related to the appliance's life cycle occur mostly during the use phase:

- Total energy (GER) 99.3%
- Electricity (in primary MJ) 99.9%
- Water (process) 99.5%
- Water (cooling) 100%
- Waste, non hazardous/landfill 81.9%
- Waste, hazardous/incinerated 93.9%
- Greenhouse gases in GWP100 99.0%
- Acidification, emissions 98.7%
- VOC 90.7%
- POP 79.4%
- Heavy metals into air 94.2%
- PAHs 89.7%
- Particulate matter (PM, dust) 48.1%
- Heavy metals into water 94.6%
- Eutrophication 71.0%

Results of the EcoReport modelling indicates that the end-of-life phase has minor contributions to hazardous/incinerated waste generation, particulate matter and eutrophication. The highest contribution of the material acquisition phase is 19.1% to POP. The distribution phase has a contribution of 28.5% to particulate matter and the contribution of the manufacturing phase is less than 1% of the overall environment impacts.

5.3.2 BC-2: Centrifugal submersible mixed flow & axial pump

The Table 5.14 presents the contribution of each life cycle stage to the overall environmental impacts of centrifugal submersible mixed flow and axial pumps.

Table 5.14: Life cycle impact (per unit) of BC-2: centrifugal submersible mixed flow & axial pump

Life Cycle phases -->		Production			Distribution	Use	End of Life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debit	credit		
Total Energy (GER)	MJ	15 387	2 441	17 828	2 273	18 375 178	3 087	1 937	1 150	18 396 429
of which, electricity (in primary MJ)	MJ	590	1 458	2 048	6	18 375 020	0	2	-2	18 377 072
Water (process)	ltr	1 195	22	1 217	0	1 225 012	0	1	-1	1 226 228
Water (cooling)	ltr	973	676	1 649	0	49 000 016	0	8	-8	49 001 657
Waste, non-haz./ landfill	g	875 500	8 361	883 861	959	21 313 608	51 000	6	50 994	22 249 423
Waste, hazardous/ incinerated	g	52	0	53	19	423 414	3 600	1	3 599	427 085
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	950	136	1 086	135	801 886	230	143	87	803 194
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	11 241	588	11 829	412	4 731 681	453	180	272	4 744 194
Volatile Organic Compounds (VOC)	g	45	1	45	41	6 921	12	2	10	7 018
Persistent Organic Pollutants (POP)	ng i-Teq	5 118	54	5 172	5	120 492	351	0	351	126 020
Heavy Metals	mg Ni eq.	2 540	126	2 666	49	315 272	897	0	897	318 885
PAHs	mg Ni eq.	708	0	708	91	36 206	0	0	0	37 004
Particulate Matter (PM, dust)	g	3 736	90	3 826	6 836	101 101	4 018	3	4 014	115 778
Emissions (Water)										
Heavy Metals	mg Hg/20	956	0	956	2	118 486	257	0	257	119 700
Eutrophication	g PO_4	28	1	29	0	565	15	0	15	609
Persistent Organic Pollutants (POP)	ng i-Teq	956								

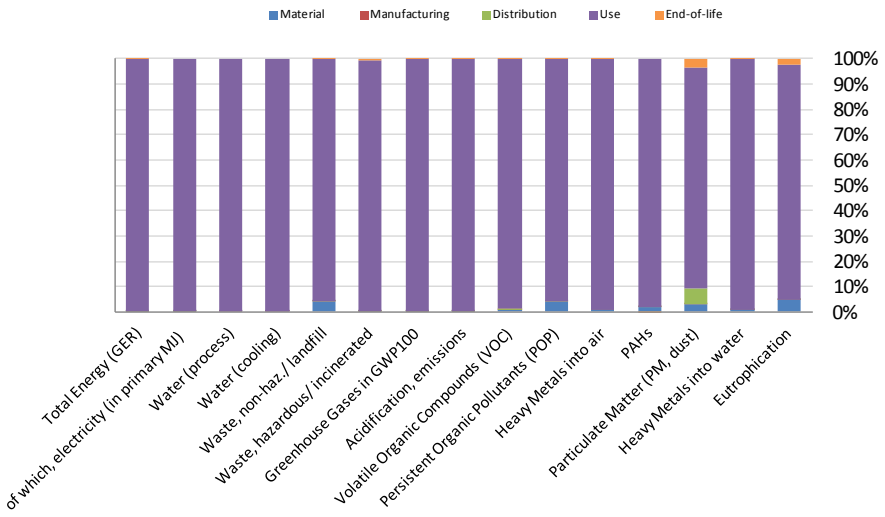


Figure 5-2: Distribution of the BC-2's environmental impacts by life cycle phase

From the analysis, the use phase is clearly the main predominant phase contributing to the environmental impacts of a centrifugal submersible mixed flow and axial pump. The following 15 out of the 17 impacts related to the appliance's life cycle occur mostly during the use phase:

- Total energy (GER) 99.9%
- Electricity (in primary MJ) 100%
- Water (process) 99.9%
- Water (cooling) 100%
- Waste, non hazardous/landfill 95.8%
- Waste, hazardous/incinerated 99.1%
- Greenhouse gases in GWP100 99.8%
- Acidification, emissions 99.7%
- VOC 98.6%
- POP 95.6%
- Heavy metals into air 98.9%
- PAHs 97.8%
- Particulate matter (PM, dust) 87.3%
- Heavy metals into water 99.0%
- Eutrophication 92.8%

Results of the EcoReport modelling indicates that material acquisition phase has some minor contributions to generation of non-hazardous/landfill waste, POP, particulate matter and Eutrophication. The distribution phase and end-of-life phase contribute 5.9% and 3.5% respectively to particulate matter emission to air. The contribution of the manufacturing phase is less than 1% of the overall environment impacts.

5.3.3 BC-3: Centrifugal submersible once a day operation pump

The Table 5.15 presents the contribution of each life cycle stage to the overall environmental impacts of centrifugal submersible once a day operation pumps.

Table 5.15: Life cycle impact (per unit) of BC-3: centrifugal submersible once a day operation pump

Life Cycle phases -->		Production			Distribution	Use	End of Life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							**debit**	**credit**		
Total Energy (GER)	MJ	1 794	362	2 156	829	3 767	570	451	120	6 872
of which, electricity (in primary MJ)	MJ	101	217	318	2	3 749	0	1	-1	4 067
Water (process)	ltr	177	3	180	0	252	0	1	-1	431
Water (cooling)	ltr	218	101	319	0	9 991	0	8	-8	10 303
Waste, non-haz./ landfill	g	71 179	1 196	72 375	369	5 066	6 131	6	6 126	83 937
Waste, hazardous/ incinerated	g	23	0	23	7	87	3 362	1	3 361	3 478
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	97	20	118	50	165	43	33	10	342
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	913	87	1 000	152	974	84	41	43	2 169
Volatile Organic Compounds (VOC)	g	5	0	5	14	1	2	1	1	23
Persistent Organic Pollutants (POP)	ng i-Teq	473	5	478	2	29	42	0	42	551
Heavy Metals	mg Ni eq.	215	11	226	19	67	161	0	161	472
PAHs	mg Ni eq.	54	0	54	33	8	0	0	0	96
Particulate Matter (PM, dust)	g	433	13	446	2 393	25	741	1	740	3 605
Emissions (Water)										
Heavy Metals	mg Hg/20	85	0	85	1	25	47	0	47	158
Eutrophication	g PO_4	3	0	4	0	0	3	0	3	6
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

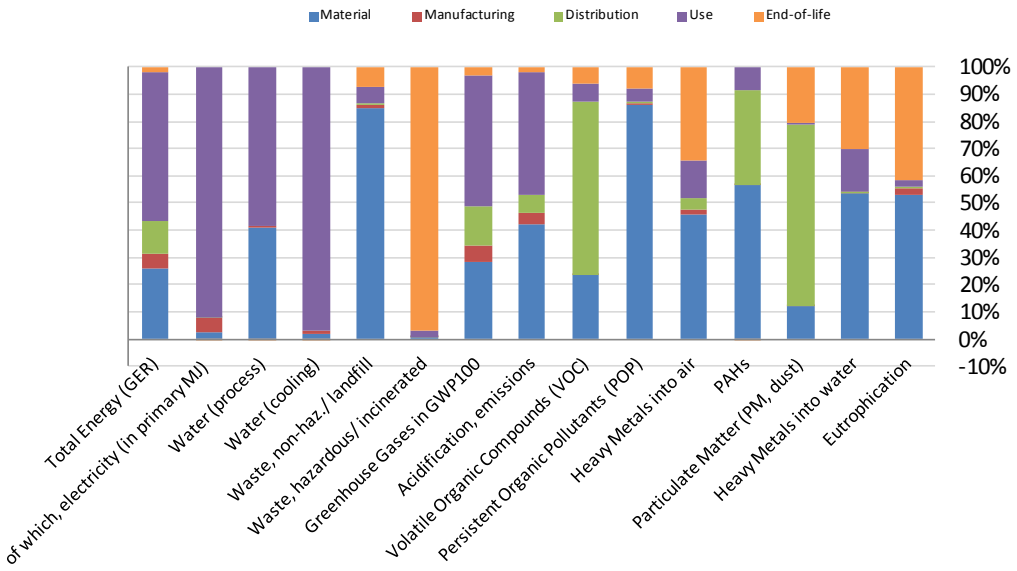


Figure 5-3: Distribution of the BC-3's environmental impacts by life cycle phase

The material acquisition phase, use phase and end-of-life phase are clearly the three predominant phases contributing to the environmental impacts of a centrifugal submersible once a day operation pump.

- The following 5 out of the 17 impacts related to the appliance's life cycle occur mostly during the material acquisition phase:
  - Waste, non hazardous/landfill 84.8%
  - POP 85.8%
  - PAHs 56.8%
  - Heavy metals into water 53.7%
  - Eutrophication 52.7%
- The following 4 out of the 17 impacts related to the appliance's life cycle occur mostly during the use phase:
  - Total energy (GER) 54.8%
  - Electricity (in primary MJ) 92.2%
  - Water (process) 58.4%
  - Water (cooling) 97.0%

End-of-life phase also has a contribution of 96.7% to hazardous/ incinerated waste. The distribution phase contributes 66.4% to the particulate matter emissions to air.

5.3.4 BC-4: Centrifugal submersible domestic drainage pump < 40 mm passage

The Table 5.16 presents the contribution of each life cycle stage to the overall environmental impacts of centrifugal submersible domestic drainage pump <40mm passage.

Table 5.16: Life cycle impact (per unit) of BC-4: centrifugal submersible domestic drainage pump < 40 mm passage

Life Cycle phases -->		Production			Distribution	Use	End of Life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debit	credit		
Total Energy (GER)	MJ	522	143	665	607	521	162	114	48	1 841
of which, electricity (in primary MJ)	MJ	30	86	115	1	516	0	1	-1	632
Water (process)	ltr	14	1	15	0	34	0	0	0	49
Water (cooling)	ltr	57	40	97	0	1 373	0	4	-4	1 466
Waste, non-haz./ landfill	g	30 019	475	30 494	278	901	883	3	881	32 555
Waste, hazardous/ incinerated	g	11	0	11	6	12	1 656	0	1 656	1 684
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	27	8	35	37	23	12	8	4	99
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	399	34	433	112	137	24	10	14	696
Volatile Organic Compounds (VOC)	g	1	0	1	10	0	0	0	0	12
Persistent Organic Pollutants (POP)	ng i-Teq	142	2	144	2	5	6	0	6	156
Heavy Metals	mg Ni eq.	78	5	83	14	10	44	0	44	151
PAHs	mg Ni eq.	27	0	27	25	1	0	0	0	53
Particulate Matter (PM, dust)	g	20	5	25	1 709	3	210	0	210	1 947
Emissions (Water)										
Heavy Metals	mg Hg/20	28	0	28	0	4	13	0	13	46
Eutrophication	g PO_4	1	0	1	0	0	1	0	1	1
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

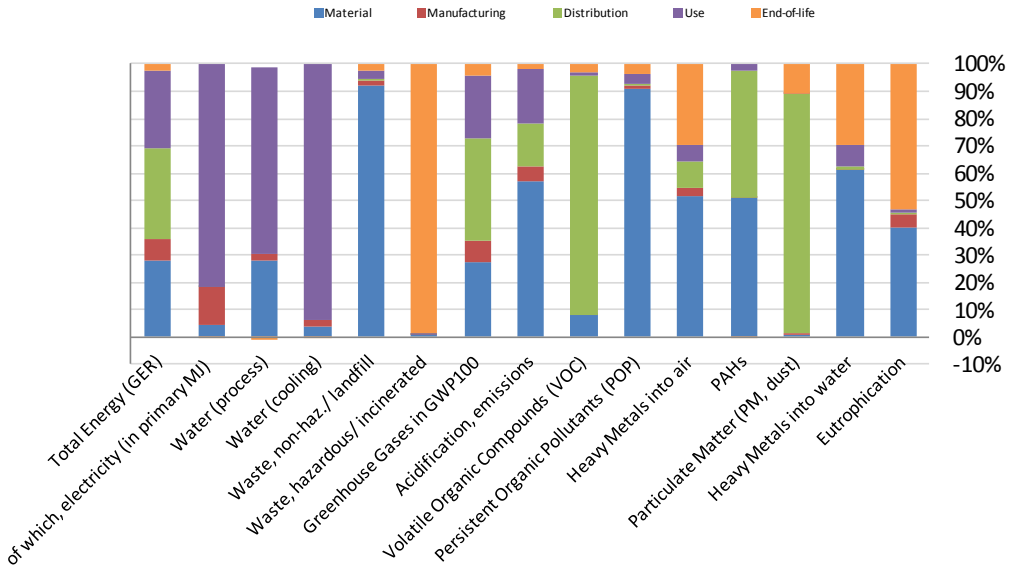


Figure 5-4: Distribution of the BC-4's environmental impacts by life cycle phase

The material acquisition phase, distribution and use phase are clearly the three predominant phases contributing to the environmental impacts of a centrifugal submersible domestic drainage pump <40mm passage.

- The following 5 out of the 17 impacts related to the appliance's life cycle occur mostly during the material acquisition phase:
  - Waste, non hazardous/landfill 92.2%
  - Acidification, emissions 57.3.6%
  - POP 90.7.2%
  - Heavy Metal into water 61.6%
  - Heavy Metal into air 51.6%
- The following 4 out of the 17 impacts related to the appliance's life cycle occur mostly during the use phase:
  - Total Energy (GER) 28.3%
  - Electricity (in primary MJ) 81.6%
  - Water (process) 70.0%
  - Greenhouse Gases 23.0%

The distribution phase also has a contribution of 87.4% to VOC and the end-of-life phase contributes 54.1% to Eutrophication.

5.3.5 BC-5: Submersible dewatering pump

The Table 5.17 presents the contribution of each life cycle stage to the overall environmental impacts of submersible dewatering pumps.

Table 5.17: Life cycle impact (per unit) of BC-5: Submersible dewatering pump

Life Cycle phases -->		Production			Distribution	Use	End of Life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debit	credit		
Total Energy (GER)	MJ	2 934	375	3 309	940	1 102 533	307	35	272	1 107 054
of which, electricity (in primary MJ)	MJ	91	224	315	2	1 102 503	0	0	0	1 102 820
Water (process)	ltr	44	3	48	0	73 500	0	0	0	73 548
Water (cooling)	ltr	41	104	145	0	2 940 001	0	1	-1	2 940 145
Waste, non-haz./ landfill	g	260 257	1 295	261 553	414	1 280 902	4 955	1	4 954	1 547 823
Waste, hazardous/ incinerated	g	12	0	13	8	25 405	450	0	450	25 876
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	180	21	201	57	48 114	23	2	20	48 392
Ozone Depletion, emissions	mg R-11 eq.	Negligible								
Acidification, emissions	g SO_2 eq.	3 678	90	3 768	172	283 931	45	3	42	287 913
Volatile Organic Compounds (VOC)	g	4	0	4	17	415	1	0	1	437
Persistent Organic Pollutants (POP)	ng i-Teq	896	9	905	2	7 235	34	0	34	8 177
Heavy Metals	mg Ni eq.	706	21	727	21	18 922	89	0	89	19 759
PAHs	mg Ni eq.	257	0	257	38	2 175	0	0	0	2 469
Particulate Matter (PM, dust)	g	223	14	236	2 735	6 066	399	0	399	9 436
Emissions (Water)										
Heavy Metals	mg Hg/20	209	0	209	1	7 111	26	0	26	7 346
Eutrophication	g PO_4	3	0	3	0	34	1	0	1	39
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

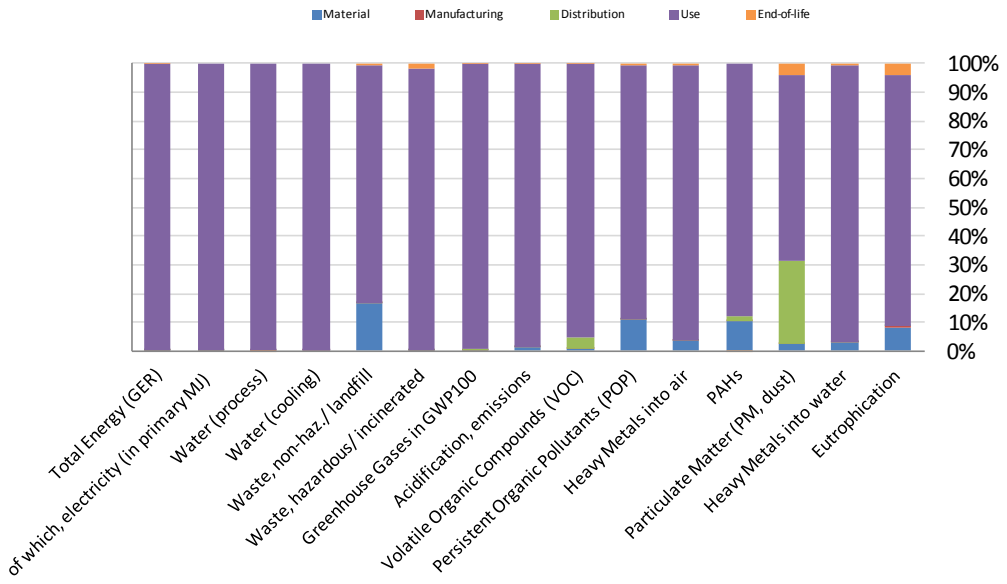


Figure 5-5: Distribution of the BC-5's environmental impacts by life cycle phase

The use phase is clearly the predominant phase contributing to the environmental impacts of a submersible dewatering pump. The following 15 out of the 17 impacts related to the appliance's life cycle occur mostly during the use phase:

- Total energy (GER) 99.6%
- Electricity (in primary MJ) 100%
- Water (process) 99.9%
- Water (cooling) 100%
- Waste, non hazardous/landfill 82.8%
- Waste, hazardous/incinerated 98.2%
- Greenhouse gases in GWP100 99.4%
- Acidification, emissions 98.6%
- VOC 94.9%
- POP 88.5%
- Heavy metals into air 95.8%
- PAHs 88.1%
- Particulate matter (PM, dust) 64.3%
- Heavy metals into water 96.8%
- Eutrophication 87.8%

Results of the EcoReport modelling indicate that material acquisition phase has some minor contributions to generation of non-hazardous/landfill waste, POP, PAHs and eutrophication. While the end-of-life phase mostly impacts particulate matter and Eutrophication. On the other hand, the manufacturing phase contributes less than 1% of the overall environment impacts. The highest contribution from distribution phase is particulate matter emissions (29%).

5.3.6 BC-6: Centrifugal dry well pump

The Table 5.18 presents the contribution of each life cycle stage to the overall environmental impacts of centrifugal dry well pumps.

Table 5.18: Life cycle impact (per unit) of BC-6: Centrifugal Dry Well Pump

Life Cycle phases -->		Production			Distribution	Use	End of Life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debit	credit		
Total Energy (GER)	MJ	1 932	346	2 277	1 051	1 969 540	783	384	399	1 973 268
of which, electricity (in primary MJ)	MJ	137	208	345	3	1 969 521	0	0	0	1 969 868
Water (process)	ltr	323	3	326	0	131 304	0	0	0	131 630
Water (cooling)	ltr	390	97	487	0	5 252 051	0	3	-3	5 252 536
Waste, non-haz./ landfill	g	40 753	1 121	41 874	460	2 283 962	12 675	2	12 673	2 338 969
Waste, hazardous/ incinerated	g	9	0	9	9	45 384	1 122	0	1 121	46 523
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	138	19	157	63	85 950	58	28	30	86 201
Ozone Depletion, emissions	mg R-11 eq.	Negligible								
Acidification, emissions	g SO_2 eq.	394	83	477	192	507 155	115	36	79	507 904
Volatile Organic Compounds (VOC)	g	12	0	12	19	742	3	0	3	775
Persistent Organic Pollutants (POP)	ng i-Teq	716	3	719	3	12 917	87	0	87	13 725
Heavy Metals	mg Ni eq.	211	7	218	23	33 792	227	0	227	34 260
PAHs	mg Ni eq.	2	0	2	42	3 880	0	0	0	3 924
Particulate Matter (PM, dust)	g	1 361	13	1 374	3 077	10 846	1 018	1	1 018	16 314
Emissions (Water)										
Heavy Metals	mg Hg/20	107	0	107	1	12 700	65	0	65	12 872
Eutrophication	g PO_4	5	0	5	0	61	4	0	4	69
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

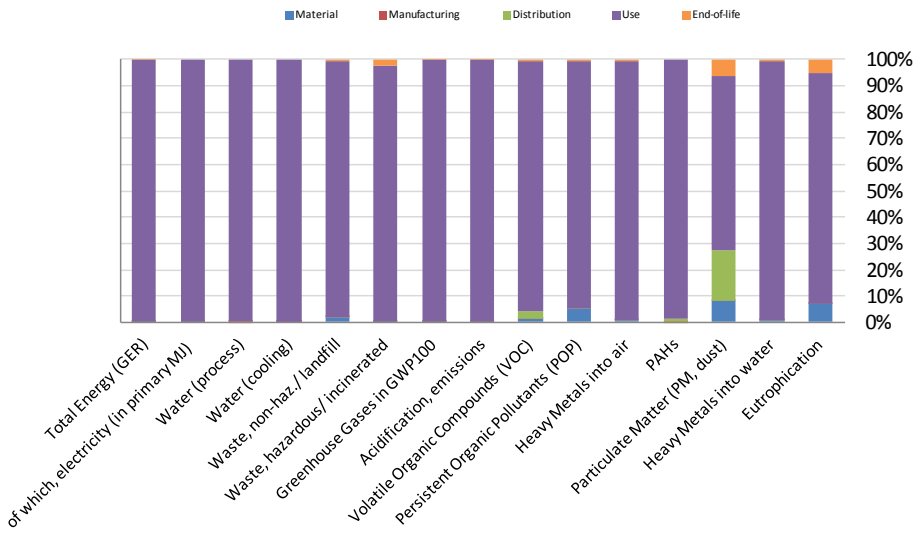


Figure 5-6: Distribution of the BC-6's environmental impacts by life cycle phase

The use phase is clearly the predominant phase contributing to the environmental impacts of a centrifugal dry well pump. The following 15 out of the 17 impacts related to the appliance's life cycle occur mostly during the use phase:

- Total energy (GER) 99.8%
- Electricity (in primary MJ) 100%
- Water (process) 99.8%
- Water (cooling) 100%
- Waste, non hazardous/landfill 97.6%
- Waste, hazardous/incinerated 97.6%
- Greenhouse gases in GWP100 99.7%
- Acidification, emissions 99.9%
- VOC 95.7%
- POP 94.1%
- Heavy metals into air 98.6%
- PAHs 98.9%
- Particulate matter (PM, dust) 66.5%
- Heavy metals into water 98.7%
- Eutrophication 87.4%

Results of the EcoReport modelling indicates that material acquisition phase has some minor contributions to POP, particulate matter and eutrophication. The contribution of the manufacturing phase is less than 1% of the overall environment impacts. The highest

contribution from distribution phase and end-of-life phase is particulate matter with 18.9% and 6.2% respectively.

5.3.7 BC-7A: Slurry pump – Light Duty

The Table 5.19 will present the contribution of each life cycle stage to the overall environmental impacts of slurry pumps with Light Duty

Table 5.19: Life cycle impact (per unit) of BC-7A: Slurry pump – Light Duty

Life Cycle phases -->		Production			Distribution	Use	End of Life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debit	credit		
Total Energy (GER)	MJ	22 499	3 674	26 173	4 494	34 125 262	7 502	1 705	5 797	34 161 725
of which, electricity (in primary MJ)	MJ	7 016	2 195	9 211	11	34 125 092	0	0	0	34 134 315
Water (process)	ltr	5 831	32	5 864	0	2 275 059	0	0	0	2 280 922
Water (cooling)	ltr	2 243	1 018	3 261	0	91 000 033	0	0	0	91 003 293
Waste, non-haz./ landfill	g	461 032	12 568	473 600	1 866	39 570 737	134 606	0	134 606	40 180 809
Waste, hazardous/ incinerated	g	138	0	138	37	786 342	0	0	0	786 517
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	1 560	205	1 765	266	1 489 214	560	127	433	1 491 677
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	4 688	884	5 572	812	8 787 243	1 098	159	939	8 794 566
Volatile Organic Compounds (VOC)	g	94	1	95	83	12 853	31	2	29	13 060
Persistent Organic Pollutants (POP)	ng i-Teq	7 565	80	7 645	11	223 752	926	0	926	232 333
Heavy Metals	mg Ni eq.	1 831	187	2 018	95	585 476	2 196	0	2 196	589 785
PAHs	mg Ni eq.	19	0	19	179	67 227	0	0	0	67 424
Particulate Matter (PM, dust)	g	9 012	136	9 148	13 673	187 779	9 767	3	9 764	220 364
Emissions (Water)										
Heavy Metals	mg Hg/20	1 103	0	1 103	3	220 039	623	0	623	221 769
Eutrophication	g PO_4	36	2	38	0	1 050	36	0	36	1 123
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

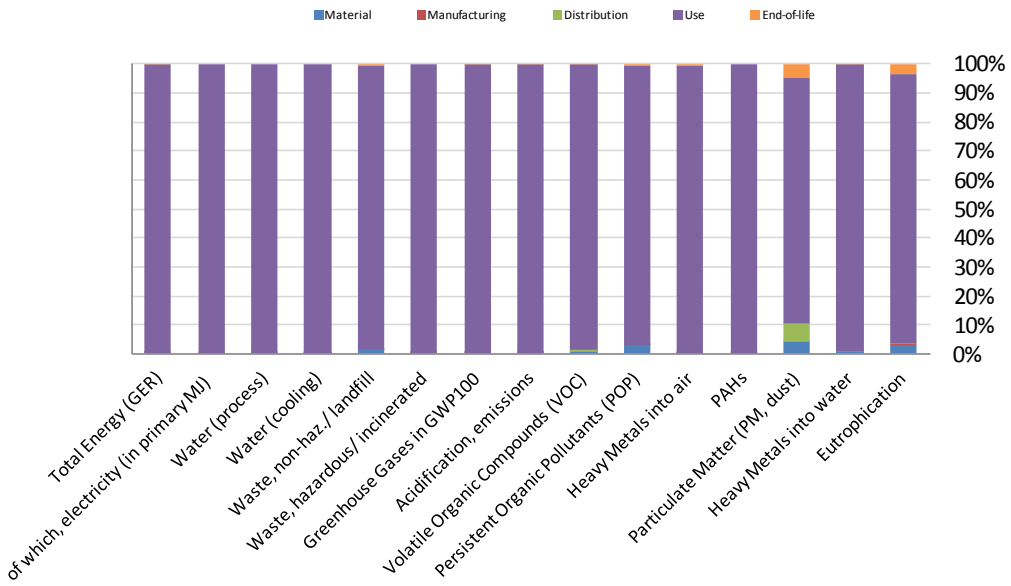


Figure 5-7: Distribution of the BC-7A's environmental impacts by life cycle phase

The use phase is clearly the predominant phase contributing to the environmental impacts of a centrifugal dry well pump. The following 15 out of the 17 impacts related to the appliance's life cycle occur mostly during the use phase:

- Total energy (GER) 99.9%
- Electricity (in primary MJ) 100%
- Water (process) 99.7%
- Water (cooling) 100%
- Waste, non hazardous/landfill 98.5%
- Waste, hazardous/incinerated 100.0%
- Greenhouse gases in GWP100 99.8%
- Acidification, emissions 99.9%
- VOC 98.4%
- POP 96.3%
- Heavy metals into air 99.3%
- PAHs 99.7%
- Particulate matter (PM, dust) 85.2%
- Heavy metals into water 99.2%
- Eutrophication 93.4%

Results of the EcoReport modelling indicates that material acquisition phase has some minor contributions to POP, particulate matter and eutrophication. The contribution of the manufacturing phase is less than 1% of the overall environment impacts. The highest

contribution from distribution phase and end-of-life phase is particulate matter with 6.2% and 4.4% respectively.

5.3.8 BC-7B: Slurry pump – Heavy Duty

The Table 5.19 will present the contribution of each life cycle stage to the overall environmental impacts of slurry pumps with Heavy Duty

Table 5.20: Life cycle impact (per unit) of BC-7B: Slurry pump – Heavy Duty

Life Cycle phases -->		Production			Distribution	Use	End of Life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							**debit**	**credit**		
Total Energy (GER)	MJ	64 621	14 550	79 171	4 494	15 540 792	32 396	1 432	30 963	15 655 421
of which, electricity (in primary MJ)	MJ	1 308	8 744	10 052	11	15 540 101	0	0	0	15 550 164
Water (process)	ltr	8 222	131	8 353	0	1 036 084	0	0	0	1 044 436
Water (cooling)	ltr	20 767	4 109	24 876	0	41 440 249	0	0	0	41 465 124
Waste, non-haz./ landfill	g	2 024 548	46 540	2 071 088	1 866	18 038 459	581 285	0	581 285	20 692 698
Waste, hazardous/ incinerated	g	6	0	6	37	358 087	0	0	0	358 130
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	6 458	808	7 266	266	678 230	2 418	107	2 311	688 073
Ozone Depletion, emissions	mg R-11 eq.					negligible				
Acidification, emissions	g SO_2 eq.	19 457	3 486	22 942	812	4 001 779	4 742	134	4 608	4 030 141
Volatile Organic Compounds (VOC)	g	688	2	689	83	5 860	134	2	132	6 764
Persistent Organic Pollutants (POP)	ng i-Teq	37 503	72	37 575	11	102 234	3 999	0	3 999	143 818
Heavy Metals	mg Ni eq.	11 728	168	11 895	95	266 727	9 483	0	9 483	288 200
PAHs	mg Ni eq.	84	0	85	179	30 615	0	0	0	30 878
Particulate Matter (PM, dust)	g	79 796	537	80 334	13 673	86 273	42 178	2	42 176	222 455
Emissions (Water)										
Heavy Metals	mg Hg/20	5 629	0	5 629	3	100 254	2 692	0	2 692	108 578
Eutrophication	g PO_4	168	8	176	0	480	154	0	154	809
Persistent Organic Pollutants (POP)	ng i-Teq					negligible				

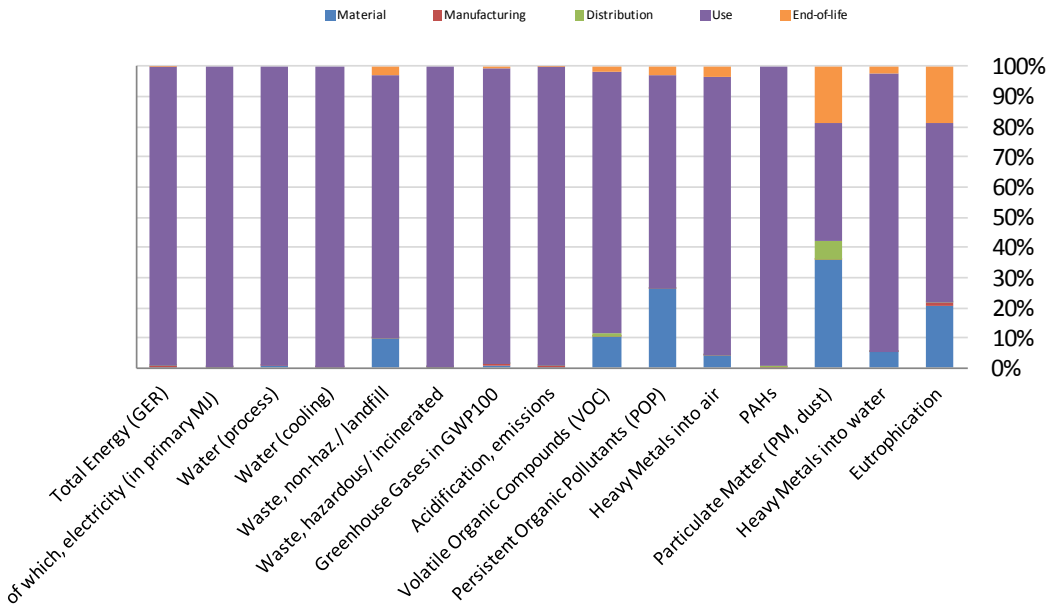


Figure 5-8: Distribution of the BC-7B's environmental impacts by life cycle phase

The use phase is clearly the predominant phase contributing to the environmental impacts of a centrifugal dry well pump. The following 15 out of the 17 impacts related to the appliance's life cycle occur mostly during the use phase:

- Total energy (GER) 99.3%
- Electricity (in primary MJ) 99.9%
- Water (process) 99.2%
- Water (cooling) 99.9%
- Waste, non hazardous/landfill 87.2%
- Waste, hazardous/incinerated 100.0%
- Greenhouse gases in GWP100 98.6%
- Acidification, emissions 99.3%
- VOC 86.6%
- POP 71.1%
- Heavy metals into air 92.5%
- PAHs 99.1%
- Particulate matter (PM, dust) 38.8%
- Heavy metals into water 92.3%
- Eutrophication 59.2%

Results of the EcoReport modelling indicates that material acquisition phase has some contributions to POP, particulate matter and eutrophication with 26.1%, 35.9% and 20.7% respectively. The contribution of the manufacturing phase is less than 1% of the overall

environment impacts. The highest contribution from distribution phase and end-of-life phase is particulate matter with 6.1% and 19% respectively.

5.4 Base-case life cycle costs

This section presents the results of the Life Cycle Cost (LCC) analysis of the Base-Cases using the EcoReport tool. In this analysis, all the consumer expenditures throughout the life of the product are considered which include:

- Average purchase cost of the Bases-Cases of the Base-Cases (in Euro)
- Average installation costs, if any (in Euro)
- Average repair and maintenance costs, if any (in Euro)
- Average electricity rates (Euro Cent/kWh)
- Average lifetime of the Base-Case (in years)
- Average annual energy consumption including on-mode, standby and off-mode (in kWh)

This analysis will serve to compare the total expenditure of the different design options identified for each Base-Case.

The life cycle costs are calculated as follows:

$$LCC = PP + PWF * OE$$

Where PP is the purchase and installation price, OE is the operating expense and PWF is the present worth factor, calculated as follows:

$$PWF = \frac{1 - \frac{1}{(1+r)^N}}{r}$$

Where N is the product life in years and r is the discount rate.

Table 5.21: EcoReport outcomes of the LCC calculations for all the Base cases

	BC-1		BC-2		BC-3		BC-4		BC-5		BC-6		BC-7A		BC-7B	
	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%
Product price	3 373	*18%*	15 000	*8%*	1 617	*42%*	300	66%	5 000	*28%*	3 433	*12%*	20 000	*7%*	20 000	*14%*
Installation/ acquisition costs (if any)	1 434	*8%*	3 750	*2%*	1 133	*29%*	150	33%	250	*1%*	1 563	*5%*	5 000	*2%*	5 000	*3%*
Electricity	7 112	*39%*	156 135	*86%*	33	*1%*	5	1%	9 368	*51%*	15 294	*52%*	223 396	*83%*	101 731	*69%*
Repair & maintenance costs	6 347	*35%*	7 705	*4%*	1 094	*28%*	0	0%	3 751	*20%*	8 970	*31%*	19 918	*8%*	19 918	*14%*
Total	**18 266**	***100%***	**182 590**	***100%***	**3 877**	***100%***	**455**	**100%**	**18 369**	***100%***	**29 258**	***100%***	**268 314**	***100%***	**127 528**	***100%***

There are similarities between BC-1, BC-2, BC-5, BC-6, BC-7A and BC-7B concerning the life cycle cost. The cost of energy consumption in use phase is the main life cycle cost for these base cases (more than 50% of LCC). The gains in energy efficiency of these pumps may therefore significantly reduce the LCC. For BC-3 and BC-4, the product price has the major contribution to the LCC. These pumps have lower annual operation hours, thus the amount of energy consumed by them is not as significant as the other group of pumps.

5.5 EU Totals

In this section the environmental impact data and the Life Cycle Cost data are aggregated at the EU-27 level using stock and market data from Task 2. It is assumed that the entire installed stock in the EU-27 in 2011 is represented by the Base-Cases.

5.5.1 Life-cycle environmental impact at EU-27 level

The aggregated results of the environmental impact per year of the EU stock of products are presented in Table 5.22. The total primary energy consumption per year of the stock of each of the 8 Base-Cases in 2011 in the EU-27 varies significantly depending on the BC, between 1 PJ and 111 PJ.

BC-1 has the highest contribution to the overall environmental impacts at the EU level. BC 1 represents more than 50% of both the overall energy consumption and the overall greenhouse gas emissions. This is due to the large number of centrifugal submersible radial sewage pumps for 1 to 160 kW installed in EU and the annual energy consumption of the pumps is high.

Table 5.22: EU-27 total impact of the installed stock (2011) of the Base-Cases

Life Cycle phases -->		BC-1	BC-2	BC-3	BC-4	BC-5	BC-6	BC-7A	BC-7B	TOTAL
Other Resources & Waste										
Total Energy (GER)	PJ	111	9	1	3	31	27	82	9	273
of which, electricity (in primary MJ)	PJ	110	9	1	1	31	26	82	9	269
Water (process)	mln. m3	7	1	0.1	0.1	2	2	5	1	18
Water (cooling)	mln. m3	292	24	2	3	82	71	218	25	717
Waste, non-haz./ landfill	kt	166	11	20	49	47	35	96	12	434
Waste, hazardous/ incinerated	kt	3	0.2	1	3	1	1	2	0.2	10
Emissions (Air)										
Greenhouse Gases in GWP100	mt CO_2 eq.	5	0.4	0.1	0.2	1	1	4	0.4	12
Ozone Depletion, emissions	t R-11 eq.	negligible								
Acidification, emissions	kt SO_2 eq.	29	2.3	0.5	1.1	8	7	21	2,4	71
Volatile Organic Compounds (VOC)	kt	0.05	0.003	0.01	0.02	0.01	0.01	0	0.004	0.1
Persistent Organic Pollutants (POP)	g i-Teq	1	0.1	0.1	0.2	0.2	0.2	1	0.1	2
Heavy Metals	ton Ni eq.	2	0.2	0.1	0.2	1	0.5	1	0.2	5
PAHs	ton Ni eq.	0.2	0.02	0.02	0.1	0.1	0.1	0.2	0.02	1
Particulate Matter (PM, dust)	kt	1	0.1	0.8	2.9	0.3	1	0.5	0.1	7
Emissions (Water)										
Heavy Metals	ton Hg/20	1	0.1	0.04	0.1	0.2	0.2	1	0.06	2
Eutrophication	kt PO_4	0.01	0.0003	0.001	0.002	0.001	0.001	0.003	0.0004	0.01
Persistent Organic Pollutants (POP)	g i-Teq	negligible								

5.5.2 Life-cycle costs at EU-27 level

The aggregated results of the annual consumer expenditure per Base-Case in the EU-27 based on the year 2011 are presented in Table 5.23. This represents the total expenditure at EU level per year, assuming that the Base-Cases represent the entire installed stock in the EU-27.

The product price, electricity cost and repair and maintenance are the predominant aspects of the total annual consumer expenditure at the EU-27 with 25%, 40% and 24% respectively. These results also indicate that the assessment of the energy efficiency of these pumps is essential.

Table 5.23: EU-27 total annual consumer expenditure (2011)

	BC-1	BC-2	BC-3	BC-4	BC-5	BC-6	BC-7A	BC-7B	TOTAL EU-27	Share of the annual consumer expenditure by item
Product price (€)	597	11	380	450	200	89	30	6	**1 763**	*25%*
Installation/ acquisition costs (if any) (€)	254	3	266	225	10	41	8	2	**809**	*11%*
Electricity (€)	1 149	94	8	9	323	277	858	98	**2 816**	*40%*
Repair & maintenance costs (€)	1 025	5	256	0	130	163	77	19	**1 675**	*24%*
Total (€)	**3 025**	**113**	**910**	**684**	**663**	**570**	**973**	**125**	**7 063**	***100%***
Share of the annual consumer expenditure by BC	43%	2%	13%	9%	9%	8%	14%	2%	100%	

5.5.3 EU-27 total system impact

In this section, the total environmental impacts calculated for the base-cases at EU-27 level are compared with other results from similar studies. The annual primary energy consumption of the stock of all pumps covered within the ENER Lot 28 preparatory study is around 273 PJ (76.4 TWh).

From Table 5.23 above, it is evident that the energy consumption of ENER Lot 28 pumps is around 18.2% that of ENER Lot 11 pumps. ENER Lot 28 pumps contribute 18.2% to the environmental impacts on the energy consumptions, emissions of CO_2 and of SO_2 per year.

5.6 Conclusions

Task 5 report analysed the environmental impacts and economic costs of the likely eight Base-Cases most relevant for proposing Ecodesign requirements for ENER Lot 28 pumps. The selection of Base-Cases and subsequent analysis was based upon the market analysis presented in Task 2, the consumer behaviour and existing infrastructure described in Task 3 and the technical analysis of products carried out in Task 4. The Base-Cases were constructed as an "abstraction" of the average product in the EU market representing the wide range of products considered in this ENER Lot 28 preparatory study. These Base-Cases are used to estimate the environmental impacts of ENER Lot 28 pump in the EU.

The combined energy consumption of the installed stock of all Base-Cases is around 273 PJ/year (75.8 TWh/year). Based on the environmental impact assessment carried out in this chapter using the EcoReport tool, some general findings are observed for all the ENER Lot 28 pumps such as:

- The use phase is the most dominant phase of the entire life cycle in the contribution to the environmental impacts.
- The material acquisition phase is also a dominant phase especially for BC-3 and BC-4 in terms of non-hazardous/landfill waste generation, POPs, PAHs, particulate matter and Eutrophication.
- The manufacturing phase generally has minor contributions to the overall environment impacts compared to other phases.
- Distribution phase contributes noticeable impacts to the indicators such as particulate matter, volatile organic compounds and PAHs.
- The end-of-life phase has significant contribution to the indicators such as hazardous/incinerated waste generation, heavy metal in air and water, particulate matter and eutrophication.

It must however be noted that the distribution of the environmental impacts varies considerably across the analysed Base-Cases. For example, more than 90% of contribution to environmental indicators is due to the use phase for some Base-Cases (BC-1, BC-2, BC-5, BC-6, BC-7A and BC-7B), while for other Base-Cases (BC-3 and BC-4), the use phase and the material acquisition phase have similar contributions (even if distributed differently over the indicators). This is primarily

due to the influence of the factors such as the weight of the appliance, its lifespan and its power output.

The environmental and economic analysis of the Base-Cases will serve as point of reference when evaluating the possible improvement potentials in Task 6 and the design options in Task 7.



02 April 2014

185 avenue Charles de Gaulle
92200 Neuilly-sur-Seine
France
+ 33 (0) 5561 6755
www.bio.deloitte.fr

Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 6: Technical Analysis BAT

Final report to the European Commission, DG ENER
2 April 2014



European Commission

Developed by:

bio by Deloitte.

ATKINS

Document information

CLIENT	European Commission, DG ENER
CONTRACT NUMBER	ENER/C3/403/2010
REPORT TITLE	ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 6: Technical Analysis BAT
PROJECT NAME	Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC
PROJECT CODE	ENER Lot 28
PROJECT TEAM	Bio by Deloitte, Atkins
DATE	2 April 2014
AUTHORS	Mr. Shailendra Mudgal, Bio by Deloitte Mr. Sandeep Pahal, Bio by Deloitte Mr. Benoit Tinetti, Bio by Deloitte Mr. Alvaro De Prado Trigo, Bio by Deloitte Dr. Hugh Falkner, Atkins Mr. Keeran Jugdoyal, Atkins
KEY CONTACTS	Mr. Sandeep Pahal spahal@bio.deloitte.fr Or Mr. Shailendra Mudgal shmudgal@bio.deloitte.fr
DISCLAIMER	This document has been prepared for the European Commission however, it reflects the views only of the authors, and the Commission cannot be held responsible for any use, which may be made of the information contained therein. The project team does not accept any liability for any direct or indirect damage resulting from the use of this report or its content.

Please cite this publication as:
Bio by Deloitte (2014), Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC, ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – *Task 6: Technical Analysis BAT* prepared for European Commission, DG ENER.

Photo credit: cover @ Per Ola Wiberg
©Bio by Deloitte 2014

Table of Contents

6.1 State-of-the-art for the products 6
6.1.1 BC-1: Centrifugal submersible radial sewage pumps 1-160 kW 6
6.1.2 BC-2: Centrifugal submersible mixed flow and axial pumps 8
6.1.3 BC-3: Centrifugal submersible once a day operation pump 9
6.1.4 BC-4: Centrifugal submersible domestic drainage pump < 40 mm passage 10
6.1.5 BC-5: Submersible dewatering pumps 10
6.1.6 BC-6: Centrifugal dry well pumps 11
6.1.7 BC-7A&7B: Slurry pumps 12
6.1.8 Centrifugal Pumps with intelligent controls 12
6.2 State-of-the-art at component level 13
6.2.1 Impellers 13
6.2.2 Motors 13
6.2.3 Variable speed drives 14
6.2.4 Summary of BAT options 16
6.3 State-of-the-art of best existing product technology outside the EU 22
6.4 Conclusion 22

List of Tables

Table 6-1: Summary of BAT options for BC 1: centrifugal submersible pump - radial sewage pumps 1 to 160 kW 16

Table 6-2: Summary of BAT options for BC 2: centrifugal submersible pump - mixed flow and axial pumps 17

Table 6-3: Summary of BAT options for BC 3: centrifugal submersible pump – once a day operation 18

Table 6-4: Summary of BAT options for BC 4: centrifugal submersible domestic drainage pump < 40 mm passage 18

Table 6-5: Summary of BAT options for BC 5: submersible dewatering pumps 19

Table 6-6: Summary of BAT options for BC 6: centrifugal dry well pumps - radial sewage pumps 1 to 160 kW 19

Table 6-7: Summary of BAT options for BC 7A: light duty slurry pumps 20

List of Figures

Figure 6-1 Typical Grinder Element 10

Figure 6-2 Dewatering pumps inlet shroud 11

Figure 6-3 Example of slurry pump 12

Chapter 6: Technical analysis of best available technology (Task 6)

A Best Available Technology (BAT) for a product in this study is a technology or change in design that leads to less environmental impacts and is already available on the market, or whose technical feasibility has already been demonstrated (and expected to be introduced within 2-3 years). Best not yet Available Technology (BNAT) refers to a technology that has the potential to lead to further environmental performance improvements, but still is subject to research and development. BNAT is rather a future option or long-term trend.

The identification and analysis of BAT and BNAT provides input for the assessment of the improvement potential in Task 7. The intellectual property, technical feasibility and the availability on the market of BATs in a strict sense are not judged here, as the objective is to illustrate various technically available (or potentially available) options. However, Task 7 will consider these issues when suggesting possible improvement options applicable to wastewater pumps.

The results of this task are predominantly based upon available literature, which includes technical journals, magazines and research publications, as well as other sources such as interviews with technology experts, research institutes and the stakeholders of this study.

The centrifugal pump is a mature product, which has been under development for over 300 years. However, it was not until high-speed turbines and electric motors became available in the late 19th century that real improvements became possible. By the 1880's pump's hydraulic efficiencies of 80% were achieved. Today, hydraulic efficiencies well over 90% are achieved in larger clean water pumps. The hydraulic efficiency of wastewater pumps has to be considered in tandem with their ability to handle solids and become blocked or clogged by solids. As such, the maximum hydraulic efficiency of centrifugal wastewater pumps is around 89%, with the average hydraulic efficiency for radial centrifugal pumps with channel impellers being between 71% – 77%.

Innovation in wastewater pumps is driven by three key drivers:

- Energy consumption
- Reliability
- Ease of maintenance

Critically for wastewater pumps, hydraulic efficiency must not be bought at the price of reliability. This is a particular issue when regulating these pumps, as simple laboratory tests of a pump may not be representative of in –life service where complex geometries will quickly be worn down to a more representative "run-in" hydraulic efficiency.

Of the three drivers, the most important is the need for reliability, as the costs of call –out and damage if there is blockage are very high and a constant worry.

The BATs identified in this study only cover the energy consumption aspects of the pumps, this is because, as demonstrated in Task 5, the energy is responsible for the majority of the eco-impacts of the pumps in scope.

6.1 State-of-the-art for the products

Pumps, including wastewater pumps, are a very well established technology that has been refined for several hundred years, and therefore there is very little in terms of Best Not yet Available Technology (BNAT) appearing on the horizon. There will inevitably be small improvements in efficiency as computational fluid dynamics allows more experimentation and refinement to take place in the design process, and also as closer manufacturing tolerances become feasible.

Any significant improvements in the energy associated with wastewater pumping is likely to be achieved through the use of integrated controls for several pumps in a wastewater collection system at a network level. Controlling pumps together could potentially reduce the peaks in flowrate currently seen by holding some flow back to off-peak periods, thereby reducing the dynamic friction losses in the rising mains. As these types of control improvements are achieved at a network level, and not the product level, they are beyond the scope of this study.

This section presents an overview of the BATs currently available on the market both at the component and product level for the Base Cases selected in Task 5. BATs are design options, which allow a product to operate significantly better in terms of environmental performance than the average product on the market (represented by the Base Cases).

It is very important to note while reading the following section that the issues affecting the efficiency of pumps, such as hydraulics, surface friction and leakage are all interlinked to some extent and improvements made in one area may have a consequential effect on another. Also, the size and geometry of each pump will have play role in the extent to which these factors affect the pump's efficiency. All this makes it difficult to accurately attribute an efficiency improvement % to any one specific measure.

The overall % savings shown are as indicated by Europump.

6.1.1 BC-1: Centrifugal submersible radial sewage pumps 1-160 kW

The axial thrust from the pump is normally accommodated in the motor. Only roller bearings are used in these pumps. Seal losses for pumps above 5kW can be neglected. For smaller pumps seal losses can be a significant part of the total losses..

The remaining power losses are looked at theoretically for a specific pump in Appendix 1 of Task 4. These can be viewed as the hydraulic losses due to turbulence and surface friction, plus the leakage losses. These are considered in more detail below.

- **Hydraulic design**

The geometry of the impeller and the casing affects the hydraulic losses. Each manufacturer will have their own (confidential) method of choosing this geometry. With many years of feedback,

an established manufacturer should have arrived at close to the optimum impeller vane number, vane shape, impeller inlet diameter, impeller cross-sectional profile, and casing geometry. This should produce an effective compromise between the various curve shapes for head, power, hydraulic efficiency, NPSHR against flow, solids handling and resistance to blocking.

The principles of using smaller distance between impellers discs and smaller inlet diameters to improve hydraulic efficiency are not feasible in wastewater pumps as this will lead to an increase in friction and limitation of solids passing. Hydraulic design should not be adapted to increase efficiency to the point where it reduces the ability to handle solids effectively without blocking. This would result in increased life cycle costs and unreliable performance.

- **Surface friction**
  - **Impeller**

When considering channel impellers the outer surfaces should be fully machined to a hydraulically smooth finish, but in practice, this is rarely done. The inner surfaces should be as smooth as possible. Mechanical methods of smoothing the rough cast interiors of impellers in iron or bronze are time-consuming and not entirely effective due to inaccessibility. Precision casting methods can give a good finish, at a high cost, but has never been justified on this type of pump. In practice it shows, that any fine surface treatment will be deteriorating after short operational time, due to the abrasive components in the wastewater.

Surface friction is not an issue when using vortex type impellers as they are designed to specifically minimise the contact between the impeller and the wastewater. Therefore, the smoothness of the impeller makes little difference to the overall hydraulic efficiency of the system.

