Work on Preparatory studies for implementing measures of the Ecodesign Directive2009/125/EC

ENER Lot 29 – Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under ENER Lot 11) – Task 1: Definition

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Task 1: Definition

The scope of the study includes pumps for private and public swimming pools, ponds, fountains and aquariums, as well as clean water pumps larger than those regulated under TREN Lot 11[1].

Note that pumps for private and public wastewater are covered by ENER Lot 28 (see: http://www.ecopumps.eu/).

The main objective of this working document is to set a solid foundation for the ENER Lot 29 preparatory study by defining the product scope for pumps for public and private swimming pools, ponds, fountains and aquariums, and to understand these products from a functional and technical point of view. It also structures appropriate pump categories while providing a first screening on the basis of their sales volumes and improvement potential.

- Section 1.1 provides a technical introduction to pumping, and some basic concepts.
- Section 1.2 sets out primary and secondary functional parameters and existing product categorisations.
- Section 1.3 defines the scope of pumps to be considered for analysis and includes a screening exercise. Brief product introductions are also provided.
- Section 1.4 lists existing test standards at the EU, Member State and third country levels.
- Section 1.5 lists existing legislation at the EU and third country levels.
- Section 1.6 discusses 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 to discuss a proposed methodology for the analysis of water pumps.
- Section 1.7 lists the main conclusions of Task 1.

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

1.1 Technical introduction

1.1.1 How Pumps Work

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.



Figure 1-1: Operating principles of positive displacement and rotodynamic water pumps

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 and usually with a small increase in velocity.

In vertical multistage and submersible multistage well pumps, the volute function is carried out by several vanes which guide the water from the discharge of one impeller to the inlet of the next. Ideally these will be designed for minimum loss but, in small submersible pumps, getting the maximum flow from a fixed borehole diameter may force a reduction in the diameter of the guide vanes or alter their geometry so as to cause a small loss in pump efficiency. Figure 1-2 illustrates the flow paths of the rotodynamic pumps and shows the cutaway of motor coupled pumps.

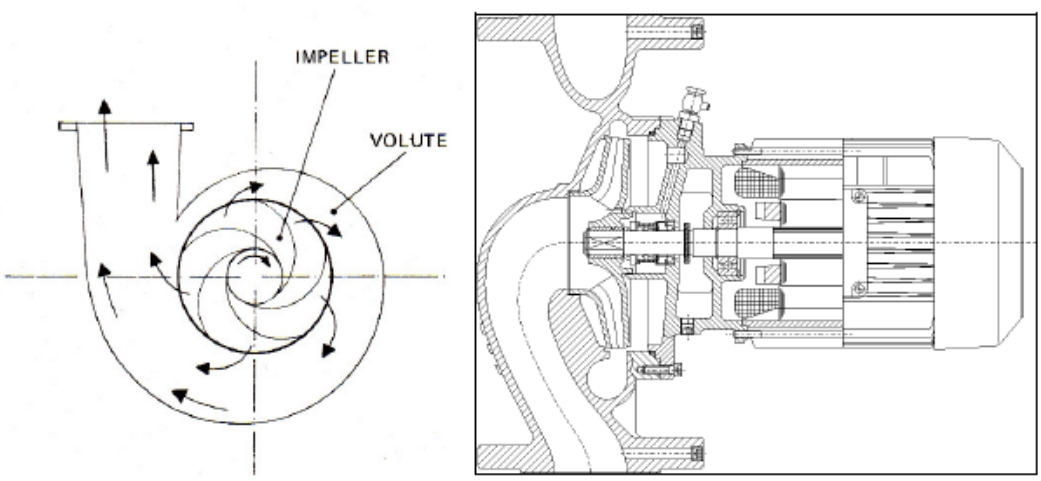


Figure 1-2: How rotodynamic pumps work: flow paths (left) and cutaway of motor coupled pump (right) (Source ENER Lot 11 preparatory study on ecodesign of motors)

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 considered in this study.

The pumps in this study are all centrifugal types, and there are various ways that these could be put into different categories. 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 in the secondary functional parameters and so be flawed.