  - **Casing**

The sidewalls should be fully machined to a hydraulically smooth finish. This is only partially done at present, as this is increasing cost and in many cases the entire sidewalls of the volutes are not accessible for a surface finish by machining.

- **Leakage**

Hydraulic efficiency could be improved by reducing the leakage at the wear rings, by reducing the clearance.

This would require a combination of tighter manufacturing tolerances, increased shaft diameter to minimise contact and wear at reduced or increased flow, and very hard but compatible wear ring materials (e.g. tungsten carbide). This approach does not often produce a sufficient cost increase compared to the efficiency gain.

Alternatively wear ring geometry could be changed, e.g. non-plane surfaces. However, the effect would be small and would be offset by reducing the small but beneficial hydrostatic centring force.

Another option is to periodically adjust the wear rings over time to minimise the clearances.

- **Non-clogging performance**

The ability of a wastewater pump to resist clogging, (also referred to as ragging or blocking) will affect its environmental performance. The hydraulic efficiency of centrifugal pumps is related to the number of impeller vanes and channel depth.1 The issue with clogging pumps arises, as solids, especially fibrous materials, tend to attach themselves to the leading edge of impeller vanes. This in turn reduces the hydraulic performance in real world operation.

The BAT for these types of pump can achieve efficiencies of up to 88.7% if using a channel impeller and 63% when using a vortex impeller. However one must bear in mind that the attainable efficiencies are depending on the specific application and channel and vortex impellers have their specific advantages and disadvantages.

The benefits in clogging performance with vortex impellers are predominant in the small power range. For larger sizes especially designed channel impellers can reach equal clogging performance.

6.1.2 BC-2: Centrifugal submersible mixed flow and axial pumps

The axial thrust from the pump is normally accommodated in a ball type thrust bearing. There is little that can be done to reduce these small thrust bearing losses. The loss in the mechanical seal is negligible.

The remaining power losses are looked at theoretically for a specific pump in Appendix 1 of Task 4. These can be viewed as the hydraulic losses due to turbulence and surface friction. These are considered below.

- **Hydraulic design**

Axial pump have propellers rather than impellers, however there are similar issues surrounding the efficient hydraulic design. Each manufacturer will have their own (confidential) method of choosing this geometry. With many years of feedback, an established manufacturer should have arrived at close to the optimum propeller vane number, vane shape, inlet diameter, cross-sectional profile, and casing geometry. This should produce an effective compromise between the various curve shapes for head, power, hydraulic efficiency, NPSHR against flow, solids handling and resistance to blocking.

Axial flow pumps are fitted with fixed diffuser blades on the discharge, which are used to convert the rotational energy in the fluid that is produced by the action of the propeller, into additional pressure. The design of these diffuser blades can play an important role in the overall hydraulic efficiency of the pump, and each manufacturer will have their own method of choosing this geometry.

- **Surface friction**
  - **Propeller**

The propellers of low head axial pumps are mostly made from pressed steel, for larger pumps this is not possible regarding the high axial loads. The vast majority of propellers are machined and

[1] Sustained Pump Efficiency – A True Measure of Hydraulic Efficiency (Xylem)

polished after casting. In most cases the casting method is precision casting which gives a good hydraulic performance.

- **Casing**

The side walls should be fully machined to a hydraulically smooth finish. This is only partially done at present.

- **Non-blocking performance**

Propeller pumps have normally to be operated with a screen in front, because of the high speed they are not designed to pump e.g. stones and because of the sharp leading edges they are only able to pump fibrous matter at limited extend.

6.1.3 BC-3: Centrifugal submersible once a day operation pump

The performance of a centrifugal submersible radial sewage pump 1 to 10kW once a day operation and a centrifugal submersible pump where the volute is part of the tank once a day operation is affected by all the same issues associated with standard submersible radial sewage pumps. However, they do tend to be physically smaller which in turn leads to them having lower overall average efficiencies. These pumps are generally lower cost items and as such they may not have the same attention given to them in terms of their hydraulic design and manufacturing tolerances. This goes some way to explain the wide spread of efficiencies from 26% to 78% for centrifugal submersible radial sewage pump 1 to 10kW once a day operation and 14% to 71% for pumps where the volute is part of the tank.

6.1.3.1 Grinder pumps

Grinder pumps are nearly identical to radial submersible pumps; however, they incorporate a grinder attachment on the pump inlet. The fact that the motor is used to operate two systems, the grinder and the pump impeller, make this type of pump unique in this lot insofar as the efficiency of both the grinder and pump are considered together. An example of a grinder is shown in Figure 6-1. Grinder pumps are designed for the special purpose to disintegrate solids. Hence they can be pumped through pipes with small diameters. In principle these units have 3 elements: grinder – hydraulic – motor. For these applications there is no economical alternative, which can be used as substitute. Basically the increase of the discharge pipes in diameter are not possible as by the low wastewater production of single households otherwise the retention and septicity time of the sewage in the pipes would exceed any tolerance band.

The average efficiency of a grinder pump is 32%, however the BAT can operate at 42% if they have good hydraulics on the larger pumps.



Figure 6-1 Typical Grinder Element[2]

6.1.4 BC-4: Centrifugal submersible domestic drainage pump < 40 mm passage

These pumps are affected by the same modes of inefficiency that affect larger submersible centrifugal pumps in terms of hydraulic design and non-blocking performance. They tend to be constructed from a high proportion of steel and plastic, therefore they will generally have low surface friction. The biggest limiting factor in their efficiency is their size, as they are small relative to the size of solids they handle. This means that their impellers tend to be optimised for non-clogging performance rather than hydraulic efficiency. The BAT in domestic drainage pumps <40 mm passage pumps can achieve efficiencies of around 60.8% although this efficiency is only attainable for larger pumps with relative small solids passage. This base case contains pumps for cellar drainage, which need only a solids passage of about 10mm as well as small vortex pumps with a solids passage of 25 to 40mm.

6.1.5 BC-5: Submersible dewatering pumps

Dewatering pumps are essentially portable submersible radial sewage pumps, used for pumping abrasive solids. As such they are designed with highly wear resistant components to maintain good hydraulic efficiency across the lifetime of the pump. Dewatering pumps do have shrouds around the inlet to prevent larger solids from entering; therefore they are able to incorporate high efficiency, multi vane impellers. Therefore the efficiency of the pump can reach 72% on the BAT pumps with much of the variations in efficiency arising from the individual pump design. It is important that any improvements to the efficiency of the pumps do not remove the portable nature of the pumps.

The requirement on dewatering pumps is in general to have a steep performance curve. This makes the impeller channels small. In general, dewatering pumps has a strainer that prevents

[2] "Flygt centrifugal grinder pumps – for heavy duty shredding applications" Xylem – Brochure http://www.flygtus.com/3431809.pdf

larger solids from entering into the hydraulic end. In some applications the amount of solids coming to the pump is so large so the strainer will get plugged quickly. In these applications the customer needs a pump that can handle larger solids but still have a steep curve. For these applications the only alternative available is what we call a sludge pump. These pumps have a vortex impeller. The total sales in Europe are estimated to be 5000 pumps per year and that the average shaft power is 2 kW. These sludge pumps cannot be in the same category as the other submersible dewatering pumps due to the difference in efficiency.



Figure 6-2 Dewatering pumps inlet shroud[3]

6.1.6 BC-6: Centrifugal dry well pumps

There are mechanical losses in the two anti-friction bearings and the mechanical seal in these pumps but they are not capable of significant reduction.

- **Hydraulic design**

Centrifugal dry well pumps are hydraulically identical to submersible pumps and therefore the same issues apply. Refer to section 6.1.1 for details.

- **Surface friction**

Centrifugal dry well pumps are identical to submersible pumps in terms of surface friction and therefore the same issues apply.

- **Leakage**

Centrifugal dry well pumps are identical to submersible pumps in terms of leakage and therefore the same issues apply.

- **Non-blocking performance**

The non-blocking performance is identical to centrifugal submersible pumps.

The BAT for these types of pump can achieve efficiencies of up to 88.7%

[3] Warman Pumps – Product Information
http://www.weirminerals.com/products__services/centrifugal_dewatering_pumps/submersible_dewatering_pumps/sj_pump.aspx

6.1.7 BC-7A&7B: Slurry pumps

Slurry pumps are dry well radial pumps, designed to pump very abrasive solids, with much higher solid to water ratios than dry well radial sewage pumps. As such most of the issues that affect the efficiency of dry well radial sewage pumps are the same as those that affect slurry pumps. The most significant difference is that slurry pumps tend to be larger and therefore are able to incorporate closed multi-vane impellers which helps to maintain good hydraulic efficiencies. They are designed to incorporate highly wear resistant materials such as erosion resistant cast alloys, or they may incorporate elastomer liners made from materials such as natural rubber or polyurethane. The choice of materials and impeller will ultimately be dictated by the type of solid being pumped.



Figure 6-3 Example of slurry pump[4]

6.1.8 Centrifugal Pumps with intelligent controls

Pumps are also available which have built in diagnostics to identify possible causes of detected problems. This is useful in that it can both sound alarms and give maintenance staff ideas of what the technical problems might be. Early warning of problems can save cost and energy through making adjustments or repairs before failure of the pump. For example, when using a VSD pumps can easily be controlled to rotate the impeller in the opposite direction when blocked. By this the blockage will be removed.

The fitting of intelligent controls to pumps will give improved eco-performance in almost all applications, and so is to be welcomed. However, such controls would have no obvious impact on the design of the pump itself.

[4] Warman slurry pump – product description
http://www.weirminerals.com/products__services/centrifugal_slurry_pumps/horizontal_slurry_pumps/warman_wbh_pump.aspx

6.2 State-of-the-art at component level

6.2.1 Impellers

As described in Task 4, impellers have a key role in contributing towards the hydraulic efficiency and performance of wastewater pumps. The impellers used in wastewater pumps are different than those used in clean water pumps as they have to allow the free passage of solids through them and also have to be resistant to becoming clogged.

The state of the art in terms of sewage pump impellers is single channel and two channels, self-cleaning type ones. These impellers are designed to not only have a relatively high hydraulic efficiency when new, but also to maintain good levels of hydraulic efficiency through normal operation. This is because they are less susceptible to solids collecting on the leading edge due to the geometry of the impeller.

6.2.2 Motors

Motors for the pumps in this lot are regulated under Lot 11, or are being considered under ENER Lot 30. However it should be noted that in the case of submersible pumps, the pump and motor are integrated into one aggregate. However in almost all cases it will be possible for manufacturers to test the efficiency of pump and submersible motor separately. The chosen performance of the motor is linked to pump, the application and to other criteria, e.g. the acceptable weight for transportable drainage pumps.

Submersible pumps should therefore be managed as an Extended Product. For these products it is preferable to regulate with an Extended Product Approach since it enables much larger energy savings. Regulating on component level will not cover all losses such as losses from bearings, seals and cooling system. It also has the risk of hinder innovation and use of new technology. Regulation 641/2009 on Circulators is a great example on how far we reach in energy savings with an Extended Product Approach.

High efficiency motors are typically constructed with superior magnetic materials, larger magnetic circuits with thinner laminations, larger copper/aluminium cross-section in the stator and rotor windings, tighter tolerances, better quality control and optimized design. These motors, therefore, have lower losses and improved efficiency. Because of lower losses the operating temperature can be lower, leading to improved reliability.

Stator losses can be reduced by increasing the cross-section of stator windings which lowers their electrical resistance reducing I^2R losses. This modification is where the largest gains in efficiency are achieved. High efficiency motors typically contain about 20% more copper than standard efficiency models of equivalent size and rating.

Increasing the cross-section of the rotor conductors (conductor bars and end-plates) and/or increasing their conductivity (e.g. using copper instead of aluminium), and to a lesser extent by increasing the total flux across the air gap between rotor and stator reduces the rotor losses.

Magnetic core losses occur in the steel laminations of the stator and rotor and are mainly due to hysteresis effects and to induced eddy currents. Both types of losses approximately increase with the square of the magnetic flux density. Lengthening the lamination stack, which reduces the flux density within the stack, therefore reduces core losses. These losses can be further reduced through the use of magnetic steel with better magnetic properties (e.g. higher permeability and higher reluctance) in the laminations. Another means to reduce the eddy currents magnetic core losses is to reduce the laminations' thickness. Eddy current losses can also be reduced by ensuring adequate insulation between laminations, thus minimising the flow of current (and I^2R losses) through the stack.

The additional materials used in order to improve efficiency can present themselves as a problem, as it may be difficult to meet the standard frame sizes especially in the low power range. Of course, this is not always the case since in many cases only the stator and rotor laminations are a little longer.

Brushless Permanent Magnet (BPM) Motors are rapidly becoming one of the most popular motor types and are beginning to be used in smaller wastewater pumping applications, typically below 15 kW. They differ from Brushed Permanent magnet motors in that the magnets are in the rotor instead of the stator, and in the commutation method, which is controlled electronically. BPM Motors, therefore, avoid use of a commutator and brushes.

Main characteristics:

- Medium construction complexity
- Moderate to high cost depending on magnet materials
- High reliability (no brush and commutator wear), even at very high achievable speeds
- High efficiency
- Low EMI
- Driven by multi-phase (output) Inverter controllers, which inherently offer variable speed control
- Sensorless speed control possible

These motors are still highly customized without suitable standards (e.g. dimensions, mounting, power, torque specifications, etc.) that would allow a commodity market to develop. Because of high volumes production for individual specialized applications, their cost has been decreasing and may become a key player particularly in the low power range.

6.2.3 Variable speed drives

Variable speed drives can be used with a small subsection of wastewater pumps to improve energy efficiency. In situations where there is a need to vary the flow of the pumps, such as in

activated sludge plants in sewage treatment works, variable speed drives can be used to match pump outputs to the demand and save energy in the process.

Most wastewater pumping operations are fixed speed and therefore there would be an energy penalty associated with installing a variable speed drive to them, as they have higher losses than direct on line starters.

6.2.4 Summary of BAT options

In this section, the best available technology options are summarised for each of the seven BaseCases[5]. The data used in the tables presented in this section is party based on the inputs from the industry, literature review and own estimates of the study authors. The change in annual energy consumption data was provided by Europump, the impact on cost of motors and VSDs is based on literature review (mainly data available in ENER Lot 11 and ENER Lot 30 preparatory studies) and the remaining data on cost impact is based on the own estimates of the study authors.

Table 6-1: Summary of BAT options for BC 1: centrifugal submersible pump - radial sewage pumps 1 to 160 kW

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Impact on purchase cost	Consumer purchase cost change [€]	Unit to unit purchase cost change [€]	Impact on installation cost	Consumer installation cost change [€]	Impact on repair & maintenance costs	Consumer Repair and maintenance price change [€]
Pump/hydraulic improvements[6]	2.4%	-192	1.4%	46.7	46.7	0.0%	0	-1.9%	-24.7
Motor improvements	6.7%	-534.1	5.0%	166.9	166.9	0.0%	0	-2.0%	-24.7
VSD[7]	3.4%	-271	20.0%	161	805	5.0%	71.7	3.0%	37

It is important to note that **85%** of the pumps in this base case are in the **1 – 10kW** range. This accounts for the relatively large savings associated with the motors. It is not anticipated that savings of this level are achievable in the larger pump sizes.

[5] Please note: all statements on improvement potentials for the different pumps (BC 1 to BC 7) and their BATs are based on estimations and have to be evaluated in combination with assumptions on user behaviour

[6] This includes Improved case geometry, Surface friction reduction, Leakage reduction and Improved impeller efficiency for all base cases;

[7] VSD is applicable only when static head vs. total head is below a certain percentage, otherwise it may even lead to higher energy consumption

The savings associated with the VSDs are the total savings averaged across all the pumps in the base case. It is estimated that VSDs are only applicable to approximately 26% of these pumps, of which 6 % are already operated with them. Therefore only **20%** of the savings associated with the implementation of VSDs can be considered when assessing the base case as a whole.

The figure shown in the "Consumer purchase price change" column reflects the stock weighted average price change associated with implementing VSDs across all the pumps in the base case. The "Unit to unit price change" column reflects the increase in purchase price as a result of changing from a standard starter to a VSD on a unit to unit basis.

Table 6-2: Summary of BAT options for BC 2: centrifugal submersible pump - mixed flow and axial pumps

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Unit to unit price change [€]	Impact on Installation Cost	Consumer installation price change [€]	Impact on repair & maintenance costs	Consumer Repair and maintenance price change [€]
Pump/hydraulic improvements	2.0%	-3 502	1.4%	210	210	0.0%	0	-1.9%	-18
Motor improvements	4.0%	-7 004	5.0%	750	750	0.0%	0	-2.0%	-19
VSD7	6.0%	-10 506	5.0%	240	1 500	5.0%	187.5	3.0%	28.5

The savings associated with the VSDs are the total savings averaged across all the pumps in the base case. VSDs are in the BC-2 only applicable to the pumps, which are used as recirculation pumps. These are 40% of base, of which 24 % are already operated with them. Therefore only 16% of the savings associated with the implementation of VSDs can be considered when assessing the base case as a whole. The figure shown in the "Consumer purchase price change" column reflects the stock.

Table 6-3: Summary of BAT options for BC 3: centrifugal submersible pump – once a day operation

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Unit to unit price change [€]	Impact on Installation Cost	Consumer installation price change [€]	Impact on repair & maintenance costs	Consumer Repair and maintenance price change [€]
Pump/hydraulic improvements	4.0%	-2.0	1.4%	22.5	22.5	0.0%	0	-1.9%	-3.0
Motor improvements	6.6%	-2.9	10%	160.7	160.7	0.0%	0	-2.0%	-3.3

The annual consumption change and consumer price change figures in the above table are based on a stock weighted average for grinding pumps, radial sewage pumps 1 – 10kW, and pumps where the volute is part of the tank.

Table 6-4: Summary of BAT options for BC 4: centrifugal submersible domestic drainage pump < 40 mm passage

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Unit to unit price change [€]	Impact on Installation Cost	Consumer installation price change [€]	Impact on repair & maintenance costs	Consumer Repair and maintenance price change [€]
Pump/hydraulic improvements	10%	-1	1.4%	4.2	4.2	0.0%	0	-1.9%	0
Motor improvements	5.0%	-0.35	15%	45	45	0.0%	0	-2.0%	0

Table 6-5: Summary of BAT options for BC 5: submersible dewatering pumps

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Unit to unit price change [€]	Impact on Installation Cost	Consumer installation price change [€]	Impact on repair & maintenance costs	Consumer Repair and maintenance price change [€]
Pump/hydraulic improvements	5.0%	-525	1.4%	70	70	0.0%	0	-1.9%	-21
Motor improvements[8]	5.0%	-525	5.0%	250	250	0.0%	0	-2.0%	-22

Table 6-6: Summary of BAT options for BC 6: centrifugal dry well pumps - radial sewage pumps 1 to 160 kW

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Unit to unit price change [€]	Impact on Installation Cost	Consumer installation price change [€]	Impact on repair & maintenance costs	Consumer Repair and maintenance price change [€]
Pump/hydraulic improvements	2.0%	-250	1.4%	53	53	0.0%	0	-1.9%	-15.4
Motor improvements[9]	2.2%	-279.4	5.0%	166.9	166.9	0.0%	0	-2.0%	-24.7

[8] Dewatering pumps are hand held devices that are typically moved on a day to day basis. As such, motor improvements that increase the weight of the pump over the safe handling weight cannot be applied to these pumps.

[9] numbers provided here are taken from The Lot 30 study

VSD7	4.0%	-500.2	25.0%	192	952	5.0%	78.15	-2.0%	-16.2

It is important to note that **74%** of the pumps in this base case are in the **1 – 10kW** range. This accounts for the relatively large savings associated with the motors. It is not anticipated that savings of this level are achievable in the larger pump sizes.

The savings associated with the VSDs are the total savings averaged across all the pumps in the base case. It is estimated that VSDs are only applicable to approximately 26% of these pumps, of which 6 % are already operated with them. Therefore only **20%** of the savings associated with the implementation of VSDs can be considered when assessing the base case as a whole.

The figure shown in the "Consumer purchase price change" column reflects the stock weighted average price change associated with implementing VSDs across all the pumps in the base case. The "Unit to unit price change" column reflects the increase in purchase price as a result of changing from a standard starter to a VSD on a unit to unit basis.

Table 6-7: Summary of BAT options for BC 7A: light duty slurry pumps

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Unit to unit price change [€]	Impact on Installation Cost	Consumer installation price change [€]	Impact on repair & maintenance costs	Consumer Repair and maintenance price change [€]
Pump/hydraulic improvements	1.0%	-1 300	2%	750	750	0.0%	0	1.0%	700
Motor improvements9	2.0%	-2 600	5.0%	1 875	1 875	0.0%	0	-2.0%	-19

Table 6 8: Summary of BAT options for BC 7B: heavy duty slurry pumps

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Unit to unit price change [€]	Impact on Installation Cost	Consumer installation price change [€]	Impact on repair & maintenance costs	Consumer Repair and maintenance price change [€]
Pump/hydraulic improvements	1%	-592	2%	1 600	1 600	0.0%	0	1.0%	1000
Motor improvements9	2%	-1 184	5.0%	4 000	4 000	0.0%	0	-2.0%	-19

The annual consumption change and consumer price change figures in the above table are based on a stock weighted average for both light and heavy duty slurry pumps.

6.3 State-of-the-art of best existing product technology outside the EU

Wastewater pump products – both, residential and non-residential - available in the EU are essentially of similar design to appliances sold outside the EU. Therefore, no different more efficient technologies have been identified outside the EU.

6.4 Conclusion

As pumps are a very well established technology there is very little in terms of BNAT at the product level that is likely to be released into the market in the next 2 – 3 years. Therefore, the majority of this chapter has focused on the BATs of the wastewater pumps in the study. The energy costs for a wastewater pump represent a significant proportion of the whole life costs and therefore it is important to consider the efficiency of the pumps across its whole lifespan. It is clear that wastewater pumping is a mature technology and there are not many significant gains to be made through improvements in hydraulic efficiency. A significant area for improvement for submersible pumps is the motors, as these have not yet been subject to other minimum motor efficiency regulations. VSDs could also lead to significant energy savings for some of the Lot 28 pumps (BC 1, BC2 and BC6). The big efficiency improvements are likely to be found in terms of control improvements at the network level, where several pumps are controlled together. As these types of control improvements are achieved at a network level, and not the product level, they are beyond the scope of this study.

This page is left intentionally blank



2 April 2014

185 Avenue Charles de Gaulle
92200 Neuilly-sur-Seine
France
+ 33 (0) 1 5561 6755
www.bio.deloitte.fr

Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC ENER Lot 28 – Pumps for private and public wastewater and for fluids with high solids content

ENER Lot 28– Pumps for private and public wastewater and for fluids with high solids content – Task 7: Improvement potential – Working document

Final report for the European Commission, DG ENER
02 April 2014



European Commission

Developed by:

bio by Deloitte.

ATKINS

Document information

CLIENT	European Commission, DG ENER
CONTRACT NUMBER	ENER/C3/403/2010
REPORT TITLE	ENER Lot 28– Pumps for private and public wastewater and for fluids with high solids content – Task 7: Improvement potential – Working document
PROJECT NAME	Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC ENER Lot 28 – Pumps for private and public wastewater and for fluids with high solids content
PROJECT CODE	ENER Lot 28
PROJECT TEAM	Bio by Deloitte, Atkins
DATE	02 April 2014
AUTHORS	Mr. Shailendra Mudgal, Bio by Deloitte Mr. Sandeep Pahal, Bio by Deloitte Mr. Benoît Tinetti, Bio by Deloitte Mr. Alvaro De Prado Trigo, Bio by Deloitte Dr. Hugh Falkner, Atkins Mr. Keeran Jugdoyal, Atkins
KEY CONTACTS	Mr. Sandeep Pahal spahal@bio.deloitte.fr Or Mr. Shailendra Mudgal shmudgal@bio.deloitte.fr
DISCLAIMER	This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. The project team does not accept any liability for any direct or indirect damage resulting from the use of this report or its content.

Please cite this publication as:
Bio by Deloitte (2014), Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC ENER Lot 28 – Pumps for private and public wastewater and for fluids with high solids content, ENER Lot 28– Pumps for private and public wastewater and for fluids with high solids content – Task 7: Improvement potential – Working document prepared for. European Commission, DG ENER.

Photo credit: cover @ Per Ola Wiberg

© Bio by Deloitte 2014

Table of Contents

7.1 Identification of design options 7
7.1.1 Base-case 1: Centrifugal submersible: radial sewage pump 1-160 kW 8
7.1.2 Base-case 2: Centrifugal submersible: mixed flow and axial pumps 9
7.1.3 Base-case 3: Centrifugal submersible pump – once a day operation 10
7.1.4 Base-case 4: Centrifugal submersible domestic drainage pump<40mm passage 11
7.1.5 Base-case 5: Submersible dewatering pumps 12
7.1.6 Base-case 6: Centrifugal dry well pump 13
7.1.7 Base-case 7A: Slurry pumps: Light duty 14
7.1.8 Base-case 7B: Slurry pumps: Heavy duty 14
7.2 Analysis BAT and LLCC 16
7.2.1 Base-case 1: Centrifugal submersible pump: Radial sewage pumps 1 to 160 kW 16
7.2.2 Base-case 2: Centrifugal submersible pump: Mixed flow & axial pumps 20
7.2.3 Base-case 3: Centrifugal submersible pump – once day operation 24
7.2.4 Base-case 4: Centrifugal submersible domestic drainage pump<40 mm passage 28
7.2.5 Base-case 5: Submersible dewatering pump 32
7.2.6 Base-case 6: Centrifugal well pump 36
7.2.7 Base-case 7A: Slurry pumps: Light duty 40
7.2.8 Base-case 7B: Slurry pumps: Heavy duty 44
7.3 BNAT and long-term systems analysis 49
7.4 Conclusions 50

List of Tables

Table 7-1: Identified energy savings potentials for BC1: centrifugal submersible pump: radial sewage pumps 1 to 160 kW 8

Table 7-2: Identified energy savings potentials for BC2: Centrifugal submersible pump: Mixed flow and axial pumps 9

Table 7-3: Identified energy savings potentials for BC3: Centrifugal submersible pump – once a day operation 10

Table 7-4: Identified energy savings potentials for BC4: Centrifugal submersible domestic drainage pump<40mm passage 11

Table 7-5: Identified energy savings potentials for BC5: Submersible dewatering pumps 12

Table 7-6: Identified energy savings potentials for BC6: Centrifugal dry well pump 13

Table 7-7: Identified energy savings potentials for BC7A: Slurry pumps: Light duty 14

Table 7-8: Identified energy savings potentials for BC7B: Slurry pumps: Heavy duty 15

Table 7-9: Environmental impacts of the BC1 and its improvement options 17

Table 7-10: Environmental impacts of the BC2 and its improvement options 21

Table 7-11: Environmental impacts of the BC3 and its improvement options 25

Table 7-12: Environmental impacts of the BC4 and its improvement options 29

Table 7-13: Environmental impacts of the BC5 and its improvement options 33

Table 7-14: Environmental impacts of the BC6 and its improvement options 37

Table 7-15: Environmental impacts of the BC7A and its improvement options 41

Table 7-16: Environmental impacts of the BC7B and its improvement options 45

List of Figures

Figure 7-1: Life cycle costs of the improvement options for BC1 19

Figure 7-2: Identification of design improvement options with the least energy consumption and LLCC for BC1 20

Figure 7-3: Life cycle costs of the improvement options for BC2 23

Figure 7-4: Identification of design improvement options with the least energy consumption and LLCC for BC2 24

Figure 7-5: Life cycle costs of the improvement options for BC3 27

Figure 7-6: Identification of design improvement options with the least energy consumption and LLCC for BC3 28

Figure 7-7: Life cycle costs of the improvement options for BC4 31

Figure 7-8: Identification of design improvement options with the least energy consumption and LLCC for BC4 32

Figure 7-9: Life cycle costs of the improvement options for BC5 35

Figure 7-10: Identification of design improvement options with the least energy consumption and LLCC for BC5 36

Figure 7-11: Life cycle costs of the improvement options for BC6 39

Figure 7-12: Identification of design improvement options with the least energy consumption and LLCC for BC6 40

Figure 7-13: Life cycle costs of the improvement options for BC7A 43

Figure 7-14: Identification of design improvement options with the least energy consumption and LLCC for BC7A 44

Figure 7-15: Life cycle costs of the improvement options for BC7B 47

Figure 7-16: Identification of design improvement options with the least energy consumption and LLCC for BC7B 48

This page is left intentionally blank

Chapter 7: Improvement Potential (Task 7)

Task 7 quantitatively analyses design improvement options, based on the Best Available Technologies (BATs) described in Task 6 for each of the product base-cases. The payback time indicates the duration of repayment required to offset the investments associated with the different options, it takes into account changes in purchase price, installation cost, repair and maintenance cost compared with unit-to-unit energy savings. The environmental impacts of each of these options are calculated by using the MEErP EcoReport tool. The economic impacts of each design option are assessed in terms of Life Cycle Cost (LCC). The assessment of LCC is relevant as it indicates the level of impact design options may have on the cost to users over the whole lifetime of the product. The assessment of both environmental and economic impacts allows the identification of the design improvement options with the Least Life Cycle Costs (LLCC) and the one that results in the most significant reductions in environmental impacts. The Best Not yet Available Technologies (BNAT) are also discussed, assessing long-term improvement potential of the wastewater pumps.

7.1 Identification of design options

This section presents the different improvement options applicable to each base-case. These design options are carefully selected keeping in mind that they:

- Do not result in significant variation in the functionality and the performance parameter of the pumps compared to the base-cases
- Have a significant potential for improvement in the environmental performance
- Not entail excessive costs on the manufacturer

The cost-effectiveness of an improvement option is expressed in terms of payback time in years, defined as a ratio between:

$$\frac{\Delta(\text{investment})}{\Delta(\text{annual running costs})}$$

Where "investment" includes the purchase and installation costs and "annual running costs" include the cost of the energy consumed and the costs of repair and maintenance. In the case of a payback time longer than the lifetime of the product, the return of the investment would not be possible.

7.1.1 Base-case 1: Centrifugal submersible: radial sewage pump 1-160 kW

Task 5 identified that reducing total energy consumption during use phase would be an effective way to also reduce the overall environmental impacts of a base-case 1 (BC1). Task 6 identified the improvement options that aim to reduce the total energy consumption. Each of the improvement options applicable to BC1 and its relative impact on the product price compared to the base-case are listed below. Table 7-1 presents the summary of the selected improvement options.

As can be seen from this table, option 1 provides electricity savings due to improved hydraulic performance by modifying the geometry of the impeller and the casing design. These modifications will increase the efficiency and result in electricity savings.

Of all non-combined improvement options, option 2 provides the biggest electricity savings compared to the base-case. This option comprises a number of improvements for different motor components. However, use of additional materials[1] to improve efficiency can be a problem, as it may be difficult to meet the standard frames sizes, especially in the low power range.

Apart from positive effects such as electricity savings and efficiency improvements, design options can have negative effects, which would have to be considered. For example, reducing the surface friction may result in high costs and time-consuming operations and reducing leakages will lead to an increase in costs and require tighter manufacturing tolerances.

Table 7-1: Identified energy savings potentials for BC1: centrifugal submersible pump: radial sewage pumps 1 to 160 kW

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Base-case 1	**Centrifugal submersible pump: radial sewage pumps 1 to 160**	7 972	3 373	1 434	782	
Option 1 (OP1)	Pump/hydraulics improvements	7 780	3 420	1 434	757	0.3

[1] The BoM of this option is assumed to same as that of the base-case due to unavailability of such data.

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Option 2 (OP2)	Motor improvements	7 438	3 542	1 434	757	0.8
Option 3 (OP3)	VSD[2]	7 262	4 047	1 506	819	No return of investment possible[3]
Option 4 (OP1+OP2+ OP3)	Pump/hydraulic, motor and VSD improvements	6 537	4 263	1 506	770	4.1

7.1.2 Base-case 2: Centrifugal submersible: mixed flow and axial pumps

The selected improvement options for centrifugal submersible pumps with mixed flow and axial pumps do not differ much from those analysed for BC1. One of the main differences though, is that axial pumps have propellers rather than impellers. The implementation of high efficiency propellers will be done through the modification of the propellers' geometry.

Table 7-2: Identified energy savings potentials for BC2: Centrifugal submersible pump: Mixed flow and axial pumps

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Base-case 2	**Centrifugal submersible pump: Mixed flow & axial pumps**	175 000	15 000	3 750	950	
Option 1 (OP1)	Pump/hydraulics improvements	171 500	15 210	3 750	932	0.37

[2] Energy savings used for the calculation of payback time is based on the unit to unit rate of 8.89% energy savings compared to Base-Case

[3] The increase in costs associated with the implementation of the option, compared to the base-case, outweighs the cost reductions generated by the energy savings of this option.

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Option 2 (OP2)	Motor improvements	168 000	15 750	3 750	931	0.78
Option 3 (OP3)	VSD[4]	133 000	16 200	3 937.5	978.5	0.32
Option 4 (OP1+OP2+OP3)	Pump/hydraulic, motor and VSD improvements	122 500	17 160	3 937.5	941.5	0.40

shows the potential electricity savings, price increase and payback periods for each of the design options selected.

7.1.3 Base-case 3: Centrifugal submersible pump – once a day operation

The summary of potential design improvements for centrifugal submersible pumps of once a day operation is presented in the Table 7-3.These improvements options for once a day operation pumps do not differ much from the ones analysed in the section on submersible radial sewage pumps. However, once a day operation pumps are smaller than radial sewage pumps, which leads to lower overall average efficiency. The implementation of motors improvements will result in lower losses of efficiency and improved efficiency of the pumps, and because of lower losses, operating temperature can be lower, which will lead to an improved reliability. These pumps are generally lower cost items and, therefore, less attention is given to their hydraulic design and manufacturing tolerances.

Table 7-3: Identified energy savings potentials for BC3: Centrifugal submersible pump – once a day operation

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Base-case 3	**Centrifugal submersible**	45	1 617	1 130	162	

[4] Energy savings used for the calculation of payback time is based on the unit to unit rate of 24%

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
	pump – Once a day operation					
Option 1 (OP1)	Pump/hydraulics improvements	43	1 640	1 130	159	0.9
Option 2 (OP2)	Motor improvements	42	1 779	1 130	158.7	6.1
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	40	1 801	1 130	155.7	3.6

7.1.4 Base-case 4: Centrifugal submersible domestic drainage pump<40mm passage

As can be drawn from the Table 7-4, which presents improvement potentials of the various options for centrifugal submersible domestic drainage pumps, similar performance enhancements could be achieved as those for centrifugal submersible pumps. These pumps are affected by the same modes of inefficiency that affect larger submersible centrifugal pumps in terms of hydraulic design, leakage and non-blocking performance. The biggest limiting factor in their efficiency is their size, as they are small relative to the size of solids they handle. This means that their impellers tend to be optimised for non-clogging performance rather than for hydraulic efficiency. For both, the domestic drainage pumps and the submersible pumps, the combination of improvements will also entail the same constrains for each individual option.

Table 7-4: Identified energy savings potentials for BC4: Centrifugal submersible domestic drainage pump<40mm passage

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Base-case 4	**Centrifugal submersible domestic drainage pump<40mm passage**	7.00	300	150	0	

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulics improvements	6.30	304	150	0	No return of investment possible3
Option 2 (OP2)	Motor improvements	6.65	345	150	0	No return of investment possible3
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	5.95	349	150	0	No return of investment possible3

7.1.5 Base-case 5: Submersible dewatering pumps

The summary of potential design improvements for submersible dewatering pumps can be seen in the Table 7-5. As dewatering pumps are essentially submersible radial sewage used to pump abrasive solids, similar performance enhancements could be achieve as those for submersible radial sewage pumps. Because of the conditions in which these pumps work, they are designed with highly wear resistant component to maintain good efficiency across their lifetime. An improvement of the hydraulics can increase the efficiency of a pump and reduce electricity requirements.

Table 7-5: Identified energy savings potentials for BC5: Submersible dewatering pumps

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Base-case 5	**Submersible dewatering pumps**	10 500	5 000	250	463	
Option 1 (OP1)	Pump/hydraulics improvements	9 975	5 070	250	442	0.5

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Option 2 (OP2)	Motor improvements[5]	9 975	5 250	250	441	1.7
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	9 450	5320	250	420	1.1

7.1.6 Base-case 6: Centrifugal dry well pump

The summary of potential design improvements for centrifugal dry well pumps can be seen in the Table 7-6. Similar performance enhancements could be achieved for centrifugal dry well pumps as those for submersible pumps. Centrifugal dry well pumps are identical to submersible pumps in term of hydraulics, surface friction, leakage and non-blocking performance. Therefore, apart from one additional design improvement option (VSD), the same constrains and issues will arise for centrifugal dry well pumps as for submersible pumps.

Table 7-6: Identified energy savings potentials for BC6: Centrifugal dry well pump

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Base-case 6	**Centrifugal dry well pump**	12 505	3 433	1 563	807	
Option 1 (OP1)	Pump/hydraulics improvements	12 255	3 481	1 563	791.6	0.2
Option 2 (OP2)	Motor improvements[6]	12 230	3 604	1 563	782.3	0.6

[5] Motor improvements for submersible dewatering pumps needs a very sensitive approach, as any such motor improvements should not negative influence their portable (transportable /handheld) functionality.

[6] Please note that the motor saving values for this BC are only presented here for statistical evaluation purpose. The dry installed standard motors are at the majority already regulated by EC 640/2009, otherwise are currently considered in the scope of the Lot 30 preparatory study.

Option 3 (OP3)	VSD[7]	11 393	4 291	1 641.15	790.8	2.6
Option 4 (OP1+OP2+OP3)	Pump/hydraulic, motor and VSD improvements	10 993	4 511	1 641.15	750.7	1.3

7.1.7 Base-case 7A: Slurry pumps: Light duty

The summary of potential design improvements for slurry pumps with light duty can be seen in the Table 7-7. Slurry pumps work as dry well radial pumps designed to pump very abrasive solids. Because of that, most of the issues that affect the efficiency of dry well radial sewage pumps are the same as those that affect slurry pumps. Because slurry pumps are bigger, they are able to incorporate closed multi-vane impellers, what helps to maintain good hydraulics efficiencies, thereby reducing electricity consumption.

Table 7-7: Identified energy savings potentials for BC7A: Slurry pumps: Light duty

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Base-case 7A	**Slurry pumps: Light Duty**	130 000	20 000	5 000	1 275	
Option 1 (OP1)	Pump/hydraulics improvements	128 700	20 400	5 000	1 975	No return of investment possible3
Option 2 (OP2)	Motor improvements[6]	127 400	21 000	5 000	1 256	1.1
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	126 100	21 400	5 000	1 956	1.9

7.1.8 Base-case 7B: Slurry pumps: Heavy duty

The selected improvement options for slurry pumps with heavy duty do not differ significantly from those analysed in the previous section. As explained above, slurry pumps work like dry well radial pumps. This type of slurry pumps has a much heavier duty than the one mentioned in the

[7] Energy savings used for the calculation of payback time is based on the unit to unit rate of 8.89%

section 7.1.8. Therefore, modifications on the hydraulics of the impellers will affect efficiency and energy consumption. In addition, the choice of materials and impellers of the pumps will be dictated by the type of solids being pumped.

Table 7-8 shows the potential electricity savings, price increase and payback periods for each of the design options selected.

Table 7-8: Identified energy savings potentials for BC7B: Slurry pumps: Heavy duty

Improvement Options	Description	Annual energy consumption (kWh)	Product price (€)	Installation cost [€]	Repair & maintenance costs [€/year]	Payback time at product level (years)
Base-case 7B	**Slurry pumps: Heavy Duty**	59 200	20 000	5 000	1 275	
Option 1 (OP1)	Pump/hydraulics improvements	58 608	20 400	5 000	2 275	No return of investment possible3
Option 2 (OP2)	Motor improvements[6]	58 016	21 000	5 000	1 256	1.3
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	57 424	21 400	5 000	2 256	2.7

7.2 Analysis BAT and LLCC

The design options identified in the technical, environmental and economic analyses are ranked to identify the design improvement option with the least cycle environmental impacts and the Least Life Cycle Costs (LLCC). Building an energy-LCC curve (Y-axis= energy consumed and LCC, X-axis=options) allows the LLCC and BATs to be identified[8].

The performance of each improvement option will be compared using the base-case. The comparison is made in terms of primary energy consumption and LCC.

LCC is the sum of the product price, costs of energy and the costs of installation and maintenance as described in Task 4.

7.2.1 Base-case 1: Centrifugal submersible pump: Radial sewage pumps 1 to 160 kW

An environmental and economic assessment was carried out for each improvement option relevant for centrifugal submersible pump: Radial sewage pumps 1 to 160 kW using the EcoReport tool. Outcomes for the whole life cycle are provided in absolute values (in units) and in variations compared to the base-case.

[8] This is usually the last data point of the curve showing the product design with the lowest environmental impact, irrespective of the price.

Table 7-9: Environmental impacts of the BC1 and its improvement options[9]

Life-Cycle indicators per unit	Unit	Base-case 1	Option 1	Option 2	Option 3	Option 4
Total Energy (GER)	GJ	842.6	822.6	786.6	814.2	738.0
	% change with BC	0%	-2%	-7%	-3%	-12%
Of which, electricity	Primary GJ	837.6	817.5	781.5	809.1	732.9
	Final MWh	79.8	77.9	74.4	77.1	69.8
	% change with BC	0%	-2%	-7%	-3%	-12%
Water (process)	Kg SO_2 eq.	56.1	54.7	52.3	54.2	49.1
	% change with BC	0%	-2%	-7%	-3%	-12%
Water (cooling)	Kg SO_2 eq.	2232.6	2179.0	2083.0	2156.7	1953.6
	% change with BC	0%	-2%	-7%	-3%	-12%
Waste, non-haz./ landfill	Kg SO_2 eq.	1188.1	1164.8	1123.0	1155.1	1066.8
	% change with BC	0%	-2%	-5%	-3%	-10%
Waste, hazardous/ incinerated	Kg SO_2 eq.	20.5	20.1	19.2	19.9	18.1
	% change with BC	0%	-2%	-6%	-3%	-12%
Greenhouse Gases in GWP100	Kg SO_2 eq.	36.9	36.0	34.4	35.7	32.3
	% change with BC	0%	-2%	-7%	-3%	-12%
Acidification, emissions	Kg SO_2 eq.	218.5	213.3	204.0	211.2	191.5
	% change with BC	0%	-2%	-7%	-3%	-12%
Volatile Organic Compounds (VOC)	kg	0.3	0.3	0.3	0.3	0.3
	% change with BC	0%	-2%	-6%	-3%	-11%
Persistent Organic Pollutants	µg i-Teq	6.9	6.8	6.6	6.7	6.2

[9] The numbers in red show the option with the highest environmental impacts, and the green shows the option with the lowest environmental impacts

Life-Cycle indicators per unit	Unit	Base-case 1	Option 1	Option 2	Option 3	Option 4
(POP)	% change with BC	0%	-2%	-5%	-3%	-10%
Heavy Metals to air	g Ni eq.	15.3	14.9	14.3	14.8	13.5
	% change with BC	0%	-2%	-6%	-3%	-12%
PAHs	g Ni eq.	1.8	1.8	1.7	1.8	1.6
	% change with BC	0%	-2%	-6%	-3%	-11%
Particulate Matter (PM, dust)	kg	9.6	9.5	9.3	9.4	9.0
	% change with BC	0%	-1%	-3%	-2%	-6%
Heavy Metals to water	g Hg/20	5.7	5.6	5.3	5.5	5.0
	% change with BC	0%	-2%	-6%	-3%	-12%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0	0.0
	% change with BC	0%	-2%	-5%	-2%	-9%
Life-cycle cost	€	18,265.5	18,015.1	17,830.7	18,960.4	18,275.2
	% change with BC	0%	-1%	-2%	4%	0%

Design improvement options

Option 1 (OP1)	Option 2 (OP2)	Option 3 (OP3)	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	OP1+OP2+OP3

Figure 7-1 shows that option 3 achieves the lowest environmental impacts of all the non-combined options. However, the combination of options 1+2+3 is the one achieving the lowest primary energy consumption in comparison with the base-case.

The ratio of LCC and the improvements options to the base-case is shown in the Figure 7-1. Electricity costs and maintenance and repair costs have the highest share of the LCC, while purchase price over the lifetime of the pump is the second biggest expenditure.

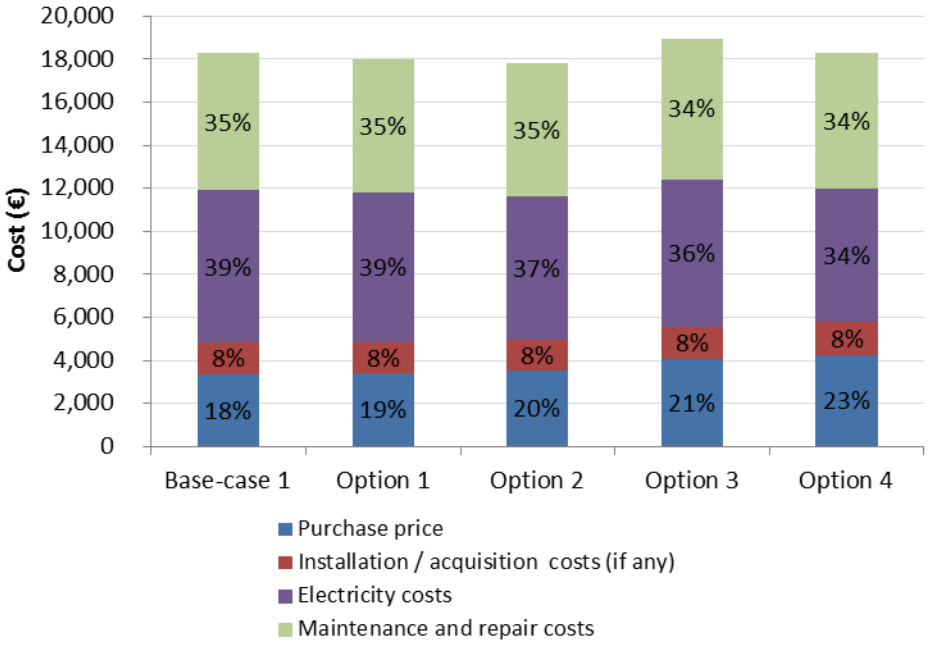


Figure 7-1: Life cycle costs of the improvement options for BC1

Option 1 (OP1)	Option 2 (OP2)	Option 3 (OP3)	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	OP1+OP2+OP3

Figure 7-2 presents the comparison between primary energy consumption and life cycle costs of the base-case and its design options. The Least Life Cycle Cost option is option 2. The combination Option 4 is the BAT, however, the LLC of option 4 is similar to the LLC of the base-case.

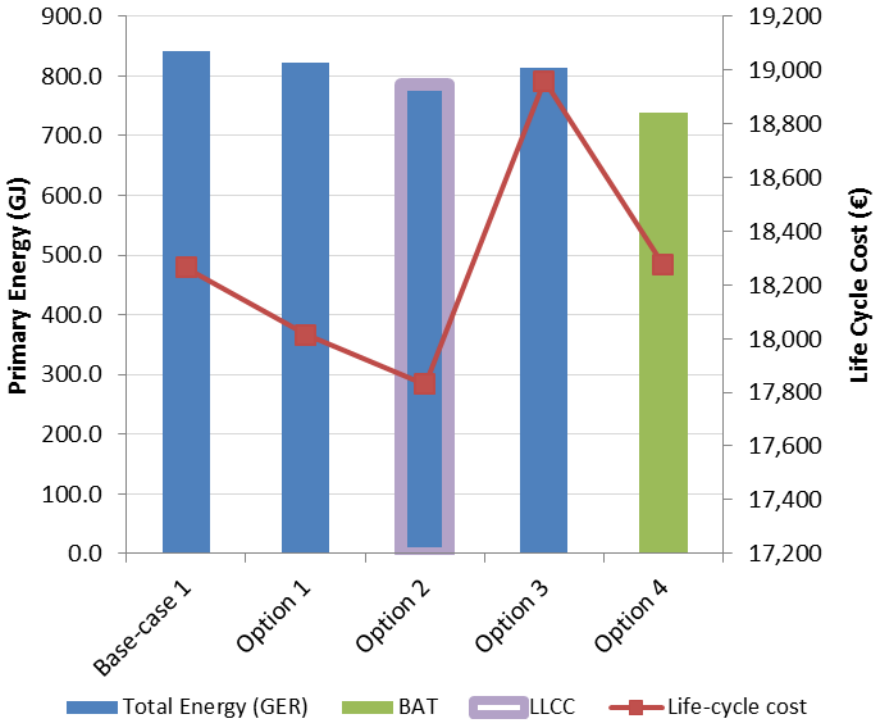


Figure 7-2: Identification of design improvement options with the least energy consumption and LLCC for BC1

Option 1 (OP1)	Option 2 (OP2)	Option 3 (OP3)	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	OP1+OP2+OP3

7.2.2 Base-case 2: Centrifugal submersible pump: Mixed flow & axial pumps

Table 7-9 shows the environmental and economic impacts of the improvement options selected for BC2. Option 3 achieves the highest reduction in primary energy consumption, but the combination of all options (1+2+3) achieves the highest reduction in environmental impacts compared to the base-case. The lowest life cycle costs are also achieved through the combination of all options (1+2+3).

Table 7-10: Environmental impacts of the BC2 and its improvement options

Life-Cycle indicators per unit	Unit	Base-case 2	Option 1	Option 2	Option 3	Option 4
Total Energy (GER)	GJ	18396.4	18028.9	17661.4	17293.9	16191.4
	% change with BC	0%	-2%	-4%	-6%	-12%
Of which, electricity	Primary GJ	18377.1	18009.6	17642.1	17274.6	16172.1
	Final MWh	1750.2	1715.2	1680.2	1645.2	1540.2
	% change with BC	0%	-2%	-4%	-6%	-12%
Water (process)	Kg SO_2 eq.	1226.2	1201.7	1177.2	1152.7	1079.2
	% change with BC	0%	-2%	-4%	-6%	-12%
Water (cooling)	Kg SO_2 eq.	49001.7	48021.7	47041.7	46061.7	43121.7
	% change with BC	0%	-2%	-4%	-6%	-12%
Waste, non-haz./ landfill	Kg SO_2 eq.	22249.4	21823.3	21397.2	20971.1	19692.9
	% change with BC	0%	-2%	-4%	-6%	-11%
Waste, hazardous/ incinerated	Kg SO_2 eq.	427.1	418.6	410.1	401.7	376.3
	% change with BC	0%	-2%	-4%	-6%	-12%
Greenhouse Gases in GWP100	Kg SO_2 eq.	803.2	787.2	771.1	755.1	707.0
	% change with BC	0%	-2%	-4%	-6%	-12%
Acidification, emissions	Kg SO_2 eq.	4744.2	4649.6	4554.9	4460.3	4176.4
	% change with BC	0%	-2%	-4%	-6%	-12%
Volatile Organic Compounds (VOC)	kg	7.0	6.9	6.7	6.6	6.2
	% change with BC	0%	-2%	-4%	-6%	-12%
Persistent Organic Pollutants (POP)	µg i-Teq	126.0	123.6	121.2	118.8	111.6
	% change with BC	0%	-2%	-4%	-6%	-11%
Heavy Metals to	g Ni eq.	318.9	312.6	306.3	300.0	281.1

Life-Cycle indicators per unit	Unit	Base-case 2	Option 1	Option 2	Option 3	Option 4
air	% change with BC	0%	-2%	-4%	-6%	-12%
PAHs	g Ni eq.	37.0	36.3	35.6	34.8	32.7
	% change with BC	0%	-2%	-4%	-6%	-12%
Particulate Matter (PM, dust)	kg	115.8	113.8	111.7	109.7	103.7
	% change with BC	0%	-2%	-3%	-5%	-10%
Heavy Metals to water	g Hg/20	119.7	117.3	115.0	112.6	105.5
	% change with BC	0%	-2%	-4%	-6%	-12%
Eutrophication	Kg PO_4	0.6	0.6	0.6	0.6	0.5
	% change with BC	0%	-2%	-4%	-6%	-11%
Life-cycle cost	€	182,590.1	179,531.0	176,940.6	174,390.7	165,682.1
	% change with BC	0%	-2%	-3%	-4%	-9%

Design improvement options

Option 1 (OP1)	Option 2 (OP2)	Option 3 (OP3)	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	OP1+OP2+OP3

Figure 7-3 shows different shares of consumer expenses throughout the life cycle of BC2 and the design options. For all cases, electricity costs have the highest share (between 84% and 86% of the total).

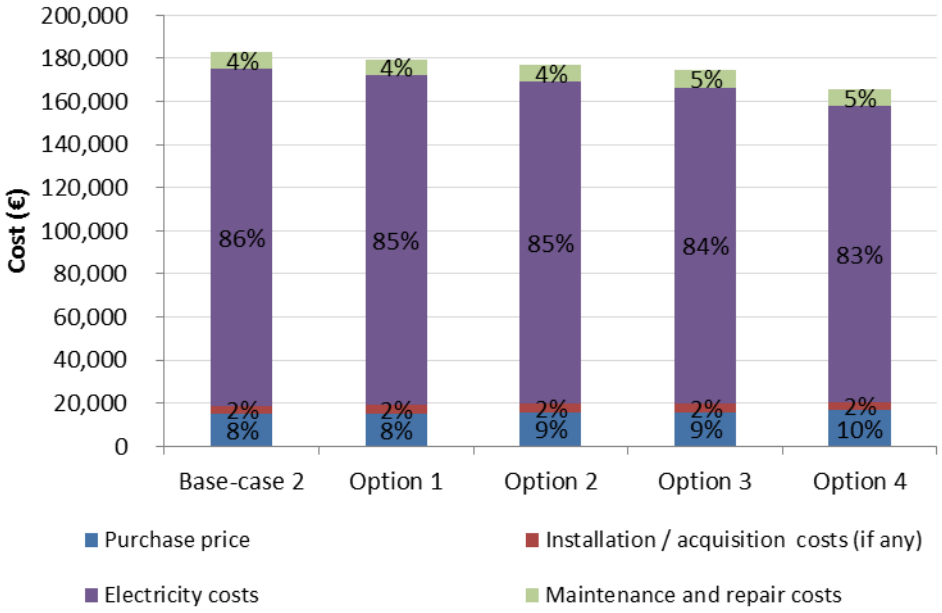


Figure 7-3: Life cycle costs of the improvement options for BC2

Option 1 (OP1)	Option 2 (OP2)	Option 3 (OP3)	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	OP1+OP2+OP3

Figure 7-4 presents the comparison between LCC and primary energy consumption of BC2 and its design options. A combination option 4 is the option with the lowest environmental impacts and LLCC. This combination of options presents the LCC 9% lower that the base-case and the primary energy consumption 12% lower than the base-case.

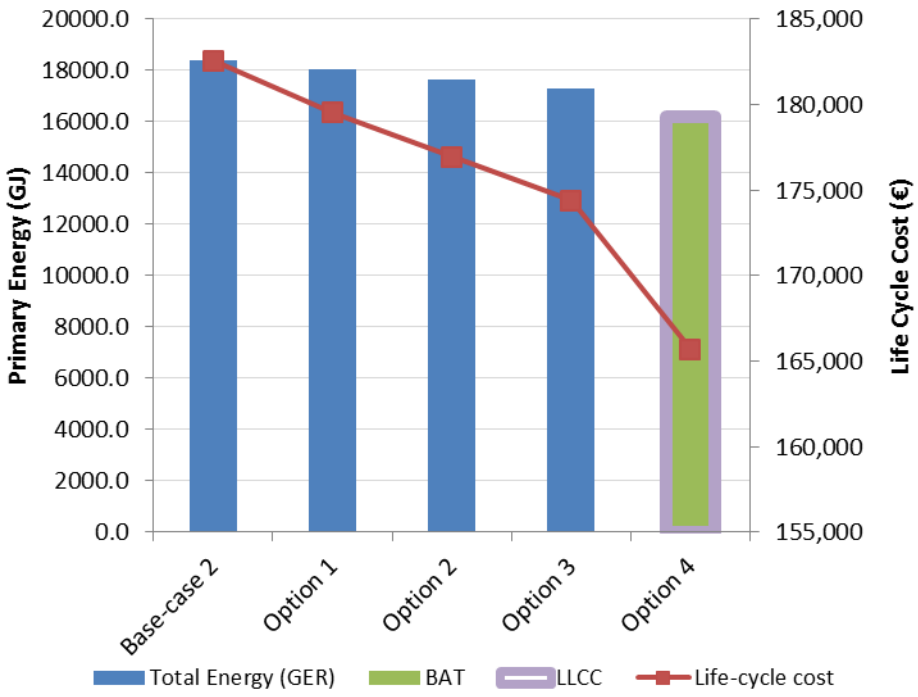


Figure 7-4: Identification of design improvement options with the least energy consumption and LLCC for BC2

Option 1 (OP1)	Option 2 (OP2)	Option 3 (OP3)	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	OP1+OP2+OP3

7.2.3 Base-case 3: Centrifugal submersible pump – once day operation

The results of the environmental analysis of the different designs options for BC3 are presented in the Table 7-11. Option 2 results in the largest reductions of environmental impacts compared to Option 1 and the base-case, but it is the combination of options 1+2 that shows the most optimal results regarding environmental impacts.

Option 2 also shows higher life cycle costs than the base-case.

Table 7-11: Environmental impacts of the BC3 and its improvement options

Life-Cycle indicators per unit	Unit	Base-case 3	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	6.9	6.7	6.6	6.5
	% change with BC	0%	-2%	-4%	-6%
Of which, electricity	Primary GJ	4.1	3.9	3.8	3.7
	Final MWh	0.4	0.4	0.4	0.3
	% change with BC	0%	-4%	-6%	-10%
Water (process)	Kg SO2 eq.	0.4	0.4	0.4	0.4
	% change with BC	0%	-2%	-4%	-6%
Water (cooling)	Kg SO2 eq.	10.3	9.9	9.6	9.2
	% change with BC	0%	-4%	-6%	-10%
Waste, non-haz./ landfill	Kg SO2 eq.	83.9	83.8	83.6	83.5
	% change with BC	0%	0%	0%	-1%
Waste, hazardous/ incinerated	Kg SO2 eq.	3.5	3.5	3.5	3.5
	% change with BC	0%	0%	0%	0%
Greenhouse Gases in GWP100	Kg SO2 eq.	0.3	0.3	0.3	0.3
	% change with BC	0%	-2%	-3%	-5%
Acidification, emissions	Kg SO2 eq.	2.2	2.1	2.1	2.1
	% change with BC	0%	-2%	-3%	-5%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	-1%
Persistent Organic Pollutants (POP)	µg i-Teq	0.6	0.6	0.5	0.5
	% change with BC	0%	0%	0%	0%
Heavy Metals to air	g Ni eq.	0.5	0.5	0.5	0.5

Life-Cycle indicators per unit	Unit	Base-case 3	Option 1	Option 2	Option 3
	% change with BC	0%	-1%	-1%	-1%
PAHs	g Ni eq.	0.1	0.1	0.1	0.1
	% change with BC	0%	0%	-1%	-1%
Particulate Matter (PM, dust)	kg	3.6	3.6	3.6	3.6
	% change with BC	0%	0%	0%	0%
Heavy Metals to water	g Hg/20	0.2	0.2	0.2	0.2
	% change with BC	0%	-1%	-1%	-2%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	0%
Life-cycle cost	€	3 876.9	3 877.4	4 014.5	4 015.1
	% change with BC	0%	0%	4%	4%

Design improvement options

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

Figure 7-5 shows the share of different life cycle costs throughout the life cycle of BC_3 and the design options. For all cases, the purchase price has the highest share (42%-45% of the total). The installation and acquisition costs represent the second largest share of the LCC. The electricity costs are very low (1%of total) compared to the purchasing and installation costs.

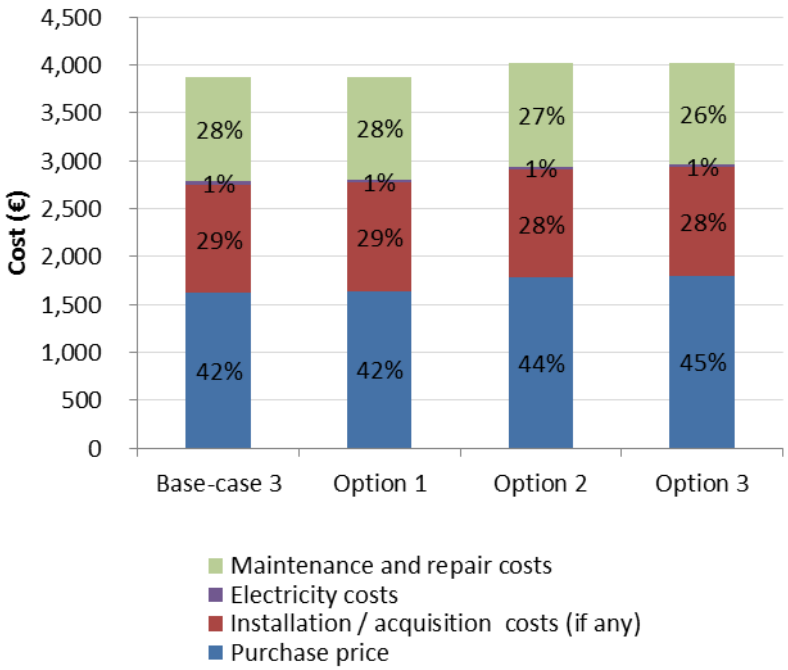


Figure 7-5: Life cycle costs of the improvement options for BC_3

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

Figure 7-6 presents the comparison between LCC and the primary energy consumption for BC_3 and the design options. For this base-case, the combination of options 1+2 is the BAT, achieving 10.6% energy savings compared to the base-case. However, it has an increase of 4% in life cycle cost making the base-case the option with the LLCC.

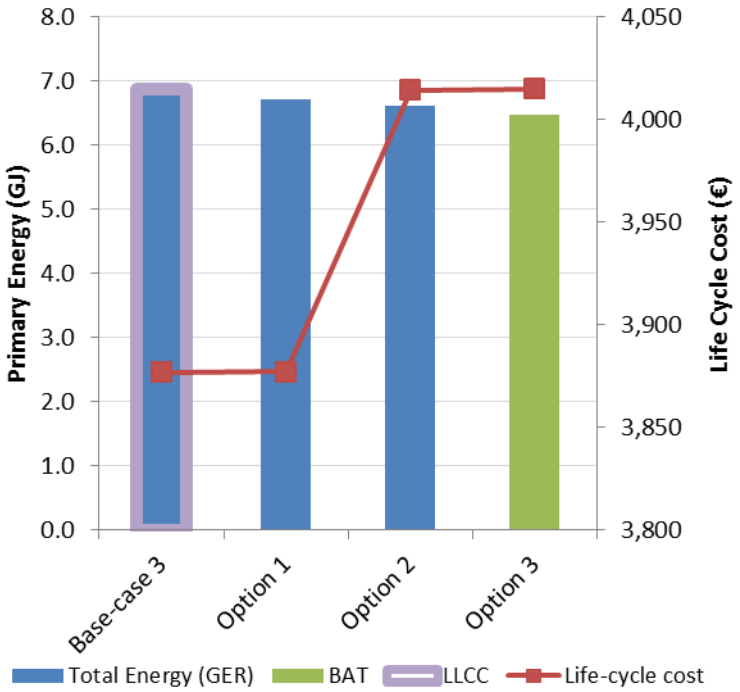


Figure 7-6: Identification of design improvement options with the least energy consumption and LLCC for BC3

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

7.2.4 Base-case 4: Centrifugal submersible domestic drainage pump<40 mm passage

The results of the environmental analysis of the different designs options for BC4 are presented in the Table 7-12. Option 1 provides reductions in the environmental impacts compare to the base-case but it is the combination of options 1+2 that shows the most optimal results regarding environmental impacts.

As in the BC3, the combination of options 1+2 allows a reduction of electricity of 12% but there is an increase of the LCC equal to 11%.

Table 7-12: Environmental impacts of the BC4 and its improvement options

Life-Cycle indicators per unit	Unit	Base-case 4	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	1.8	1.8	1.8	1.8
	% change with BC	0%	-3%	-1%	-4%
Of which, electricity	Primary GJ	0.6	0.6	0.6	0.6
	Final MWh	0.1	0.1	0.1	0.1
	% change with BC	0%	-8%	-4%	-12%
Water (process)	Kg SO_2 eq.	0.0	0.0	0.0	0.0
	% change with BC	0%	-7%	-3%	-10%
Water (cooling)	Kg SO_2 eq.	1.5	1.3	1.4	1.3
	% change with BC	0%	-9%	-5%	-14%
Waste, non-haz./ landfill	Kg SO_2 eq.	32.6	32.5	32.5	32.5
	% change with BC	0%	0%	0%	0%
Waste, hazardous/ incinerated	Kg SO_2 eq.	1.7	1.7	1.7	1.7
	% change with BC	0%	0%	0%	0%
Greenhouse Gases in GWP100	Kg SO_2 eq.	0.1	0.1	0.1	0.1
	% change with BC	0%	-2%	-1%	-3%
Acidification, emissions	Kg SO_2 eq.	0.7	0.7	0.7	0.7
	% change with BC	0%	-2%	-1%	-3%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	0%
Persistent Organic Pollutants (POP)	µg i-Teq	0.2	0.2	0.2	0.2
	% change with BC	0%	0%	0%	0%
Heavy Metals to air	g Ni eq.	0.2	0.2	0.2	0.1
	% change with BC	0%	-1%	0%	-1%

Life-Cycle indicators per unit	Unit	Base-case 4	Option 1	Option 2	Option 3
PAHs	g Ni eq.	0.1	0.1	0.1	0.1
	% change with BC	0%	0%	0%	0%
Particulate Matter (PM, dust)	kg	1.9	1.9	1.9	1.9
	% change with BC	0%	0%	0%	0%
Heavy Metals to water	g Hg/20	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-1%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	0%
Life-cycle cost	€	454.6	458.4	499.4	503.1
	% change with BC	0%	1%	10%	11%

Design improvement options

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

In Figure 7-7 shows the share of different life cycle costs throughout the life cycle of BC4 and the design options. For all cases, the purchase price has the highest share (between 66% and 69% of the total). The electricity costs are very low (1%of total) compare to the purchasing and installation costs.

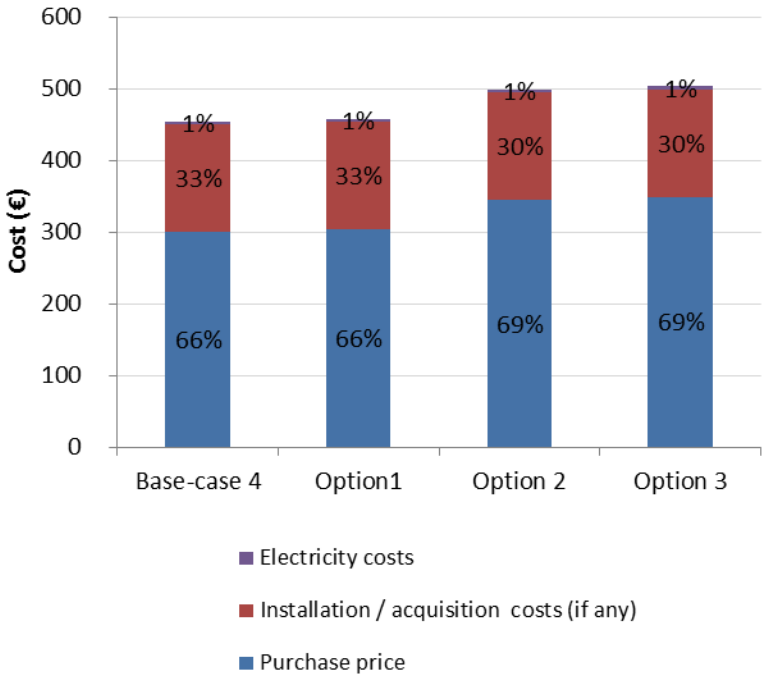


Figure 7-7: Life cycle costs of the improvement options for BC4

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

Figure 7-8 shows the comparison between LCC and the primary energy consumption for BC4 and the design options. For this base-case, the combination of options 1+2 is the BAT, achieving 4% energy savings, but has an increase of 11% in life cycle costs. The LLCC is the base-case although the cost reduction compared to option 1 is only 1%.

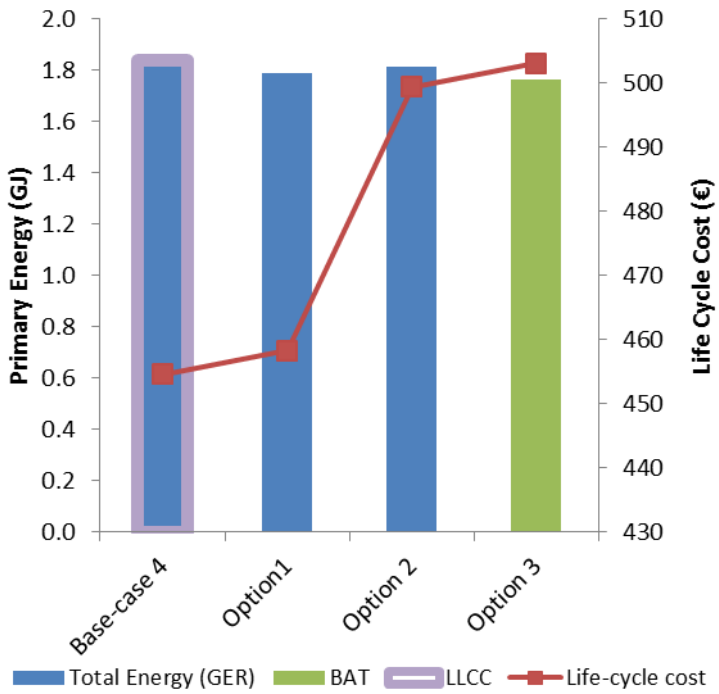


Figure 7-8: Identification of design improvement options with the least energy consumption and LLCC for BC4

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

7.2.5 Base-case 5: Submersible dewatering pump

The results of the environmental analysis of the different designs options for BC5 are presented in the Table 7-13. Option 1 and option 2 respectively provide reductions in the environmental impacts compared to the base-case and total energy reductions equal to 5% but it is the combination of options 1+2 that allows the highest reduction of environmental impacts and consumer expenditure over the life cycle.

Table 7-13: Environmental impacts of the BC5 and its improvement options

Life-Cycle indicators per unit	Unit	Base-case 5	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	1 107.1	1 051.9	1 051.9	996.8
	% change with BC	0%	-5%	-5%	-10%
Of which, electricity	Primary GJ	1 102.8	1 047.7	1 047.7	992.6
	Final MWh	105.0	99.8	99.8	94.5
	% change with BC	0%	-5%	-5%	-10%
Water (process)	Kg SO2 eq.	73.5	69.9	69.9	66.2
	% change with BC	0%	-5%	-5%	-10%
Water (cooling)	Kg SO2 eq.	2 940.1	2 793.1	2 793.1	2 646.1
	% change with BC	0%	-5%	-5%	-10%
Waste, non-haz./ landfill	Kg SO2 eq.	1 547.8	1 483.9	1 483.9	1 420.0
	% change with BC	0%	-4%	-4%	-8%
Waste, hazardous/ incinerated	Kg SO2 eq.	25.9	24.6	24.6	23.3
	% change with BC	0%	-5%	-5%	-10%
Greenhouse Gases in GWP100	Kg SO2 eq.	48.4	46.0	46.0	43.6
	% change with BC	0%	-5%	-5%	-10%
Acidification, emissions	Kg SO2 eq.	287.9	273.7	273.7	259.5
	% change with BC	0%	-5%	-5%	-10%
Volatile Organic Compounds (VOC)	kg	0.4	0.4	0.4	0.4
	% change with BC	0%	-5%	-5%	-9%
Persistent Organic Pollutants (POP)	µg i-Teq	8.2	7.8	7.8	7.5
	% change with BC	0%	-4%	-4%	-9%
Heavy Metals to air	g Ni eq.	19.8	18.8	18.8	17.9
	% change with BC	0%	-5%	-5%	-10%

Life-Cycle indicators per unit	Unit	Base-case 5	Option 1	Option 2	Option 3
PAHs	g Ni eq.	2.5	2.4	2.4	2.3
	% change with BC	0%	-4%	-4%	-9%
Particulate Matter (PM, dust)	kg	9.4	9.1	9.1	8.8
	% change with BC	0%	-3%	-3%	-6%
Heavy Metals to water	g Hg/20	7.3	7.0	7.0	6.6
	% change with BC	0%	-5%	-5%	-10%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0
	% change with BC	0%	-4%	-4%	-9%
Life-cycle cost	€	18 369.4	17 899.7	18 075.9	17 606.3
	% change with BC	0%	-3%	-2%	-4%

Design improvement options

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

Figure 7-9 shows the share of different life cycle costs throughout the life cycle of BC5 and the design options. For all cases, the electricity costs have the highest share (between 51% and 48% of the total). The purchase prices and maintenance costs are the second largest contributors to the LCC. Installation costs have an impact of only 1% throughout the life cycle of BC5 and the design options.

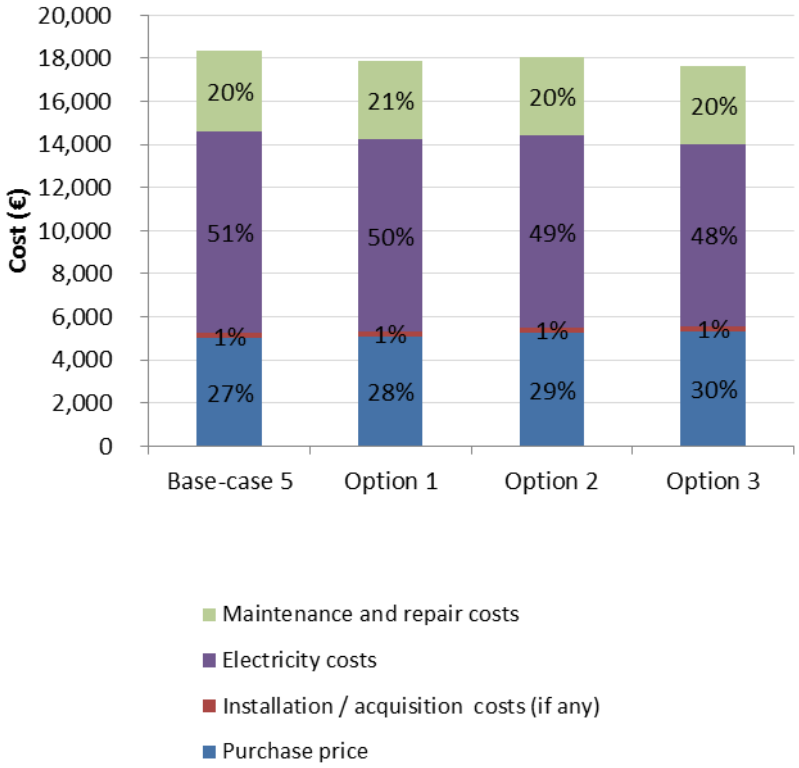


Figure 7-9: Life cycle costs of the improvement options for BC5

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

Figure 7-10 shows the comparison between LCC and the primary energy consumption for BC5 and the design options. For this base-case, the combination of options 1+2 is the BAT as well as the LLCC, achieving 10% energy savings and a reduction of 4% in life cycle costs compared to the base-case.

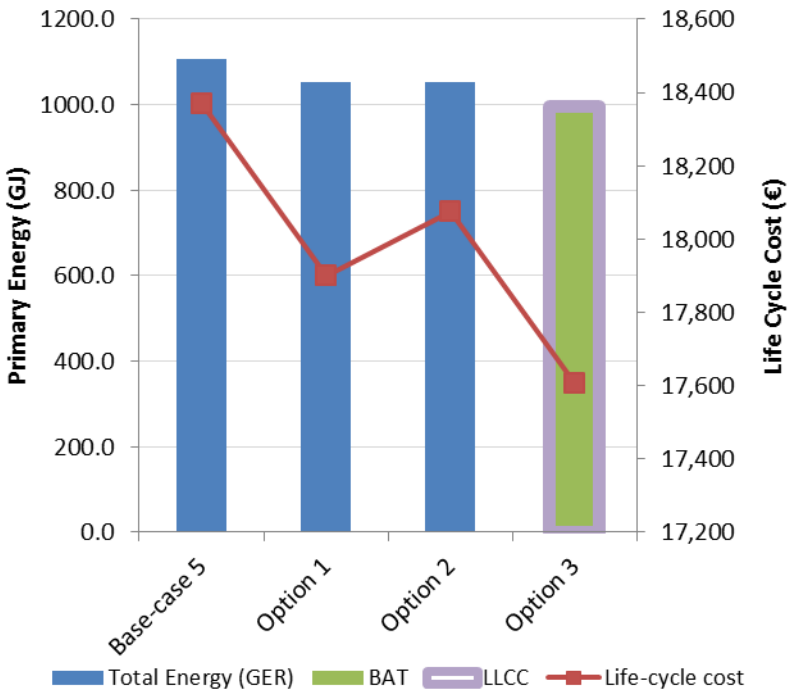


Figure 7-10: Identification of design improvement options with the least energy consumption and LLCC for BC5

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

7.2.6 Base-case 6: Centrifugal well pump

The results of the environmental analysis of the different designs options for BC6 are presented in Table 7-14. Option 3 provides reductions in the environmental impacts compared to the base-case and primary energy reduction of 4% but it is the combination of options 1+2+3that allows the highest reduction of environmental impacts and consumer expenditures over the life cycle.

Table 7-14: Environmental impacts of the BC6 and its improvement options

Life-Cycle indicators per unit	Unit	Base-case 6	Option 1	Option 2	Option 3	Option 4
Total Energy (GER)	GJ	1973.3	1933.9	1929.9	1894.5	1811.8
	% change with BC	0%	-2%	-2%	-4%	-8%
Of which, electricity	Primary GJ	1969.9	1930.5	1926.5	1891.1	1808.4
	Final MWh	187.6	183.9	183.5	180.1	172.2
	% change with BC	0%	-2%	-2%	-4%	-8%
Water (process)	Kg SO2 eq.	131.6	129.0	128.7	126.4	120.9
	% change with BC	0%	-2%	-2%	-4%	-8%
Water (cooling)	Kg SO2 eq.	5252.5	5147.5	5137.0	5042.5	4821.9
	% change with BC	0%	-2%	-2%	-4%	-8%
Waste, non-haz./ landfill	Kg SO2 eq.	2339.0	2293.3	2288.7	2247.6	2151.7
	% change with BC	0%	-2%	-2%	-4%	-8%
Waste, hazardous/ incinerated	Kg SO2 eq.	46.5	45.6	45.5	44.7	42.8
	% change with BC	0%	-2%	-2%	-4%	-8%
Greenhouse Gases in GWP100	Kg SO2 eq.	86.2	84.5	84.3	82.8	79.2
	% change with BC	0%	-2%	-2%	-4%	-8%
Acidification, emissions	Kg SO2 eq.	507.9	497.8	496.7	487.6	466.3
	% change with BC	0%	-2%	-2%	-4%	-8%
Volatile Organic Compounds (VOC)	kg	0.8	0.8	0.8	0.7	0.7
	% change with BC	0%	-2%	-2%	-4%	-8%
Persistent Organic Pollutants (POP)	µg i-Teq	13.7	13.5	13.4	13.2	12.7
	% change with BC	0%	-2%	-2%	-4%	-8%
Heavy Metals to air	g Ni eq.	34.3	33.6	33.5	32.9	31.5

Life-Cycle indicators per unit	Unit	Base-case 6	Option 1	Option 2	Option 3	Option 4
	% change with BC	0%	-2%	-2%	-4%	-8%
PAHs	g Ni eq.	3.9	3.8	3.8	3.8	3.6
	% change with BC	0%	-2%	-2%	-4%	-8%
Particulate Matter (PM, dust)	kg	16.3	16.1	16.1	15.9	15.4
	% change with BC	0%	-1%	-1%	-3%	-5%
Heavy Metals to water	g Hg/20	12.9	12.6	12.6	12.4	11.8
	% change with BC	0%	-2%	-2%	-4%	-8%
Eutrophication	Kg PO_4	0.1	0.1	0.1	0.1	0.1
	% change with BC	0%	-2%	-2%	-3%	-7%
Life-cycle cost	€	29,258.5	28,830.2	28,914.3	29,403.6	28,631.2
	% change with BC	0%	-1%	-1%	0%	-2%

Design improvement options

Option 1 (OP1)	Option 2 (OP2)	Option 3 (OP3)	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	OP1+OP2+OP3

Figure 7-11 shows he share of different life cycle costs throughout the life cycle of BC6 and the design options. For all cases, the electricity costs have the highest share (between 49% and 52% of the total). The maintenance and repair costs are the second largest contributor to the LCC with a share of 29%- 31% respectively. Installations costs and have comparatively little impacts throughout the life cycle of BC6 and the design options.

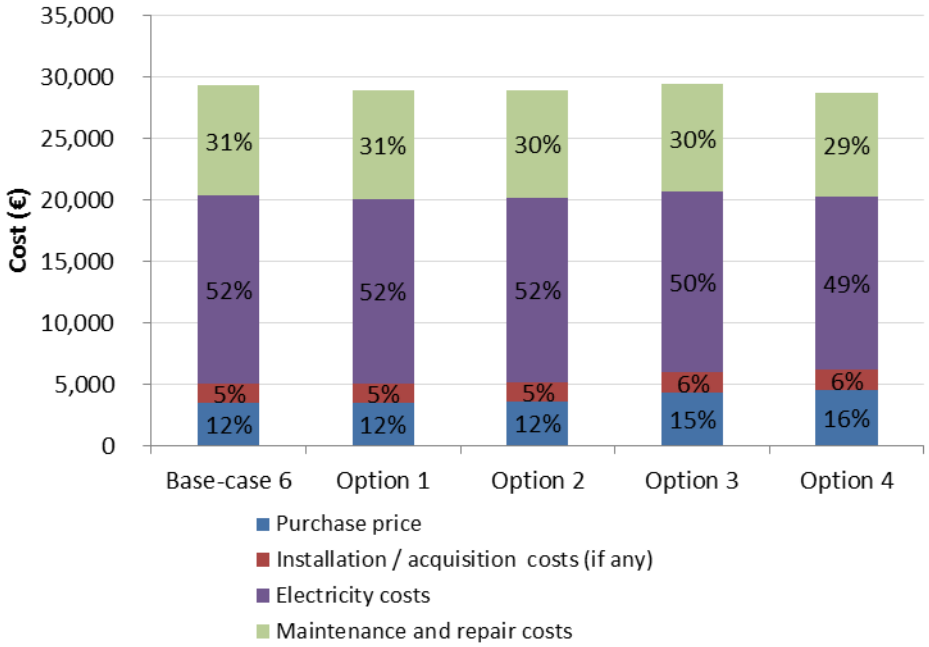


Figure 7-11: Life cycle costs of the improvement options for BC6

Option 1 (OP1)	Option 2 (OP2)	Option 3 (OP3)	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	OP1+OP2+OP3

Figure 7-12 presents the comparison between LCC and the primary energy consumption for BC6 and the design options. The combination option 4 is the BAT as well as the LLCC, achieving 8% energy savings and a reduction of 2% in life cycle costs compared to the base-case.

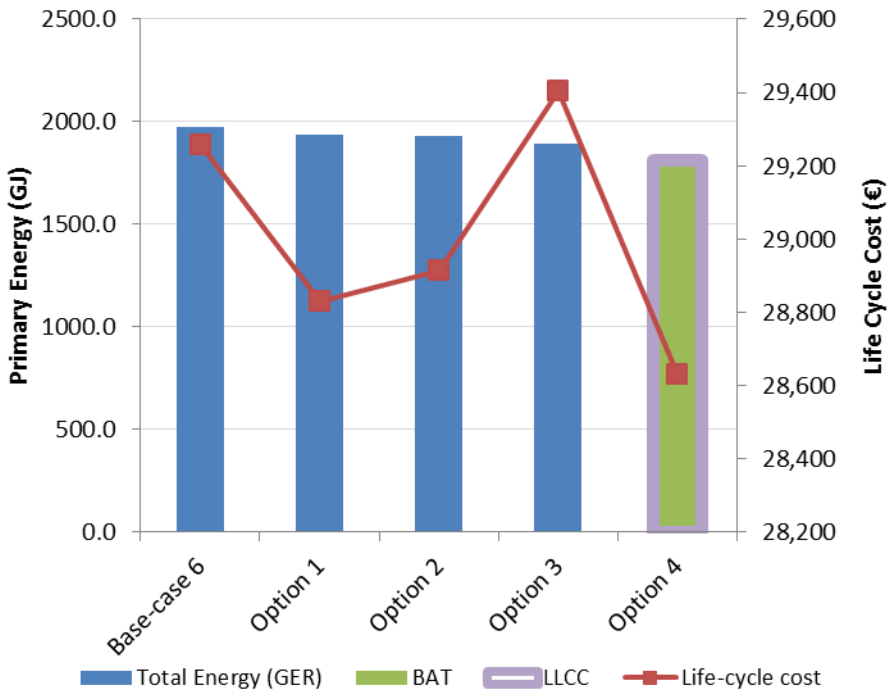


Figure 7-12: Identification of design improvement options with the least energy consumption and LLCC for BC6

Option 1 (OP1)	Option 2 (OP2)	Option 3 (OP3)	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	OP1+OP2+OP3

7.2.7 Base-case 7A: Slurry pumps: Light duty

The results of the environmental analysis of the different designs options for BC7A are presented in Table 7-15. The combination of options 1+2, option 3 provides highest reductions in environmental impacts compared to the base-case and a total energy reduction of 3%. Option 3 also displays the LLCC with a 2% reduction compared to the LCC of the base-case.

Table 7-15: Environmental impacts of the BC7A and its improvement options

Life-Cycle indicators per unit	Unit	Base-case 7A	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	34 161.7	33 820.5	33 479.2	33 138.0
	% change with BC	0%	-1%	-2%	-3%
Of which, electricity	Primary GJ	34 134.3	33 793.1	33 451.8	33 110.6
	Final MWh	3 250.9	3 218.4	3 185.9	3 153.4
	% change with BC	0%	-1%	-2%	-3%
Water (process)	Kg SO2 eq.	2 280.9	2 258.2	2 235.4	2 212.7
	% change with BC	0%	-1%	-2%	-3%
Water (cooling)	Kg SO2 eq.	91 003.3	90 093.3	89 183.3	88 273.3
	% change with BC	0%	-1%	-2%	-3%
Waste, non-haz./ landfill	Kg SO2 eq.	40 180.8	39 785.1	39 389.5	38 993.8
	% change with BC	0%	-1%	-2%	-3%
Waste, hazardous/ incinerated	Kg SO2 eq.	786.5	778.7	770.8	762.9
	% change with BC	0%	-1%	-2%	-3%
Greenhouse Gases in GWP100	Kg SO2 eq.	1 491.7	1 476.8	1 461.9	1 447.0
	% change with BC	0%	-1%	-2%	-3%
Acidification, emissions	Kg SO2 eq.	8 794.6	8 706.7	8 618.8	8 531.0
	% change with BC	0%	-1%	-2%	-3%
Volatile Organic Compounds (VOC)	kg	13.1	12.9	12.8	12.7
	% change with BC	0%	-1%	-2%	-3%
Persistent Organic Pollutants (POP)	µg i-Teq	232.3	230.1	227.9	225.6
	% change with BC	0%	-1%	-2%	-3%
Heavy Metals to air	g Ni eq.	589.8	583.9	578.1	572.2
	% change with BC	0%	-1%	-2%	-3%

Life-Cycle indicators per unit	Unit	Base-case 7A	Option 1	Option 2	Option 3
PAHs	g Ni eq.	67.4	66.8	66.1	65.4
	% change with BC	0%	-1%	-2%	-3%
Particulate Matter (PM, dust)	kg	220.4	218.5	216.6	214.7
	% change with BC	0%	-1%	-2%	-3%
Heavy Metals to water	g Hg/20	221.8	219.6	217.4	215.2
	% change with BC	0%	-1%	-2%	-3%
Eutrophication	Kg PO_4	1.1	1.1	1.1	1.1
	% change with BC	0%	-1%	-2%	-3%
Life-cycle cost	€	268 313.9	266 679.1	264 447.6	262 812.8
	% change with BC	0%	-1%	-1%	-2%

Design improvement options

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

Figure 7-13 shows the share of different life cycle costs throughout the life cycle of BC7A and the design options. For all cases, the electricity costs have the highest share (82% -83% of the total). The purchase prices and maintenance costs are the second largest contributors to the LCC with between 7% - 8% of the share. Both installations costs have very little impact throughout the life cycle of BC7A and the design options.

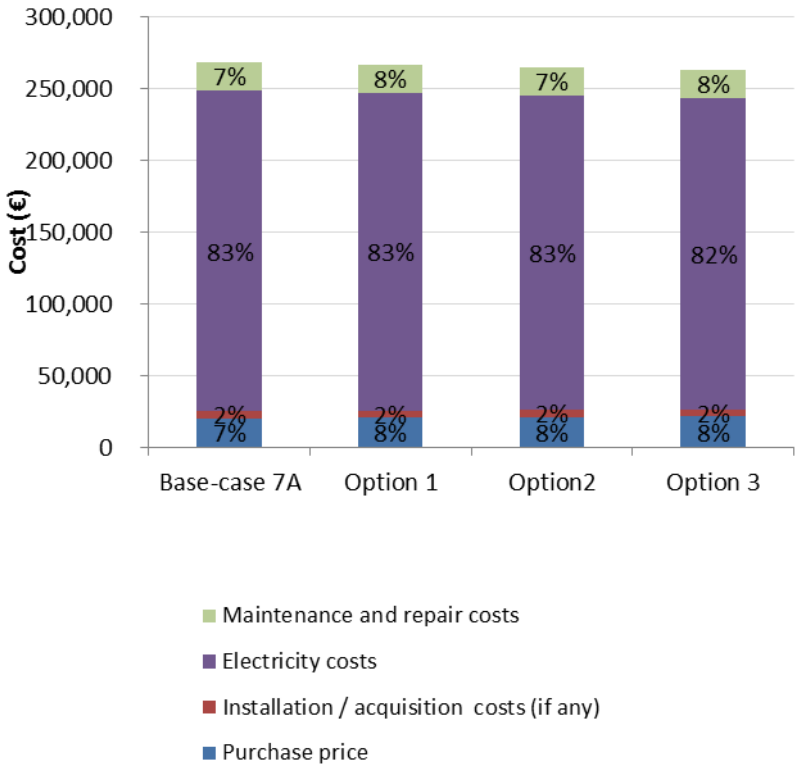


Figure 7-13: Life cycle costs of the improvement options for BC7A

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

Figure 7-14 presents the comparison between LCC and the primary energy consumption for BC7A and the design options. The combination option 3 appears as the BAT and the LLCC, with energy savings of 3% and reduction of the LLC of 2% compared to the base-case.

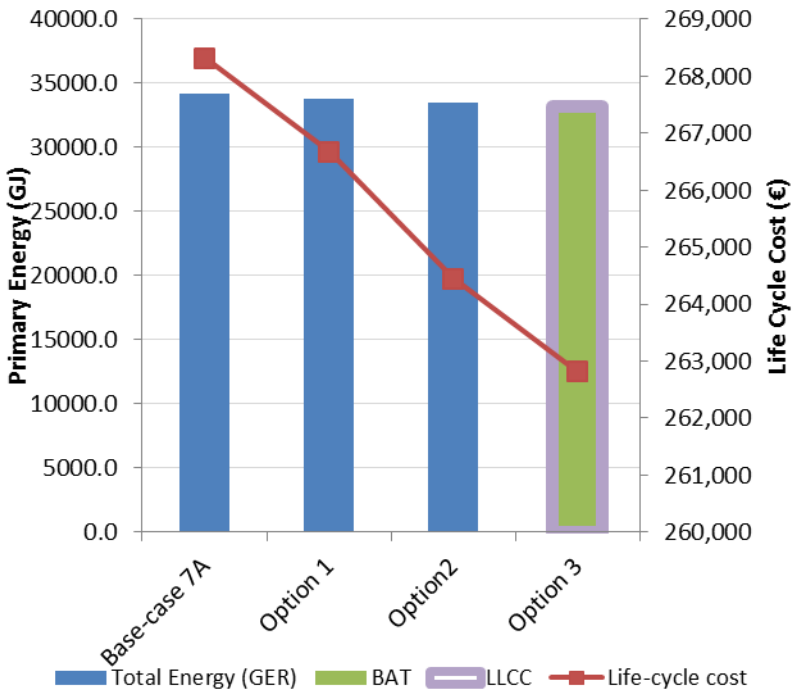


Figure 7-14: Identification of design improvement options with the least energy consumption and LLCC for BC7A

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

7.2.8 Base-case 7B: Slurry pumps: Heavy duty

The results of the environmental analysis of the different design options for BC7B are presented in the Table 7-16. As demonstrated for BC7A, the combination option 3, provides the highest reductions in the environmental impacts compared to the base-case and a reduction in the total energy share of 3%. But also both option 1 and option 2 show environmental improvements respectively compared to the base-case.

Table 7-16: Environmental impacts of the BC7B and its improvement options

Life-Cycle indicators per unit	Unit	Base-case 7B	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	15 655.4	15 500.0	15 344.6	15 189.2
	% change with BC	0%	-1%	-2%	-3%
Of which, electricity	Primary GJ	15 550.2	15 394.8	15 239.4	15 084.0
	Final MWh	1 481.0	1 466.2	1 451.4	1 436.6
	% change with BC	0%	-1%	-2%	-3%
Water (process)	Kg SO_2 eq.	1 044.4	1 034.1	1 023.7	1 013.4
	% change with BC	0%	-1%	-2%	-3%
Water (cooling)	Kg SO_2 eq.	41 465.1	41 050.7	40 636.3	40 221.9
	% change with BC	0%	-1%	-2%	-3%
Waste, non-haz./ landfill	Kg SO_2 eq.	20 692.7	20 512.5	20 332.3	20 152.2
	% change with BC	0%	-1%	-2%	-3%
Waste, hazardous/ incinerated	Kg SO_2 eq.	358.1	354.5	351.0	347.4
	% change with BC	0%	-1%	-2%	-3%
Greenhouse Gases in GWP100	Kg SO_2 eq.	688.1	681.3	674.5	667.7
	% change with BC	0%	-1%	-2%	-3%
Acidification, emissions	Kg SO_2 eq.	4 030.1	3 990.1	3 950.1	3 910.1
	% change with BC	0%	-1%	-2%	-3%
Volatile Organic Compounds (VOC)	kg	6.8	6.7	6.6	6.6
	% change with BC	0%	-1%	-2%	-3%
Persistent Organic Pollutants (POP)	µg i-Teq	143.8	142.8	141.8	140.8
	% change with BC	0%	-1%	-1%	-2%
Heavy Metals to air	g Ni eq.	288.2	285.5	282.9	280.2
	% change with BC	0%	-1%	-2%	-3%

Life-Cycle indicators per unit	Unit	Base-case 7B	Option 1	Option 2	Option 3
PAHs	g Ni eq.	30.9	30.6	30.3	30.0
	% change with BC	0%	-1%	-2%	-3%
Particulate Matter (PM, dust)	kg	222.5	221.6	220.7	219.9
	% change with BC	0%	0%	-1%	-1%
Heavy Metals to water	g Hg/20	108.6	107.6	106.6	105.6
	% change with BC	0%	-1%	-2%	-3%
Eutrophication	Kg PO_4	0.8	0.8	0.8	0.8
	% change with BC	0%	-1%	-1%	-2%
Life-cycle cost	€	146 649.1	146 231.0	145 216.2	144 798.0
	% change with BC	0%	0%	-1%	-1%

Design improvement options

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

Figure 7-15 shows the share of different life cycle costs throughout the life cycle of BC7B and the design options. For all cases, the electricity costs have the highest share (68% - 69% of the total). The purchase price and maintenance costs are the second largest contributor to the LCC with a share of around 14%.

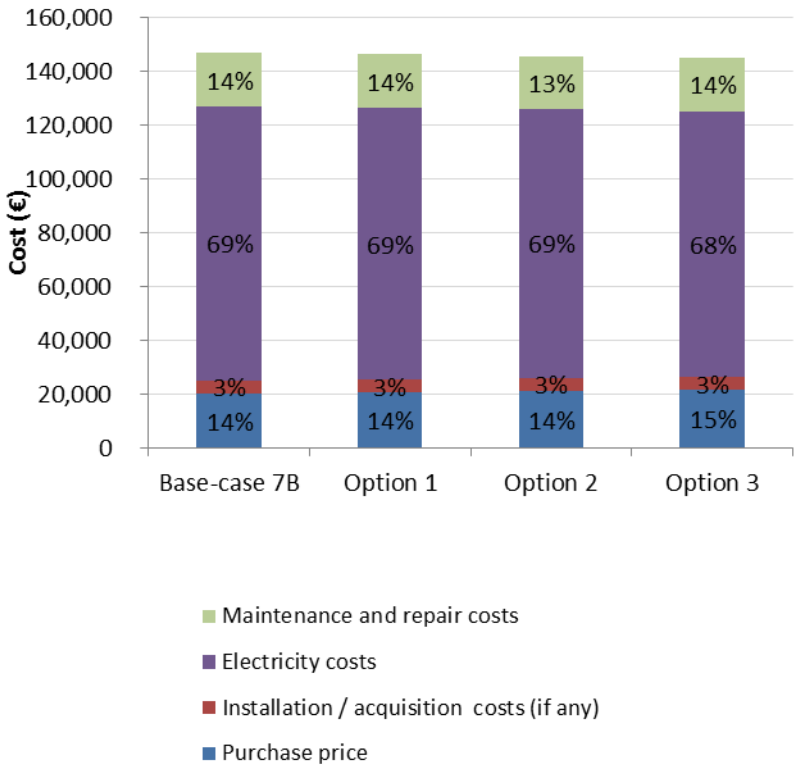


Figure 7-15: Life cycle costs of the improvement options for BC7B

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

Figure 7-16 presents the comparison between LCC and the primary energy consumption for BC7B and the design options. The option 3 appears to be the BAT and the LLCC with a reduction of 1% of the life cycle cost.

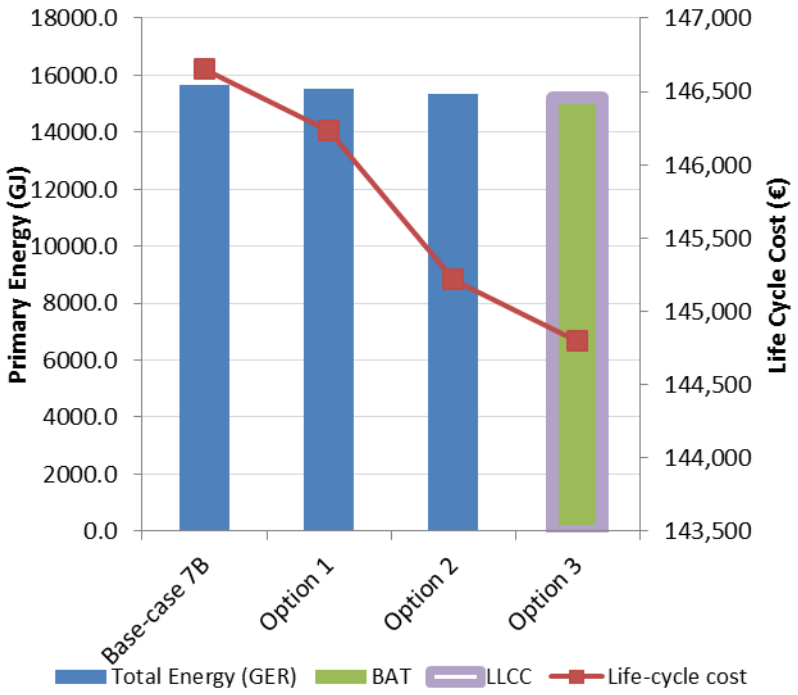


Figure 7-16: Identification of design improvement options with the least energy consumption and LLCC for BC7B

Option 1 (OP1)	Option 2 (OP2)	Option 3
Pump/hydraulic improvements	Motor improvements	OP1+OP2

7.3 BNAT and long-term systems analysis

Pumps, including wastewater pumps, are a very well established product that has been refined for several hundred years, and, therefore, there are just minor things that can be considered for the Best Not yet Available Technology (BNAT). There will inevitably be small improvements in efficiency as computational fluid dynamics allows more experimentation and refinement to take place in the design process, and also because closer manufacturing tolerances become feasible.

Any significant improvements in the energy associated with wastewater pumping are likely to be achieved through the use of integrated controls for several pumps in a wastewater collection system at a network level. Controlling several pumps together could potentially reduce the peaks in flow rate that are currently observed by holding some flow back to off-peak periods, thereby reducing the dynamic friction losses in the rising mains. As these types of control improvements are achieved at a network level, and not at a product level, they are beyond the scope of this study.

7.4 Conclusions

Several improvement options are available for each base-case, with different payback periods and a small number of constraints. Combinations of these improvement options (which forms the basis of extended product approach) provide potential for significant energy savings, leading to the minimisation of negative environmental impacts.

In terms of potential energy savings, all three improvement options offer different prospects depending on the respective base-cases. Whereas motor improvements and some pump/hydraulic improvements, which include: improved case geometry, surface friction reduction, leakage reduction and improved impeller efficiency, are applicable to all base-cases, VSD[10] is only feasible for BC1, BC2 and BC6.

Motor improvements alone, seem to offer the biggest potential energy consumption savings that range from 4% to 6.7%. The savings achieved by VSD range from 3.4% to 6% for the pumps which these improvements can be implemented on[10]. However, a combination of pump/hydraulic improvements yields 10% energy savings for BC4 and savings range between 1-5% for all other base-cases.

In terms of investments payback period, the following base-cases offer the shortest payback periods (around 2 years) for all of their design improvement options

- Base-case 2: Centrifugal submersible pump - mixed flow & axial pumps
- Base-case 5: Submersible dewatering pumps
- Base-case 6: Centrifugal dry well pump

Unlike all other improvement options, hydraulic improvement requires no significant additional investments and is applicable to all base-cases. However, the payback time of hydraulic improvements varies widely between the different base-cases, from less than 1 year (BC 1, BC2, BC3, BC5 and BC6) to not ever generating returns on investments (BC4, BC7A and BC7B). Although motor improvement is the options that offer biggest energy savings for all base – cases except for BC4, payback time is longer. For VSD, which is applicable for three base-cases (BC1, BC2 and BC6), the payback time is low for BC2 and BC6 (0.32 and 2,6 years, respectively) but too high to justify investments for BC1. .

The results show that throughout all the base-cases, the BAT is always a combination of several improvement options. A combination of all options considered is the BAT for all the base-cases.

The following results were obtained for LLCC. In three base-cases (BC1, BC3 and BC4), the option with LLCC is not the combination of all improvement options. For BC1 motor improvements is the LLCC option. For both BC3 and BC4 on the other hand, the LLCC is associated with no improvement option at all, but with the base case itself.

[10] Please note that the VSD technology only provides a benefit in applications where variable speed is needed. Some pump applications would not benefit from this option if they only operate at full speed.

For the remaining five base-cases, the LLCC is a combination of all the independent improvement options. For these five base-cases the LLCC is therefore the same as the BAT.

Currently, not available improvement options have a potential to become more affordable over the coming years. This is the case for the use of integrated controls for several pumps in wastewater collection system at a network level.

Hence, steadily increasing levels of energy efficiency can be achieved without significant additional economic impacts. These results will be discussed in context of potential policy measures in Task 8.



02 April 2014

185 avenue Charles de Gaulle
92200 Neuilly-sur-Seine
France
+ 33 (0) 5561 6755
www.bio.deloitte.fr

Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 28– Pumps for private and public wastewater and for fluids with high solids content – Task 8: Scenario, policy, impact and sensitivity analysis

Final report to the European Commission, DG ENER
02 April 2014



European Commission

Developed by:

bio by Deloitte.

Document information

CLIENT	European Commission, DG ENER
CONTRACT NUMBER	ENER/C3/403/2010
REPORT TITLE	ENER Lot 28– Pumps for private and public wastewater and for fluids with high solids content – Task 8: Scenario, policy, impact and sensitivity analysis
PROJECT NAME	Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC
PROJECT CODE	ENER Lot 28
PROJECT TEAM	Bio by Deloitte, Atkins
DATE	02 April 2014
AUTHORS	Mr. Sandeep Pahal , Bio by Deloitte Mr. Benoît Tinetti, Bio by Deloitte Mr. Shailendra Mudgal, Bio by Deloitte Mr. Alvaro de Prado Trigo, Bio by Deloitte Dr. Hugh Falkner, Atkins Mr. Keeran Jugdoyal, Atkins
KEY CONTACTS	Mr. Sandeep Pahal spahal@bio.deloitte.fr Or Mr. Shailendra Mudgal shmudgal@bio.deloitte.fr
DISCLAIMER	The project team does not accept any liability for any direct or indirect damage resulting from the use of this report or its content. This report contains the results of research by the authors and is not to be perceived as the opinion of the European Commission.