The argument is always based firstly on the primary functional parameters, which are the flow and head. In these simple terms, within the centrifugal category, different styles are better suited for different head:flow duties. The style alters in a general way with reference to specific speed. While there will always be overlaps between different styles and their suggested range of application, the pragmatic way forward is to use the basic classification shown in the table to split the continuum of styles into manageable groups. Without this, it would be impossible to have a single implementing measure that could sensibly apply to all types.

1.1.2 The pump system

A pump will be described in a catalogue in terms of head, flow and, usually, power. In order to include a power curve, a specific gravity of unity 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:

$$P_{mech} = Q \times H \times \text{density} \times g / \text{pump efficiency}.$$

Where,

Q = flow

H = head

g = gravitational constant

This means that it is not possible to give standard curves of power consumption against duty for all liquids, as generally the power consumption varies with fluid properties – although for this study because the project team are only considering clean water this is not a problem. In addition, the same pump can be used with different motor speeds and impeller sizes, which adds additional variation.

Because a pump will on average spend most of its life operating below its Best Efficiency Flow, part flow operation is also of interest. 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.

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

Thus,

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

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.

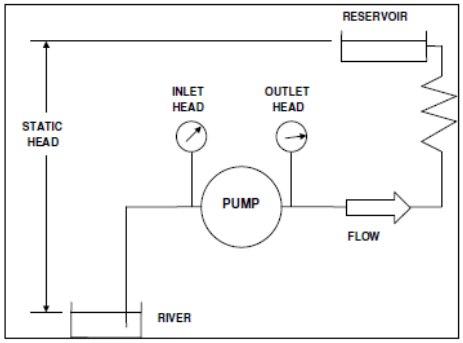


Figure 1-3: Illustration of an open pumping system

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

1.1.3 Basic pump laws

The fundamental similarity (scaling) laws applying to rotodynamic pumps are:

$$\frac{Y_{P2}}{Y_{P1}} = \frac{H_{P2}}{H_{P1}} = \left(\frac{n_{P2}}{n_{P1}}\right)^2 \cdot \left(\frac{D_{P2}}{D_{P1}}\right)^2 \qquad \text{(Equation 1)}$$

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

$$\frac{Q_{P2}}{Q_{P1}} = \frac{n_{P2}}{n_{P1}} \cdot \left(\frac{D_{P2}}{D_{P1}}\right)^3 \qquad \text{(Equation 2)}$$

where Q = flow

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

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

With a Q_{P_1} = 1m³/s, H_{P_1} = 1m and Pump 2 at best efficiency point equation 3 leads to the specific speed n_s (usually used in literature for n_{P_1})

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

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.

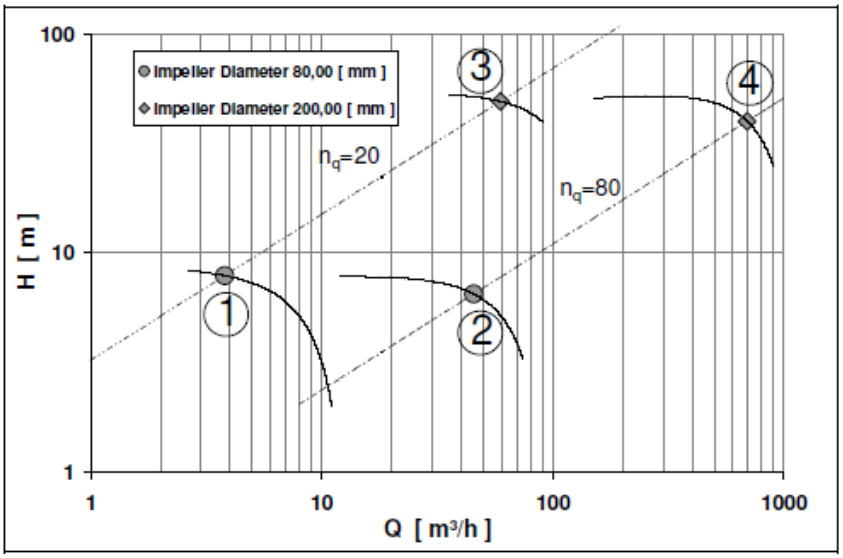


Figure 1-4: Duty points of pumps of different sizes but same specific speed

Figure 1-4 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 1-5 in more detail. The impeller diameter of pumps with the same specific speed is different and hence their flow rate at best efficiency point. 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 NPSH-figure, noise, dirt etc.