Please cite this publication as:
Bio by Deloitte (2014), Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC, ENER Lot 28– Pumps for private and public wastewater and for fluids with high solids content – Task 8: Scenario, policy, impact and sensitivity analysis prepared for European Commission, DG ENER

Photo credit: cover @ Per Ola Wiberg
© Bio by Deloitte 2014

Table of Contents

8.1 Introduction 9
8.2 Policy analysis 9
8.3 Scenario analysis 24
8.3.1 Type of scenarios considered 24
8.3.2 Inputs to scenario analysis tool 26
8.3.3 Comparison of scenarios 30
8.4 Impact analysis 41
8.4.1 Impacts on manufacturer and competition 41
8.4.2 Impact on consumers 43
8.4.3 Impacts on innovation and development 43
8.4.4 Social impacts 44
8.5 Sensitivity analysis 44
8.6 Conclusions 69

This page is left intentionally blank

List of Tables

Table 8-1: Contribution of each Base-Case to the overall "product level" and "extended product level" energy savings potential of ENER Lot 28 pumps (in 2011) 13

Table 8-2: Task 7 data used as the basis of MEI calculation for Lot 28 pumps 18

Table 8-3: MEI values to be used for Lot 28 pumps considered for specific ecodesign requirements 20

Table 8-4: Proposed cut-off scenarios 25

Table 8-5: Improvement of worst performing pumps due to MEI requirements, for different levels of market response 26

Table 8-6: The energy and economic inputs for the policy option scenarios 28

List of Figures

Figure 8-1: Total annual electricity consumption savings (in GWh) for BC 1 across four key years for the 12 policy option scenarios 31

Figure 8-2: Total annual electricity consumption savings (in GWh) for BC 2 across four key years for the 12 policy option scenarios 32

Figure 8-3: Total annual electricity consumption savings (in GWh) for BC 4 across four key years for the 12 policy option scenarios 33

Figure 8-4: Total annual electricity consumption savings (in GWh) for BC 5 across four key years for the 12 policy option scenarios 34

Figure 8-5: Total annual electricity consumption savings (in GWh) for BC 6 across four key years for the 12 policy option scenarios 35

Figure 8-6: Total annual electricity consumption savings (in GWh) for BC 7A across four key years for the 12 policy option scenarios 36

Figure 8-7: Total annual electricity consumption savings (in GWh) for all selected Base-Cases (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) across four key years for the 12 policy option scenarios 36

Figure 8-8: Total annual consumer expenditure reduction (in Million Euros) for BC 1 across four key years for the 12 policy option scenarios 37

Figure 8-9: Total annual consumer expenditure reduction (in Million Euros) for BC 2 across four key years for the 12 policy option scenarios 38

Figure 8-10: Total annual consumer expenditure reduction (in Million Euros) for BC 4 across four key years for the 12 policy option scenarios 38

Figure 8-11: Total annual consumer expenditure reduction (in Million Euros) for BC 5 across four key years for the 12 policy option scenarios 39

Figure 8-12: Total annual consumer expenditure reduction (in Million Euros) for BC 6 across four key years for the 12 policy option scenarios 39

Figure 8-13: Total annual consumer expenditure reduction (in Million Euros) for BC 7A across four key years for the 12 policy option scenarios 40

Figure 8-14: Total annual consumer expenditure reduction (in Million Euros) for all selected Base-Cases (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) across four key years for the 12 policy option scenarios 40

Figure 8-15: Sensitivity analysis of total electricity consumption to product lifetime for BC 1 47

Figure 8-16: Sensitivity analysis of life cycle cost to product lifetime for BC 1 47

Figure 8-17: Sensitivity analysis of total electricity consumption to product lifetime for BC 2 48

Figure 8-18: Sensitivity analysis of life cycle cost to product lifetime for BC 2 48

Figure 8-19: Sensitivity analysis of total electricity consumption to product lifetime for BC 4 49

Figure 8-20: Sensitivity analysis of life cycle cost to product lifetime for BC 4 49

Figure 8-21: Sensitivity analysis of total electricity consumption to product lifetime for BC 5 50

Figure 8-22: Sensitivity analysis of life cycle cost to product lifetime for BC 5 50

Figure 8-23: Sensitivity analysis of total electricity consumption to product lifetime for BC 6 51

Figure 8-24: Sensitivity analysis of life cycle cost to product lifetime for BC 6 51

Figure 8-25: Sensitivity analysis of total electricity consumption to product lifetime for BC 7A 52

Figure 8-26: Sensitivity analysis of life cycle cost to product lifetime for BC 7A 52

Figure 8-27: Sensitivity analysis of total electricity consumption to product lifetime for All BCs 53

Figure 8-28: Sensitivity analysis of life cycle cost to product lifetime for All BCs 53

Figure 8-29: Sensitivity analysis of life cycle cost to product price for BC 1 54

Figure 8-30: Sensitivity analysis of life cycle cost to product price for BC 2 54

Figure 8-31: Sensitivity analysis of life cycle cost to product price for BC 4 55

Figure 8-32: Sensitivity analysis of life cycle cost to product price for BC 5 55

Figure 8-33: Sensitivity analysis of life cycle cost to product price for BC 6 56

Figure 8-34: Sensitivity analysis of life cycle cost to product price for BC 7A 56

Figure 8-35: Sensitivity analysis of life cycle cost to product price for All BCs 57

Figure 8-36: Sensitivity analysis of total electricity consumption to sales growth rate for BC 1 58

Figure 8-37: Sensitivity analysis of life cycle cost to sales growth rate for BC 1 58

Figure 8-38: Sensitivity analysis of total electricity consumption to sales growth rate for BC 2 59
Figure 8-39: Sensitivity analysis of life cycle cost to sales growth rate for BC 2 59
Figure 8-40: Sensitivity analysis of total electricity consumption to sales growth rate for BC 4 60
Figure 8-41: Sensitivity analysis of life cycle cost to sales growth rate for BC 4 60
Figure 8-42: Sensitivity analysis of total electricity consumption to sales growth rate for BC 5 61
Figure 8-43: Sensitivity analysis of life cycle cost to sales growth rate for BC 5 61
Figure 8-44: Sensitivity analysis of total electricity consumption to sales growth rate for BC 6 62
Figure 8-45: Sensitivity analysis of life cycle cost to sales growth rate for BC 6 62
Figure 8-46: Sensitivity analysis of total electricity consumption to sales growth rate for BC 7A 63
Figure 8-47: Sensitivity analysis of life cycle cost to sales growth rate for BC 7A 63
Figure 8-48: Sensitivity analysis of total electricity consumption to sales growth rate for All BCs64
Figure 8-49: Sensitivity analysis of life cycle cost to sales growth rate for All BCs 64
Figure 8-50: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 1 65
Figure 8-51: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 2 65
Figure 8-52: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 4 66
Figure 8-53: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 5 66
Figure 8-54: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 6 67
Figure 8-55: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 7A 67
Figure 8-56: Sensitivity analysis of life cycle cost to maintenance and repair cost for All BCs 68

This page is left intentionally blank.

Chapter 8: Task 8: Scenario, policy, impact and sensitivity analysis

8.1 Introduction

This task summarises the outcomes of all previous tasks and tries to identify a suitable policy, which will allow achieving reduction of environmental impacts with consideration to energy savings and reduction in Life Cycle Cost (LCC). Some scenarios analyses allow examining and quantifying the energy and LCC savings for the period of 2013-2040.

Although Tasks 1-7 set the foundations for future work to be carried out by the European Commission, Task 8 presents a summary of policies that the authors of the report believe to be of use in order to achieve the desired reduction of the environmental impacts of Lot 28 pumps. A sensitivity analysis on some of the key parameters is carried out in order to examine the robustness of the results.

Note that the preliminary policy discussions are the opinions of the consultants and do not reflect the views of the European Commission.

8.2 Policy analysis

In this section on policy analysis, policy options are identified considering the outcomes of all previous tasks. They are based on the definition of the product, according to Task 1 and modified/ confirmed by the other tasks. Specific recommendations to the pumps covered by the Lot 28 study are detailed in the following sub-sections.

8.2.1 Caveat

Some of the options considered in this section require the conversion of electricity into primary energy. For that purpose, the conversion factor of 2.5 used is derived from Annex II of the Energy Service Directive (2006/32/EC), reflecting the estimated 40% average EU generation efficiency. This factor is also used in other Ecodesign preparatory studies including the DG ENER Lot 11 and Lot 29 studies on clean water pumps.

Please note that all other primary energy consumption values presented in this study (Task 5, Task 7 and in the other sections of Task 8) were calculated using the EcoReport tool, as required by the European Commission to undertake the cost and environmental impact analysis in Ecodesign preparatory studies.

8.2.2 Scope and product definitions

This preparatory study examined a very wide range of pumps commonly used to handle wastewater (WW) and solids. The primary function of ENER Lot 28 pumps is to pump the three main types of WW (urban WW, domestic WW and industrial WW as earlier defined in Task 1). The WW properties are important as the Lot 28 pumps are required to pump fluids with a range of per cent dry solids content, solids sizes, fibre length, hardness of solid, temperature, corrosive chemical content and viscosity.

As ENER Lot 30 deals with (all) motors (other than the ones already covered by Lot 11 preparatory study), it would be appropriate to cover all the motors used by ENER Lot 28 pumps, including the ones used in submersible pumps within the scope of ENER Lot 30 Implementing Measure. This would create clear and precise borderlines for the legislative scope of ecodesign of motors thus allowing timely taking into account of energy efficiency issue of submersible sewage pumps, in parallel in ENER Lot 28 study. Such procedure also follows the Extended Product Approach - created by EUROPUMP[1].

The following types of pumps are proposed to be included within the scope of the ENER Lot 28 study (with an upper power limit of 160 kW):

- Centrifugal submersible pumps
  - Radial sewage, mixed flow and axial flow
  - Once a day operation centrifugal submersible pump (shredding, grinding, radial sewage and where volute is part of tank)
  - Domestic drainage < 40 mm passage centrifugal submersible pump
  - Dewatering centrifugal submersible pump
- Centrifugal dry well pumps
  - Radial sewage centrifugal dry well pumps
  - Mixed flow centrifugal dry well pumps
  - Axial pumps centrifugal dry well pumps
- Slurry pumps
  - Light duty slurry pumps
  - Heavy duty slurry pumps

Centrifugal submersible pumps

A submersible pump consists of an electric motor and pump, which is sealed into a single unit and submersed in the media being pumped. These pumps are typically found in wastewater networks, as the submersed concept has a small visual impact and allows a narrow and simplified

[1] It was agreed in the 3rd stakeholder meeting to consider the motors of submersible pumps under the scope of ENER Lot 30 study instead of ENER Lot 28 study. This means that the motors for Lot 28 submersible pumps will need to adhere to the energy efficiency requirements as proposed in ENER Lot 30 study.

pumping station design. As seen in Task 1, standard submersible wastewater pumps are commonly available from very small sizes up to 600-1000 kW and are designed for flow rates from about 4 l/s up to over 2000 l/s. Sizes on the upper end of this type, typically above 160 kW are usually designed as per customer's specifications ("engineered products"). The pumps included in the centrifugal submersible pumps and the centrifugal submersible dewatering pumps that are normally used to empty liquids holding abrasive solids in mines, quarries and construction sites. They are designed to be portable, to include a built in lifting handle to facilitate movement by hand or with a forklift, and to be able to stand alone on the ground with a hose or pipe connected to its discharge.

- **Centrifugal dry well pumps (non-submersible)**

The centrifugal dry well pumps comprise an easily separable coupled assembly of an electric motor and a pump which is located outside the pumped liquid. The centrifugal dry well pumps are available in similar sizes (up to 600-800 kW and from about 4 l/s up to over 1600 l/s) as the centrifugal submersible pumps. Sizes on the upper end of this type, typically above 160 kW are usually designed as per customer's specifications ("engineered products"). The centrifugal domestic drainage pumps are designed to lift wastewater and drainage into the local sewerage collection network.

- **Slurry pumps**

Slurry pumps are designed to pump heavy slurries, primarily in mining applications. They are therefore designed to handle high concentrations of fine solids that are often very abrasive. The overwhelming design goal of slurry pumps is to minimise wear. The features for increased efficiency usually drive down reliability. Slurry pumps have a big variety of material options, to cope with the abrasiveness and corrosive behaviour of the pump liquids. Manufacturers are offering more than 100 of these options, to guaranty an optimum performance and wear behaviour. The material options for manufacturing of these pumps are mostly within the range of:

- Steel or cast iron, which may contain high amounts of Chromium
- Ceramics of different kind
- Rubber liners

According to the pumped liquid/solids and conveying process, it is normal that slurry pumps are not selected at BEP (Best Efficiency Point), e.g. for heavy duty applications pumps are selected at 70 to 90% of BEP. Both light and heavy duty slurry pumps are therefore engineered for every duty to choose the optimum pump type, materials and performance.

During this preparatory study, several other pump types that are closely related to ENER Lot 28 pumps but are either not used for their primary functionality or are typically engineered (above 160 kW) were identified. These pump types are not considered for the ecodesign implementing measures proposed in this study. These pump types are listed below:

- **Progressive Cavity Pumps** are basically not designed for wastewater, but for heavy sludge. On this basis, they are excluded from scope.

- **Peristaltic pumps** are only used for sludge applications and very rarely in small number in engineered wastewater applications. These pumps are basically not designed for wastewater, but for heavy sludge. There is a small application overlap with Progressive Cavity pumps.
- **Rotary Lobe pumps** are used for pumping very delicate high viscosity products such as many foodstuffs, and again have design features for different types of product that would make setting a benchmark hard. Other similar positive displacement pumps which are not used for solids handling include **rotary vane pumps** and **gear pumps**.
- **Plunger and Piston pumps** are used for moving high viscosity product. The output of the pumps is not linear as there is nothing being pumped when the plunger/piston is retracting. These pumps are not typically used in the wastewater industry, as progressing cavity pumps provide the same solids handling capability but have a linear (non-pulsating) output.
- **Diaphragm pumps** are either compressed air driven or driven by electric motors, pumping slurries by alternately inflating two membranes. These are inherently inefficient, but are popular for example in the ceramics industry for clay pumping. These are excluded on the basis that they are used predominantly in highly viscous slurry applications, very different from the defined scope of the study.
- In addition, wastewater treatment (WWT) aeration plants have **turbo-blowers** and **surface mixers**, which are not strictly pumps, and so they are excluded from the scope of the study.
- **Tank mixers** are really a form of stirrer, and are used to prevent solids from settling in WWT tanks.
- **Archimedean screw pumps** are engineered products. These pumps have to be designed case by case for each wastewater plant individually. Typically, for these pumps, the screw is welded to sheet metal and the trough is individually formed from concrete in situ. They have a high resistance to blockages and ragging, this makes them very attractive where there is space for them to be installed. The devices are custom manufactured for each application. Their design has to take into account desired flow and given static head. In many cases, space availability at the installation site is a critical factor and determines slope, screw diameter, helix angle and speed. There is no standard product offering for these pumps, not even some kind of a modular system.
- **Paper and Pulp pumps** describe a large and diverse variety of pumps used in the paper manufacturing process. These are specifically designed to handle various stages of the paper making process, and will need to be able to handle hot fluids with varying solids content. These should though be excluded on the basis that the properties of hot paper and pulp fluids are very different from those of wastewater or other high solids content fluids.

8.2.3 Specific Ecodesign requirements

8.2.3.1 *Scope of specific ecodesign requirements*

The typical users for large submersible and dry well pumps consist of wastewater treatment plants and wastewater pumping stations (as described earlier in Task 3), which are mainly interested in the reliability of the pumps due to large losses incurred when pumps are not operational. This means that stabilised technologies and less complex products are usually preferred to energy saving alternatives, if their reliability has not been asserted. Other non-technical aspects, such as lack of incentives, may also explain why energy efficiency might not directly impact customer behaviour. Only those technologies that achieve improvement in energy efficiency without any loss of reliability are preferred by the pump industry and their customers.

Task 7 of this preparatory study showed that for many types of centrifugal pumps (BC 1, BC 2, BC 5, BC 6 and BC 7), there exists some potential for product level energy savings sold in the EU market. Consequently, Ecodesign Implementing Measures regarding energy efficiency of these types of pumps may be a recommended policy option.

Table 8-1: Contribution of each Base-Case to the overall "product level" and "extended product level" energy savings potential of ENER Lot 28 pumps (in 2011)

Pump Type	Base-Case name	Stock electricity consumption	Pump level electricity savings	BC contribution to overall pump level electricity savings	EPA level electricity savings	BC contribution to overall EPA level electricity savings
		GWh/year	GWh/year	%	GWh/year	%
BC 1	Centrifugal submersible pump: Radial sewage pumps 1 to 160 kW	15 028	361	52.4%	1909	66.9%
BC 2	Centrifugal submersible pump: Mixed flow & axial pumps	858	17	2.5%	103	3.6%
BC 3	Centrifugal submersible pump – once a day operation	70	3	0.4%	7	0.3%
BC 4	Centrifugal submersible domestic drainage pump < 40 mm passage	88	9	1.3%	13	0.5%
BC 5	Submersible dewatering pumps	2 940	147	21.4%	294	10.3%
BC 6	Centrifugal dry well pump	3 267	65	9.5%	268	9.4%

Pump Type	Base-Case name	Stock electricity consumption	Pump level electricity savings	BC contribution to overall pump level electricity savings	EPA level electricity savings	BC contribution to overall EPA level electricity savings
		GWh/year	GWh/year	%	GWh/year	%
BC 7A	Slurry Pumps – Light Duty*	7 800	78	11.3%	234	8.2%
BC 7B	Slurry Pumps – Heavy Duty*	800	8	1.2%	24	0.8%
TOTAL		30 851	688	100%	2 852	100%

** The EPA savings for BC 7 (slurry pumps) only include hydraulic and motor savings but does not include the VSDs as these are not appropriate for slurry pumps (users change speed by changing pulleys).*

Table 8-1 shows that more than 95% of the overall product level energy savings (hydraulic efficiency improvements) for Lot 28 pumps comes from the following five Base-Cases:

- BC 1: Submersible radial sewage pumps 1 to 160 kW
- BC 2: Submersible fixed flow & axial pumps
- BC 5: Submersible dewatering pumps
- BC 6: Dry well radial sewage pumps 1 to 160 kW
- BC 7A: Light duty slurry pumps

Table 8-1 also shows these five Base-Cases also contributes to more 98% of the overall extended product level energy savings (use of VSD , hydraulic and motor efficiency improvements) for Lot 28 pumps. These five Base-Cases are therefore good candidates for considering specific ecodesign requirements.

BC 4 (Centrifugal submersible domestic drainage pump<40mm passage) although only have a small share (less than 2%) to the product level energy savings of Lot 28 pumps, but these pumps comprise the largest share of sales (more than 75% in 2011, as presented in Task 2) of Lot 28 pumps. For this reason, it is important to also consider these pumps for the specific ecodesign requirements.

The remaining Base-Cases (BC 3 and BC 7B), whose contribution to total energy savings of Lot 28 pumps is insignificant (less than 2% at product level and less than 1% at the extended product level) are therefore recommended not to be considered by the scope of specific ecodesign requirements.

8.2.3.2 *Timeline of specific ecodesign requirements*

The Ecodesign requirements discussed hereafter are proposed in a provisional timetable consisting in one or several progressive steps: A single tier would cut off the worst products in the market in one step, thus achieving energy savings in a relatively short time frame. It would also be a simple regulation that would ease its implementation and comprehension by manufacturers and consumers. This option is valid for the pumps in Lot 28 proposed for regulation since the available improvement options are already implemented in some pumps in the market and the redesign cycle of these pumps is relatively short.

The implementation of Ecodesign requirements in the form of tiers takes into account the redesign cycles of around 2 to 4 years and the availability of new technologies. It also enables to keep the most ambitious targets as a final goal and gives a clear signal to industry regarding the direction in which the market should be heading. As seen in Task 7, the most efficient technologies are already available in the market and there is no BNAT expected to be developed in the near future.

Therefore, a tiered approach in 2-year steps is proposed for establishing specific ecodesign requirements for wastewater pumps. A maximum of three tiers is considered sufficient to introduce ambitious requirements and provide a long term visibility to the manufacturers. The potential benefits in terms of energy savings and the related consumer expenditure estimated for each of the tiers proposed are analysed in detail in the Scenario Analysis.

The specific ecodesign requirements discussed hereafter are therefore based on the following tiers of their combinations:

- **First tier**: 2016 or two years after the approval of the implementing measure
- **Second tier**: 2018 or four years after the approval of the implementing measure
- **Third tier**: 2020 or six years after the approval of the implementing measure

8.2.3.3 *Type of specific ecodesign requirements*

It is recommendable that any regulation on pump types or applications is based on parameters and approaches (MEI, Minimum Efficiency Index and EEI, Energy Efficiency Index) comparable to other pump regulations (e.g. 641/2009 or 547/2012). Manufacturers of Lot 28 pumps very often also produce other pumps (such as clean water pumps covered under Lot 11) for which they have to already perform the MEI and EEI calculations[2]. Therefore, having a similar approach as other pump regulations (e.g. 641/2009 or 547/2012) would allow Lot 28 pump manufacturers to perform energy efficiency calculations with relative ease. Similarly, the users of Lot 28 pumps who are mostly big water management companies also use clean water pumps for their businesses. Having a harmonised approach as other pump regulations (e.g. 641/2009 or 547/2012) would allow the users to easily relate to the more efficient Lot 28 pumps. The choice of MEI/EEI for setting specific ecodesign requirements for Lot 28 pumps could thus speed up the ecodesign legislative process for Lot 28 pumps.

[2] As an example, the EEI approach and equations used for Circulators (in Regulation 547/2012) is presented in Annex A.

Ideally, the possible MEPS (Minimum Energy Performance Standard) should be based on the Extended Product Approach presented in Task 1 of this preparatory study. This Extended Product Approach takes into account the load profile of pumps for specific applications, in a way that a single energy efficiency parameter (i.e. EEI, Energy Efficiency Index) would reflect the efficiency of the pump for a specific application and load profile.

EEI is an efficiency index, where a lower value is equivalent to higher efficiency. It takes into consideration efficiency related factors from load profiles and control methods. The EEI is based on the market distribution of pumps in the EU and their efficiencies, and on the load profiles of the pumps equipped with variable speed or two speeds. This EEI index development is part of an on-going project on the Extended Product Approach being carried out by EUROPUMP and the University of Darmstadt, and expected to continue over 2015. Until that work is finished, the present preparatory study cannot develop policy recommendations based on EEI. The formulation of EEI values corresponding to each pump type and load profiles will have to be calculated during the above mentioned project, and standardised for the specific Lot 28 pumps to be regulated.

Energy efficiency requirements for motors used by Lot 28 pumps are to be covered by MEPS requirement for motors proposed by Lot 30 study[3]. This means that the energy efficiency of all motors is regulated through one legislation instead of a situation where the motors used in centrifugal submersible pumps in Lot 28 are regulated separately through the same energy efficiency legislation as for Lot 28 pumps. Regulating all motors in the former way should make it easier for manufacturers to understand and implement these requirements thus leading to a more effective implementation of the legislation.

Another efficiency parameter, the Minimum hydraulic Efficiency Index (MEI), is defined in the Commission Regulation 547/2012 on ecodesign of water pumps. MEI is a dimensionless figure that is derived from a complex calculation based on a pump's efficiencies at the best efficiency point (BEP), 75% BEP and 110% BEP and the specific speed. MEI is based on the efficiency of Lot 28 pumps at product level. MEI is a value between 0 and 1. This index value, multiplied by 100, corresponds to the percentage of pumps currently in the market that do not meet the required level of efficiency.

MEI is based on the market distribution of pumps in the EU and their efficiencies, but unlike EEI, the MEI does not take into account the load profiles of different pump applications.

The policy options presented in this task are based on simply removing the worst "n"% of Lot 28 pumps, corresponding to an MEI value of "0.n"[4]. A number of potential MEPS based on the MEI cut-off criteria for specific Lot 28 pumps (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) are considered, as presented below:

- Option 1: MEI cut-off values as 0.1 as Tier 1 and 0.4 as Tier 2
- Option 2: MEI cut-off values as 0.4 in a single Tier

[3] Ecodesign of Electric motors (www.eco-motors-drives.eu/Eco/Home.html)

[4] For example, an MEI of 0.4 means that 40% of Lot 28 pumps currently sold would fall below this line and hence could not be placed on the EU market anymore.

- Option 3: MEI cut-off values as 0.1 as Tier 1, 0.4 as Tier 2 and 0.7 as Tier 3
- Option 4: MEI cut-off values at the level of the Base-Case (MEI = 0.4) as Tier 1 and BAT (MEI = 1) as Tier 2

These policy options allows to reflect on the various timelines (just one tier in Option 2, whereas 3 tiers in Option 3 and two tiers in Options 1 and 4) and of different level of ambitions[5] to high energy savings ambition in Option 4 (MEI =1 requirement as final tier) of energy savings for the Lot 28 pumps. The impact of implementation of these policy options on energy savings and consumer expenditure is assessed later in the report (under the scenario analysis, section 8.3).

8.2.3.4 *Minimum Efficiency Index*

The method for calculating the MEI is stated in the Commission Regulation 547/2012 (with regard to ecodesign requirement for water pumps), and the method for calculating the EEI value is given in the Commission regulation 641/2009. The specific MEI values are calculated based on the energy savings and market data presented previously in Task 7 report of this study for each of the Lot 28 pumps (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) considered for specific ecodesign requirements. This data is presented in Table 8-2.

It would be reasonable to assume an MEI value of 0.5 for the average product placed on the market (sales). However, due to the long lifetime of Lot 28 pumps (up to 25 years), the energy (hydraulic) efficiency of the pump in the average installed stock would be a bit lower than the average pump sold today. This can be explained based on degradation in original hydraulic efficiency due numerous years of use for the installed stock and considering the natural evolution of the energy efficiency of the pumps over these years. In order to take into account this discrepancy, a penalty of 0.1 MEI is applied to the MEI value of average product sold (MEI = 0.5) in order to reflect the average energy consumption of the installed stock. Therefore, an MEI value corresponding to 0.4 is assigned to the Base-Cases analysed in this study.

To calculate the cumulative energy savings and consumer expenditure (changes in product purchase price and maintenance and repair costs)[6] from setting the different MEI requirements, the distribution of Lot 28 pumps is split into 10 discrete bands from 0% (reference, denoted by WP: Worst pump) to 100% cut off, as presented in Table 8-2 and Table 8-3.

It is important to note that this method is an approximation made by the study authors and would need an exhaustive data collection on pumps in the EU market in order to calculate the appropriate MEI values[7].

[5] Relatively low energy savings ambition level in Option 1, MEI = 0.4 requirement as final tier.

[6] Installation cost is not considered as a parameter here as there are no changes in installation cost concerning the hydraulic efficiency improvements for the various design options considered for these Base-Cases, as described earlier in Task 7.

[7] A data collection based on ENER Lot 11 pumps may not be appropriate for ENER Lot 28 pumps as the pump efficiency correlates with pump size and specific speed in a different manner. This fact is a result of requirements for a free passage of certain dimensions and simple and robust clearances. These requirements will limit the attainable efficiency for small pumps in general and especially pumps of low specific speeds. This will lead to difference in slope between the polynomials based on ENER Lot 11 and ENER Lot 28 pumps, which a constant C-value cannot compensate.

Table 8-2: Task 7 data used as the basis of MEI calculation for Lot 28 pumps

Improvement option		BAT						BC			WP
Market share		100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
MEI Value		1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Difference in purchase cost compared to Base-Case (%)	BC 1	**1.4%**	1.17%	0.93%	0.70%	0.47%	0.23%	**0.0%**	-0.23%	-0.47%	-0.70%
	BC 2	**1.4%**	1.17%	0.93%	0.70%	0.47%	0.23%	**0.0%**	-0.23%	-0.47%	-0.70%
	BC 4	**1.4%**	1.17%	0.93%	0.70%	0.47%	0.23%	**0.0%**	-0.23%	-0.47%	-0.70%
	BC 5	**1.4%**	1.17%	0.93%	0.70%	0.47%	0.23%	**0.0%**	-0.23%	-0.47%	-0.70%
	BC 6	**1.4%**	1.17%	0.93%	0.70%	0.47%	0.23%	**0.0%**	-0.23%	-0.47%	-0.70%
	BC 7A	**2.0%**	1.67%	1.33%	1.00%	0.67%	0.33%	**0.0%**	-0.33%	-0.67%	-1.00%
Difference in maintenance cost compared to Base-Case (%)	BC 1	**-2.0%**	-1.67%	-1.33%	-1.00%	-0.67%	-0.33%	**0.0%**	0.33%	0.67%	1.00%
	BC 2	**-1.9%**	-1.58%	-1.27%	-0.95%	-0.63%	-0.32%	**0.0%**	0.32%	0.63%	0.95%
	BC 4	**-1.9%**	-1.58%	-1.27%	-0.95%	-0.63%	-0.32%	**0.0%**	0.32%	0.63%	0.95%
	BC 5	**-1.9%**	-1.58%	-1.27%	-0.95%	-0.63%	-0.32%	**0.0%**	0.32%	0.63%	0.95%
	BC 6	**-1.9%**	-1.58%	-1.27%	-0.95%	-0.63%	-0.32%	**0.0%**	0.32%	0.63%	0.95%
	BC 7A	**1.0%**	0.83%	0.67%	0.50%	0.33%	0.17%	**0.0%**	-0.17%	-0.33%	-0.50%

Improvement option		BAT						BC			WP
Market share		100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
MEI Value		1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Difference in electricity savings compared to Base-Case (%)	BC 1	**2.4%**	2.0%	1.6%	1.2%	0.8%	0.4%	**0%**	-0.4%	-0.8%	-1.2%
	BC 2	**2%**	1.7%	1.3%	1.0%	0.7%	0.3%	**0%**	-0.3%	-0.7%	-1.0%
	BC 4	**10%**	8.3%	6.7%	5.0%	3.3%	1.7%	**0%**	-1.7%	-3.3%	-5.0%
	BC 5	**5%**	4.2%	3.3%	2.5%	1.7%	0.8%	**0%**	-0.8%	-1.7%	-2.5%
	BC 6	**2.0%**	1.7%	1.3%	1.0%	0.7%	0.3%	**0%**	-0.3%	-0.7%	-1.0%
	BC 7A	**1.0%**	0.8%	0.7%	0.5%	0.3%	0.2%	**0%**	-0.2%	-0.3%	-0.5%

Table 8-3: MEI values to be used for Lot 28 pumps considered for specific ecodesign requirements

Improvement option		BAT						BC			WP
Market share		100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
MEI Value		1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Annual electricity consumption (kWh/unit/year)	BC 1	7 781	7 813	7 844	7 876	7 908	7 940	**7 972**	8 004	8 036	8 068
	BC 2	171 500	172 083	172 667	173 250	173 833	174 417	**175 000**	175 583	176 167	176 750
	BC 4	6	6.4	6.5	6.7	6.8	6.9	**7.0**	7.1	7.2	7.4
	BC 5	9 975	10 063	10 150	10 238	10 325	10 413	**10 500**	10 588	10 675	10 763
	BC 6	12 255	12 297	12 338	12 380	12 422	12 463	**12 505**	12 547	12 588	12 630
	BC 7A	128 700	128 917	129 133	129 350	129 567	129 783	**130 000**	130 217	130 433	130 650
Purchase cost (€/unit)	BC 1	3 420	3 412	3 404	3 397	3 389	3 381	**3 373**	3 365	3 357	3 349
	BC 2	15 210	15 175	15 140	15 105	15 070	15 035	**15 000**	14 965	14 930	14 895
	BC 4	304	304	303	302	301	301	**300**	299	299	298
	BC 5	5 070	5 058	5 047	5 035	5 023	5 012	**5 000**	4 988	4 977	4 965
	BC 6	3 481	3 473	3 465	3 457	3 449	3 441	**3 433**	3 425	3 417	3 409
	BC 7A	20 400	20 333	20 267	20 200	20 133	20 067	**20 000**	19 933	19 867	19 800

Improvement option		BAT						BC			WP
Market share		100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
MEI Value		1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Maintenance and repair cost (€/year)	BC 1	798	795	792	790	787	785	**782**	779	777	774
	BC 2	968	965	962	959	956	953	**950**	947	944	941
	BC 4	0	0	0	0	0	0	**0**	0	0	0
	BC 5	472	470	469	467	466	464	**463**	462	460	459
	BC 6	822	820	817	815	812	810	**807**	804	802	799
	BC 7A	1 288	1 286	1 284	1 281	1 279	1 277	**1 275**	1 273	1 271	1 269

Based on the selected cut-off MEI values, the Implementing Measure could be developed with requirements of minimum efficiency (η) at Best Efficiency Point (BEP), at Part Load (PL), and at Over Load (OL) calculated by using specific C-values[8] for each of the MEI selected:

$$(\eta\ BEP) = F_1 x + F_2 y - F_3 x^2 - F_5 y^2 - F_6 x y - C$$

$$(\eta\ PL) = F_7 \cdot (\eta\ BEP)$$

$$(\eta\ OL) = F_8 \cdot (\eta\ BEP)$$

Where,

$x = ln(n_s)$;

$y = ln(Q)$;

ln = natural logarithm;

Q = flow in [m^3/h];

n_s = specific speed in [min^{-1}];

C = specific values calculated for each pump type;

F_1 to F_8 = specific factors of the formulae calculated for each pump type.

Ecodesign requirements based on MEI (hydraulic efficiency) for wastewater pumps needs to adhere to specific design requirements and technical parameters to avoid making wastewater pumps incapable of pumping wastewater. An independent study (by EUROPUMP and the University of Berlin) is in progress to develop standardised wastewater classes[9]. This could form the basis of further developing the wastewater calibration for the polynomials / efficiency surface shapes, specific factors of the formulae presented above. The outcome of this will be a function factor respecting the influencing constraint in wastewater business. This function factor takes into account the diversity of applications and broad range of capacities covered by the Lot 28 Base-Cases. These function factors are reflected in the figures used for C-values. These function factors allow correction of the hydraulic efficiency of the Lot 28 pumps by adjusting the C-values so that MEI of 0.1 corresponds to banning 10% of the worst performing pumps. A preliminary estimate by the project team of the adjusted (incorporating function factors) C- values for the Lot 28 pumps is presented in Annex B[7].

8.2.4 Generic Ecodesign requirements

One of the key factors to ensure energy efficient pump systems is the correct dimensioning, design and installation of the specific pumping system needed for each function. It is therefore recommended to set requirements of minimum information that the manufacturers should provide to designers, installers and customers.

[8] C-values is a parameter specific to each type of Lot 28 pump that is used for the calculation of hydraulic efficiency, using the equation presented in this section 8.2.3.4.

[9] Note that a similar categorisation of slurries/solids would be needed to set up the "Function Factor" for the different types of slurry pumps

For all wastewater pumps covered in this preparatory study, manufacturers should provide the following information:

- Information on how to install, use and maintain the water pump in order to minimise its impact on the environment.
- Information about the recommended use and load profiles for the pump shall be provided on the packaging and in the technical documentation of water pumps.
- Information concerning disassembly, recycling, or disposal at end-of-life of components and materials, shall be made available for treatment facilities.

The information listed above shall be visibly displayed on freely accessible websites and documentation (such as product catalogues and technical manuals) of the water pump manufacturers.

For Lot 28 specific pumps (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) considered in this preparatory study, manufacturers should also provide the following information:

- The MEI of pumps, calculated in accordance with section 8.2.3.4, shall be indicated on the name plate and packaging of the product and in the technical documentation as follows: 'MEI ≥ 0,[##]'
- The following information shall be provided: 'The benchmark for most efficient Lot 28 specific pumps (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) is MEI ≥ 0,[##]

8.2.5 Recommendations on standardisation mandates

To achieve a traceable and reliable test procedure for wastewater pumps, following elements still needs to be addressed:

- A test procedure to define the wastewater types (normally more than one);
- Development of function factors; and
- A mathematical algorithm to calculate the C-values and load profiles for the (BC 1, BC 2, BC 4, BC 5 BC 6 and BC 7) pumps proposed to be covered by specific ecodesign requirements in this study.

This can be done by means of a CEN standard. A VDMA[10] Working Group (WG) in collaboration with the Technical University (TU) of Berlin has been carrying out research work in this context since 2012. At present, these preliminary results are being used by a EUROPUMP WG as the basis for the work on definition of wastewater types and the function factors (indicating the fitness of specific pumps to specific applications/wastewater). All this work will be accompanied by conducting of pilot tests on the wastewater types by TU Berlin. EUROPUMP indicated that it may take at least one more year to fix the definition of different wastewater types. Tests to develop function factors for the specific pump types will take another year. To elaborate an algorithm will take another 3-6 month. This means that that the definition for wastewater types and the

[10] VDMA (Verband Deutscher Maschinen- und Anlagenbau e.V.) is a German engineering association.

requirements for the test rig and test procedure should be fixed by end of 2014, the algorithm for calculation of function factors and adjusted C-values will follow by end of 2015 and finally the corresponding CEN standard will only be available towards the end of 2016. If this timeline is met, then it is recommended that during the next revision of potential MEPS Regulation for Lot 28 pumps, the EC should take into account the EEI approach for Lot 28 MEPS instead of the MEPS proposed in this Task based on MEI approach.

8.3 Scenario analysis

8.3.1 Type of scenarios considered

This section presents the scenario analysis to evaluate which of the proposed MEPS (the four policy options concerning ecodesign specific measures, identified in section 8.2.3.3) is the most beneficial from the environmental and economic point of view compared to the Business-as-usual (BaU) scenario. The scenario analysis in this section is performed from 2013 (latest year corresponding to the drafting of this report) till 2040. The time duration (28 years) of the scenario analysis is more than the longest lifetime of the Base-Cases considered (BC 7A with a lifetime of 25 years). Ecodesign Implementing Measures only apply to the new sales. The choice of long duration of scenario analysis in this section allows replenishment of the overall stock of Lot 28 pumps by the more efficient pumps (due to their sales resulting from Ecodesign Implementing Measures), thus reflecting on the overall energy savings potential and impact on consumer expenditure. The four policy options scenarios are compared against the BaU scenario in order to estimate the overall potential of energy savings and consumer expenditure impact of potential Implementing Measures.

The scenario analysis is performed for only those pumps for which specific ecodesign requirements are considered earlier in section 8.2.3.3, which include:

- BC 1: Submersible radial sewage pumps 1 to 160 kW
- BC2: Submersible fixed flow & axial pumps
- BC 5: Submersible dewatering pumps
- BC 4: Centrifugal submersible domestic drainage pump<40mm passage
- BC 6: Dry well radial sewage pumps 1 to 160 kW
- BC 7A: Light duty slurry pumps

The four scenarios (other than BaU) analysed in this section are presented in Table 8-4. These four policy scenarios compare the potential environmental benefits and economic impacts on consumers of policies with different levels of ambition. The Scenario 1 corresponds to the approach taken in the Regulation on water pumps issued from the ENER Lot 11 preparatory study (Commission Regulation (EU) No 547/2012). The Scenario 2 achieves the same level of ambition than Scenario 1 in a shorter period. The Scenario 3 follows the two tiers of Scenario 1 and adds more ambitious requirements in a third tier at long term, but without achieving the level of BAT. The Scenario 4 represents a very ambitious (and unsuitable) scenario in which any

product worse than the current EU average would be banned for sale at short term, and the current BAT would become mandatory at EU level at medium term. This scenario is only intended to show which is the maximum potential savings of MEPS for Lot 28 pumps at EU level.

Table 8-4: Proposed cut-off scenarios

	MEI*		
	Tier 1: 2016	Tier 2: 2018	Tier 3: 2020
Scenario 0: (BaU)	0	0	0
Scenario 1	0.1	0.4	-
Scenario 2	0.4	-	-
Scenario 3	0.1	0.4	0.7
Scenario 4	0.4	1	-

*MEI = 0.1 corresponds to the worst performing product in the market.
MEI = 0.4 corresponds to the Base-Case.
MEI = 1 corresponds to the BAT.

For each of these four policy option scenarios (BaU excluded), following three different possibilities are further analysed as sub-scenarios to take into account the consumer market response to the potential implementing measures (entry into force of the MEI cut-off requirements):

- Pessimistic sub-scenario: the ban of pumps below a certain MEI will lead to increased sales of the low efficiency permitted. For example, an MEI requirement of 0.1 would mean that the worst 10% of pumps are improved to the 20% cut off line. The MEI requirement of 0.2 is calculated by assuming that the worst 10% improve to the 30% cut off, and the 10-20% band of pumps improve to the 30% cut off. This is repeated to the MEI requirement of 1.0
- Pragmatic sub-scenario: the ban of pumps below certain MEI will lead to increased sales of mid-range efficiency pumps. For example, an MEI requirement of 0.1 would mean that the worst 10% of pumps are improved to the 40% cut off line (an MEI jump of 0.3 points). The MEI requirement of 0.2 is calculated by assuming that the worst 10% improve to the 50% cut off, and the 10-20% band of pumps improve to the 50% cut off. This is repeated to the MEI requirement of 1.0
- Optimistic sub-scenario: the ban of pumps below certain MEI will lead to increased sales of high efficiency pumps (i.e. the efficiency of the BAT)[11].

Therefore, in total twelve scenarios are compared with the BaU scenario in order to estimate the overall potential of the four policy options.

The assumptions about consumer response to the MEI requirements, banning the share of Lot 28 pumps below the MEI cut-off value for the four policy option scenarios across the three different

[11] This sub-scenario is unlikely but allow estimating the maximum energy savings.

possibilities (sub-scenarios) are presented in the Table 8-5. The efficiency numbers in this table represent the value to which the worst performing pumps are improved to, under each of the sub-scenarios of concerning the tiers proposed for the four policy options. This allows to in turn calculate the energy and economic inputs for the policy option scenarios (as presented in next section 8.3.2).

Table 8-5: Improvement of worst performing pumps due to MEI requirements, for different levels of market response

Scenario	Sub-scenario	Expected efficiency of the worst performing pumps after a cut-off regulation entries into force		
		Tier 1	Tier 2	Tier 3
Scenario 1	Pessimistic 1	0.2	0.5	-
	Pragmatic 1	0.4	0.7	-
	Optimistic 1	1	1	-
Scenario 2	Pessimistic 2	0.5	-	-
	Pragmatic 2	0.7	-	-
	Optimistic 2	1	-	-
Scenario 3	Pessimistic 3	0.2	0.5	0.8
	Pragmatic 3	0.4	0.7	1
	Optimistic 3	1	1	1
Scenario 4	Pessimistic 4	0.5	1	-
	Pragmatic 4	0.7	1	-
	Optimistic 4	1	1	-

8.3.2 Inputs to scenario analysis tool

An Excel tool is created to allow the impacts of the different scenarios to be modelled (2013-2040). The tool is designed in a simple manner and relies on the following assumptions:

- The model builds upon a discrete annual basis to match the available data.
- Sales (annual growth rate of 2.5% from 2011 until 2040) and stock forecast detailed in Task 2 are used as input.
- 70% of the annual sales are replacement sales (for replacement of the existing installed stock, meaning only 30% of the annual sales for new installations).
- Total Electricity consumption and consumer expenditure were judged to be the most relevant and representative indicators to be modelled using the tool and to allow the environmental cost – benefits to be compared with other Ecodesign Lots.

- The total electricity consumption results are not limited to the use phase but also take into account the energy required over the whole lifecycle (including the manufacturing distribution and end-of-life phases). Overall life cycle energy consumption is allocated uniformly over the lifetime of the product although in theory this is only true for the use phase. Given the relatively small shares of other life cycle phases in energy consumption (see Task 5), this assumption is considered reasonable in order to carry out the analysis; a more "realistic" modelling would not make a significant difference to the overall results.
- Expenditure measures the yearly value of the entire market. It consists of the money spent to buy and install the product (purchase cost), taken into account at the time of purchase, and the operating costs (energy, maintenance and repair), which are spread over the lifecycle of the pump.
- The tool calculates the cost for consumer expenditure in Euros and total electricity in GWh, for the different policy scenarios.

The electricity consumption and economic inputs used for the four policy option scenarios are presented in Table 8-6.

Table 8-6: The energy and economic inputs for the policy option scenarios

		MEI = 0.1			MEI = 0.4			MEI = 0.7			MEI =1.0
Market response		Pessimistic (0.2)	Pragmatic (0.4)	Optimistic (1)	Pessimistic (0.5)	Pragmatic (0.7)	Optimistic (1)	Pessimistic (0.8)	Pragmatic (1)	Optimistic (1)	Pragmatic/Pessimistic /Optimistic (1)
BC1	Electricity consumption (kWh/unit/year)	7 949	7 941	7 918	7 915	7 884	7 838	7 846	7 792	7 792	7 781
BC2		174 580	174 440	174 020	173 950	173 390	172 550	172 690	171 710	171 710	171 500
BC4		6.92	6.89	6.80	6.79	6.68	6.51	6.54	6.34	6.34	6
BC5		10 437	10 416	10 353	10 343	10 259	10 133	10 154	10 007	10 007	9 975
BC6		12 475	12 465	12 435	12 430	12 390	12 330	12 340	12 270	12 270	12 255
BC7A		129 844	129 792	129 636	129 610	129 402	129 090	129 142	128 778	128 778	128 700
BC1	New purchase cost (€/unit)	3 379	3 381	3 386	3 387	3 395	3 406	3 404	3 417	3 417	3 420
BC2		15 025	15 034	15 059	15 063	15 097	15 147	15 139	15 197	15 197	15 210
BC4		300.5	300.7	301.2	301.3	301.9	302.9	302.8	303.9	303.9	304
BC5		5 008	5 011	5 020	5 021	5 032	5 049	5 046	5 066	5 066	5 070
BC6		3 439	3 441	3 446	3 447	3 455	3 467	3 465	3 478	3 388	3 481
BC7A		20 048	20 064	20 112	20 120	20 184	20 280	20 264	20 376	20 376	20 400

		MEI = 0.1			MEI = 0.4			MEI = 0.7			MEI =1.0
Market response		Pessimistic (0.2)	Pragmatic (0.4)	Optimistic (1)	Pessimistic (0.5)	Pragmatic (0.7)	Optimistic (1)	Pessimistic (0.8)	Pragmatic (1)	Optimistic (1)	Pragmatic/Pessimistic /Optimistic (1)
BC1	New maintenance cost (€/year)	783.9	784.5	786.4	786.7	789.2	792.9	792.3	796.7	796.7	798
BC2		952.2	952.9	955.1	955.4	958.3	962.6	961.9	967.0	967.0	968
BC4		0	0	0	0	0	0	0	0	0	0
BC5		464.1	464.4	465.5	465.6	467.0	469.2	468.8	471.3	471.3	472
BC6		808.8	809.5	811.3	811.6	814.1	817.7	817.1	821.4	821.4	822
BC7A		1 277	1 277	1 279	1 279	1 281	1 284	1 283	1 287	1 263	1 288

8.3.3 Comparison of scenarios

This subsection provides a comparison of the results of the twelve policy option (sub-)scenarios against the BaU scenario over the period 2013-2040 for the following two indicators:

- Total electricity consumption
- Overall consumer expenditure

This comparative analysis is carried out for each of the six Base-Cases (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) recommended for specific ecodesign requirements in section 8.2.3.1. The comparative analysis for these two indicators is presented for the following years:

- 2018
- 2020
- 2030
- 2040

The selection of above years allows for reflecting the savings across a wide timeline, reflecting the progressive penetration of more energy efficient pumps (as required by the different requirements on MEI and tiers for the twelve policy option scenarios) in the EU. The year 2018 corresponds to the time when the more energy efficient pumps just start to appear in the installed stock (year 2018, 2 years after the first tier of requirements, 2016). Year 2020 corresponds to the EU 2020 headline target set in the Europe 2020 strategy[12]. Year 2030 corresponds to almost half of the EU installed stock of Lot 28 pumps represented by more energy efficient pumps. Lastly, year 2040 corresponds to the time by when most of the EU installed stock of Lot 28 pumps is replenished by more energy efficient pumps (as required under the 12 policy option scenarios).

- **Total electricity consumption[13]**

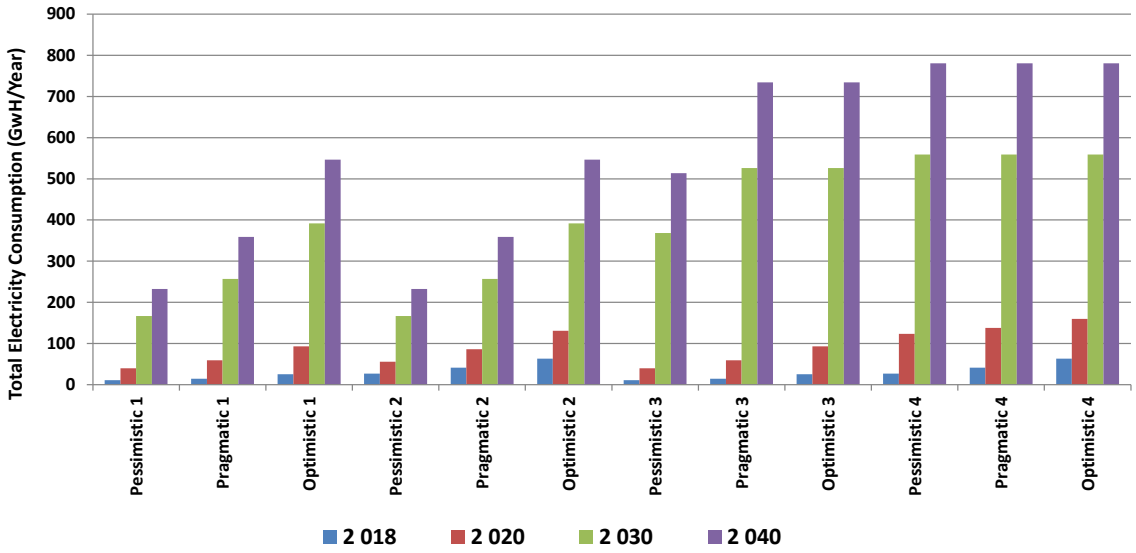
The savings in annual electricity consumption for each of the six Base-Cases for the twelve policy option scenarios are calculated by subtracting the overall annual electricity consumption in the policy option scenarios from those of BaU scenario.

Figure 8-1 to Figure 8-7 present the comparison of annual savings in electricity consumption for each of the six Base-Cases (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) for the twelve different sub-scenarios. (Note that the scale of the Y-axis is not always the same in all figures but was chosen each time to allow a comprehensive understanding of the figures).

[12] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF

[13] Total Electricity Consumption over the life cycle of the Base-Case.

Figure 8-1: Total annual electricity consumption savings (in GWh) for BC 1 across four key years for the 12 policy option scenarios

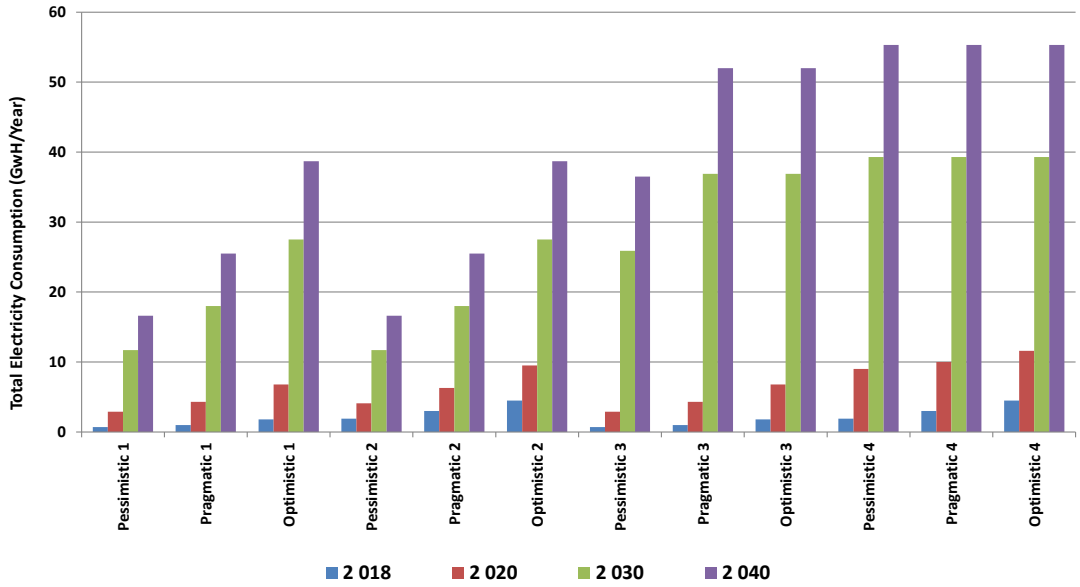


For Base-Case 1, the most ambitious scenario corresponds to Policy Option 4 (cut-offs of 0.4 and 1.0 in 2016 and 2018 respectively), which could save up to 780 GWh per year in 2040 at EU level. In the most modest scenario (i.e. Policy Option 1 and 2), the maximum electricity savings at EU level in the same year would be around 547 GWh.

In this comparison of scenarios it can be seen that the scenario 2 (Policy Option 2 with a single tier at 0.4) could bring savings faster than the scenario 1 (Policy Option 1 with two tiers at 0.1 and 0.4), but the difference in electricity savings potential is negligible.

The difference between the maximum potential electricity savings in pragmatic and optimistic scenarios of a cut-off of 0.7 (in Policy Option 3) and 1.0 (Policy Option 4) is also negligible (less than 7% as scenario 3 has electricity savings of 734 GWh as against 780 GWh of scenario 4); except in the case of the pessimistic sub-scenario. Scenario 4 would achieve slightly higher electricity savings faster than scenario 3 (the electricity savings for pessimistic sub-scenario 3 are estimated to be 514 GWh as compared to 780 GWh for pessimistic sub-scenario 4).

Figure 8-2: Total annual electricity consumption savings (in GWh) for BC 2 across four key years for the 12 policy option scenarios

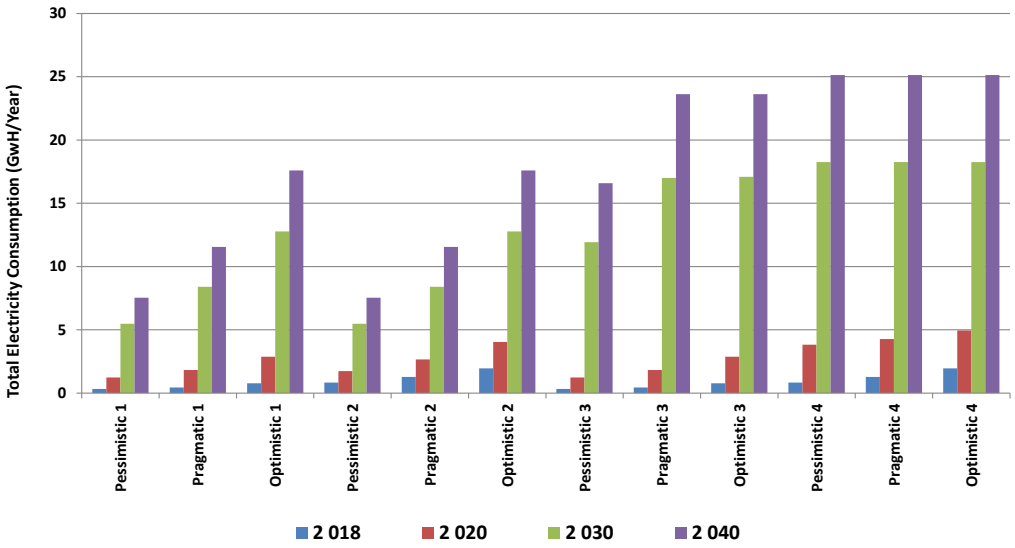


For Base-Case 2, the most ambitious scenario corresponds to Scenario 4, which could save up to 55 GWh per year in 2040 at EU level. In the most modest scenario (i.e Policy Option 1 and 2), the maximum electricity savings at EU level in the same year would be around 39 GWh per year in 2040.

As in the previous Base-Case, the difference in electricity savings potential between Scenario 1 and Scenario 2 is negligible, as well as the difference between Scenario 3 and Scenario 4, except in the case of the pessimistic sub-scenario. Scenario 4 would achieve slightly higher electricity savings faster than scenario 3 (the electricity savings for pessimistic sub-scenario 3 are estimated to be 37 GWh as compared to 55 GWh for pessimistic sub-scenario 4).

In both cases, Scenario 2 and Scenario 4 could bring electricity savings faster at EU level than Scenario 1 and Scenario 3, respectively.

Figure 8-3: Total annual electricity consumption savings (in GWh) for BC 4 across four key years for the 12 policy option scenarios

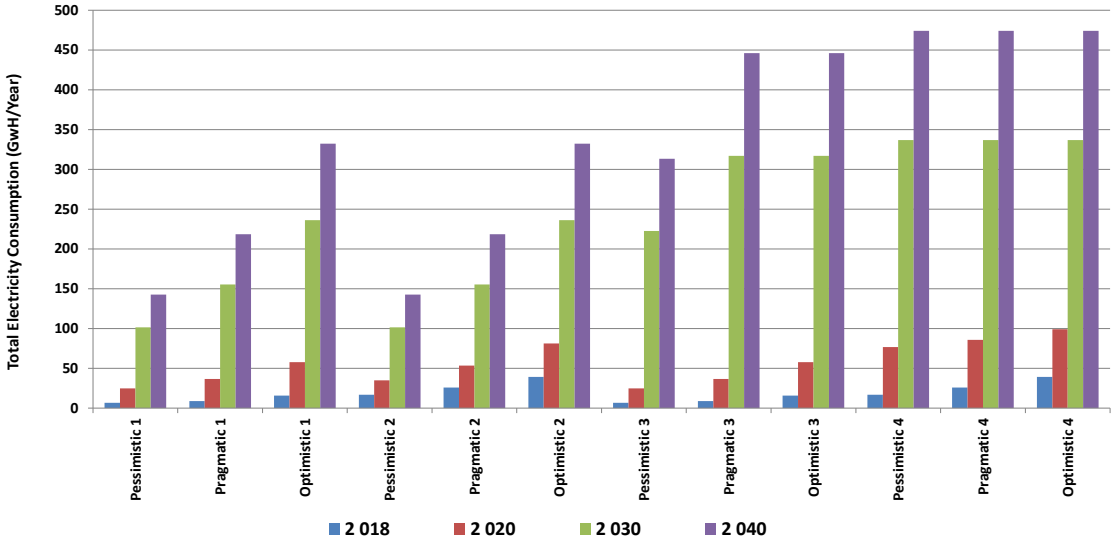


For Base-Case 4, the most ambitious scenario corresponds to Scenario 4. This scenario would save up to 25.1 GWh per year in 2040 at EU level. In the most modest scenario (i.e. Policy Option 1 and 2), the maximum electricity savings at EU level in the same year would be around 17.6 GWh per year in 2040.

As in the previous Base-Case, the difference in electricity savings potential between Scenario 1 and Scenario 2 is negligible, as well as the difference between Scenario 3 and Scenario 4, except in the case of the pessimistic sub-scenario. Scenario 4 would achieve slightly higher electricity savings faster than scenario 3 (the electricity savings for pessimistic sub-scenario 3 are estimated to be 16.6 GWh as compared to 25.1 GWh for pessimistic sub-scenario 4).

In both cases, Scenario 2 and Scenario 4 could bring electricity savings faster at EU level than Scenario 1 and Scenario 3, respectively.

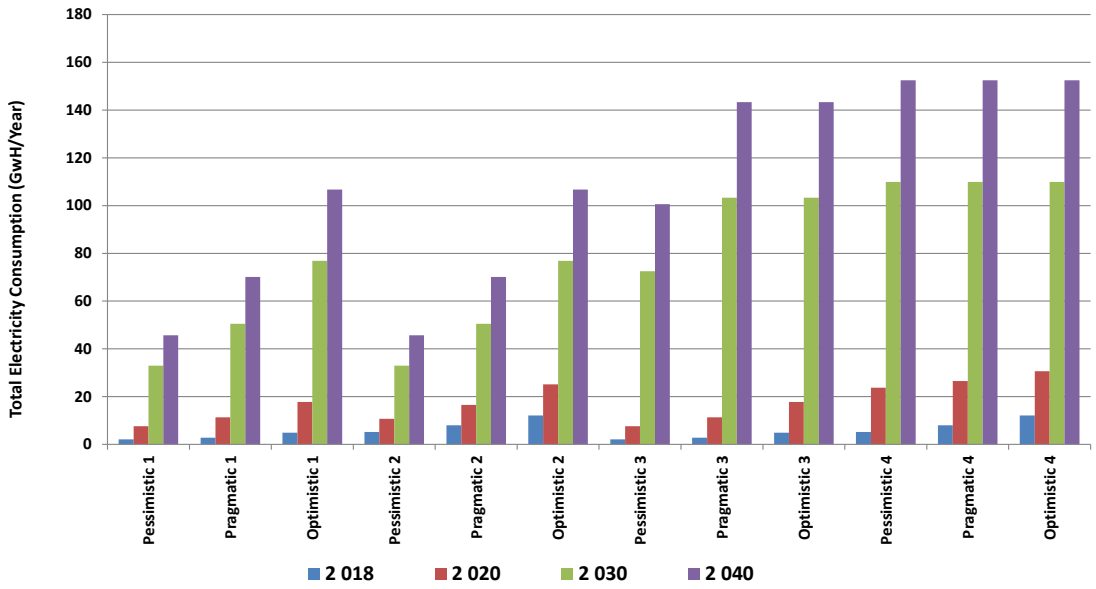
Figure 8-4: Total annual electricity consumption savings (in GWh) for BC 5 across four key years for the 12 policy option scenarios



For Base-Case 5, the most ambitious scenario corresponds to Scenario 4 and could save up to 474 GWh per year in 2040 at EU level. In the most modest scenario (i.e. Policy Option 1 and 2), the maximum electricity savings at EU level in the same year would be around 332 GWh. The difference between scenarios 1 and 2 is negligible. In a similar manner, the difference between the maximum potential electricity savings of scenario 3 and scenario 4 is also negligible, except in the case of the pessimistic sub-scenario. Scenario 4 would achieve slightly higher electricity savings faster than scenario 3 (the electricity savings for pessimistic sub-scenario 3 are estimated to be 313 GWh as compared to 474 GWh for pessimistic sub-scenario 4).

In both cases, Scenario 2 and Scenario 4 could bring electricity savings faster at EU level than Scenario 1 and Scenario 3, respectively.

Figure 8-5: Total annual electricity consumption savings (in GWh) for BC 6 across four key years for the 12 policy option scenarios

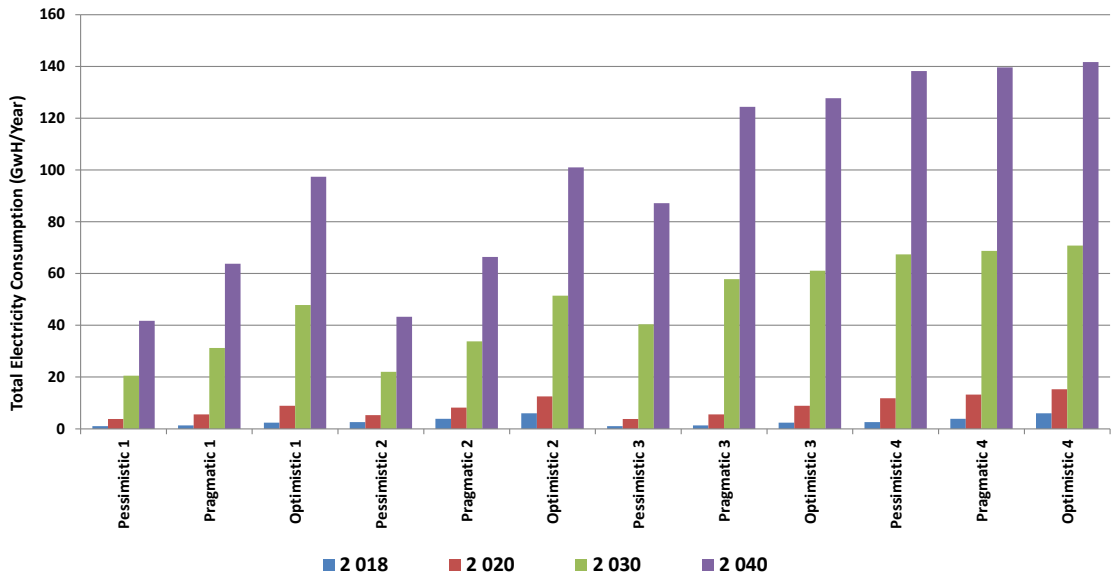


For Base-Case 6, the most ambitious scenario corresponds to Scenario 4 and could save up to 153 GWh per year in 2040 at EU level.

In the most modest scenario (i.e. Policy Option 1 and 2), the maximum electricity savings at EU level in the same year would be around 107 GWh. The difference between scenarios 1 and 2 is negligible. In a similar manner, the difference between the maximum potential electricity savings of scenario 3 and scenario 4 is also negligible, except in the case of the pessimistic sub-scenario. Scenario 4 would achieve slightly higher electricity savings faster than scenario 3 (the electricity savings for pessimistic sub-scenario 3 are estimated to be 101 GWh as compared to 153 GWh for pessimistic sub-scenario 4).

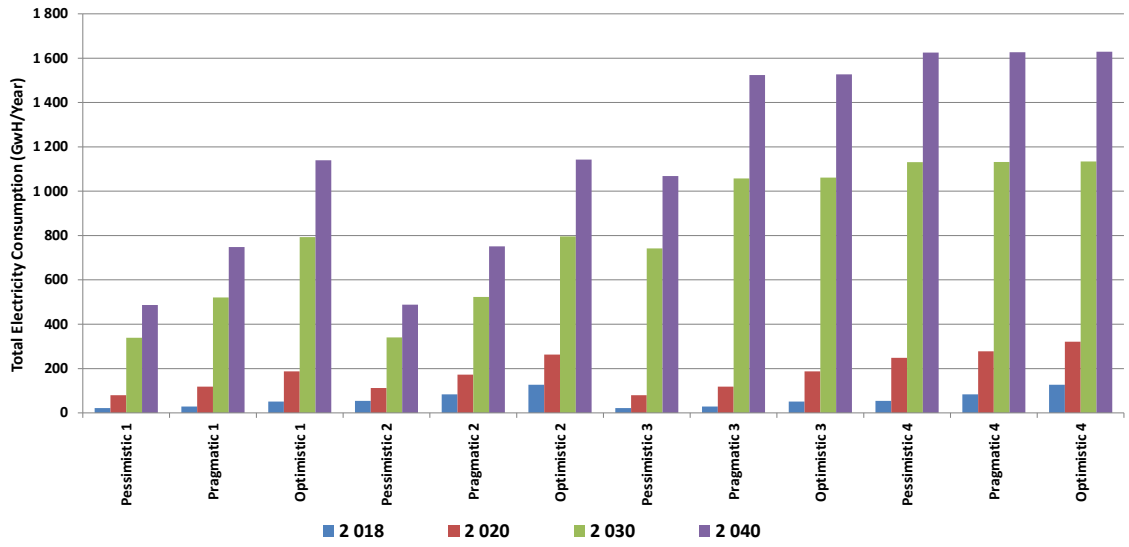
In both cases, Scenario 2 and Scenario 4 could bring electricity savings faster at EU level than Scenario 1 and Scenario 3, respectively.

Figure 8-6: Total annual electricity consumption savings (in GWh) for BC 7A across four key years for the 12 policy option scenarios



For Base-Case 7A the most ambitious scenario is Scenario 4, which could save up to 142 GWh per year in 2040 at EU level. In one of the most modest scenarios (i.e. Policy Option 1 and 2), the maximum electricity savings at EU level in the same year would be around 97 GWh and 101 GWh respectively. The difference between scenarios 1 and 2 is negligible. In a similar manner, the difference between the maximum potential electricity savings of scenario 3 and scenario 4 is also negligible, except in the case of the pessimistic sub-scenario. Scenario 4 would achieve slightly higher electricity savings faster than scenario 3 (the electricity savings for pessimistic sub-scenario 3 are estimated to be 87 GWh as compared to 138 GWh for pessimistic sub-scenario 4).

Figure 8-7: Total annual electricity consumption savings (in GWh) for all selected Base-Cases (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) across four key years for the 12 policy option scenarios



The comparison of the total electricity savings achieved by policy implementation on all the Base-Case included in this analysis shows that the maximum electricity savings per year that could be achieved in 2040 are between 486.6 GWh and 1628.9 GWh per year at EU level, depending on the level of ambition of the scenario selected.

There is not much difference between Scenario 1 and Scenario 2, which would suggest that regulating waste water pumps in a single cut-off tier would be sufficient and more simple than enforcing a two-tier regulation. In a similar way, the potential savings of Scenario 3 and Scenario 4 are similar, although the pessimistic sub-scenario 3 achieves slightly (less than 7%) lower electricity savings.

Overall consumer expenditure

The reduction in annual consumer expenditure for each of the six Base-Cases for the twelve policy option (sub-)scenarios are calculated by subtracting the overall annual consumer expenditure in the policy option scenarios from those of BaU scenario.

Figure 8-8 to Figure 8-14 presents the comparison of annual consumer expenditure reduction for each of the six Base-Cases (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) for the twelve different sub-scenarios.

Note that the scale of the Y-axis is not always the same in all figures but was chosen each time to allow a comprehensive understanding of the figure. Also, negative values in the figures below represent increase in consumer expenditure.

Figure 8-8: Total annual consumer expenditure reduction (in Million Euros) for BC 1 across four key years for the 12 policy option scenarios

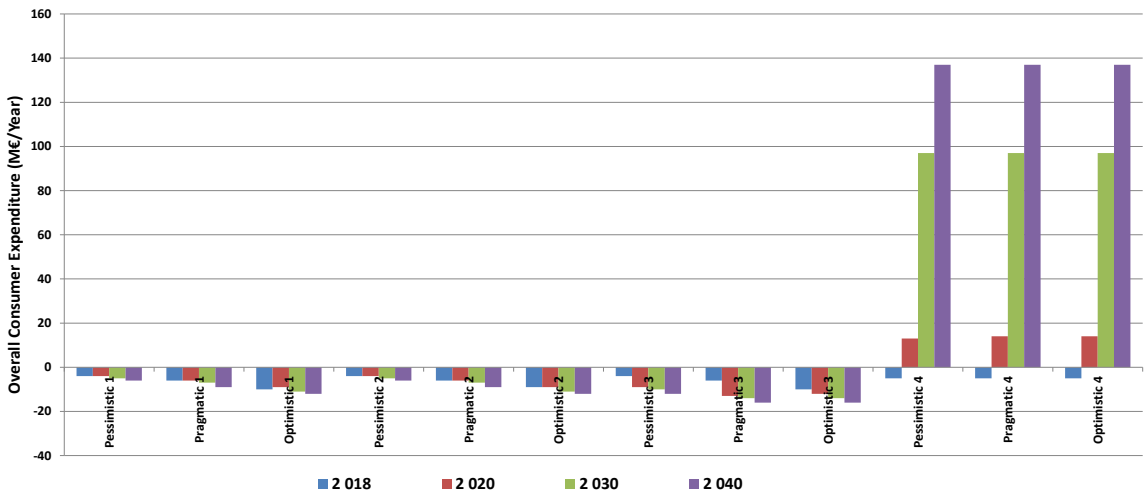


Figure 8-9: Total annual consumer expenditure reduction (in Million Euros) for BC 2 across four key years for the 12 policy option scenarios

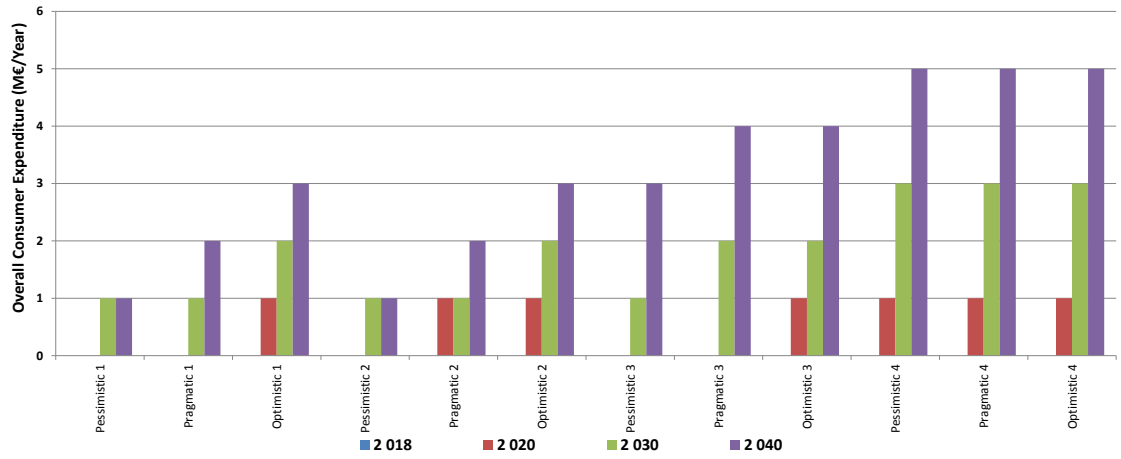


Figure 8-10: Total annual consumer expenditure reduction (in Million Euros) for BC 4 across four key years for the 12 policy option scenarios

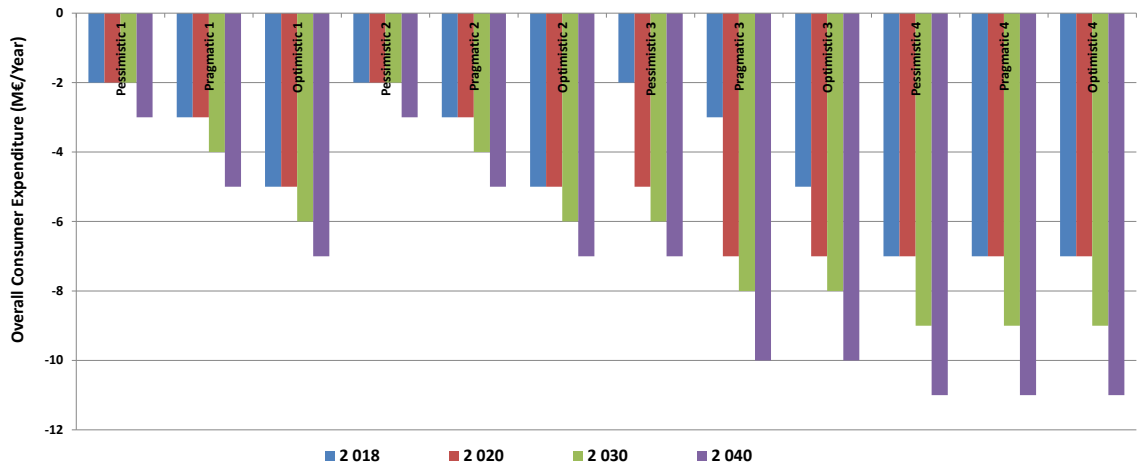


Figure 8-11: Total annual consumer expenditure reduction (in Million Euros) for BC 5 across four key years for the 12 policy option scenarios

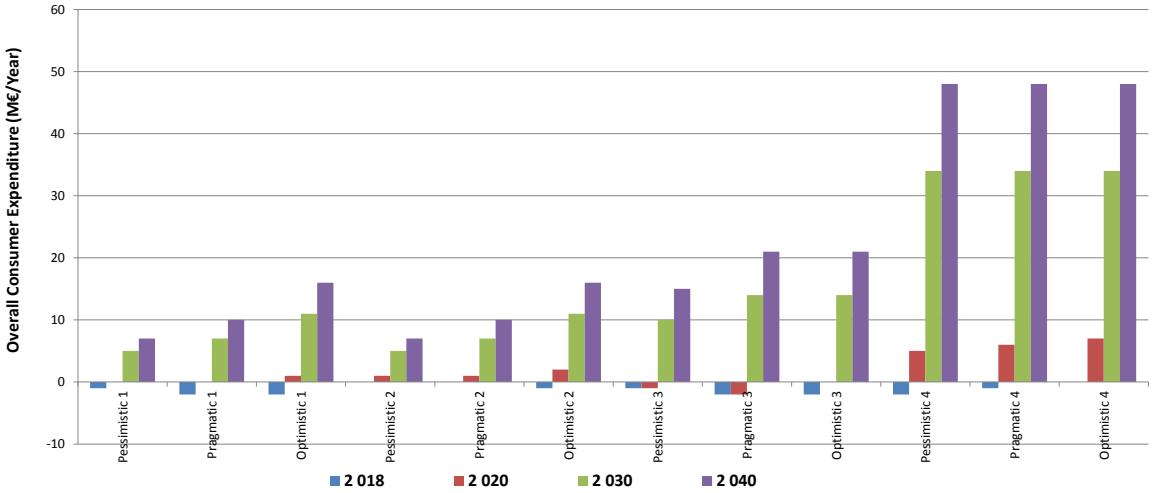


Figure 8-12: Total annual consumer expenditure reduction (in Million Euros) for BC 6 across four key years for the 12 policy option scenarios

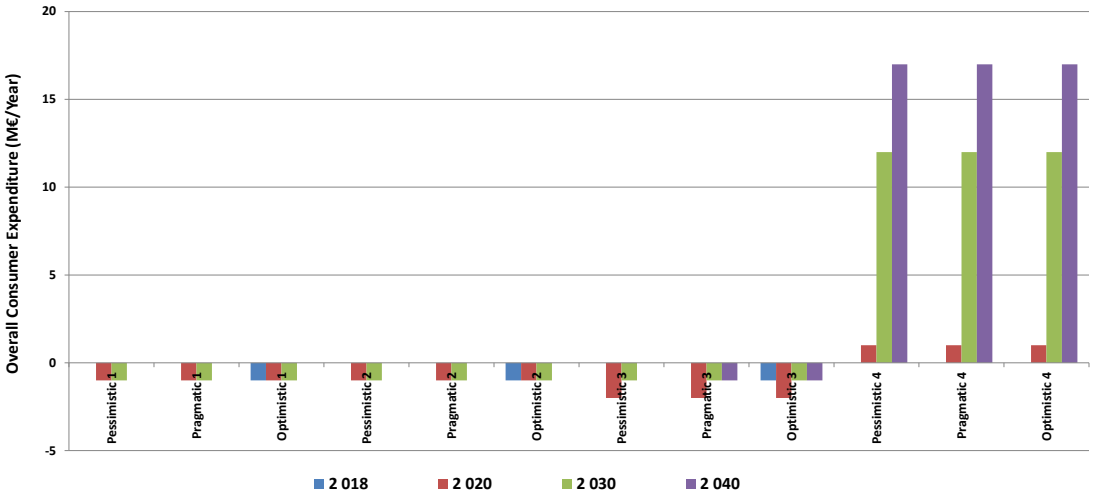


Figure 8-13: Total annual consumer expenditure reduction (in Million Euros) for BC 7A across four key years for the 12 policy option scenarios

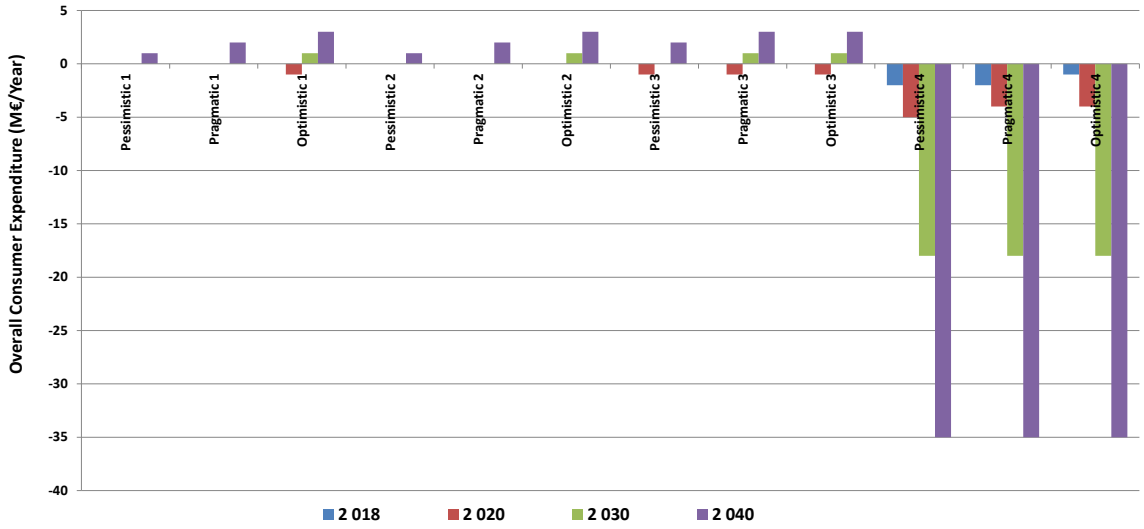
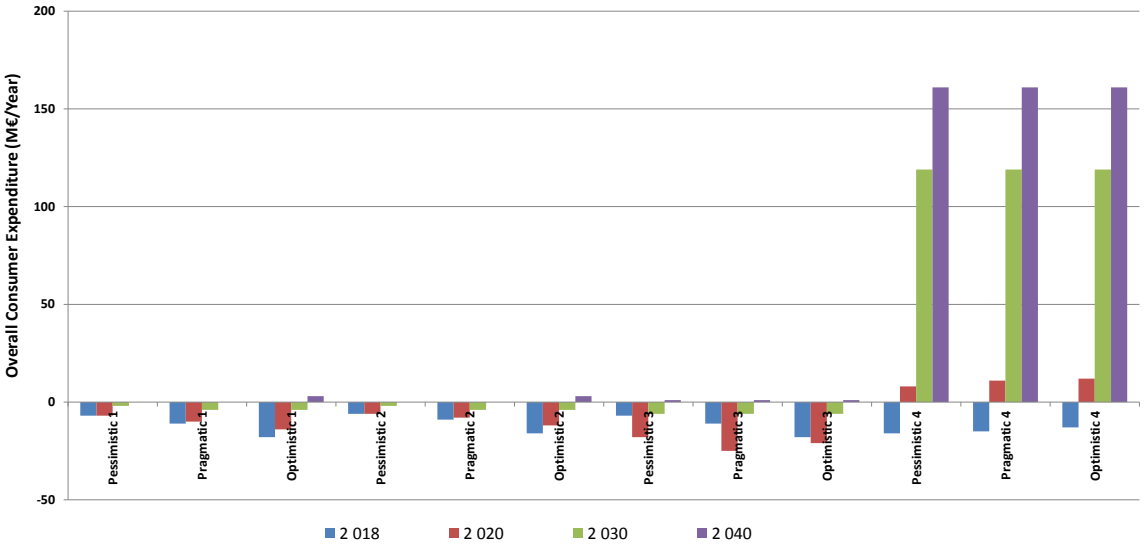


Figure 8-14: Total annual consumer expenditure reduction (in Million Euros) for all selected Base-Cases (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) across four key years for the 12 policy option scenarios



There is a reduction in consumer expenditure is across all the twelve scenarios considered for BC 2 and BC 5 by as soon as 2020. For BC 2, in one of the most ambitious scenarios (i.e. Policy Option 3 and 4), the maximum reduction in consumer expenditure at EU level in 2040 would be around 4 Million Euros and 5 Million Euros respectively. For BC 5, in one of the most ambitious scenarios (i.e. Policy Option 3 and 4), the maximum reduction in consumer expenditure at EU level in 2040 would be around 21 Million Euros and 48 Million Euros respectively.

The For BC 4, the consumer expenditure increases with time for all the twelve scenarios, which can be explained on the basis of their very small number of annual operating hours. In one of the most modest scenarios (i.e. Policy Option 3 and 4), the maximum increase in consumer

expenditure at EU level in 2040 would be around 10 Million Euros and 11 Million Euros respectively.

There is a slight increase in consumer expenditure for BC 1 and BC 6 for three scenarios (Policy Options 1, 2 and 3). As the sales of more efficient pumps replaces the existing stock, by 2040, there is almost negligible (less than a Million Euros) impact on consumer expenditure of BC 6 for the first 3 scenarios (scenario 1, 2 and 3). However, scenario 4 leads to some reduction in consumer expenditure for these Base-Cases in 2040 (137 Million Euros for BC 1 and 17 Million Euros for BC 6).

For BC 7A, there is slight reduction in consumer expenditure (around 3 Million Euros) in 2040 for the three scenarios (Policy Options 1, 2 and 3). However, scenario 4 leads to some increase in consumer expenditure for BC 7A in 2040 (35 Million Euros).

The comparison of the total consumer expenditure achieved by policy implementation on all the Base-Case included in this analysis shows that the maximum reduction that could be achieved in 2040 are between Zero (in Pragmatic Scenario 1) and 161 Million Euros (in Pragmatic Scenario 4) at EU level. There is not much difference between Scenario 1, Scenario 2 and Scenario 3.

8.4 Impact analysis

As mentioned in the Ecodesign Directive, any ecodesign requirements should not entail excessive costs nor undermine the competitiveness of European enterprises and should not have a significant negative impact on consumers or others users. This will be studied in detail in an Impact Assessment commissioned by the European Commission at a later stage in the policy-making process but a first analysis is provided here. In this section, the following impacts are assessed:

- Impacts on manufacturers of wastewater pumps and competition
- Impacts on consumers
- Impacts on innovation and development
- Social impacts

8.4.1 Impacts on manufacturer and competition

As presented in Task 2, the PRODCOM statistics are the official EU source for economic data, but it has some limitations as pump products are classified into wide range of categories that do not match exactly the classification proposed for pumps in Lot 28. However, the data collected and presented in Task 2 can give a rough economic overview of the sector of wastewater pumps in the EU. According to that, the sector presents a minor growth trend in recent years and the same small growth is forecasted for the coming years. Most of the wastewater pump sales in the EU are replacement of old pumps (assumption of 70% in the scenario analysis, see section 8.3.2), and only a small part are new pump installations. This means that the wastewater pump market in the EU is close to saturation, and the introduction of new pumps and technologies in the market would take time. Because of that, the return of investment on new launches of products by

manufacturers would be small over a long period.

The timeline to implement the MEPS should take into account the development of test standards, product redesign cycle and adaptation of production lines. All the technologies described in this study and considered as improvement options in the scenarios are already available on the market. As a result, the implementation of MEPS is technically achievable although it may require an economical effort from the manufacturers. While the improvement technologies are already used in some wastewater pumps, not all the manufacturers include them in their designs, and the launching of new products will require product redesign (such as patterns and tooling). Product redesign for hydraulic improvement in slurry pumps would be particular expensive to manufacturers because they have different pump designs i.e. metal, ceramic and rubber lined and the metal pumps are made in many different materials. Each of these needs different patterns/moulds. Manufacturers also have a large number of hydraulic sizes because of the importance of selecting the pumps at the right operating point on the head flow curve to maximise pump life and reliability. So the implementation of MEPS might require investment in technology and product development or in adapting their production lines to offer the required more efficient products. The impact of these investments would depend on the level of ambition of the MEPS adopted and on the energy performance of models proposed by each manufacturer.

The redesign time varies depending on the type of product and extent of desired change. As seen in Task 2, the redesign cycles of wastewater pumps are between 2 to 4 years, including all the time necessary to launch a new product. As the considered design improvement options are already available in the market, it is estimated that the redesign of Lot 28 pumps would be on the lower part of this range. Therefore, a lapse of around 24 months should be sufficient for all the manufacturers to redesign their products, adapt the production lines and develop test methods to verify the compliance with the legal requirements.

The test standard development, as described earlier in section 8.2.5, is expected to be completed by end of 2016. If this timeline is met ,then it is recommended that during the next revision of potential MEPS Regulation for Lot 28 pumps, the EC should take into account the EEI approach for Lot 28 MEPS instead of the MEPS proposed in this Task based on MEI approach.

Most of the pump production is done inside the EU and there are some imports of different products, but these quantities are not as representative as the ones produced inside the EU. Few big manufacturers dominate the European market of Lot 28 pumps. If MEPS are set, it is believed that they should all be able to keep up with the market requirements, as most of these manufacturers already claim to produce highly efficient pumps. Therefore, the implementation of MEPS is not expected to significantly hamper the economic development of these manufacturers in the EU. However, the European market of slurry pumps is quite small on a global scale (as communicated by Europump). The main markets for the slurry pumps are countries with intensive mining activities outside EU, e.g. Australia, South Africa, Chile, Russia. Therefore, the annual sales of these pumps in EU are generally decreasing. There is a concern amongst European manufacturers (as communicated by Europump) that they may be

disadvantaged in the world market of slurry pumps where reliability is the main criteria for purchase decision instead of energy efficiency[14].

8.4.2 Impact on consumers

In the case of any additional costs to manufacturers, these could be passed on to the customers, and even though this could be seen as a downside, the lower energy consumption during the use phase would compensate the higher purchase price of the pump. This would also mean that more capital to purchase the more efficient products would be required. The scenario analysis already shows some of the expected monetary impacts for users. The higher price of a more efficient pump could be paid back by the savings in energy consumed during the use phase. This seems to be the case for BC 2 and BC 5 for most of the policy options considered in this Task whereas for BC 1 and BC 6, reduction in consumer expenditure occurs but only for policy option 4 (high energy efficiency requirements).

8.4.3 Impacts on innovation and development

The proposed policy options will remove inefficient wastewater pumps from the market in a first tier, thus achieving energy savings at EU level in a short time lapse. The introduction of second and third tiers with more ambitious targets would push manufacturers to design more efficient products and achieve higher energy savings in the long term, but it is unlikely to lead to big technological changes. This happens mainly because the products with the improvement options identified in this study already exist as a small share of the products in the market. However, a shift can be expected towards more efficient models with intelligent controls within the EU although, such controls have no such big impacts on the design of the pump itself.

The standardisation of new energy efficiency indexes such as MEI and EEI would have a positive impact on the innovation and competitiveness of the EU market of pumps. If these indexes are widely used by manufacturers and communicated to installers and users, this will help create awareness in the market of the different technologies available and their corresponding benefits. This could also drive the customer's choice towards more energy-efficient products. The manufacturers can also provide recommendations on the installation and concerning efficient use of waste water pumps, which could help optimise the energy efficiency of pumping systems further than the pump itself, even though the systems are not directly regulated.

The proposed MEPS can be seen as an opportunity for manufacturers to search for innovative and efficient technological solutions. As mentioned, it seems that with the current trend of research and development activities in EU manufacturing companies, it should be feasible that manufacturers can meet the requirements considered in this report.

[14] This is in line with the payback time calculation for slurry pumps carried out in Task 7 which showed that the hydraulic improvement options for these pumps do not pay back the users.

8.4.4 Social impacts

Most of the manufacturers of wastewater pumps have production plants within the EU. Upgrading or changing production lines in the EU is often viewed as an opportunity to decide whether to relocate the production plant to another country – within or outside the EU – or not. If Ecodesign requirements were set, they are not thought to have a detrimental impact on the number of jobs or the well-being of the EU manufacturers' employees[15]. In addition, the ecodesign improvement options presented do not require any specific material that might be difficult to obtain within the EU so that the supply would not be unduly affected nor the EU industries disadvantaged.

8.5 Sensitivity analysis

The objective of the sensitivity analysis is to examine the accuracy of the results of the study and to see how susceptible they are to unreliable data. Parameters included in the sensitivity analysis are in accordance with the Annex II of the Ecodesign Directive. The parameters that are considered the most relevant for this sensitivity analysis (because of their importance and/or uncertainty) in the case of wastewater pumps are listed below:

- Product lifetime
- Maintenance and repair cost
- Product price
- Annual sales growth rate

The sensitivity analysis is carried out for each of the six Base-Cases (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) around the pragmatic scenarios[16] of the four policy options:

- Pragmatic Scenario 1: MEI cut-off values as 0.1 as Tier 1 and 0.4 as Tier 2
- Pragmatic Scenario 2: MEI cut-off values as 0.4 in a single Tier
- Pragmatic Scenario 3: MEI cut-off values as 0.1 as Tier 1, 0.4 as Tier 2 and 0.7 as Tier 3
- Pragmatic Scenario 4: MEI cut-off values at the level of the Base-Case (MEI = 0.4) as Tier 1 and BAT (MEI = 1) as Tier 2

[15] Europump however raised the concern that if the Ecodesign requirements were to result in need for manufacturing extensive new patterns and castings, the pump industry may take it as an opportunity to consider lower cost overseas even if the parts are currently made in the EU. This can pose a risk to pump industry jobs in EU.
Particularly for slurry pumps, with the small market size in the EU, there is a concern amongst manufacturers (as communicated by Europump) mining and process industries may move to areas of lower labour cost and lower operating costs to avoid EU energy efficiency regulations imposed on these business.

[16] As the pragmatic option represents most closely the reality, hence it was chosen for the sensitivity analysis instead of the pessimistic or optimistic options. It is however expected that the order of magnitude of impacts of the parameters assessed in sensitivity analysis would be similar of these other two options (pessimistic and optimistic) as that of pragmatic option.

The sensitivity analysis allows checking if any of the results change significantly with different data. This helps to determine how robust and reliable the findings of this study are.

The sensitivity analysis graphs provides a comparison of the change in energy savings or expenditure reduction for each of the four scenarios for a particular a Base-Case by varying the values of the four parameters selected, one by one. As an example for BC 1, if:

- BaU EC 2020 = Electricity consumption of BC 1 stock in 2020 in Business as Usual scenario
- PS1 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 1
- PS2 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 2
- PS3 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 3
- PS4 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 4
- LL PS1 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 1 for a Lower value of lifetime
- LL PS2 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 2 for a Lower value of lifetime
- LL PS3 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 3 for a Lower value of lifetime
- LL PS4 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 4 for a Lower value of lifetime
- UL PS1 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 1 for a Upper value of lifetime
- UL PS2 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 2 for a Upper value of lifetime
- UL PS3 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 3 for a Upper value of lifetime
- UL PS4 EC 2020 = Electricity consumption of BC 1 stock in 2020 in pragmatic Scenario 4 for a Upper value of lifetime

Then the sensitivity analysis assesses for an increase in lifetime for each of the four scenarios the following value (percentage change in energy savings):

$$[(\text{UL PS1 EC 2020} - \text{PS1 EC 2020}) / \text{BaU EC 2020}] \times 100$$

Similarly, the sensitivity analysis also assesses for a decrease in lifetime for each of the four

scenarios the following value(percentage change in energy savings):

[(LL PS1 EC 2020 – PS1 EC 2020)/ BaU EC 2020] x 100

8.5.1 Assumptions related to the product lifetime

Average lifetimes are used in the EcoReport tool to assess environmental and LCC of the Base-Cases. However, some products can have a shorter or a longer lifetime. Such extreme values, are considered for two scenarios (presented below) used in this sensitivity analysis to assess the impact of this parameter on the LCC of the Base-Cases and their electricity consumption during the use phase.

Variation in product lifetime (in years):

- An increase of 50% (upper limit)
- A decrease of -25% (lower limit)

The following figures (Figure 8-15 to Figure 8-28) show the influence of the product lifetime on the total electricity consumption and life-cycle costs of the different Base-Cases and associated improvement options. For all situations, despite the expected variations in absolute values, the ranking of the different improvement options remains the same whether the minimum or maximum parameter is used[17].

[17] The background data used for the sensitivity analysis graphs presented in this section is presented in Annex C.

Figure 8-15: Sensitivity analysis of total electricity consumption18 to product lifetime for BC 1

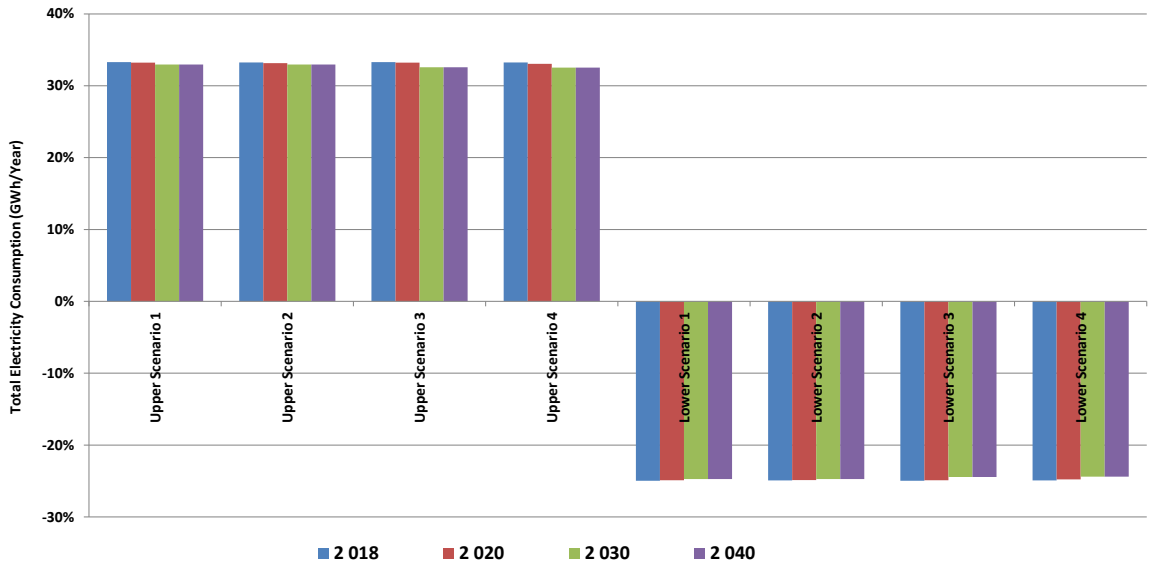
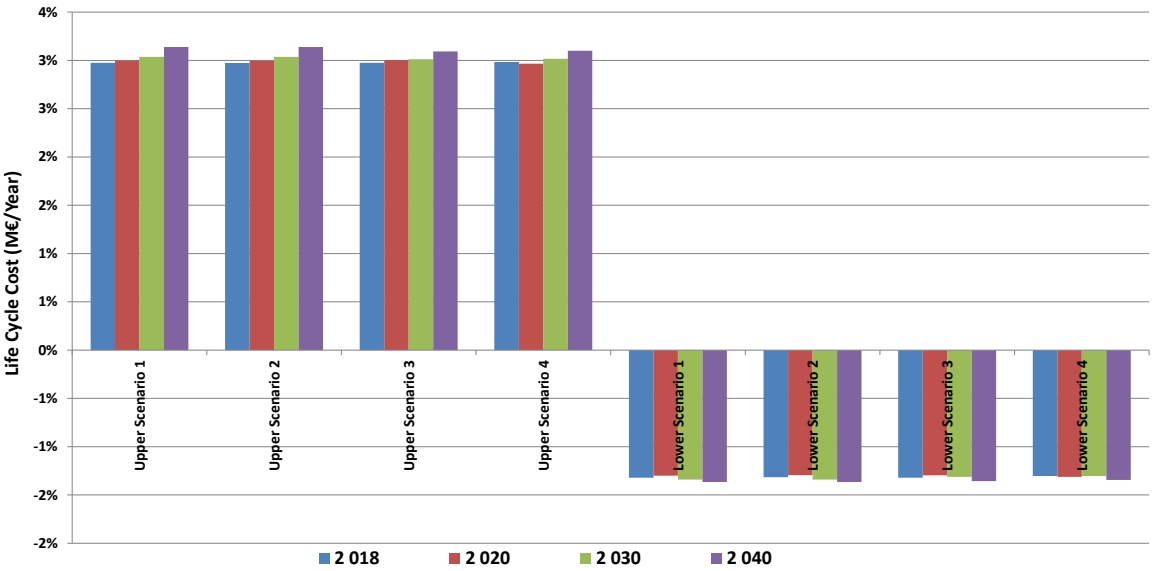


Figure 8-16: Sensitivity analysis of life cycle cost to product lifetime for BC 1



[18] Total Electricity Consumption over the life cycle of the Base-Case

Figure 8-17: Sensitivity analysis of total electricity consumption to product lifetime for BC 2

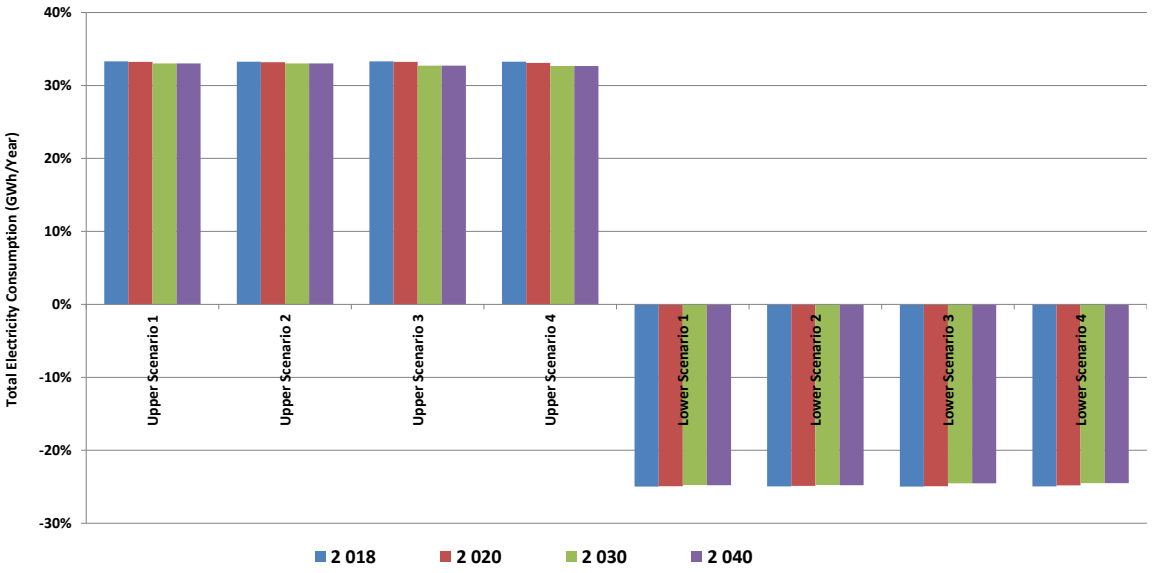


Figure 8-18: Sensitivity analysis of life cycle cost to product lifetime for BC 2

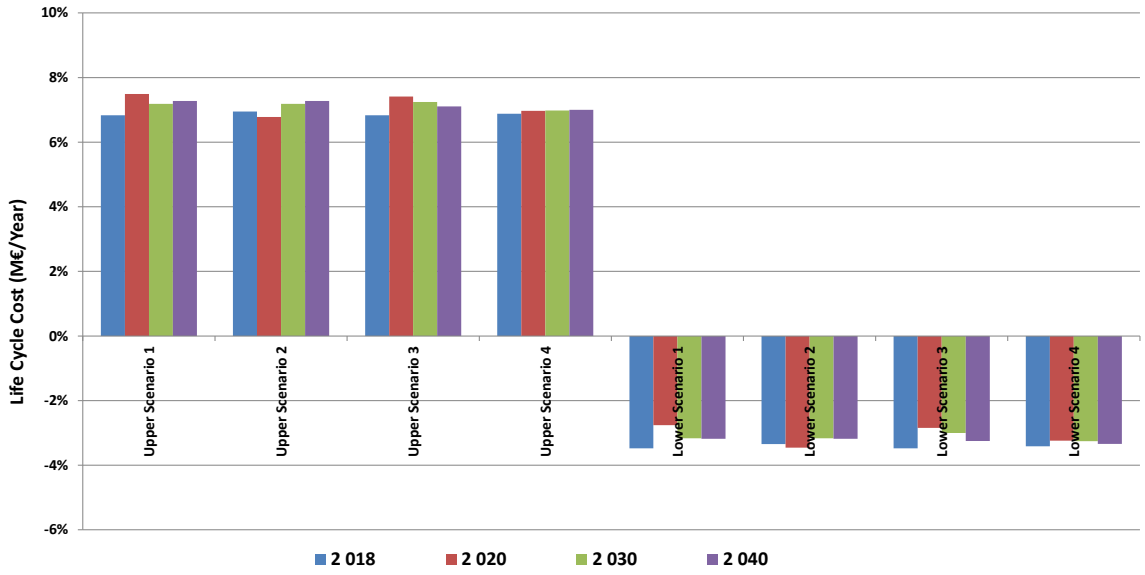


Figure 8-19: Sensitivity analysis of total electricity consumption to product lifetime for BC 4

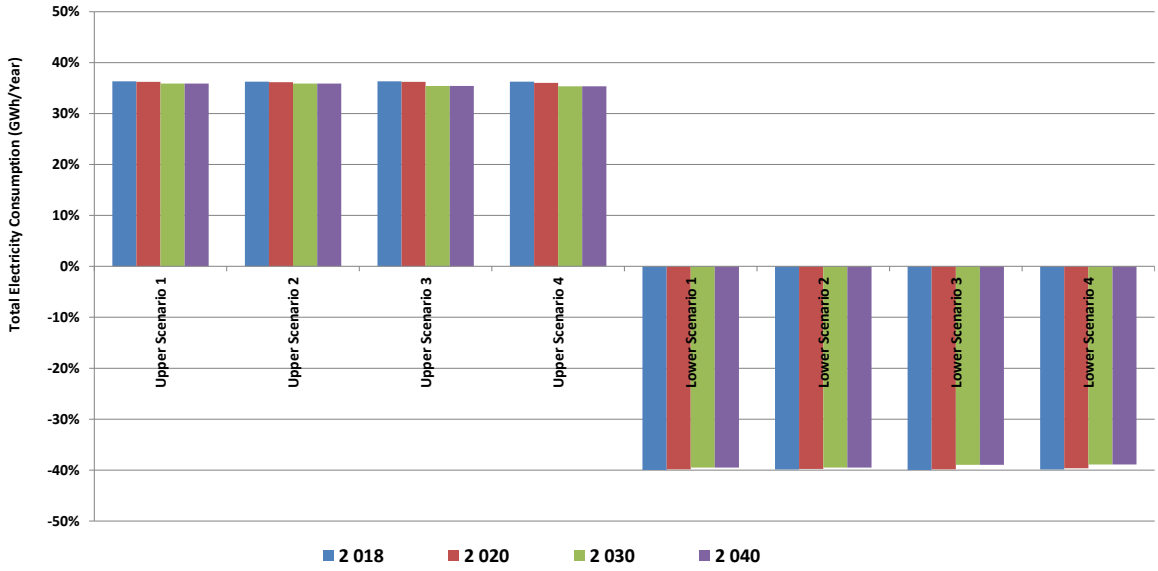


Figure 8-20: Sensitivity analysis of life cycle cost to product lifetime for BC 4

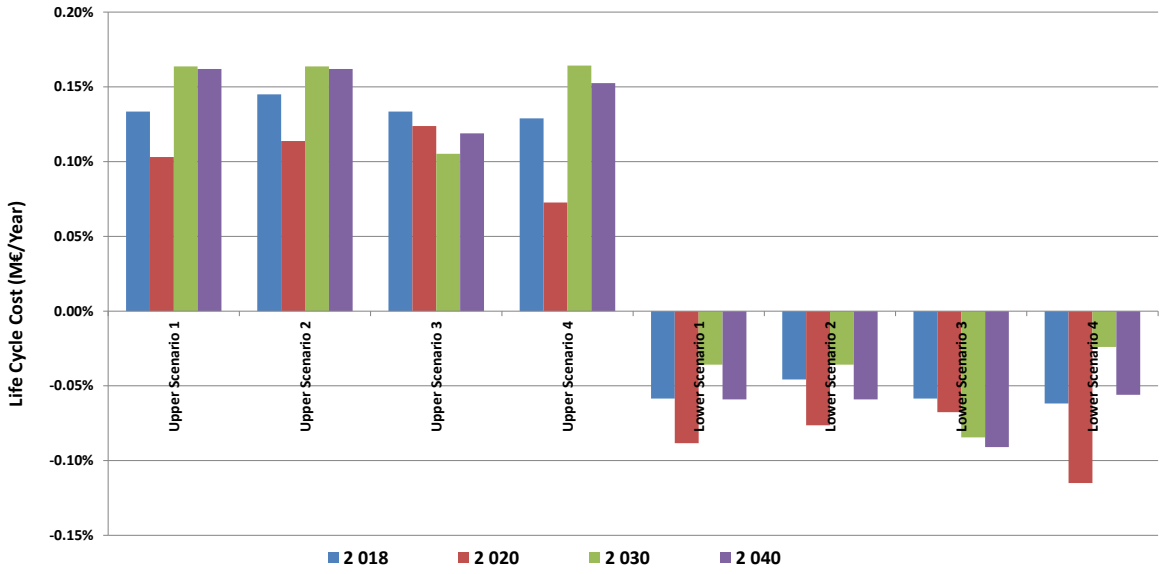


Figure 8-21: Sensitivity analysis of total electricity consumption to product lifetime for BC 5

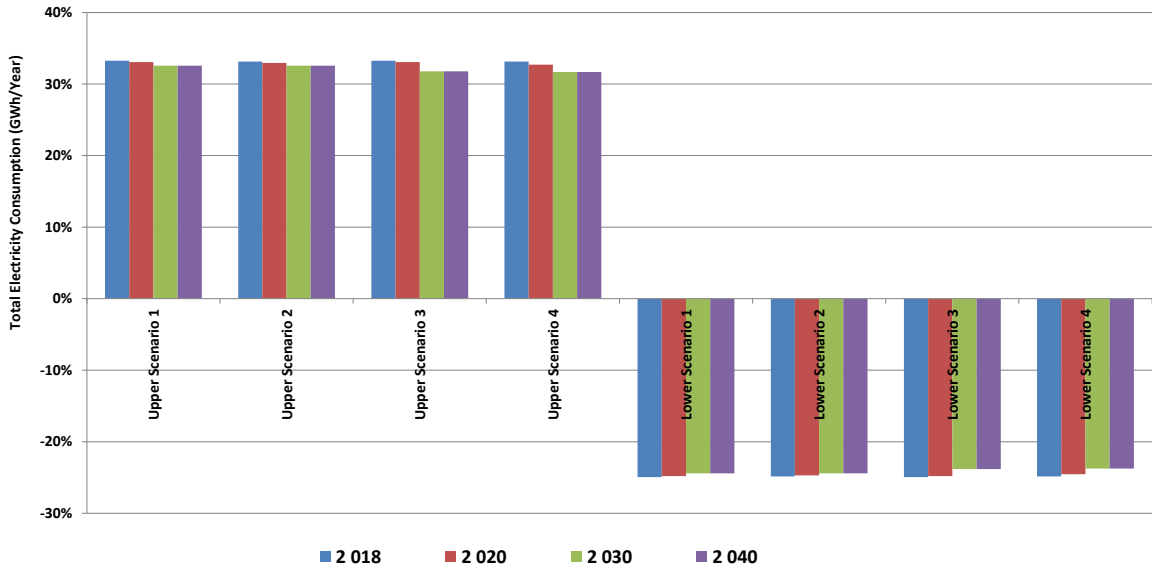


Figure 8-22: Sensitivity analysis of life cycle cost to product lifetime for BC 5

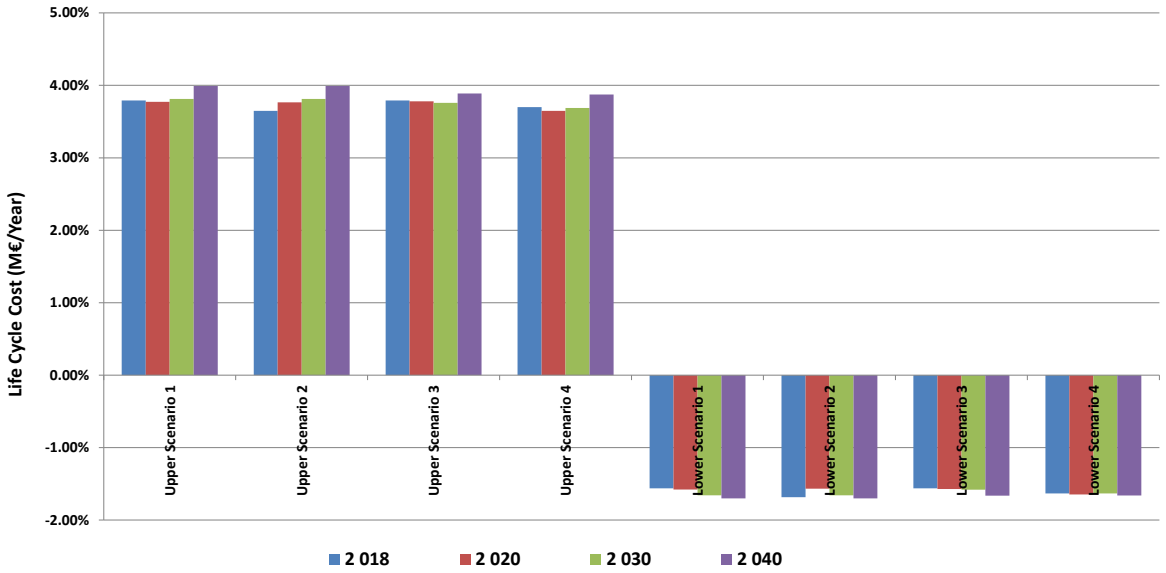


Figure 8-23: Sensitivity analysis of total electricity consumption to product lifetime for BC 6

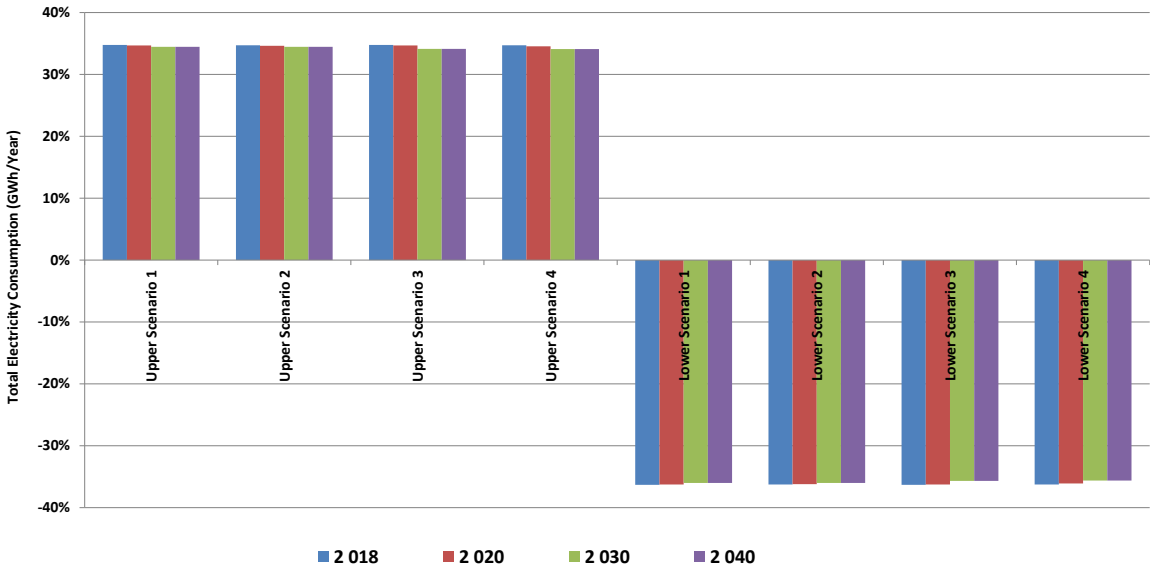


Figure 8-24: Sensitivity analysis of life cycle cost to product lifetime for BC 6

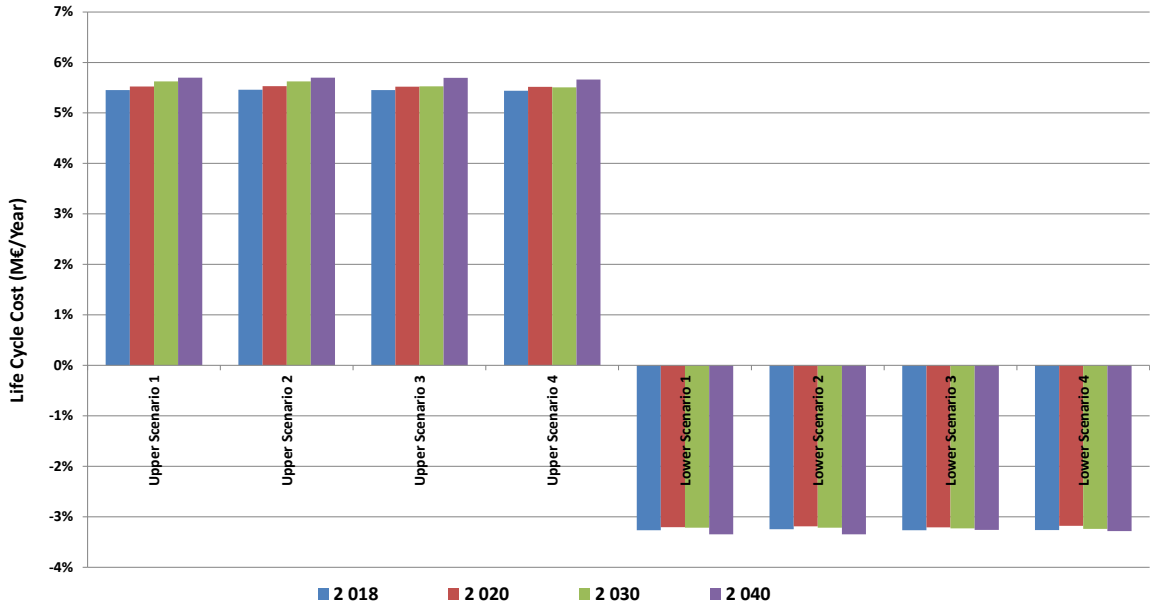


Figure 8-25: Sensitivity analysis of total electricity consumption to product lifetime for BC 7A

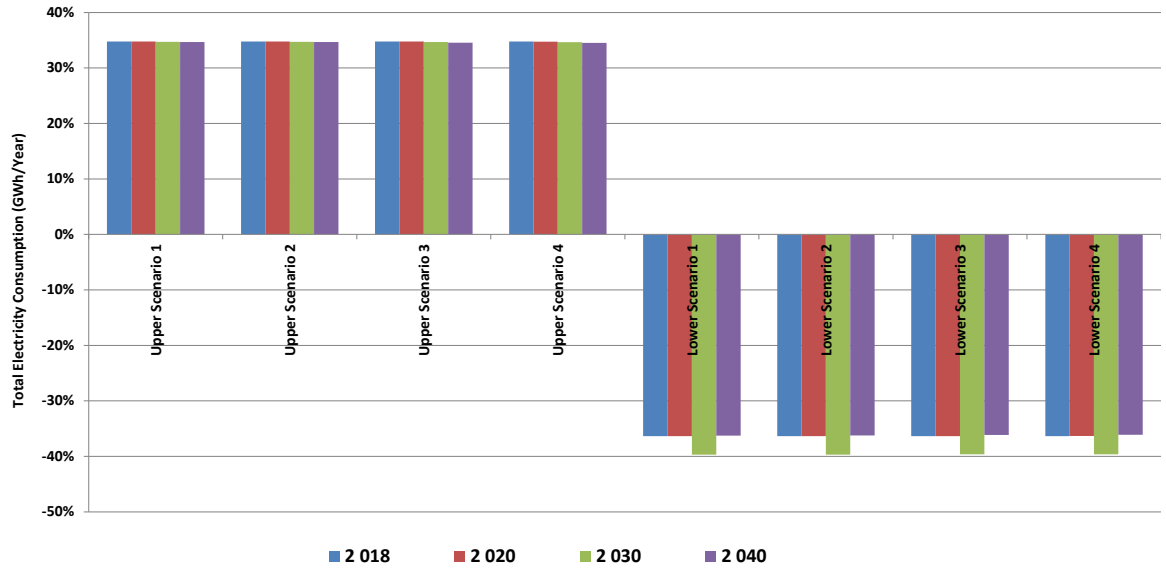


Figure 8-26: Sensitivity analysis of life cycle cost to product lifetime for BC 7A

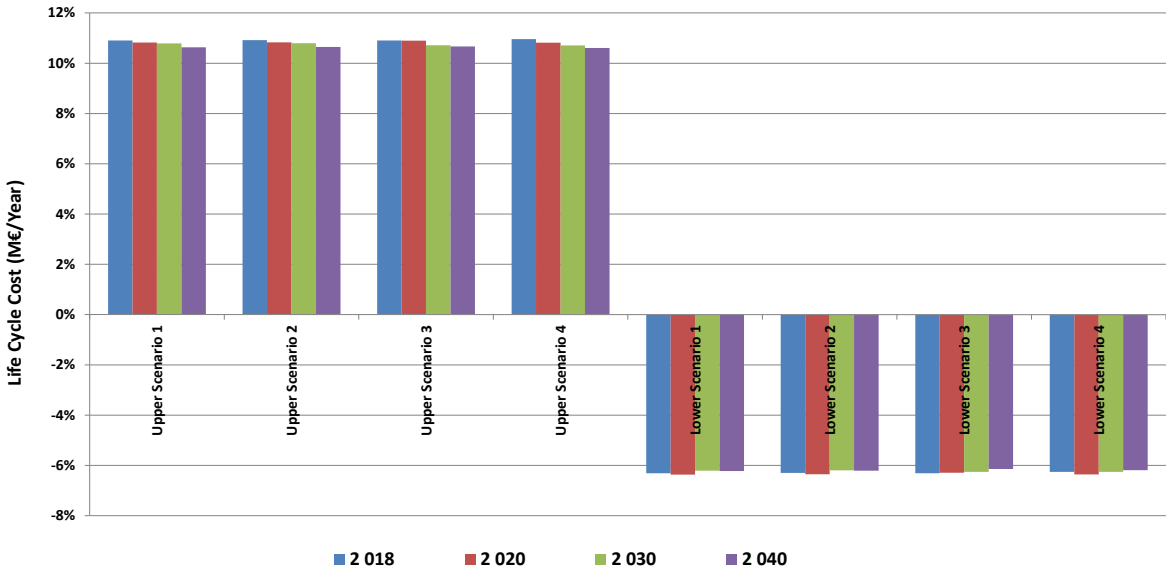


Figure 8-27: Sensitivity analysis of total electricity consumption to product lifetime for All BCs

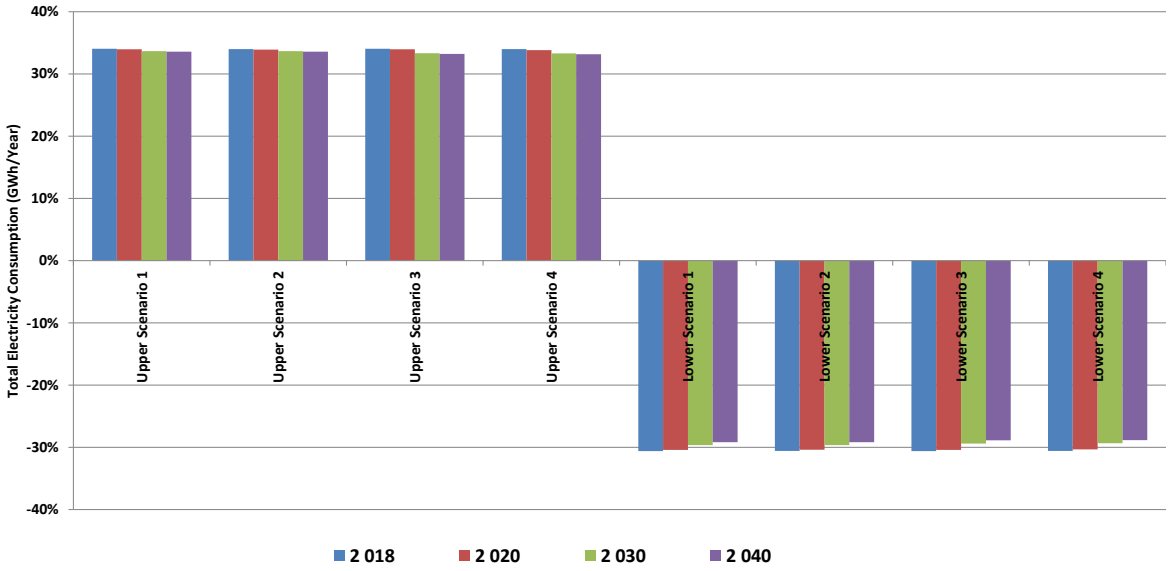
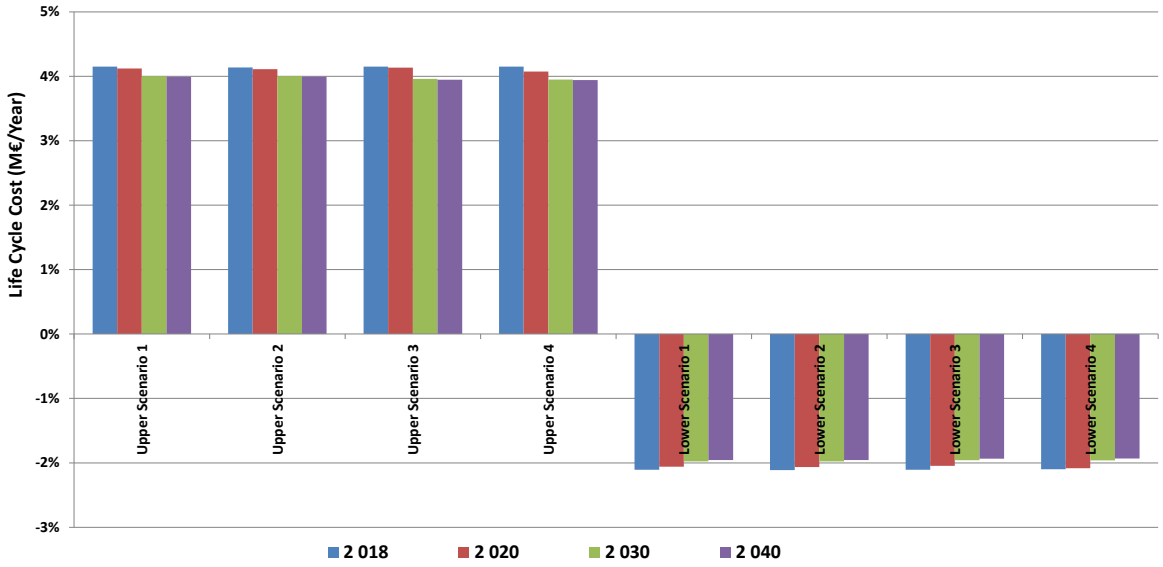


Figure 8-28: Sensitivity analysis of life cycle cost to product lifetime for All BCs



8.5.2 Assumptions related to the product price

The ranges of Lot 28 pumps covered by each of the product groups (Base-Cases) are very wide. Lot 28 pumps with a variety of characteristics, applications and different purchase prices exist on the EU market.

Therefore, compared to the product price defined for Base-Cases, two scenarios are defined, to take into account the fact that on the one hand, the price may be underestimated and on the other that it is overestimated.

Variation in product price:

- An increase of 25% (upper limit)
- A decrease of - 50% (lower limit)

The following figures (Figure 8-29 to Figure 8-35) show the influence of the product price on the life-cycle costs of the different base-cases and associated improvement options. For all situations, despite the expected variations in absolute values, the ranking of the different improvement options remains the same whether the minimum or maximum parameter is used[17].

Figure 8-29: Sensitivity analysis of life cycle cost to product price for BC 1

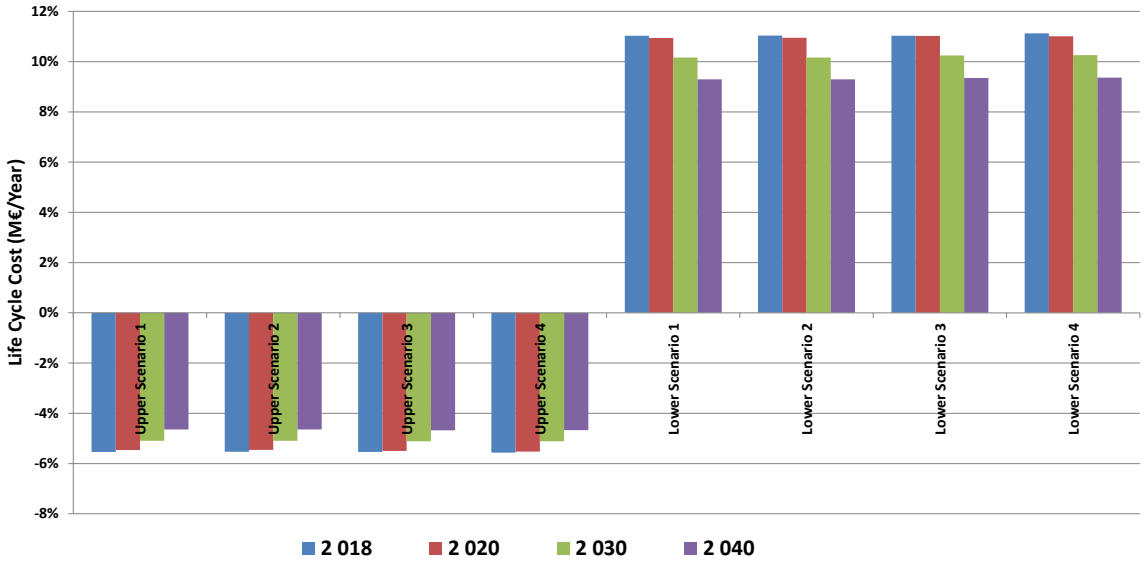


Figure 8-30: Sensitivity analysis of life cycle cost to product price for BC 2

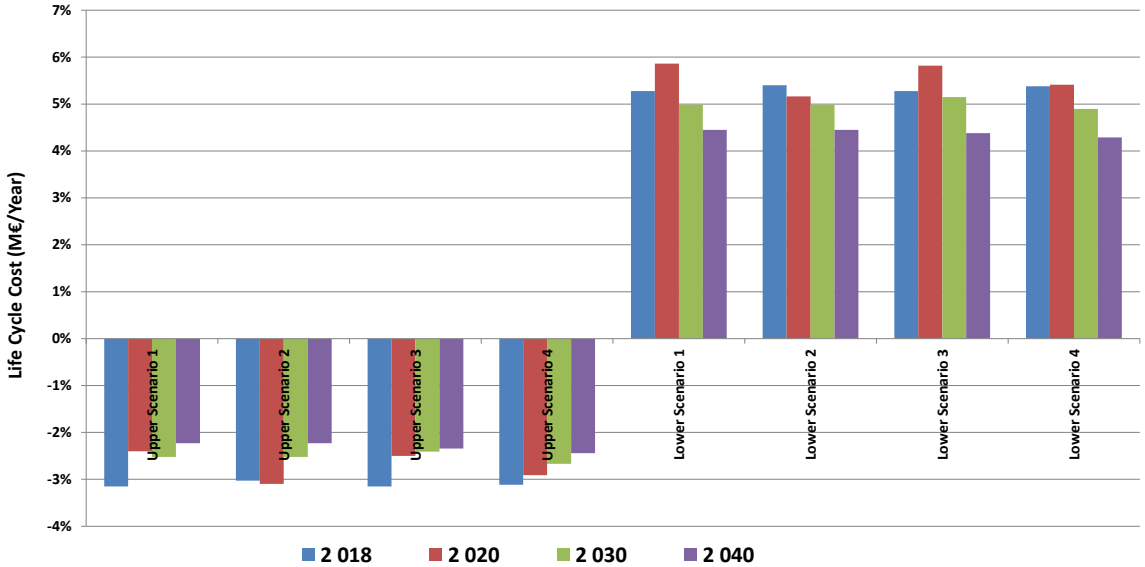


Figure 8-31: Sensitivity analysis of life cycle cost to product price for BC 4

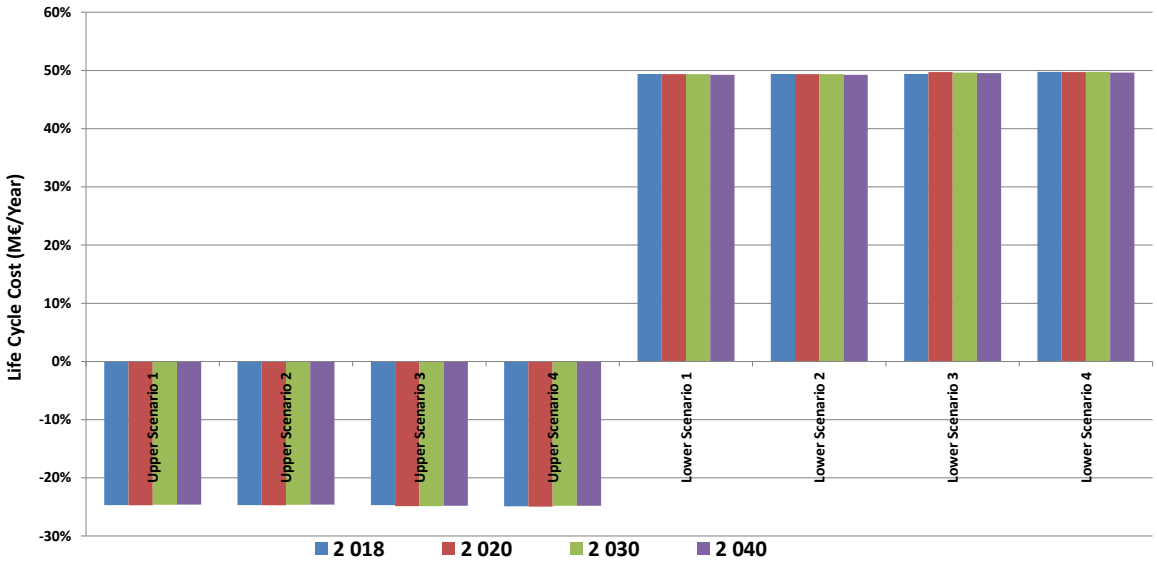


Figure 8-32: Sensitivity analysis of life cycle cost to product price for BC 5

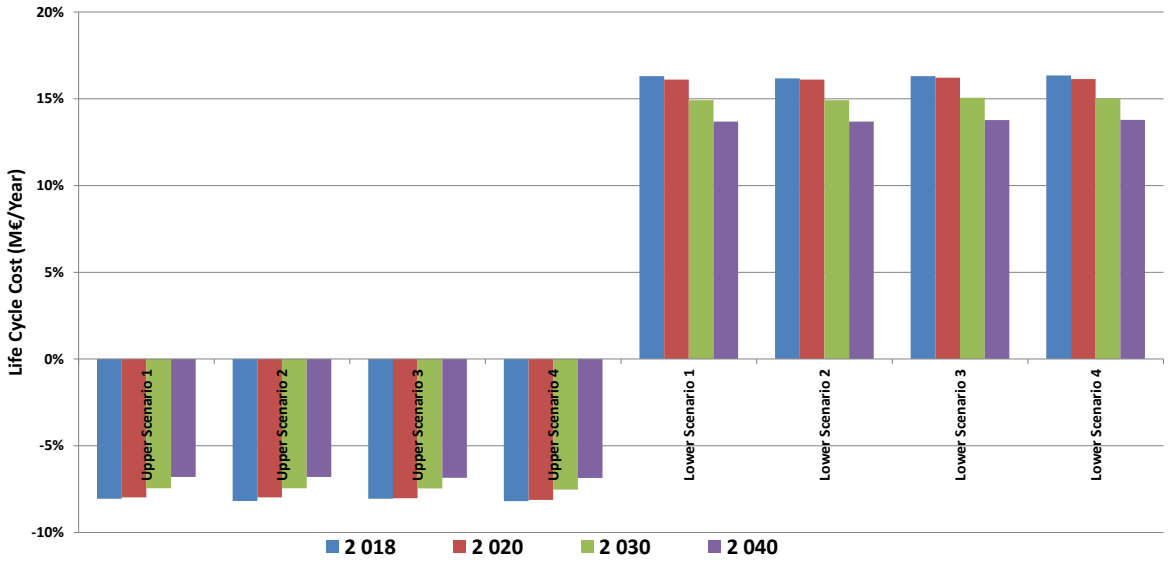


Figure 8-33: Sensitivity analysis of life cycle cost to product price for BC 6

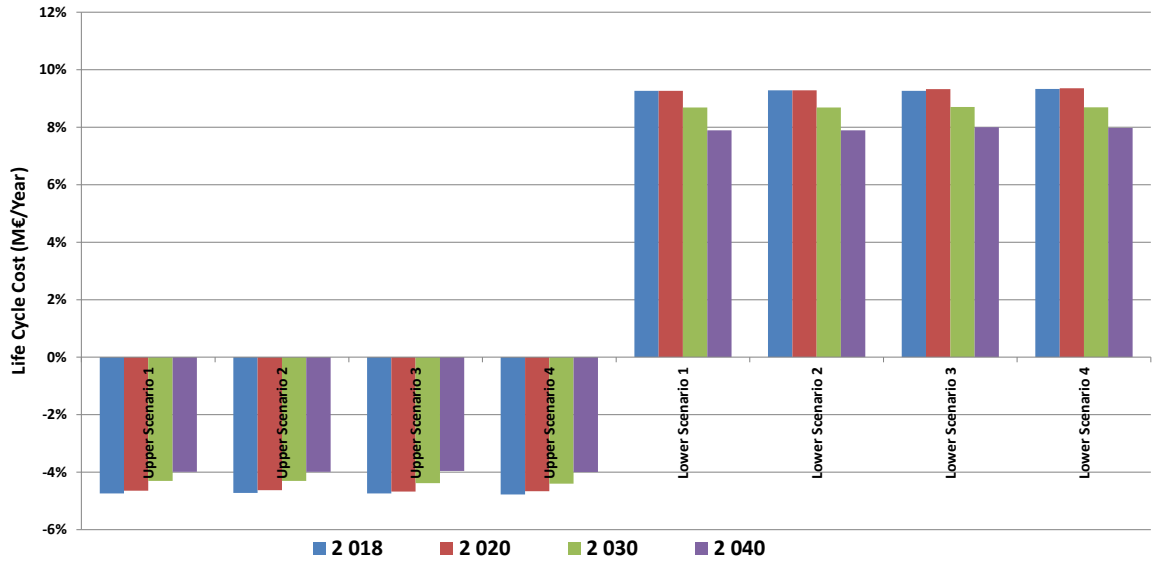


Figure 8-34: Sensitivity analysis of life cycle cost to product price for BC 7A

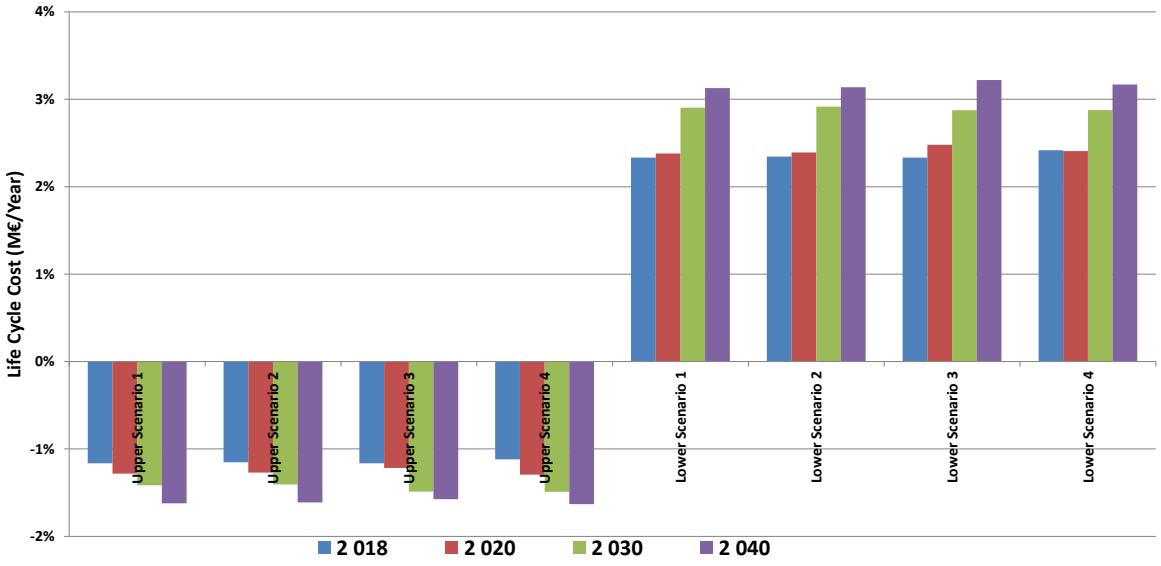
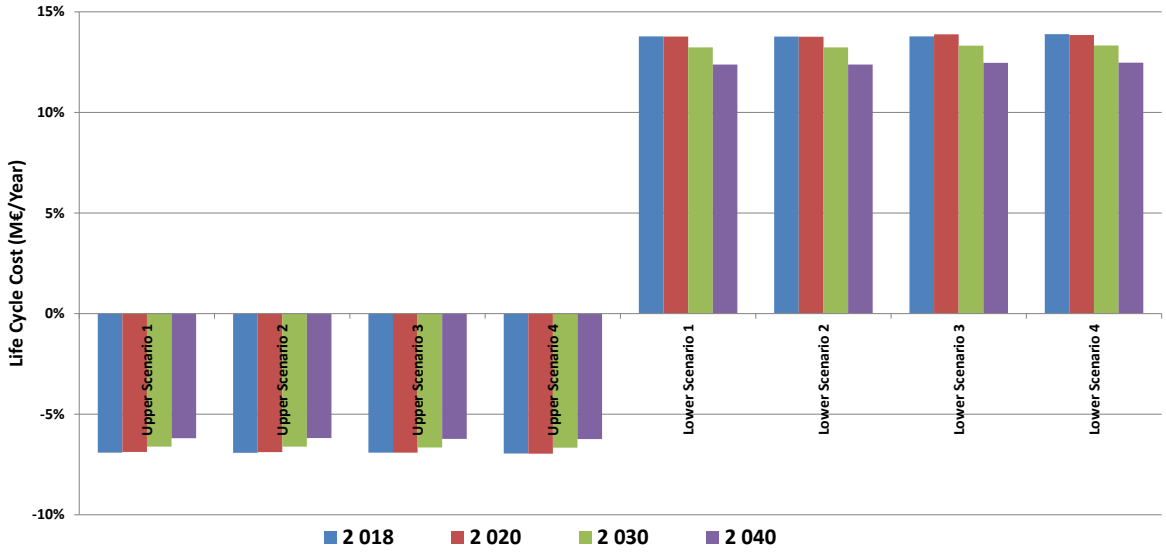


Figure 8-35: Sensitivity analysis of life cycle cost to product price for All BCs



8.5.3 Assumptions related to the sales growth rate

Estimating the stock of Lot 28 pumps in EU was not an easy task due to the fragmented nature of the market and limited availability of corresponding market data particularly concerning sales growth rate.

In Task 2, stock for 2011 was defined based on available information and inputs provided by stakeholders. Sales growth rate was estimated to be 2.5% till 2017 by industry stakeholders. The same growth rate was assumed by project team to be applicable till 2040.

Variation in sales growth rate:

- An increase to 5%
- A decrease to 0%

The following figures (Figure 8-36 to Figure 8-49) show the influence of the sales growth rate on the total electricity consumption (TEC) and life-cycle costs of the different base-cases and associated improvement options. For all situations, despite the expected variations in absolute values, the ranking of the different improvement options remains the same whether the minimum or maximum parameter is used[17].

Figure 8-36: Sensitivity analysis of total electricity consumption to sales growth rate for BC 1

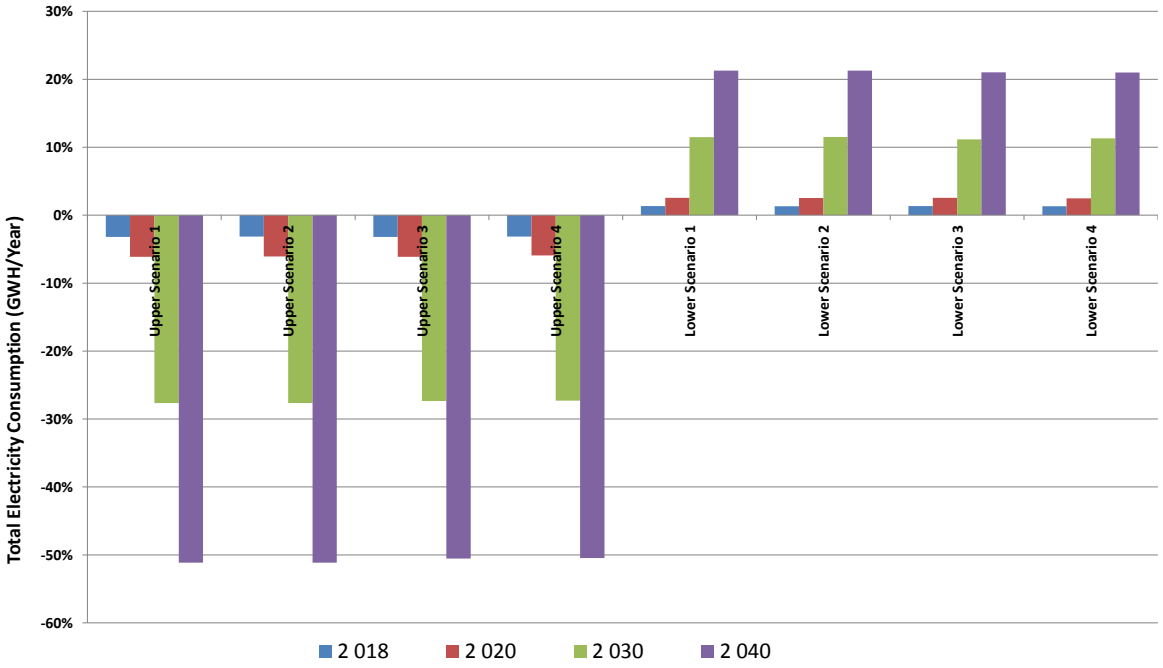


Figure 8-37: Sensitivity analysis of life cycle cost to sales growth rate for BC 1

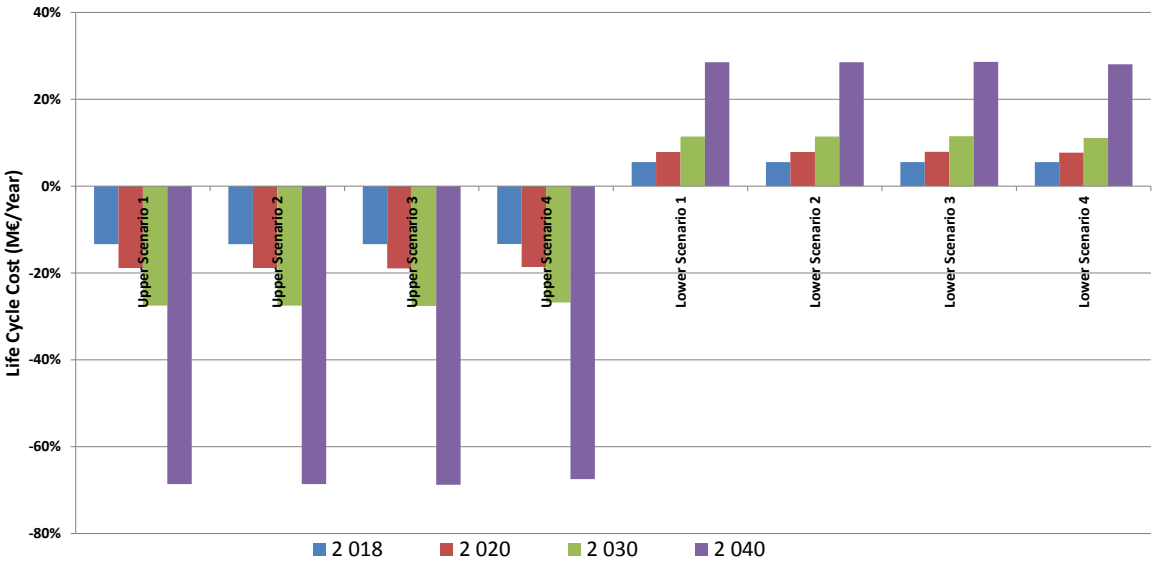


Figure 8-38: Sensitivity analysis of total electricity consumption to sales growth rate for BC 2

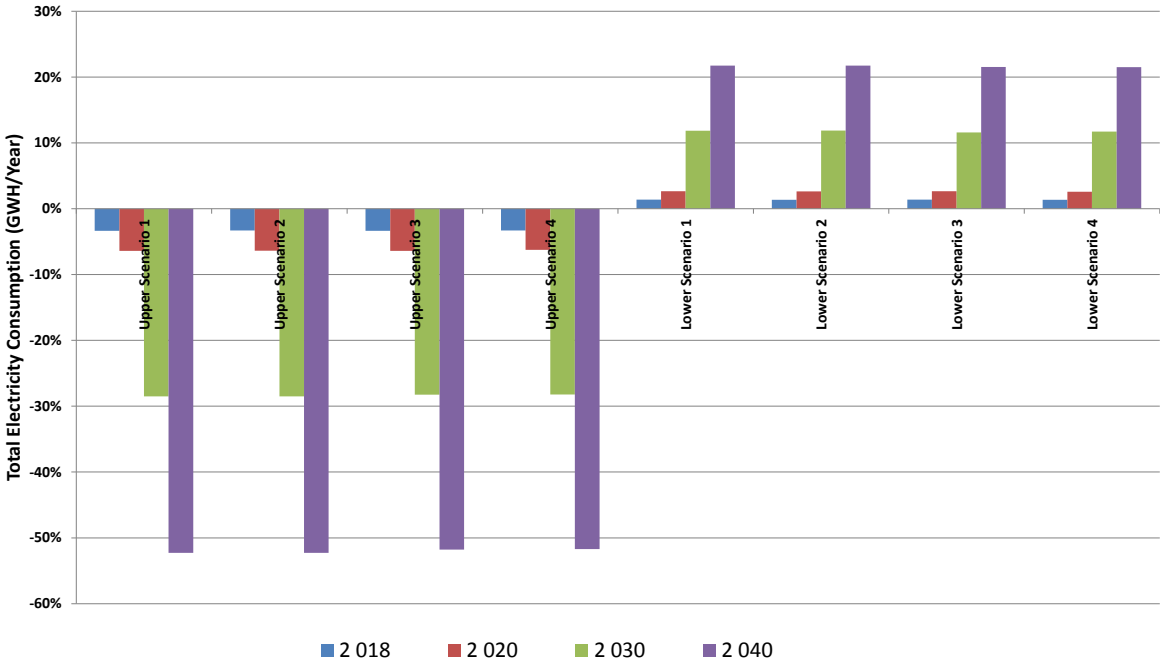


Figure 8-39: Sensitivity analysis of life cycle cost to sales growth rate for BC 2

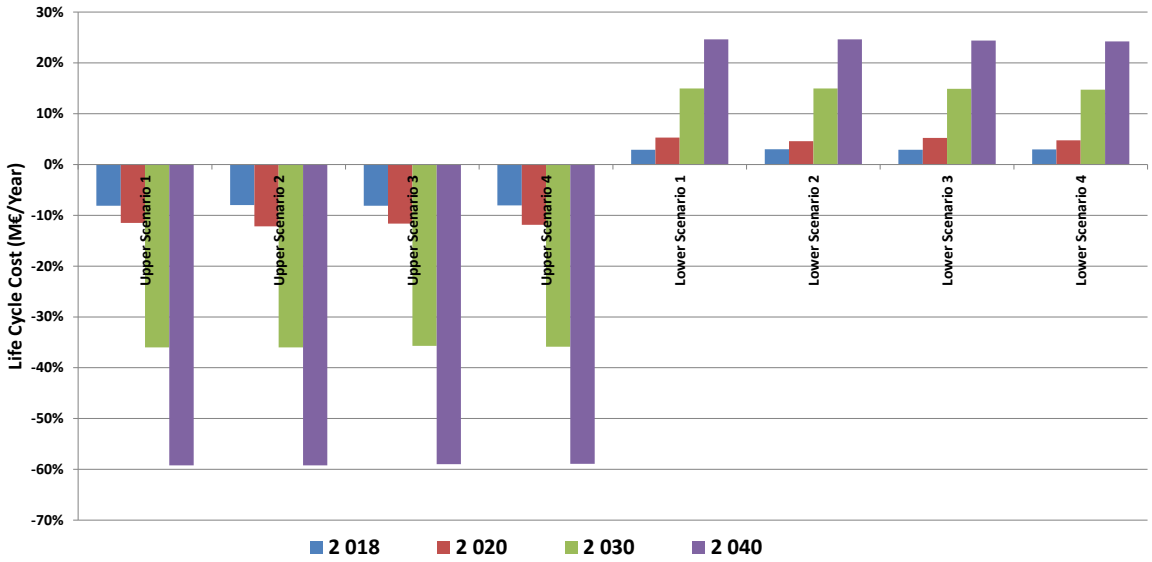


Figure 8-40: Sensitivity analysis of total electricity consumption to sales growth rate for BC 4

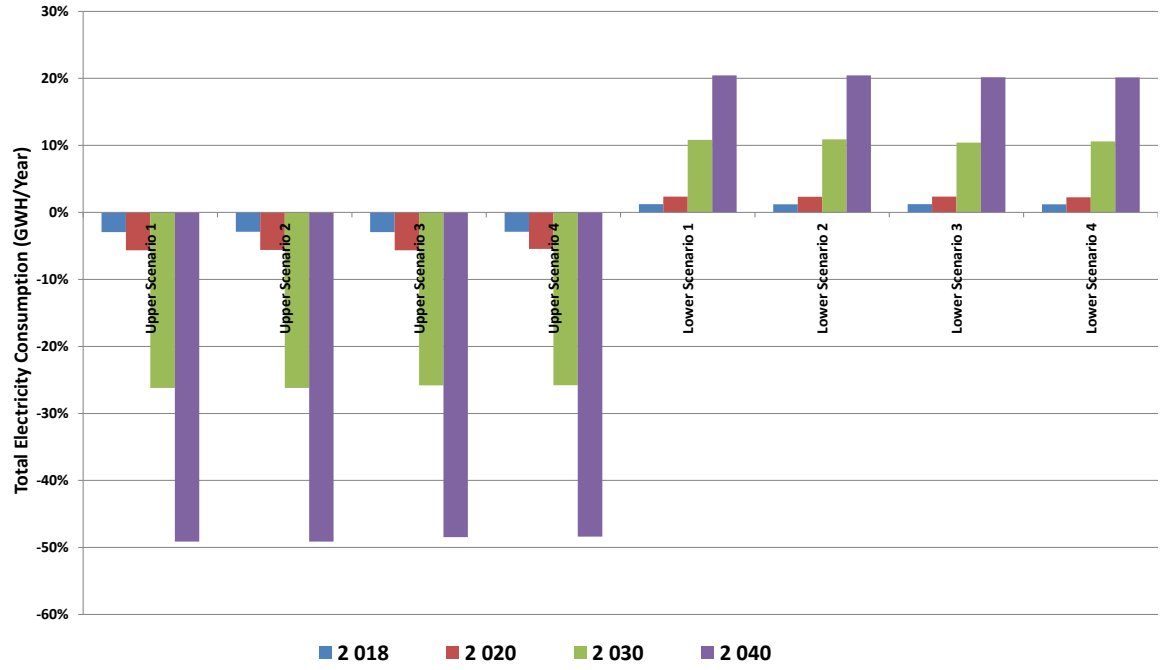


Figure 8-41: Sensitivity analysis of life cycle cost to sales growth rate for BC 4

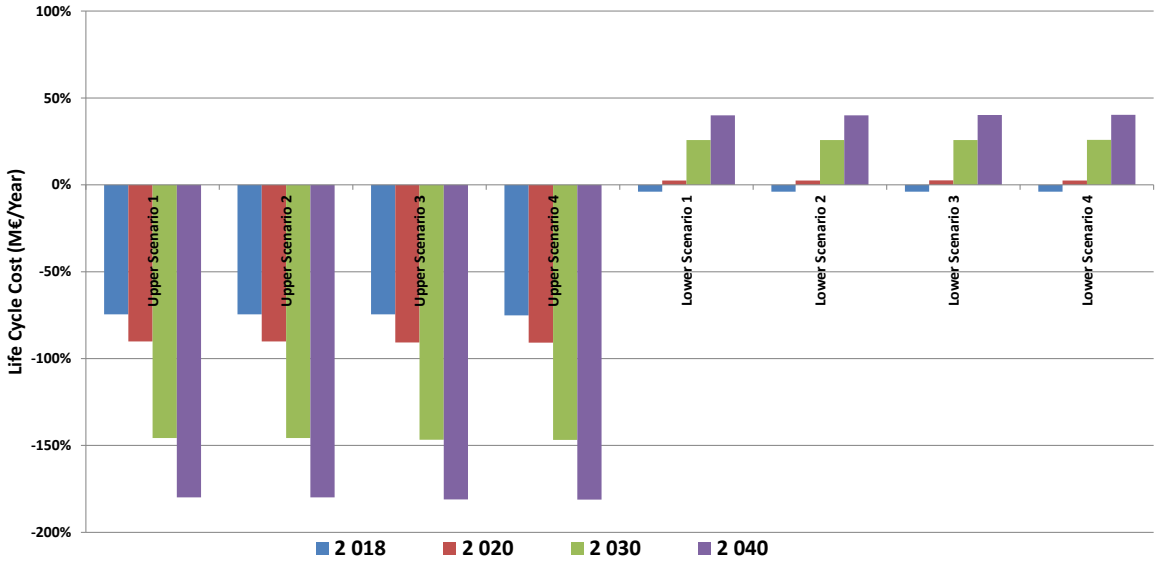


Figure 8-42: Sensitivity analysis of total electricity consumption to sales growth rate for BC 5

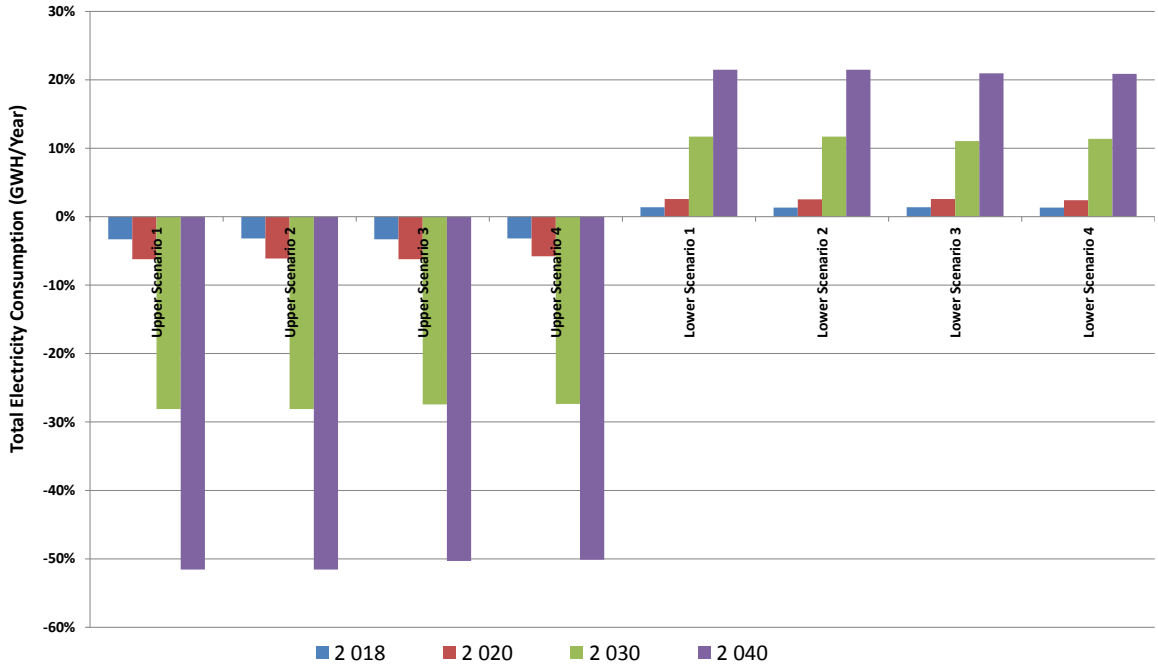


Figure 8-43: Sensitivity analysis of life cycle cost to sales growth rate for BC 5

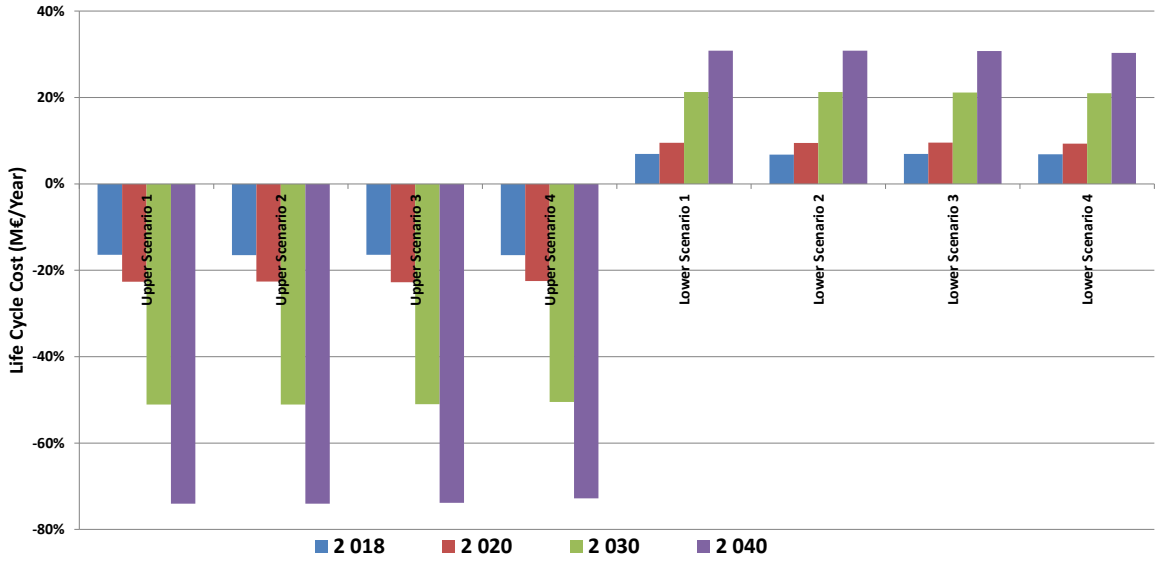


Figure 8-44: Sensitivity analysis of total electricity consumption to sales growth rate for BC 6

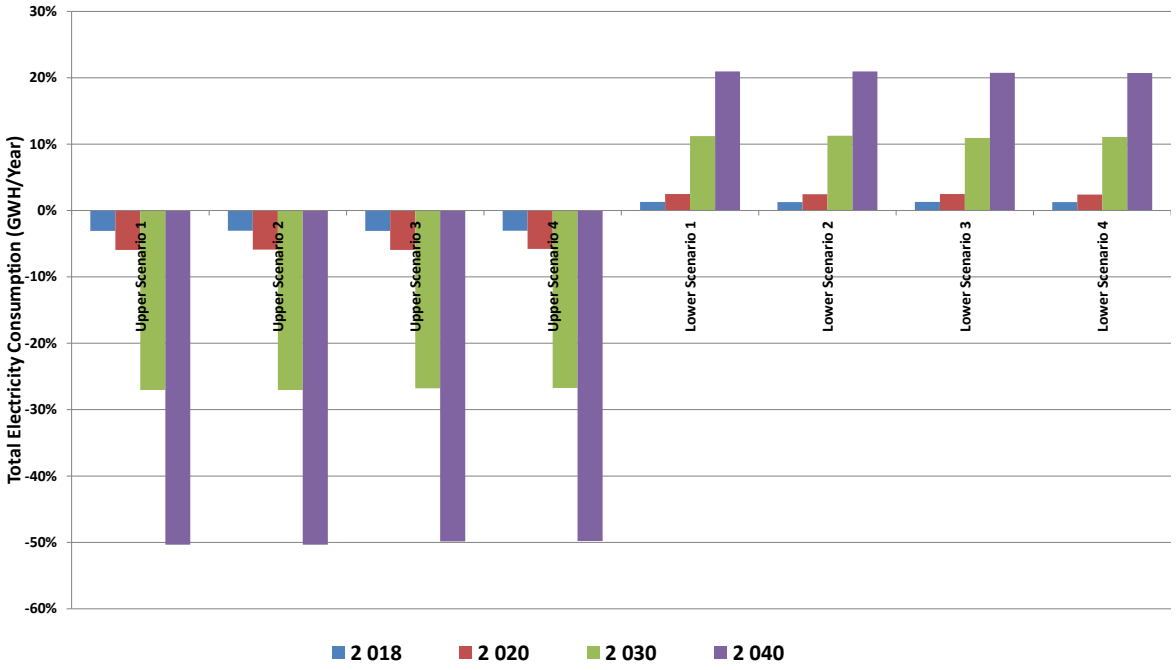


Figure 8-45: Sensitivity analysis of life cycle cost to sales growth rate for BC 6

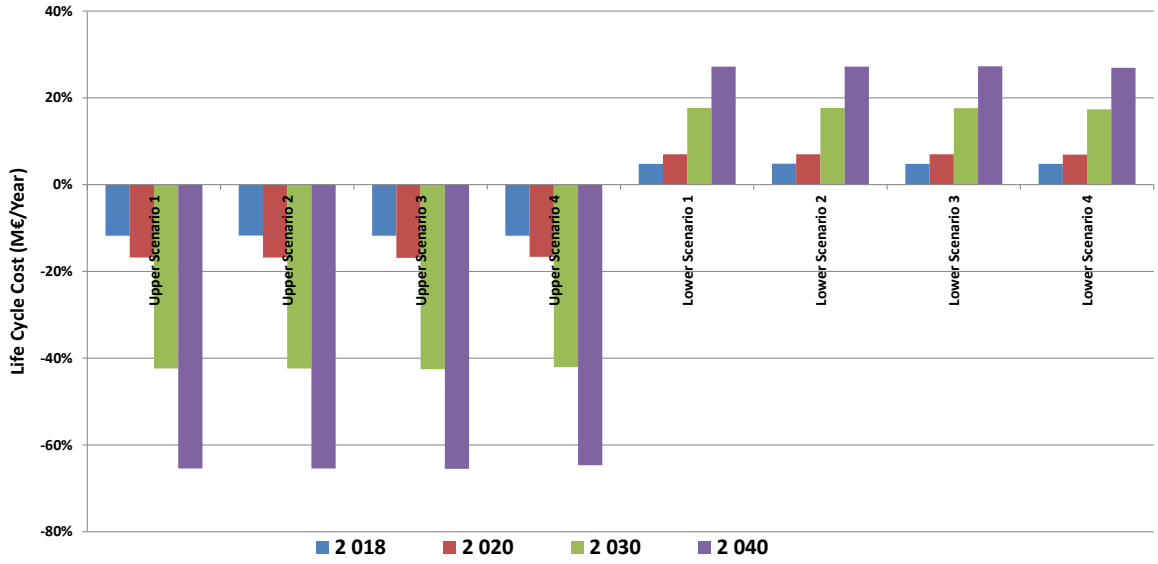


Figure 8-46: Sensitivity analysis of total electricity consumption to sales growth rate for BC 7A

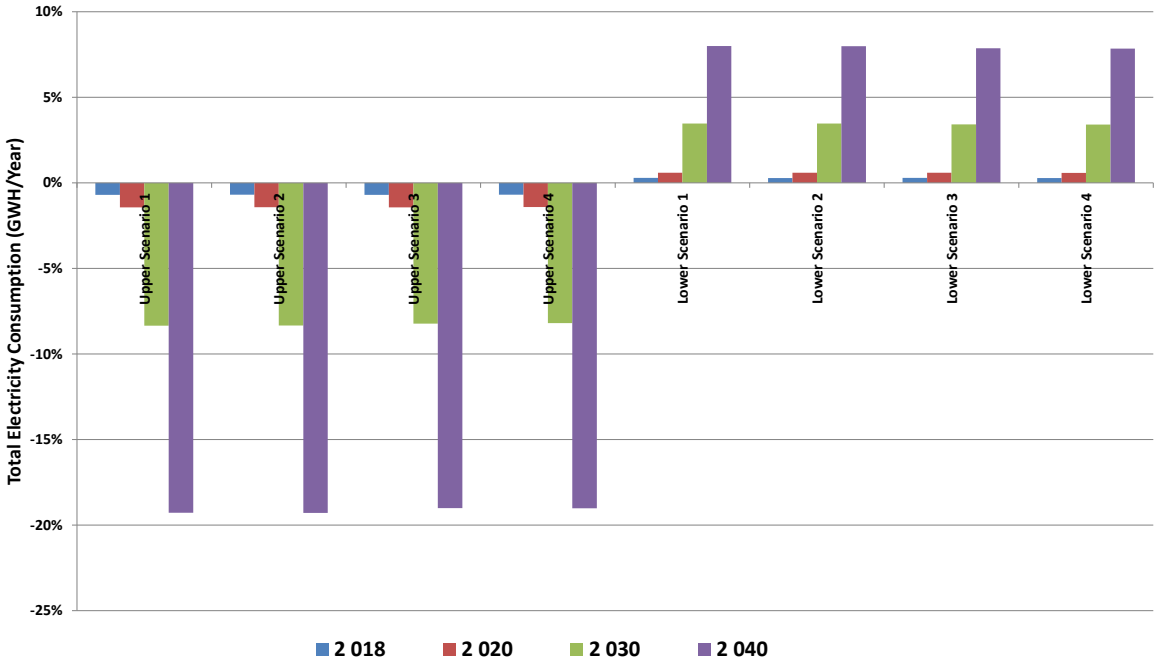


Figure 8-47: Sensitivity analysis of life cycle cost to sales growth rate for BC 7A

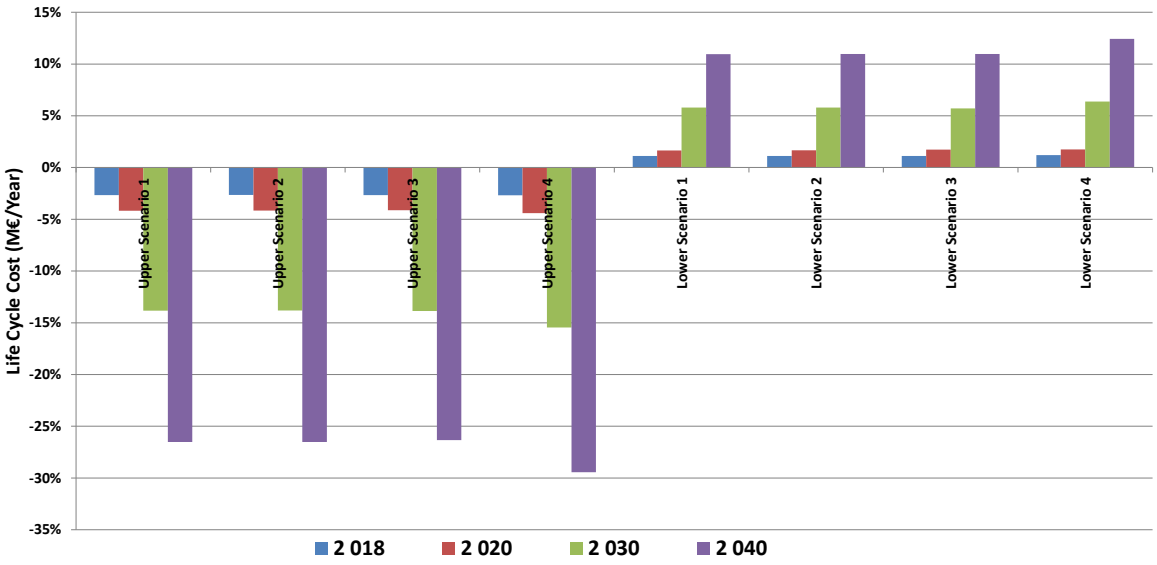


Figure 8-48: Sensitivity analysis of total electricity consumption to sales growth rate for All BCs

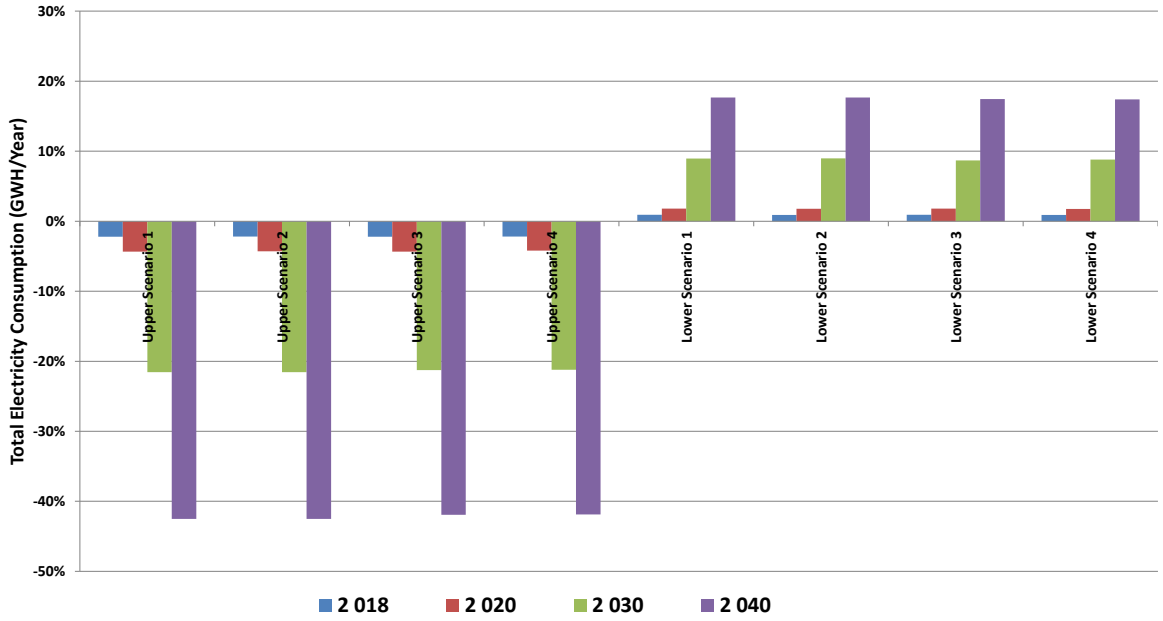
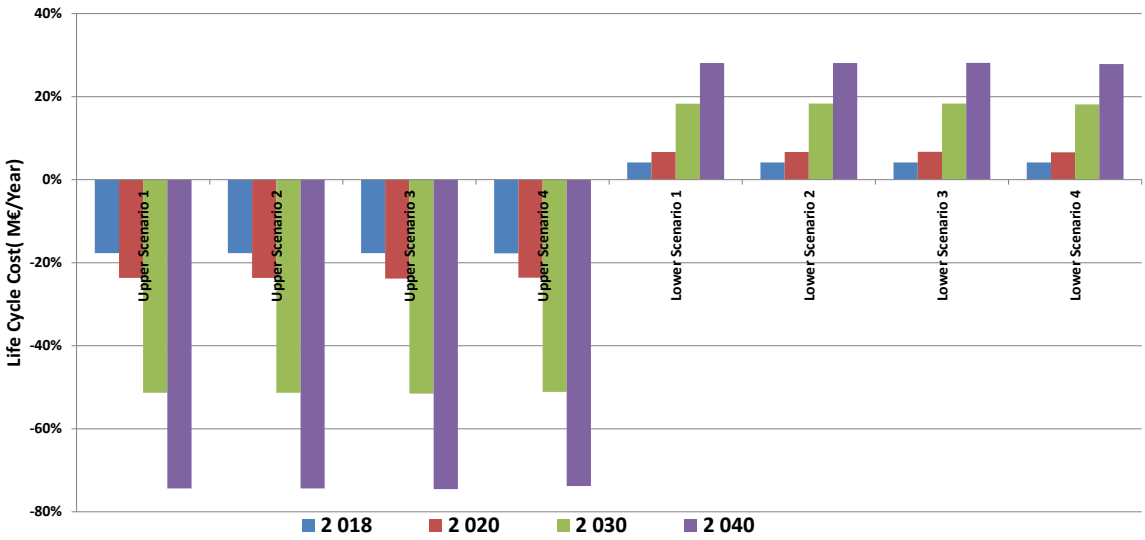


Figure 8-49: Sensitivity analysis of life cycle cost to sales growth rate for All BCs



8.5.4 Assumptions related to the maintenance and repair cost

The ranges of Lot 28 pumps covered by each of the product groups (Base-Cases) are very wide. Lot 28 pumps with a variety of characteristics, applications and different maintenance and repair costs exist on the EU market.

Therefore, compared to the maintenance and repair cost defined for Base-Cases, one scenario is defined to take into account the fact the cost may be underestimated.

- Variation in maintenance and repair cost: An increase of 100% (upper limit)

The following figures (Figure 8-50 to Figure 8-56) show the influence of the maintenance and repair cost on the life-cycle costs of the different base-cases and associated improvement options. For all situations, despite the expected variations in absolute values, the ranking of the different improvement options remains the same whether the minimum or maximum parameter is used[17].

Figure 8-50: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 1

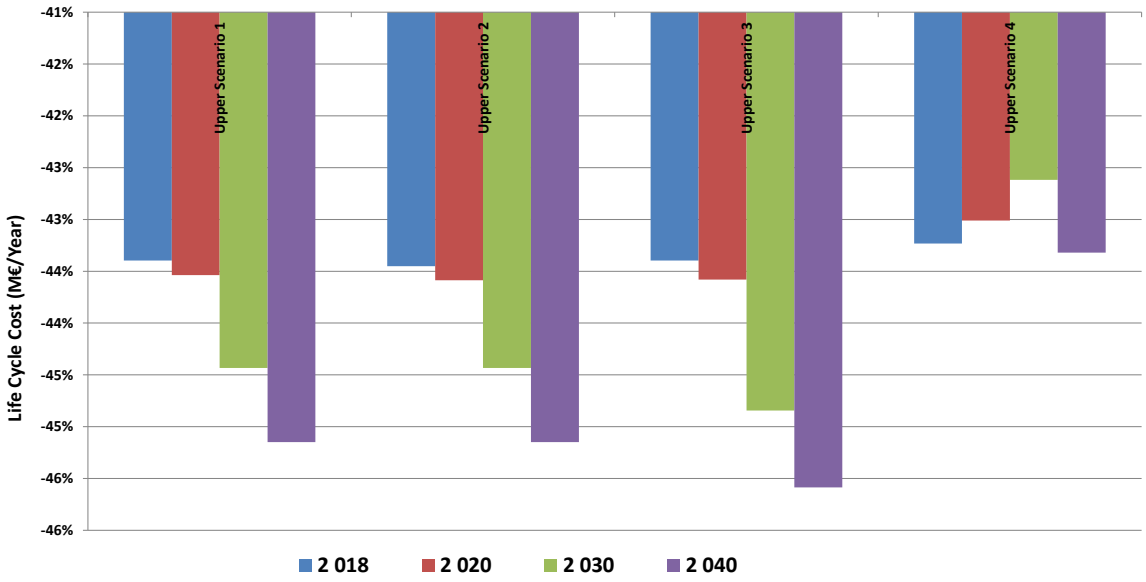


Figure 8-51: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 2

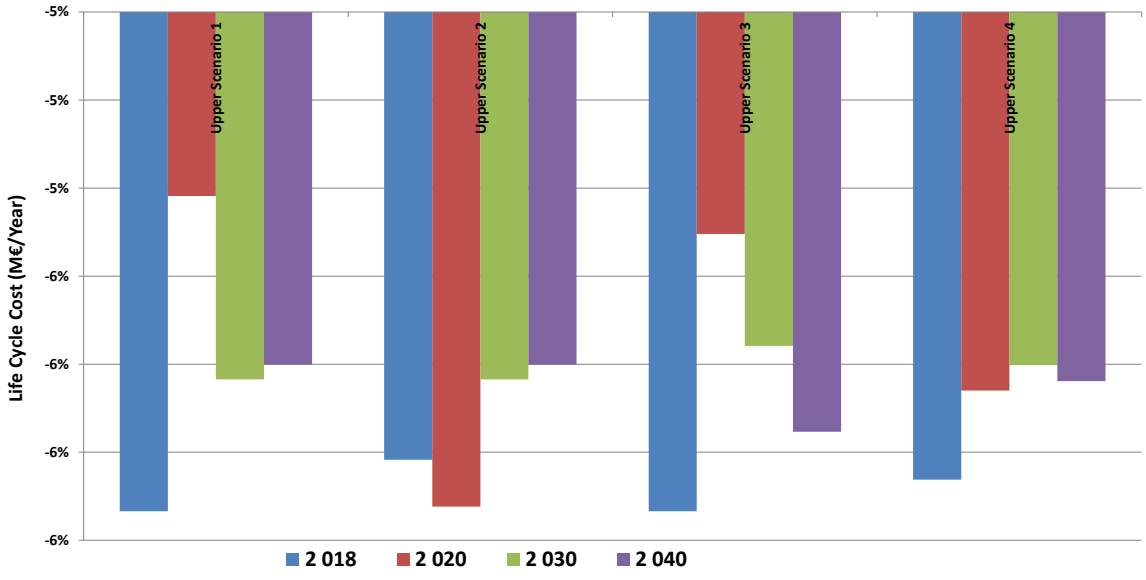


Figure 8-52: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 4

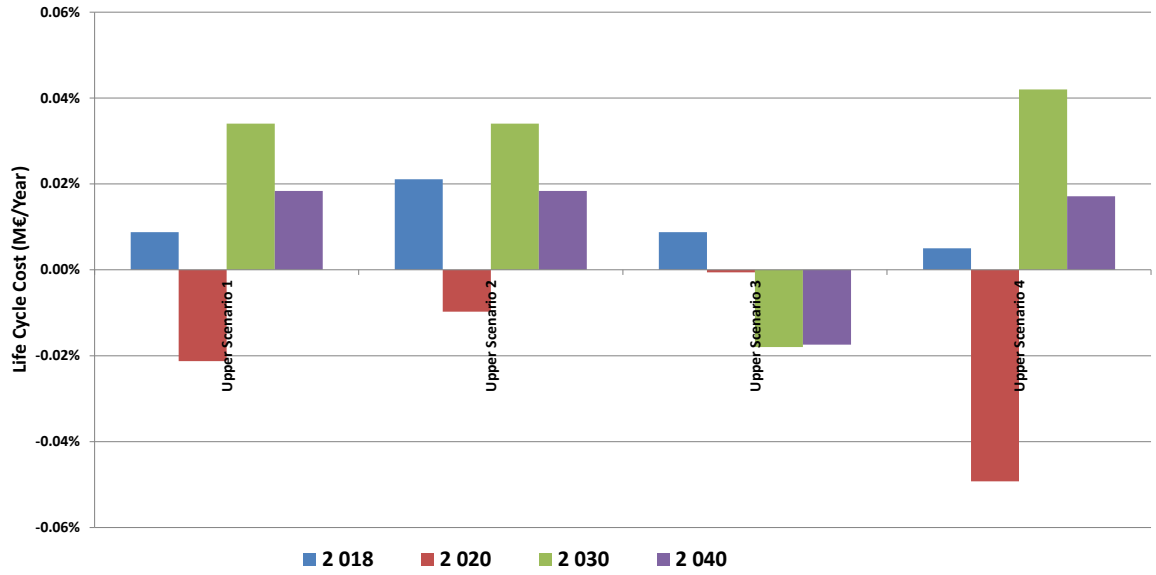


Figure 8-53: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 5

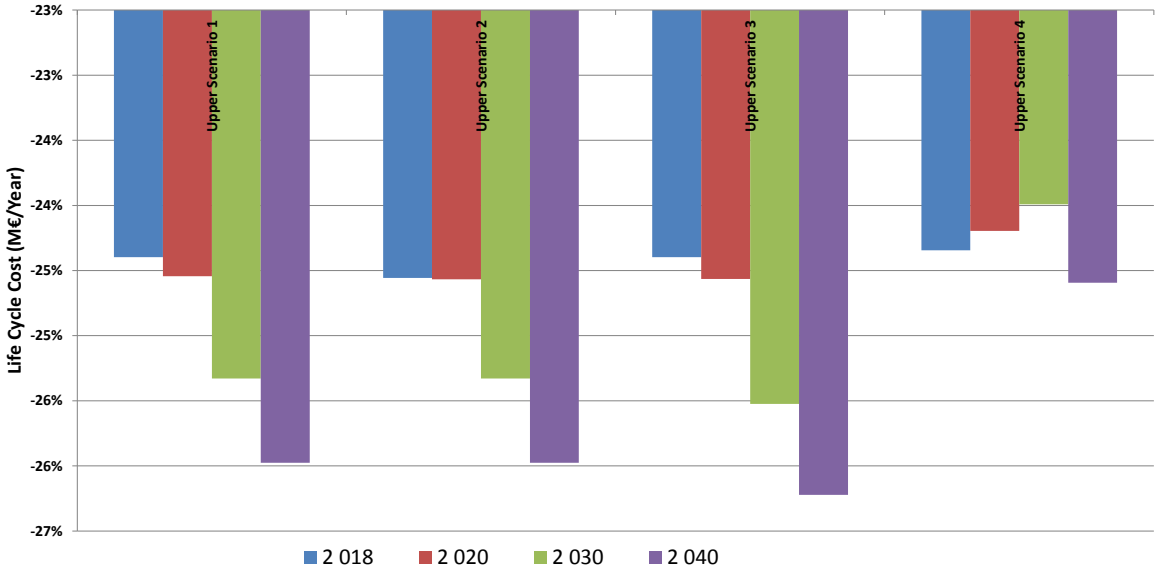


Figure 8-54: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 6

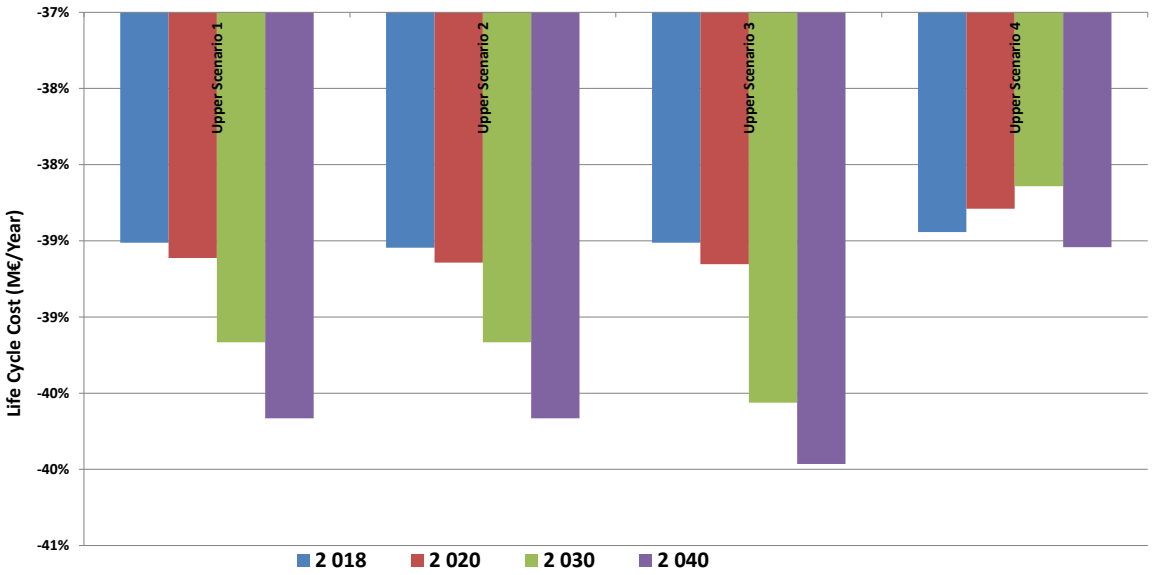


Figure 8-55: Sensitivity analysis of life cycle cost to maintenance and repair cost for BC 7A

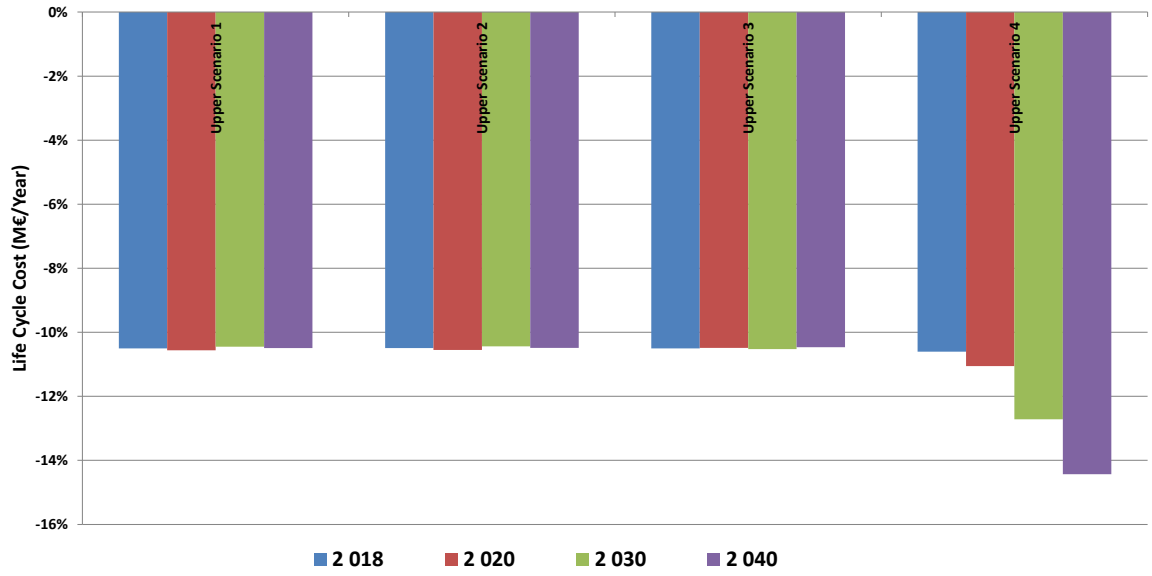
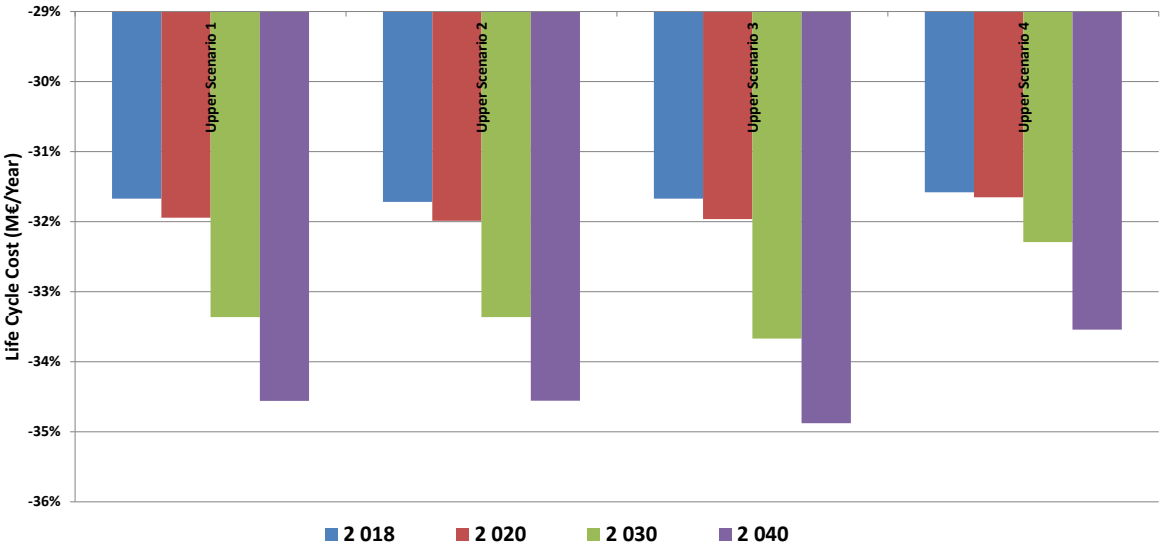


Figure 8-56: Sensitivity analysis of life cycle cost to maintenance and repair cost for All BCs



8.5.5 Conclusions of the sensitivity analysis

When varying the input data on 4 parameters: product purchase price, product lifetime, sales growth rate and maintenance and repair costs, the evolution of the four different pragmatic scenarios relative to the BaU is similar to presented in section 8.3: the maximum energy and economic savings are achieved in 2040 in all the scenarios, whilst the consumer expenditure would be penalised in 2020 and 2030. This observation strengthens the reliability of the outcomes presented in previous tasks.

8.6 Conclusions

This Task report brings together the finding of the previous seven tasks of the Lot 28 preparatory study for Ecodesign requirements of pumps for public and private wastewater and for fluids with high solids content. It looked at the possibility to propose suitable requirements for these Lot 28 pumps to achieve environmental improvements.

Generic ecodesign requirements are recommended for all the Base-Cases considered in Lot 28 study. As pumps usually require professional engineers and technicians to dimension and design the systems, relevant product information requirements were thought to be more effective than energy labelling[19].

Whereas, the possibility to set specific ecodesign requirements was analysed in this report for the following Base-Cases:

- BC 1: Submersible radial sewage pumps 1 to 160 kW
- BC2: Submersible fixed flow & axial pumps
- BC 4: Centrifugal submersible domestic drainage pump<40mm passage
- BC 5: Submersible dewatering pumps
- BC 6: Dry well radial sewage pumps 1 to 160 kW
- BC 7A: Light duty slurry pumps

A number of potential MEPS based on the MEI cut-off criteria for specific Lot 28 pumps (BC 1, BC 2, BC 4, BC 5, BC 6 and BC 7A) are considered, as presented below:

- Option 1: MEI cut-off values as 0.1 as Tier 1 and 0.4 as Tier 2
- Option 2: MEI cut-off values as 0.4 in a single Tier
- Option 3: MEI cut-off values as 0.1 as Tier 1, 0.4 as Tier 2 and 0.7 as Tier 3
- Option 4: MEI cut-off values at the level of the Base-Case (MEI = 0.4) as Tier 1 and BAT (MEI = 1) as Tier 2

Based on the findings of the scenario analysis (performed for the period 2013-2040), it is concluded that whereas there is a significant negative impact on consumer expenditure (around €11 Million/year in 2040) for setting MEI requirements on BC 4, the corresponding electricity savings are rather insignificant (around 25.1 GWh/year in 2040). **Therefore, it is recommended to not consider the pump types corresponding to this Base-Case (BC 4) for any future MEI requirements, but only generic ecodesign requirement.**

[19] Although BC 4 pumps can be a good candidate for Energy labelling as these pumps are sold in large quantities in EU and not always installed by skilled professionals but also by non-professionals (as available in DIY markets) or low-skilled professionals. However, the energy savings value for these pumps in EU is insignificant to consider any energy labelling requirements. Nonetheless, the concern about the proper installation of these pumps is already addressed via the generic ecodesign requirements proposed for these pumps in this report.

On a similar note, slurry pumps are selected for "tons of solids pumped per hour", not for m³/h or litres per second, as it is normal for all other pumps. Both light and heavy duty slurry pumps are engineered for every duty to choose the optimum pump type, materials and performance. Categorisation of slurry pumps into light and heavy duty is more by application and material handled than by pump type. The VSDs are not appropriate for slurry pumps as the users change speed by changing pulleys. **Therefore, these slurry pumps (BC 7A and 7B) are also not suitable for future MEI requirements**[20].

The MEI requirements seem to be appropriate for remaining 4 Base-Cases (BC 1, BC 2, BC 5 and BC 6). However, if MEI requirements for Lot 28 pumps (BC 1, BC 2, BC 5 and BC 6) are introduced, the methodology for MEI calculation based on ENER Lot 11 pumps may not be appropriate for ENER Lot 28 pumps as the pump efficiency correlates with pump size and specific speed in a different manner. Therefore, a new exhaustive data collection exercise specific Lot 28 pumps (BC 1, BC 2, BC 5 and BC 6) will need to be carried out and along with new standard for MEI compliance testing. In a future revision of the proposed regulation, the Extended Product Approach and the Energy Efficiency Index method could be taken up in order to develop a more ambitious regulation for wastewater pumps in the EU, which could potentially save significantly higher energy compared to regulation based on MEI approach.

The comparison of the total electricity savings achieved by policy implementation on all the Base-Case included in this analysis shows that the **maximum electricity savings per year that could be achieved in 2040 are between around 486.6 GWh and 1628.9 GWh per year at EU level,** depending on the level of ambition of the scenario selected. The comparison of the total consumer expenditure achieved by policy implementation on all the Base-Case included in this analysis shows that **the maximum reduction that could be achieved in 2040 are between Zero (in Pragmatic Scenario 1) and 161 Million Euros (in Pragmatic Scenario 4) at EU level**.

Concerning reduction in annual consumer expenditure, there is not much difference in the impact of Scenario 1, Scenario 2 and Scenario 3. The potential savings in electricity consumption of Scenario 3 and Scenario 4 are similar whereas there is not much difference between Scenario 1 and Scenario 2. This would suggest that **regulating Lot 28 pumps using Policy Option 3 (with three cut of tiers) would be more effective than enforcing a single or two-tier regulation.**

The likely economic and social impacts of the policy options were briefly described. The implementation of MEPS might require manufacturers to invest in technology and product development or in adapting their production lines to offer the required more efficient products. The impact of these investments would depend on the level of ambition of the MEPS adopted and on the energy performance of models proposed by each manufacturer.

Finally, a sensitivity analysis was performed to assess the main assumptions used in the study and it was concluded that the findings remain robust and reliable.

[20] Europump remarked that in the planned energy efficiency regulations in the USA, the Department of Energy is not considering wastewater and slurry pumps (U.S. Department of Energy, Energy Conservation Standards Rulemaking Framework Document for Commercial and Industrial Pumps, January 2013. www.pumps.org/uploadedFiles/Framework_Document_for_Commercial%20_Industrial_Pumps.pdf)

Annex A: Energy Efficiency Index

Existing regulations for the Pump product (only) are based on MEPs for a particular pump size, which are defined with reference to a Minimum Efficiency Index or "MEI" value. The Extended Product Approach energy consumption is distinguished from this by being defined in terms of the Energy Efficiency Index or "EEI" value.

The term EEI comes from the Ecodesign Regulation on circulators (EC Regulation 547/2012), where the annual energy consumption is based on the energy used by pump + motor + VSD control over a typical annual operating profile. The advantage of this EEI method is that it considers the real life operating profile of the extended product, and so gives the best representation of the actual costs of using that product.

Creating load profiles that are representative of the different types of application that will be powered by the pumps in scope is critical, but work to date suggests that just three profiles will be adequate for ENER Lot 28 pumps:

- Closed loop variable flow;
- Open loop variable flow; and
- Constant flow[21] (open and closed loop).

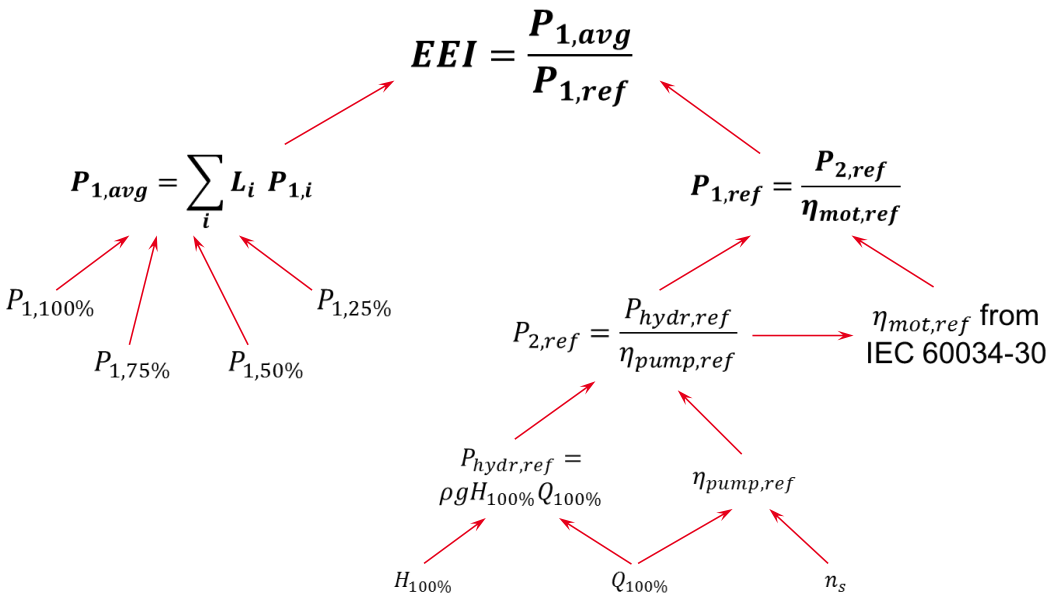
The profile just gives the proportion of the time that is spent at each load point, with the actual annual operating time for each application being used to establish energy consumption. The Lot 28 pumps concern mainly constant flow (open and closed loop).

The following factors are needed for calculating the EEI:

- Pump efficiency at different load points;
- Motor efficiency at different load points;
- VSD efficiency at different load points in as far as VSD is applicable;
- Applicable load profile; and
- Efficiency of controls (contactors) is neglected, because this is less than 0.1 % of the motor losses.

The EEI is calculated as following:

[21] The large majority of waste water pumps follow this profile.



Where:

P1,i is the electrical power input from the grid

P2,i is the mechanical power from the motor shaft

P_{hydr} is the hydraulic power produced by the pump

$P_{L,avg}$ is the weighted average power of a pump equipped with variable speed or two speeds

P_{ref} is the reference power of the pump (i.e. the relation between hydraulic power and power consumption of a pump)

The power input values *P1,i* can be measured, but this is not possible in most cases especially not for separated units. The *P1,i* values will then be calculated from Semi Analytical Models. Based on actual measurements of the pump, the head and the flow, the best efficiency point (*H100%*, *Q100%*) is determined and from that the specific speed (n_s) is calculated. Based on the hydraulic power and the efficiency, the reference shaft power *P2,ref* is calculated, which can via the IEC 600034-30 for motors be converted onto a reference power input. The reference efficiency of the VSD is set to 100% by definition. The actual efficiency of the specific VSD is captured by the power input values *P1,i* as is the case for pump and motor.

Annex B: C-values calculation approach for Lot 28 pumps

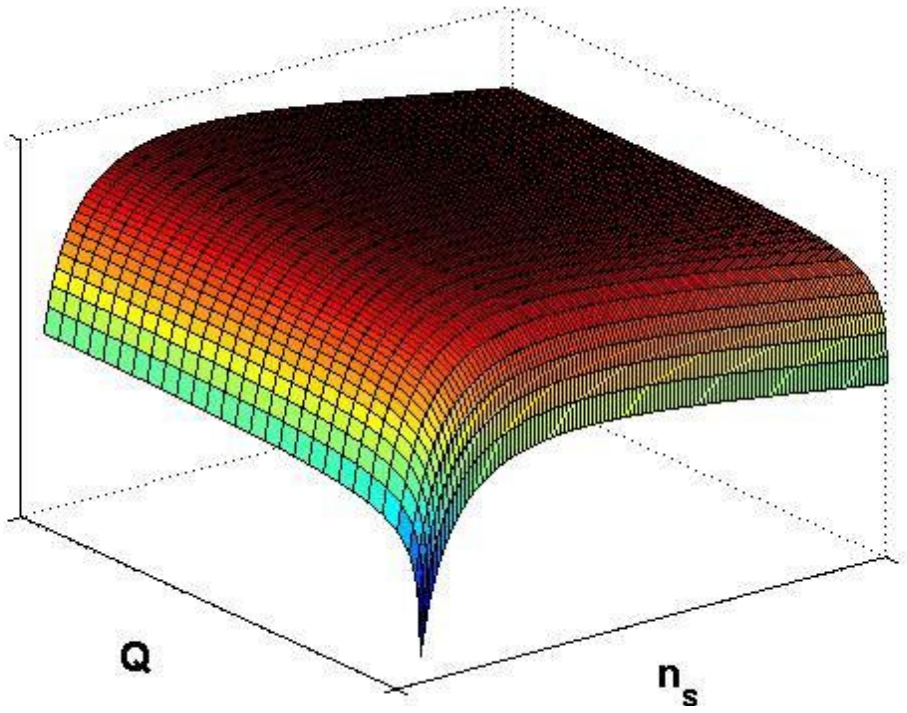
Introduction

This Annex contains a description of the methodology proposed for use to estimate the "C-values" for the pumps considered in the ENER lot 28 preparatory study. The concept of "C-values" was first used in the ENER Lot 11 study for clean water pumps. The intention of the Lot 28 study authors is to use the ENER Lot 11 C value methodology and adapt it for use with the Lot 28 pumps (even if ideally an exhaustive data collection on pumps in the EU market in order to calculate the appropriate C-values should be carried out).

Setting the efficiency levels is very complicated, as they will differ by type, speed, flow, head and impeller diameter. To simplify things (and in fact to make any kind of analysis understandable), it is based on maximum impeller. This is reasonable on the basis that the volute will be designed around maximum impeller performance, with a volute that is good at maximum diameter also being relatively good at reduced impeller sizes.

Different types of pumps must have different efficiency criteria. Unfortunately this still means that there will be different efficiency criteria for the different (flow, head) duties within the range of pumps in each category. In practical terms, it means that a simple chart or 2-D graph is not possible, instead a 3-D plane has to be used to present the data. A 3-D plane was produced in the Lot 11 report using data from Technische Universität Berlin in 1998 for an earlier SAVE project led by AEAT. This plane is shown in Figure B - i.

Figure B - i: 3D plane used in the Lot 11 pump study



Where:

N_s is specific speed (min^{-1})

Q is flow (m^3/h)

η is efficiency

The mathematical description of the plane was obtained by means of a 3-D quadratic polynomial approximation. The equation defining the efficiency plane is:

$$\eta_{Bottom} = -11.48x^2 - 0.85y^2 - 0.38xy + 88.59x + 13.46y - C$$

Where $x = \ln(n_s)$ and $y = \ln(Q)$

The numbers of pumps (in percentage of the total data of one pump type) that do not fulfil the minimum efficiency requirements imposed by the plane are lying below the surface and are therefore "cut-off" by the plane.

With C used as a variable for each pump type, it is possible to identify the pumps with the lowest efficiencies for the size and specific speed considered. The plane is shifted downwards vertically according to the value of C, until the chosen quantity cut-off criterion is fulfilled.

C-values calculation procedure used in Lot 11

In Lot 11, the following C-values were used for the pumps in scope:

Table B - i: Lot 11 C values

	C value at different cut-offs (%)									
	5	10	15	20	30	40	50	60	70	80
ESOB 1450 (L)	134.38	132.58	131.70	130.68	129.35	128.07	126.97	126.10	124.85	122.94
ESOB 2900 (S)	137.28	135.60	134.54	133.43	131.61	130.27	129.18	128.12	127.06	125.34
ESCC 1450 (L)	134.39	132.74	132.07	131.20	129.77	128.46	127.38	126.57	125.46	124.07
ESCC 2900 (S)	137.32	135.93	134.86	133.92	132.23	130.77	129.86	128.80	127.75	126.54
ESCCi 1450 (L)	138.13	136.67	135.40	134.60	133.40	132.30	131.00	130.03	128.98	127.30
ESCCi 2900 (S)	141.71	139.45	137.73	136.53	134.91	133.69	132.65	131.34	129.83	128.14
MS 1450 (L)	134.83	134.45	133.89	132.97	132.40	130.38	130.04	127.22	125.48	123.93
MS2900 (S)	139.52	138.19	136.95	135.41	134.89	133.95	133.43	131.87	130.37	127.75
MSS 2900 (L)	137.08	134.31	132.89	132.43	130.94	128.79	127.27	125.22	123.84	122.05
MSS 2900 (S)	137.08	134.31	132.89	132.43	130.94	128.79	127.27	125.22	123.84	122.05

The average pump for each pump type considered in Lot 11 was then decided upon and values for the average duty point, specific speed and x and y values were defined as follows:

Table B - ii : Lot 11 Average Pumps

Type of pump (Prep study)	Mean size	Mean Head	Mean flow	Specific Speed	x in MEPS formula	y in MEPS formula
Abbrevn.	**kW (Hyd)**	**m**	**m3/hr**	**per min**	**(ln ns) /min**	**(ln m3/hr)**
ESOB 1450 (L)	10.9	32	125	20.08	3.00	4.83
ESOB 2900 (S)	2.5	30	30	20.65	3.03	3.40
ESCC 1450 (L)	11.10	31	131	21.05	3.05	4.88
ESCC 2900 (S)	2.2	32	25	17.96	2.89	3.22
ESCCi 1450 (L)	11.1	31	132	21.13	3.05	4.88
ESCCi 2900 (S)	2.2	32	25	17.96	2.89	3.22
MS 1450 (L)	1.1	42	10	15.49	2.74	2.30
MS2900 (S)	0.5	45	4	18.60	2.92	1.39
MSS 2900 (L)	3.6	88	15	54.55	4.00	2.71
MSS 2900 (S)	1.4	59	9	31.49	3.45	2.14

Using the data presented in these two tables it was then possible to calculate the MEPS by different pump sizes at different cut-off values as shown in Table B - iii.

Table B - iii: Lot 11 Pump Cut-off efficiencies

	Min efficiency at different cut-offs (%)									
	5	10	15	20	30	40	50	60	70	80
ESOB 1450 (L)	67.74	69.54	70.42	71.44	72.77	74.05	75.15	76.02	77.27	79.18
ESOB 2900 (S)	57.74	59.42	60.48	61.59	63.41	64.75	65.84	66.90	67.96	69.68
ESCC 1450 (L)	68.74	70.39	71.06	71.93	73.36	74.67	75.75	76.56	77.67	79.06
ESCC 2900 (S)	53.77	55.16	56.23	57.17	58.86	60.32	61.23	62.29	63.34	64.55
ESCCi 1450 (L)	65.09	66.55	67.82	68.62	69.82	70.92	72.22	73.19	74.24	75.92
ESCCi 2900 (S)	49.38	51.64	53.36	54.56	56.18	57.40	58.44	59.75	61.26	62.95
MS 1450 (L)	45.81	46.19	46.75	47.67	48.24	50.26	50.60	53.42	55.16	56.71
MS2900 (S)	36.84	38.17	39.41	40.95	41.47	42.41	42.93	44.49	45.99	48.61
MSS 2900	59.70	62.47	63.89	64.35	65.84	67.99	69.51	71.56	72.94	74.73

Adapting the Lot 11 C-values calculation approach for Lot 28 pumps

For the Lot 28 pumps, EUROPUMP has provided the following information for minimum, maximum and average efficiencies for each pump type. It is important to note that this method is an approximation made by the study authors and would need an exhaustive data collection on pumps in the EU market in order to calculate the appropriate C-values[7].

Table B - iv: Efficiency range for Lot 28 pumps

Pump type	Specificity	η_{max}	η_{min}	η_{av}
Radial Sewage Pumps 1 to 10kW	vortex	63	26	43
Submersible & dry installed	channel	80	39.2	71
Radial Sewage Pumps >10 to 25kW	vortex	58.5	38.8	45.7
Submersible & dry installed	channel	87	54	71.5
Radial Sewage Pumps >25 to 160kW	all types average	88.7	55	77.3

submersible & dry installed				
Mixed flow & Axial	Activated sludge recirculation Axial (H < 2m)	68.3	35.3	56.5
	Stormwater & effluent axial and mixed flow	87.3	68	82.1
Domestic& commercial buildings	Shredding, grinding pumps	42	22.5	32.3
"Once a day operation"	Radial sewage pumps 1 to 10kW	78	26	53.5
	Where volute is part of a tank	71	14	27.62
	Centrifugal submersible domestic drainage pump < 40 mm passage	60.8	14.5	35.2
Dewatering pumps, submersible		72	46	64
Slurry pumps	light	82	45	63.5
	heavy	77	35	56

From these values it is possible to put together the efficiency cut-off bands for the pumps in scope.

Table B - v: Efficiencies at different cut-off values for the Lot 28 pumps[22]

Pump type	Specificity	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Radial Sewage Pumps 1 to 10kW	vortex	29.7	33.4	37.1	40.8	44.5	48.2	51.9	55.6	59.3	63
Submersible & dry installed	channel	43.28	47.36	51.44	55.52	59.6	63.68	67.76	71.84	75.92	80
Radial Sewage Pumps >10 to 25kW	vortex	40.77	42.74	44.71	46.68	48.65	50.62	52.59	54.56	56.53	58.5
Submersible &	channel	57.3	60.6	63.9	67.2	70.5	73.8	77.1	80.4	83.7	87

[22] Please note in the absence of availability of detailed market data, for the values presented in this table the study authors had to assume that the change in energy efficiency of Lot 28 pumps is directly proportional to their market share. However, in reality this may not be true, as the average efficiency pumps may dominate the market share whereas the highly inefficient and highly efficient pumps may only represent a small share of EU market. Therefore, ideally an exhaustive data collection on pumps in the EU market, in order to calculate the appropriate C-values, should be carried out.

Pump type	Specificity	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
dry installed											
Radial Sewage Pumps >25 to 160kW submersible & dry installed	all types average	58.37	61.74	65.11	68.48	71.85	75.22	78.59	81.96	85.33	88.7
Mixed flow & Axial	Activated sludge recirculation Axial (H < 2m)	38.6	41.9	45.2	48.5	51.8	55.1	58.4	61.7	65	68.3
	Stormwater & effluent axial and mixed flow	69.93	71.86	73.79	75.72	77.65	79.58	81.51	83.44	85.37	87.3
Domestic& commercial buildings	Shredding, grinding pumps	24.45	26.4	28.35	30.3	32.25	34.2	36.15	38.1	40.05	42
"Once a day operation"	Radial sewage pumps 1 to 10kW	31.2	36.4	41.6	46.8	52	57.2	62.4	67.6	72.8	78
	Where volute is part of a tank	19.7	25.4	31.1	36.8	42.5	48.2	53.9	59.6	65.3	71
	Centrifugal submersible domestic drainage pump < 40 mm passage	19.13	23.76	28.39	33.02	37.65	42.28	46.91	51.54	56.17	60.8
Dewatering pumps, submersible[23]		48.6	51.2	53.8	56.4	59	61.6	64.2	66.8	69.4	72
Slurry pumps	light	48.7	52.4	56.1	59.8	63.5	67.2	70.9	74.6	78.3	82
	heavy	39.2	43.4	47.6	51.8	56	60.2	64.4	68.6	72.8	77

Average shaft power values were provided by EUROPUMP for each pump type. In order to estimate C-values using the formula described previously, average head and flow values are required. For the purpose of this exercise the average power values were used as a starting point

[23] A distinction between the vortex and channel impellers might be needed for submersible dewatering pumps.

to estimate the average head and flow for each pump type[24]. The results are shown in the following table.

Table B - vi: Estimated average Lot 28 pump duties

Pump type	Specificity	Shaft power	Head (m)	Flow (m^3/h)	Specific Speed	ln ns (/min)	ln Q (m3/hr)
Radial Sewage Pumps 1 to 10kW submersible & dry installed	channel	4	10	105	44.1	3.8	4.7
Radial Sewage Pumps >10 to 25kW submersible & dry installed	channel	15	20	199	36.0	3.6	5.3
Radial Sewage Pumps >25 to 160kW submersible & dry installed	all types average	75	60	358	21.2	3.1	5.9
Mixed flow & Axial[25]	Activated sludge recirculation Axial (H < 2m)	50	4	2617	220.1	5.4	7.9
Submersible & dry installed	Stormwater & effluent axial and mixed flow	150	4	11410	368.2	5.9	9.3
Domestic& commercial buildings "once a day operation"	Shredding, grinding pumps	2	19	12.6	18.9	2.9	2.5
	Radial sewage pumps 1 to 10kW	2	15	26	32.6	3.5	3.3
	Where volute is part of a tank	1.5	12	12.8	26.8	3.3	2.5
	Centrifugal submersible domestic drainage pump < 40 mm passage	0.3	5	7.8	40.4	3.7	2.1
Dewatering pumps, submersible		7	18	92	26.6	3.3	4.5
Slurry pumps[26]	light	50	40	294	26.1	3.3	5.7
	heavy	37	40	192	21.1	3.0	5.3

Using the information in Table B - v and in Table B - vi, combination with the formula previously described, the following C-values are estimated as presented in Table B - vii.

[24] Pump data sheets from Sulzer, KSB and Xylem were consulted as part of this exercise, although no single pump was used to represent the "average" pump in any pump type.

[25] Note that the axial flow pumps do not work with the formula shown under "Introduction" of this Annex and therefore it cannot be used to accurately estimate the C-values for these pumps.

[26] Note that the independent data collection for slurry pumps would need to cover probably 6 categories so that the 'C' factor for each type, which allows minimum efficiency to be calculated, could be developed.

Table B - vii: Estimated C-values at different MEPS cut-offs for the Lot 28 pumps

Pump type	Specificity	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Radial Sewage Pumps 1 to 10kW submersible & dry installed	Channel	165.1	161.0	157.0	152.9	148.8	144.7	140.6	136.6	132.5	128.4
Radial Sewage Pumps >10 to 25kW submersible & dry installed	Channel	153.0	149.7	146.4	143.1	139.8	136.5	133.2	129.9	126.6	123.3
Radial Sewage Pumps >25 to 160kW submersible & dry installed	all types average	148.1	144.7	141.3	137.9	134.6	131.2	127.8	124.5	121.1	117.7
Mixed flow & Axial[27]	Activated sludge recirculation Axial (H < 2m)	142.4	139.1	135.8	132.5	129.2	125.9	122.6	119.3	116.0	112.7
	Stormwater & effluent axial and mixed flow[28]	83.3	81.4	79.4	77.5	75.6	73.7	71.7	69.8	67.9	65.9
Domestic& commercial buildings	Shredding, grinding pumps	162.5	160.6	158.6	156.7	154.7	152.8	150.8	148.9	146.9	145.0
"Once a day operation"	Radial sewage pumps 1 to 10kW	168.7	163.5	158.3	153.1	147.9	142.7	137.5	132.3	127.1	121.9
	Where volute is part of a tank	173.1	167.4	161.7	156.0	150.3	144.6	138.9	133.2	127.5	121.8
	Centrifugal submersible domestic drainage pump < 40 mm passage	172.7	168.1	163.4	158.8	154.2	149.5	144.9	140.3	135.7	131.0

[27] Note that the axial flow pumps do not work with the formula shown in Section 1 and therefore it cannot be used to accurately estimate the C values for these pumps.

[28] Note as the Lot 11 data collection is not valid for pumps with specific speed above 80, therefore the storm water pumps do not work with the formula shown in Section 1 and therefore it cannot be used to accurately estimate the C values for these pumps.

Pump type	Specificity	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Dewatering pumps, submersible		156.3	153.7	151.1	148.5	145.9	143.3	140.7	138.1	135.5	132.9
Slurry pumps	light	160.1	156.4	152.7	149.0	145.3	141.6	137.9	134.2	130.5	126.8
	heavy	165.3	161.1	156.9	152.7	148.5	144.3	140.1	135.9	131.7	127.5

It is important to note that this method uses the Lot 11 η_{Bot} formula in an unmodified state. This may not be appropriate as it does not account for the fact that the pumps in the Lot28 have to handle solids[7].

Annex C: Sensitivity analysis data

- Sensitivity analysis data for lifetime
  - Electricity consumption reduction and Overall consumer expenditure data for BC 1

Table C - i: Data used for analysis of life cycle sensitivity to product lifetime for BC1

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	4 993.70	5 011.61	4 993.70	5 011.61	-3 719.64	-3 686.06	-3 719.64	-3 686.06
2020	GWh/year	5 428.3	5 446.2	5 428.3	5 480.9	-3 967.9	-3 934.4	-3 967.9	-3 869.2
2030	GWh/year	7 986.8	7 986.8	8 166.0	8 188.0	-5 540.1	-5 540.1	-5 204.1	-5 162.8
2040	GWh/year	11 149.9	11 149.9	11 400.1	11 430.9	-7 734.3	-7 734.3	-7 265.3	-7 207.6
2018	%	33.3%	33.2%	33.3%	33.2%	-25.0%	-24.9%	-25.0%	-24.9%
2020	%	33.2%	33.2%	33.2%	33.0%	-24.9%	-24.9%	-24.9%	-24.8%
2030	%	33.0%	33.0%	32.6%	32.5%	-57.7%	-57.7%	-57.0%	-56.9%
2040	%	33.0%	33.0%	32.6%	32.5%	-24.7%	-24.7%	-24.4%	-24.4%

Table C - ii: Data used for analysis of life cycle sensitivity to product lifetime for BC 1

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	91.24	91.18	91.24	92.54	-49.17	-48.98	-49.17	-47.62
2020	M€/year	99.60	99.54	92.76	118.45	-51.81	-51.62	-58.66	-32.22
2030	M€/year	144.24	144.24	135.99	247.19	-73.74	-73.74	-79.34	32.08
2040	M€/year	203.08	203.08	192.97	346.50	-101.23	-101.23	-107.65	46.20
2018	%	3.0%	3.0%	3.0%	3.0%	-4.3%	-4.3%	-4.3%	-4.3%
2020	%	3.0%	3.0%	3.0%	3.0%	-4.3%	-4.3%	-4.3%	-4.3%
2030	%	3.0%	3.0%	3.0%	3.0%	-4.4%	-4.4%	-4.3%	-4.3%
2040	%	3.1%	3.1%	3.1%	3.1%	-4.5%	-4.5%	-4.4%	-4.4%

- Electricity consumption reduction and Overall consumer expenditure data for BC 2

Table C - iii: Data used for analysis of life cycle sensitivity to product lifetime for BC2

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	411.83	413.14	411.83	413.14	-307.12	-304.68	-307.12	-304.68
2020	GWh/year	449.0	450.3	449.0	452.9	-329.2	-326.8	-329.2	-322.1
2030	GWh/year	667.7	667.7	680.2	681.8	-469.2	-469.2	-445.6	-442.7
2040	GWh/year	939.9	939.9	957.6	959.78	-660.35	-660.4	-627.2	-623.0
2018	%	33.3%	33.2%	33.3%	33.2%	-25.0%	-24.9%	-25.0%	-24.9%
2020	%	33.2%	33.2%	33.2%	33.1%	-24.9%	-24.9%	-24.9%	-24.8%
2030	%	33.0%	33.0%	32.7%	32.7%	-57.8%	-57.8%	-57.2%	-57.2%
2040	%	33.0%	33.0%	32.7%	32.7%	-24.8%	-24.8%	-24.5%	-24.5%

Table C - iv: Data used for analysis of life cycle sensitivity to product lifetime for BC 2

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	7.72	7.85	7.72	7.78	-3.93	-3.78	-3.93	-3.85
2020	M€/year	9.21	9.34	9.12	9.57	-3.40	-3.25	-3.50	-2.98
2030	M€/year	13.79	13.79	14.89	15.42	-4.63	-4.63	-3.35	-2.80
2040	M€/year	20.04	20.04	21.62	22.36	-5.88	-5.88	-4.06	-3.29
2018	%	6.8%	6.9%	6.8%	6.9%	-10.3%	-10.3%	-10.3%	-10.3%
2020	%	7.5%	6.8%	7.4%	7.0%	-10.3%	-10.2%	-10.3%	-10.2%
2030	%	7.2%	7.2%	7.2%	7.0%	-10.3%	-10.3%	-10.2%	-10.2%
2040	%	7.3%	7.3%	7.1%	7.0%	-10.5%	-10.5%	-10.4%	-10.3%

- Electricity consumption reduction and Overall consumer expenditure data for BC 4

Table C - v: Data used for analysis of life cycle sensitivity to product lifetime for BC4

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	156.33	156.87	156.33	156.87	-171.03	-169.86	-171.03	-169.86
2020	GWh/year	168.904	169.438	168.90	170.47	-181.96	-180.79	-181.96	-178.522
2030	GWh/year	243.116	243.116	248.59	249.39	-249.79	-249.79	-237.74	-235.978
2040	GWh/year	334.467	334.467	342.144	343.104	-343.63	-343.63	-326.743	-324.63
2018	%	36.3%	36.3%	36.3%	36.3%	-40.0%	-39.9%	-40.0%	-39.9%
2020	%	36.2%	36.2%	36.2%	36.0%	-39.8%	-39.8%	-39.8%	-39.6%
2030	%	35.9%	35.9%	35.4%	35.3%	-75.4%	-75.4%	-74.4%	-74.2%
2040	%	35.9%	35.9%	35.4%	35.3%	-39.5%	-39.5%	-38.9%	-38.9%

Table C - vi: Data used for analysis of life cycle sensitivity to product lifetime for BC 4

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-2.26	-2.20	-2.26	-6.29	-3.32	-3.25	-3.32	-7.34
2020	M€/year	-2.39	-2.33	-6.27	-6.57	-3.52	-3.45	-7.40	-7.68
2030	M€/year	-2.73	-2.73	-7.19	-7.73	-4.28	-4.28	-8.65	-9.19
2040	M€/year	-3.44	-3.44	-8.86	-9.53	-5.57	-5.57	-10.87	-11.54
2018	%	0.1%	0.1%	0.1%	0.1%	-0.2%	-0.2%	-0.2%	-0.2%
2020	%	0.1%	0.1%	0.1%	0.1%	-0.2%	-0.2%	-0.2%	-0.2%
2030	%	0.2%	0.2%	0.1%	0.2%	-0.2%	-0.2%	-0.2%	-0.2%
2040	%	0.2%	0.2%	0.1%	0.2%	-0.2%	-0.2%	-0.2%	-0.2%

- Electricity consumption reduction and Overall consumer expenditure data for BC 5

Table C - vii: Data used for analysis of life cycle sensitivity to product lifetime for BC5

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	1 419.89	1 431.11	1 419.89	1 431.11	-1 049.28	-1 028.24	-1 049.28	-1 028.24
2020	GWh/year	1 558.6	1 569.8	1 558.6	1 591.3	-1 104.9	-1 083.9	-1 104.9	-1 043.5
2030	GWh/year	2 358.1	2 358.1	2 465.9	2 479.2	-1 496.8	-1 496.8	-1 294.8	-1 269.9
2040	GWh/year	3 319.2	3 319.2	3 470.9	3 489.6	-2 107.1	-2 107.1	-1 822.6	-1 787.6
2018	%	33.3%	33.1%	33.3%	33.1%	-24.9%	-24.8%	-24.9%	-24.8%
2020	%	33.1%	32.9%	33.1%	32.7%	-24.8%	-24.7%	-24.8%	-24.5%
2030	%	32.6%	32.6%	31.8%	31.7%	-57.0%	-57.0%	-55.6%	-55.4%
2040	%	32.6%	32.6%	31.8%	31.7%	-24.4%	-24.4%	-23.8%	-23.8%

Table C - viii: Data used for analysis of life cycle sensitivity to product lifetime for BC 5

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	26.25	27.19	26.25	26.57	-13.64	-12.55	-13.64	-13.16
2020	M€/year	30.34	31.28	28.40	35.32	-12.69	-11.59	-14.63	-7.24
2030	M€/year	50.39	50.39	56.77	75.99	-11.89	-11.89	-3.98	15.43
2040	M€/year	71.47	71.47	80.88	107.64	-16.19	-16.19	-4.63	22.41
2018	%	3.8%	3.6%	3.8%	3.7%	-5.4%	-5.3%	-5.4%	-5.3%
2020	%	3.8%	3.8%	3.8%	3.6%	-5.4%	-5.3%	-5.4%	-5.3%
2030	%	3.8%	3.8%	3.8%	3.7%	-5.5%	-5.5%	-5.3%	-5.3%
2040	%	4.0%	4.0%	3.9%	3.9%	-5.7%	-5.7%	-5.6%	-5.5%

- Electricity consumption reduction and Overall consumer expenditure data for BC 6

Table C - ix: Data used for analysis of life cycle sensitivity to product lifetime for BC6

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	1 240.56	1 243.95	1 240.56	1 243.95	-1 291.26	-1 284.18	-1 291.26	-1 284.18
2020	GWh/year	1 343.0	1 346.4	1 343.0	1 352.9	-1 381.0	-1 373.9	-1 381.0	-1 360.3
2030	GWh/year	1 949.2	1 949.2	1 983.7	1 988.0	-1 934.5	-1 934.5	-1 862.5	-1 853.5
2040	GWh/year	2 702.7	2 702.7	2 750.4	2 756.4	-2 682.1	-2 682.1	-2 582.4	-2 569.8
2018	%	34.8%	34.7%	34.8%	34.7%	-36.3%	-36.3%	-36.3%	-36.3%
2020	%	34.7%	34.6%	34.7%	34.5%	-36.3%	-36.2%	-36.3%	-36.1%
2030	%	34.5%	34.5%	34.1%	34.1%	-70.5%	-70.5%	-69.8%	-69.7%
2040	%	34.5%	34.5%	34.1%	34.1%	-36.0%	-36.0%	-35.7%	-35.6%

Table C - x: Data used for analysis of life cycle sensitivity to product lifetime for BC 6

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	31.51	31.55	31.51	31.44	-18.88	-18.76	-18.88	-18.87
2020	M€/year	33.30	33.34	32.28	35.26	-20.91	-20.80	-21.93	-18.73
2030	M€/year	48.17	48.17	47.30	60.12	-29.12	-29.12	-29.24	-16.33
2040	M€/year	67.51	67.51	66.51	84.10	-39.65	-39.65	-39.62	-21.89
2018	%	5.5%	5.5%	5.5%	5.4%	-8.7%	-8.7%	-8.7%	-8.7%
2020	%	5.5%	5.5%	5.5%	5.5%	-8.7%	-8.7%	-8.7%	-8.7%
2030	%	5.6%	5.6%	5.5%	5.5%	-8.8%	-8.8%	-8.8%	-8.7%
2040	%	5.7%	5.7%	5.7%	5.7%	-9.0%	-9.0%	-9.0%	-8.9%

- Electricity consumption reduction and Overall consumer expenditure data for BC 7A

Table C - xi: Data used for analysis of life cycle sensitivity to product lifetime for BC7A

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	5 495.97	5 497.67	5 495.97	5 497.67	-5 743.04	-5 739.49	-5 743.04	-5 739.49
2020	GWh/year	5 595.6	5 597.2	5 595.6	5 600.5	-5 838.4	-5 834.9	-5 838.4	-5 828.1
2030	GWh/year	6 192.2	6 193.8	6 209.5	6 216.7	-6 409.9	-6 406.3	-6 373.5	-6 358.6
2040	GWh/year	6 953.2	6 954.9	6 992.8	7 002.7	-7 138.8	-7 135.3	-7 056.1	-7 035.4
2018	%	34.8%	34.8%	34.8%	34.8%	-36.4%	-36.4%	-36.4%	-36.4%
2020	%	34.8%	34.8%	34.8%	34.8%	-36.4%	-36.3%	-36.4%	-36.3%
2030	%	34.7%	34.7%	34.7%	34.6%	-71.0%	-71.0%	-70.9%	-70.9%
2040	%	34.7%	34.7%	34.6%	34.5%	-36.2%	-36.2%	-36.1%	-36.1%

Table C - xii: Data used for analysis of life cycle sensitivity to product lifetime for BC 7A

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	85.06	85.14	85.06	83.50	-49.25	-49.15	-49.25	-50.79
2020	M€/year	86.04	86.12	85.66	82.01	-50.61	-50.50	-50.99	-54.57
2030	M€/year	95.58	95.67	95.92	76.85	-55.02	-54.91	-54.45	-73.43
2040	M€/year	108.26	108.34	109.55	70.93	-60.15	-60.04	-58.34	-96.83
2018	%	10.9%	10.9%	10.9%	11.0%	-17.2%	-17.2%	-17.2%	-17.2%
2020	%	10.8%	10.8%	10.9%	10.8%	-17.2%	-17.2%	-17.2%	-17.2%
2030	%	10.8%	10.8%	10.7%	10.7%	-17.0%	-17.0%	-17.0%	-17.0%
2040	%	10.6%	10.6%	10.7%	10.6%	-16.9%	-16.9%	-16.8%	-16.8%

- Electricity consumption reduction and Overall consumer expenditure data for All BCs Considered

Table C - xiii: Data used for analysis of life cycle sensitivity to product lifetime for All BCs

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	13718.29	13754.34	13718.29	13754.34	-12281.37	-12212.51	-12281.37	-12212.51
2020	GWh/year	14543.4	14579.4	14 543.4	14 649.0	-12803.5	-12 734.6	-12803.5	-12601.6
2030	GWh/year	19397.1	19398.8	19 753.9	19803.0	-16100.3	-16096.7	-15418.3	-15323.4
2040	GWh/year	25399.4	25401.1	25 913.9	25982.4	-20666.3	-20662.8	-19680.3	-19548.1
2018	%	34.0%	34.0%	34.0%	34.0%	-30.6%	-30.6%	-30.6%	-30.6%
2020	%	34.0%	33.9%	34.0%	33.8%	-30.4%	-30.4%	-30.4%	-30.3%
2030	%	33.7%	33.7%	33.3%	33.3%	-63.3%	-63.3%	-62.7%	-62.6%
2040	%	33.6%	33.6%	33.2%	33.2%	-29.2%	-29.2%	-28.9%	-28.8%

Table C - xiv: Data used for analysis of life cycle sensitivity to product lifetime for All BCs

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	239.52	240.71	239.52	235.54	-138.19	-136.47	-138.19	-141.63
2020	M€/year	256.1	257.3	241.9	274.0	-142.9	-141.2	-157.1	-123.4
2030	M€/year	349.4	349.5	343.7	467.8	-178.7	-178.6	-179.0	-54.2
2040	M€/year	466.9	467.0	462.7	622.0	-228.7	-228.6	-225.2	-64.9
2018	%	4.2%	4.1%	4.2%	4.2%	-6.3%	-6.2%	-6.3%	-6.2%
2020	%	4.1%	4.1%	4.1%	4.1%	-6.2%	-6.2%	-6.2%	-6.2%
2030	%	4.0%	4.0%	4.0%	4.0%	-6.0%	-6.0%	-5.9%	-5.9%
2040	%	4.0%	4.0%	3.9%	3.9%	-6.0%	-6.0%	-5.9%	-5.9%

- Sensitivity analysis data for product price
  - Overall consumer expenditure reduction

Table C - xv: Data used for analysis of life cycle sensitivity to product price for BC 1

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-186.97	-186.86	-186.97	-186.86	354.56	354.68	354.56	358.75
2020	M€/year	-198.39	-198.28	-206.53	-180.47	379.52	379.63	375.24	401.78
2030	M€/year	-260.70	-260.70	-268.80	-157.65	499.08	499.08	496.05	607.83
2040	M€/year	-322.57	-322.57	-332.20	-178.71	619.08	619.08	615.73	770.01
2018	%	-5.5%	-5.5%	-5.5%	-5.6%	16.6%	16.6%	16.6%	16.7%
2020	%	-5.5%	-5.5%	-5.5%	-5.5%	16.4%	16.4%	16.5%	16.5%
2030	%	-5.1%	-5.1%	-5.1%	-5.1%	15.3%	15.3%	15.4%	15.4%
2040	%	-4.6%	-4.6%	-4.7%	-4.7%	13.9%	13.9%	14.0%	14.0%

Table C - xvi: Data used for analysis of life cycle sensitivity to product price for BC 2

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-3.56	-3.42	-3.56	-3.52	5.96	6.10	5.96	6.08
2020	M€/year	-2.95	-2.81	-3.07	-2.58	7.21	7.35	7.16	7.66
2030	M€/year	-3.49	-3.49	-2.29	-1.75	9.88	9.88	11.17	11.72
2040	M€/year	-3.53	-3.53	-1.81	-1.05	13.04	13.04	14.86	15.63
2018	%	-3.2%	-3.0%	-3.2%	-3.1%	8.4%	8.4%	8.4%	8.5%
2020	%	-2.4%	-3.1%	-2.5%	-2.9%	8.3%	8.3%	8.3%	8.3%
2030	%	-2.5%	-2.5%	-2.4%	-2.7%	7.5%	7.5%	7.6%	7.6%
2040	%	-2.2%	-2.2%	-2.3%	-2.4%	6.7%	6.7%	6.7%	6.7%

Table C - xvii: Data used for analysis of life cycle sensitivity to product price for BC 4

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-139.03	-138.96	-139.03	-144.07	269.20	269.26	269.20	267.22
2020	M€/year	-148.34	-148.27	-153.19	-153.59	287.30	287.37	285.36	285.32
2030	M€/year	-194.65	-194.65	-200.33	-201.02	378.09	378.09	376.23	376.02
2040	M€/year	-241.43	-241.43	-248.36	-249.22	468.40	468.40	466.21	465.94
2018	%	-24.7%	-24.7%	-24.7%	-24.9%	74.1%	74.1%	74.1%	74.6%
2020	%	-24.7%	-24.7%	-24.9%	-24.9%	74.1%	74.1%	74.6%	74.6%
2030	%	-24.6%	-24.6%	-24.8%	-24.8%	74.0%	74.0%	74.5%	74.6%
2040	%	-24.6%	-24.6%	-24.8%	-24.8%	73.9%	73.9%	74.4%	74.4%

Table C - xviii: Data used for analysis of life cycle sensitivity to product price for BC 5

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-61.99	-60.95	-61.99	-62.02	119.44	120.48	119.44	120.78
2020	M€/year	-64.15	-63.10	-66.53	-59.33	129.47	130.51	128.38	135.74
2030	M€/year	-77.81	-77.81	-70.93	-51.65	176.74	176.74	185.32	204.81
2040	M€/year	-94.71	-94.71	-84.50	-57.64	220.77	220.77	233.08	260.21
2018	%	-8.1%	-8.2%	-8.1%	-8.2%	24.4%	24.4%	24.4%	24.5%
2020	%	-8.0%	-8.0%	-8.0%	-8.1%	24.1%	24.1%	24.2%	24.3%
2030	%	-7.5%	-7.5%	-7.5%	-7.5%	22.4%	22.4%	22.5%	22.5%
2040	%	-6.8%	-6.8%	-6.9%	-6.9%	20.5%	20.5%	20.6%	20.6%

Table C - xix: Data used for analysis of life cycle sensitivity to product price for BC 6

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-27.38	-27.29	-27.38	-27.60	53.57	53.65	53.57	53.95
2020	M€/year	-29.83	-29.74	-31.03	-27.94	56.56	56.64	55.93	59.09
2030	M€/year	-38.63	-38.63	-39.27	-26.43	74.94	74.94	75.05	87.99
2040	M€/year	-47.26	-47.26	-47.93	-30.29	93.49	93.49	93.77	111.52
2018	%	-4.7%	-4.7%	-4.7%	-4.8%	14.0%	14.0%	14.0%	14.1%
2020	%	-4.6%	-4.6%	-4.7%	-4.7%	13.9%	13.9%	14.0%	14.0%
2030	%	-4.3%	-4.3%	-4.4%	-4.4%	13.0%	13.0%	13.1%	13.1%
2040	%	-4.0%	-4.0%	-4.0%	-4.0%	11.9%	11.9%	12.0%	12.0%

Table C - xx: Data used for analysis of life cycle sensitivity to product price for BC 7A

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-9.09	-8.99	-9.09	-10.73	18.20	18.30	18.20	16.85
2020	M€/year	-10.20	-10.10	-10.67	-14.29	18.92	19.02	18.73	15.14
2030	M€/year	-12.54	-12.45	-12.18	-31.21	25.74	25.84	26.47	7.49
2040	M€/year	-14.20	-14.10	-12.73	-51.29	33.25	33.35	35.17	-3.33
2018	%	-1.2%	-1.2%	-1.2%	-1.1%	3.5%	3.5%	3.5%	3.5%
2020	%	-1.3%	-1.3%	-1.2%	-1.3%	3.7%	3.7%	3.7%	3.7%
2030	%	-1.4%	-1.4%	-1.5%	-1.5%	4.3%	4.3%	4.4%	4.4%
2040	%	-1.6%	-1.6%	-1.6%	-1.6%	4.7%	4.7%	4.8%	4.8%

Table C - xxi: Data used for analysis of life cycle sensitivity to product price for All BCs

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-428.02	-426.47	-428.02	-434.79	820.93	822.48	820.93	823.63
2020	M€/year	-453.9	-452.3	-471.0	-438.2	879.0	880.5	870.8	904.7
2030	M€/year	-587.8	-587.7	-593.8	-469.7	1 164.5	1 164.6	1 170.3	1 295.9
2040	M€/year	-723.7	-723.6	-727.5	-568.2	1 448.0	1 448.1	1 458.8	1 620.0
2018	%	-6.9%	-6.9%	-6.9%	-7.0%	20.7%	20.7%	20.7%	20.9%
2020	%	-6.9%	-6.9%	-6.9%	-7.0%	20.7%	20.7%	20.8%	20.8%
2030	%	-6.6%	-6.6%	-6.7%	-6.7%	19.8%	19.8%	20.0%	20.0%
2040	%	-6.2%	-6.2%	-6.2%	-6.2%	18.6%	18.6%	18.7%	18.7%

- Sensitivity analysis data for Sales Growth
  - Electricity consumption reduction and Overall consumer expenditure data for BC 1

Table C - xxii: Data used for analysis of life cycle sensitivity to product Sales growth for BC1

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	-463.13	-428.28	-463.13	-428.28	213.50	237.04	213.50	237.04
2020	GWh/year	-929.7	-894.9	-929.7	-820.0	470.5	494.1	470.5	536.7
2030	GWh/year	-6 227.8	-6 227.8	-5 883.9	-5 841.6	2 950.3	2 956.2	3 140.3	3 212.2
2040	GWh/year	-16 378.1	-16 378.1	-15 808.8	-15 738.8	7 324.8	7 324.8	7 619.3	7 655.6
2018	%	-3.2%	-3.1%	-3.2%	-3.1%	4.5%	4.4%	4.5%	4.4%
2020	%	-6.1%	-6.1%	-6.1%	-5.9%	8.7%	8.6%	8.7%	8.4%
2030	%	-27.7%	-27.7%	-27.3%	-27.3%	39.1%	39.2%	38.5%	38.6%
2040	%	-51.1%	-51.1%	-50.5%	-50.5%	72.4%	72.4%	71.6%	71.5%

Table C - xxiii: Data used for analysis of life cycle sensitivity to product Sales growth for BC 1

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-442.42	-442.28	-442.42	-440.37	174.94	175.03	174.94	176.17
2020	M€/year	-669.81	-669.67	-680.29	-641.88	270.57	270.67	265.23	286.37
2030	M€/year	-1 374.88	-1 374.88	-1 386.97	-1 271.96	563.66	563.76	559.24	615.88
2040	M€/year	-4 645.57	-4 645.57	-4 665.22	-4 422.03	1 921.10	1 921.10	1 918.60	2 035.12
2018	%	-13.4%	-13.3%	-13.4%	-13.3%	18.9%	18.9%	18.9%	18.9%
2020	%	-18.8%	-18.8%	-18.9%	-18.6%	26.7%	26.7%	26.8%	26.4%
2030	%	-27.5%	-27.5%	-27.6%	-26.8%	38.9%	38.9%	39.1%	37.9%
2040	%	-68.6%	-68.6%	-68.8%	-67.5%	97.2%	97.2%	97.4%	95.6%

- Electricity consumption reduction and Overall consumer expenditure datafor BC 2

Table C - xxiv: Data used for analysis of life cycle sensitivity to product Sales growth for BC2

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	-40.32	-37.78	-40.32	-37.78	18.20	19.91	18.20	19.91
2020	GWh/year	-81.4	-78.9	-81.4	-73.4	40.0	41.7	40.0	44.8
2030	GWh/year	-542.9	-542.9	-518.6	-515.6	251.4	251.5	265.1	270.0
2040	GWh/year	-1 422.2	-1 422.2	-1 381.7	-1 376.6	628.0	628.0	648.7	651.3
2018	%	-3.3%	-3.3%	-3.3%	-3.3%	4.7%	4.7%	4.7%	4.7%
2020	%	-6.4%	-6.4%	-6.4%	-6.2%	9.1%	9.0%	9.1%	8.8%
2030	%	-28.5%	-28.5%	-28.2%	-28.2%	40.4%	40.4%	39.8%	39.9%
2040	%	-52.3%	-52.3%	-51.8%	-51.7%	74.0%	74.0%	73.3%	73.2%

Table C - xxv: Data used for analysis of life cycle sensitivity to product Sales growth for BC 2

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-9.19	-9.00	-9.19	-9.11	3.27	3.40	3.27	3.34
2020	M€/year	-14.15	-13.97	-14.30	-13.61	6.51	6.63	6.43	6.84
2030	M€/year	-63.06	-63.06	-61.57	-60.85	27.61	27.62	28.52	29.19
2040	M€/year	-144.86	-144.86	-142.30	-141.11	63.12	63.12	64.53	65.12
2018	%	-8.1%	-8.0%	-8.1%	-8.1%	11.0%	11.0%	11.0%	11.0%
2020	%	-11.5%	-12.2%	-11.6%	-11.9%	16.8%	16.7%	16.9%	16.6%
2030	%	-36.0%	-36.0%	-35.7%	-35.9%	50.9%	50.9%	50.6%	50.6%
2040	%	-59.2%	-59.2%	-59.0%	-58.9%	83.9%	83.9%	83.4%	83.2%

- Electricity consumption reduction and Overall consumer expenditure data for BC 4

Table C - xxvi: Data used for analysis of life cycle sensitivity to product Sales growth for BC4

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	-12.18	-11.09	-12.18	-11.09	5.70	6.43	5.70	6.43
2020	GWh/year	-24.226	-23.138	-24.226	-20.816	12.669	13.404	12.669	14.727
2030	GWh/year	-162.846	-162.846	-151.750	-150.363	79.206	79.671	85.086	87.609
2040	GWh/year	-430.401	-430.401	-412.333	-410.074	195.507	195.507	205.072	206.268
2018	%	-2.9%	-2.9%	-2.9%	-2.9%	4.2%	4.1%	4.2%	4.1%
2020	%	-5.6%	-5.6%	-5.6%	-5.4%	8.0%	7.9%	8.0%	7.7%
2030	%	-26.2%	-26.2%	-25.8%	-25.8%	37.0%	37.1%	36.2%	36.4%
2040	%	-49.1%	-49.1%	-48.5%	-48.4%	69.6%	69.6%	68.6%	68.5%

Table C - xxvii: Data used for analysis of life cycle sensitivity to product Sales growth for BC 4

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-413.80	-413.71	-413.80	-420.88	-24.66	-24.60	-24.66	-28.86
2020	M€/year	-533.18	-533.09	-540.59	-541.25	11.83	11.89	8.05	7.75
2030	M€/year	-1 131.68	-1 131.68	-1 143.39	-1 144.85	195.31	195.34	192.00	191.73
2040	M€/year	-1 733.37	-1 733.37	-1 749.70	-1 751.74	379.51	379.51	376.50	376.13
2018	%	-74.6%	-74.5%	-74.6%	-75.1%	70.6%	70.6%	70.6%	71.1%
2020	%	-90.2%	-90.2%	-90.7%	-90.9%	92.7%	92.7%	93.3%	93.4%
2030	%	-145.7%	-145.7%	-146.7%	-146.8%	171.4%	171.4%	172.5%	172.7%
2040	%	-179.9%	-179.9%	-181.0%	-181.1%	219.9%	219.9%	221.2%	221.4%

- Electricity consumption reduction and Overall consumer expenditure data for BC 5

Table C - xxviii: Data used for analysis of life cycle sensitivity to product Sales growth for BC5

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	-131.55	-109.71	-131.55	-109.71	67.40	82.15	67.40	82.15
2020	GWh/year	-249.3	-227.5	-249.3	-181.1	155.6	170.3	155.6	196.7
2030	GWh/year	-1 746.8	-1 746.8	-1 538.6	-1 513.0	946.2	946.9	1 063.8	1 105.4
2040	GWh/year	-4 690.5	-4 690.5	-4 342.8	-4 300.1	2 261.6	2 261.6	2 439.2	2 461.0
2018	%	-3.3%	-3.2%	-3.3%	-3.2%	4.7%	4.5%	4.7%	4.5%
2020	%	-6.2%	-6.1%	-6.2%	-5.8%	8.8%	8.6%	8.8%	8.2%
2030	%	-28.1%	-28.1%	-27.4%	-27.3%	39.8%	39.8%	38.5%	38.7%
2040	%	-51.6%	-51.6%	-50.3%	-50.1%	73.0%	73.0%	71.2%	71.0%

Table C - xxix: Data used for analysis of life cycle sensitivity to product Sales growth for BC 5

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-124.30	-122.94	-124.30	-123.80	49.58	50.50	49.58	49.99
2020	M€/year	-182.22	-180.87	-185.20	-174.81	76.39	77.31	74.88	80.82
2030	M€/year	-574.35	-574.35	-566.53	-540.44	248.97	249.02	254.73	272.65
2040	M€/year	-1 130.09	-1 130.09	-1 115.72	-1 073.03	485.15	485.15	494.61	515.01
2018	%	-16.4%	-16.5%	-16.4%	-16.5%	23.3%	23.3%	23.3%	23.3%
2020	%	-22.7%	-22.6%	-22.8%	-22.5%	32.2%	32.1%	32.3%	31.8%
2030	%	-51.1%	-51.1%	-51.0%	-50.5%	72.3%	72.4%	72.2%	71.4%
2040	%	-74.0%	-74.0%	-73.8%	-72.8%	104.9%	104.9%	104.6%	103.1%

- Electricity consumption reduction and Overall consumer expenditure data for BC 6

Table C - xxx: Data used for analysis of life cycle sensitivity to product Sales growth for BC6

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	-106.95	-100.22	-106.95	-100.22	48.46	53.01	48.46	53.01
2020	GWh/year	-216.4	-209.6	-216.4	-195.2	106.0	110.6	106.0	118.8
2030	GWh/year	-1 439.3	-1 439.3	-1 372.1	-1 363.7	668.7	670.6	705.1	719.8
2040	GWh/year	-3 775.0	-3 775.0	-3 664.7	-3 650.8	1 670.5	1 670.5	1 728.2	1 735.4
2018	%	-3.1%	-3.0%	-3.1%	-3.0%	4.4%	4.3%	4.4%	4.3%
2020	%	-5.9%	-5.9%	-5.9%	-5.8%	8.4%	8.3%	8.4%	8.2%
2030	%	-27.0%	-27.0%	-26.8%	-26.7%	38.3%	38.3%	37.7%	37.8%
2040	%	-50.3%	-50.3%	-49.9%	-49.8%	71.3%	71.3%	70.6%	70.5%

Table C - xxxi: Data used for analysis of life cycle sensitivity to product Sales growth for BC 6

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-68.02	-67.91	-68.02	-68.06	27.75	27.82	27.75	27.73
2020	M€/year	-105.32	-105.21	-106.87	-102.32	42.37	42.45	41.58	44.10
2030	M€/year	-371.43	-371.43	-372.87	-355.65	153.47	153.50	153.32	163.86
2040	M€/year	-775.33	-775.33	-777.08	-749.34	322.20	322.20	322.44	335.92
2018	%	-11.8%	-11.7%	-11.8%	-11.8%	16.6%	16.6%	16.6%	16.6%
2020	%	-16.8%	-16.8%	-16.9%	-16.6%	23.8%	23.8%	23.9%	23.6%
2030	%	-42.4%	-42.4%	-42.5%	-42.1%	60.1%	60.1%	60.2%	59.4%
2040	%	-65.4%	-65.4%	-65.5%	-64.7%	92.6%	92.6%	92.8%	91.6%

- Electricity consumption reduction and Overall consumer expenditure data for BC 7A

Table C - xxxii: Data used for analysis of life cycle sensitivity to product Sales growth for BC7A

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	-108.67	-105.30	-108.67	-105.30	47.14	49.41	47.14	49.41
2020	GWh/year	-224.0	-220.7	-224.0	-213.5	101.2	103.5	101.2	107.5
2030	GWh/year	-1 448.9	-1 445.6	-1 402.0	-1 385.6	647.2	649.5	665.4	674.0
2040	GWh/year	-3 766.9	-3 766.9	-3 653.0	-3 638.8	1 652.8	1 655.1	1 689.2	1 700.1
2018	%	-0.7%	-0.7%	-0.7%	-0.7%	1.0%	1.0%	1.0%	1.0%
2020	%	-1.4%	-1.4%	-1.4%	-1.4%	2.0%	2.0%	2.0%	2.0%
2030	%	-8.3%	-8.3%	-8.2%	-8.2%	11.8%	11.8%	11.7%	11.6%
2040	%	-19.3%	-19.3%	-19.0%	-19.0%	27.3%	27.3%	26.9%	26.9%

Table C - xxxiii: Data used for analysis of life cycle sensitivity to product Sales growth for BC 7A

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-20.77	-20.64	-20.77	-22.95	8.66	8.74	8.66	7.38
2020	M€/year	-33.15	-33.02	-33.73	-39.05	13.10	13.18	12.80	9.91
2030	M€/year	-122.53	-122.41	-121.79	-154.96	51.31	51.39	51.68	38.56
2040	M€/year	-262.90	-262.90	-260.09	-329.09	111.51	111.60	112.56	89.22
2018	%	-2.7%	-2.6%	-2.7%	-2.7%	3.8%	3.8%	3.8%	3.9%
2020	%	-4.2%	-4.2%	-4.1%	-4.4%	5.8%	5.8%	5.9%	6.2%
2030	%	-13.8%	-13.8%	-13.9%	-15.5%	19.6%	19.6%	19.6%	21.8%
2040	%	-26.5%	-26.5%	-26.3%	-29.4%	37.5%	37.5%	37.3%	41.9%

- Electricity consumption reduction and Overall consumer expenditure data for All BCs

Table C - xxxiv: Data used for analysis of life cycle sensitivity to product Sales growth for All BCs

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	GWh/year	-862.79	-792.37	-862.79	-792.37	400.39	447.95	400.39	447.95
2020	GWh/year	-1 725.0	-1 654.6	-1 725.0	-1 504.0	885.9	933.5	885.9	1 019.3
2030	GWh/year	-11 568.6	-11 565.2	-10 867.0	-10 769.7	5 542.9	5 554.3	5 924.7	6 069.1
2040	GWh/year	-30 463.1	-30 463.1	-29 263.4	-29 115.1	13 733.2	13 735.5	14 329.6	14 409.7
2018	%	-2.2%	-2.2%	-2.2%	-2.2%	3.1%	3.1%	3.1%	3.1%
2020	%	-4.3%	-4.3%	-4.3%	-4.2%	6.1%	6.1%	6.1%	5.9%
2030	%	-21.6%	-21.6%	-21.3%	-21.2%	30.5%	30.5%	29.9%	30.0%
2040	%	-42.5%	-42.5%	-41.9%	-41.9%	60.2%	60.2%	59.4%	59.3%

Table C - xxxv: Data used for analysis of life cycle sensitivity to product Sales growth for BC 7A

Years	Units	Pragmatic Upper				Pragmatic Lower			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	-1 078.50	-1 076.49	-1 078.50	-1 085.17	239.54	240.89	239.54	235.75
2020	M€/year	-1 537.8	-1 535.8	-1 561.0	-1 512.9	420.8	422.1	409.0	435.8
2030	M€/year	-4 536.7	-4 536.6	-4 554.3	-4 394.8	1 612.3	1 612.6	1 612.4	1 720.2
2040	M€/year	-8 692.1	-8 692.1	-8 710.1	-8 466.3	3 282.6	3 282.7	3 289.2	3 416.5
2018	%	-17.7%	-17.7%	-17.7%	-17.7%	21.8%	21.8%	21.8%	21.9%
2020	%	-23.7%	-23.7%	-23.8%	-23.6%	30.4%	30.3%	30.5%	30.2%
2030	%	-51.3%	-51.3%	-51.5%	-51.1%	69.6%	69.6%	69.8%	69.3%
2040	%	-74.4%	-74.4%	-74.5%	-73.8%	102.4%	102.4%	102.6%	101.6%

- Sensitivity analysis data for Maintenance & Repair (M & R) costs
  - Overall consumer expenditure reduction

Table C - xxxvi: Data used for analysis of life cycle sensitivity to M & R costs for BC 1

Years	Units	Pragmatic Upper			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4
2018	M€/year	-1 424.19	-1 425.97	-1 424.19	-1 417.82
2020	M€/year	-1 539.36	-1 541.14	-1 547.91	-1 500.85
2030	M€/year	-2 219.31	-2 219.31	-2 246.74	-2 024.96
2040	M€/year	-3 059.66	-3 059.66	-3 096.20	-2 790.13
2018	%	-43.4%	-43.5%	-43.4%	-43.2%
2020	%	-43.5%	-43.6%	-43.6%	-43.0%
2030	%	-44.4%	-44.4%	-44.8%	-42.6%
2040	%	-45.1%	-45.1%	-45.6%	-43.3%

Table C - xxxvii: Data used for analysis of life cycle sensitivity to M & R costs for BC 2

Years	Units	Pragmatic Upper			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4
2018	M€/year	-6.93	-6.80	-6.93	-6.85
2020	M€/year	-6.66	-6.53	-6.77	-6.21
2030	M€/year	-9.39	-9.39	-8.25	-7.33
2040	M€/year	-12.39	-12.39	-10.76	-9.48
2018	%	-6.1%	-6.0%	-6.1%	-6.1%
2020	%	-5.4%	-6.1%	-5.5%	-5.9%
2030	%	-5.8%	-5.8%	-5.8%	-5.8%
2040	%	-5.8%	-5.8%	-6.0%	-5.8%

Table C - xxxviii: Data used for analysis of life cycle sensitivity to M & R costs for BC 4

Years	Units	Pragmatic Upper			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4
2018	M€/year	-2.95	-2.88	-2.95	-6.97
2020	M€/year	-3.12	-3.06	-7.00	-7.29
2030	M€/year	-3.74	-3.74	-8.14	-8.67
2040	M€/year	-4.82	-4.82	-10.17	-10.84
2018	%	0.0%	0.0%	0.0%	0.0%
2020	%	0.0%	0.0%	0.0%	0.0%
2030	%	0.0%	0.0%	0.0%	0.0%
2040	%	0.0%	0.0%	0.0%	0.0%

Table C - xxxix: Data used for analysis of life cycle sensitivity to M & R costs for BC 5

Years	Units	Pragmatic Upper			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4

Years	Units	Pragmatic Upper			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4
2018	M€/year	-183.76	-182.95	-183.76	-182.36
2020	M€/year	-197.33	-196.52	-199.49	-188.53
2030	M€/year	-281.24	-281.24	-276.46	-239.02
2040	M€/year	-390.04	-390.04	-382.82	-330.74
2018	%	-24.4%	-24.6%	-24.4%	-24.3%
2020	%	-24.5%	-24.6%	-24.6%	-24.2%
2030	%	-25.3%	-25.3%	-25.5%	-24.0%
2040	%	-26.0%	-26.0%	-26.2%	-24.6%

Table C - xl: Data used for analysis of life cycle sensitivity to M & R costs for BC 6

Years	Units	Pragmatic Upper			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4
2018	M€/year	-222.60	-222.79	-222.60	-222.20
2020	M€/year	-240.78	-240.97	-242.04	-236.78
2030	M€/year	-343.31	-343.31	-346.77	-321.36
2040	M€/year	-470.03	-470.03	-474.59	-439.72
2018	%	-38.5%	-38.5%	-38.5%	-38.4%
2020	%	-38.6%	-38.6%	-38.7%	-38.3%
2030	%	-39.2%	-39.2%	-39.6%	-38.1%
2040	%	-39.7%	-39.7%	-40.0%	-38.5%

Table C - xli: Data used for analysis of life cycle sensitivity to product price for BC 7A

Years	Units	Pragmatic Upper			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4
2018	M€/year	-81.91	-81.82	-81.91	-84.72

Years	Units	Pragmatic Upper			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4
2020	M€/year	-83.99	-83.90	-84.38	-91.87
2030	M€/year	-92.58	-92.50	-92.25	-130.67
2040	M€/year	-102.84	-102.76	-101.55	-179.18
2018	%	-10.5%	-10.5%	-10.5%	-10.6%
2020	%	-10.6%	-10.6%	-10.5%	-11.1%
2030	%	-10.4%	-10.4%	-10.5%	-12.7%
2040	%	-10.5%	-10.5%	-10.5%	-14.4%

Table C - xlii: Data used for analysis of life cycle sensitivity to product price for All BCs

Years	Units	Pragmatic Upper			
		Upper Scenario 1	Upper Scenario 2	Upper Scenario 3	Upper Scenario 4
2018	M€/year	-1 922.34	-1 923.22	-1 922.34	-1 920.92
2020	M€/year	-2 071.2	-2 072.1	-2 087.6	-2 031.5
2030	M€/year	-2 949.6	-2 949.5	-2 978.6	-2 732.0
2040	M€/year	-4 039.8	-4 039.7	-4 076.1	-3 760.1
2018	%	-31.7%	-31.7%	-31.7%	-31.6%
2020	%	-31.9%	-32.0%	-32.0%	-31.7%
2030	%	-33.4%	-33.4%	-33.7%	-32.3%
2040	%	-34.6%	-34.6%	-34.9%	-33.5%



02 April 2014

185 avenue Charles de Gaulle
92200 Neuilly-sur-Seine
France
+ 33 (0) 1 5561 6755
www.bio.deloitte.fr