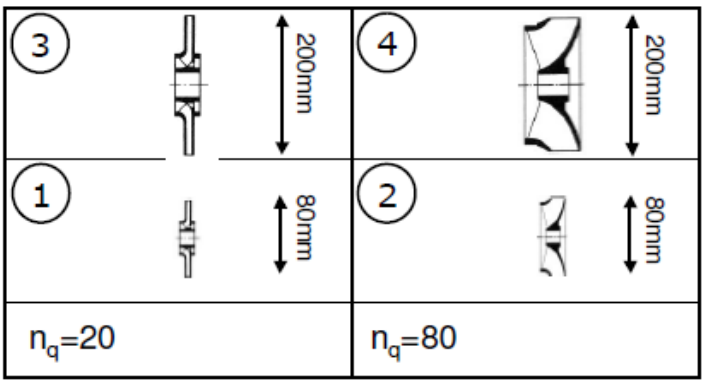


Figure 1-5: Principle impeller designs for typical pump sizes and specific speed

As induction motors are only available in fixed speeds, trimming the impeller 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. But 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 is aimed at improving pump design, this was seen as being the most appropriate impeller diameter to consider.

1.2 Product categorisation and performance assessment

1.2.1 Definition of Primary Functional Parameters

The primary functional parameters (i.e. 'what it does') are:

- Rated flow (Q, m³/hour)
- Head (H, m)
- The fluid properties

Efficiency is not a primary functional parameter, on the basis that it relates to how a product does something, not what it does. 'Fluid properties' are included to make clear that the nature of fluids has a major impact on the selection of product.

The functional unit is the reference value for any pump considered, and is independent of type. It also helps to set the boundaries for comparison of different products. For the pumps in this study, this may be assessed by considering 'the quantity of water pumped at the specified head, (m³/h, m)'.

1.2.2 Secondary Functional Parameters

The importance of secondary performance parameters is that they are often instrumental in guiding the specification of a pump, and so these must be considered when considering 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, net positive section head) 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); 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 for the same duty point (Q/H), so that the initial price advantage can be lost in a short time by increased energy costs.

- **Bearing arrangements.** Pump impellers must be positively located both radially and axially. The radial bearings must resist radial thrusts and enable the impellers to maintain fine radial running clearances to minimise leakage between the impeller and casing. The axial bearings must resist axial thrusts, maintain the relative positions of the impeller and casing and ensure accurate location of axial seals. End Suction Own Bearings pumps use two anti-friction bearings, usually grease lubricated. Vertical Multistage pumps use the motor bearings for axial location; radial location being provided partly by the motor and partly by water lubricated plain bearings in the pump. Submersible Multistage Well pumps use the motor thrust bearing to accommodate the hydraulic downthrust and the weight of the pump rotating element, with a small thrust ring in the top of the pump to resist upthrust when starting; radial location is provided by water lubricated plain bearings. Aquarium pumps, pond pumps and fountain pump that use the technology of integrated motor with wet rotor normally do not require shaft bearings because, through a system of internal recirculation, the rotor shaft is constantly lubricated and cooled by the same pumped water.'
- **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 (NPSHR) and the NPSH available to the pump (NPSHA). The NPSHR 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 NPSHA must exceed the NPSHR by a safety margin. The NPSHR reduces between pump best efficiency flow (BEQ) and about half flow, but increases rapidly above BEQ.
- **Shaft power or mechanical power**: power transmitted to a pump by the shaft. It is the product of speed and torque.

$$SP = \omega \times T$$

where,

ω is the angular speed of the shaft.

T is the torque transmitted.

- **Hydraulic power**: energy per second carried in a fluid, such as water or oil, in the form of pressure and quantity.

$$HP = Q \times \Delta p$$

where,

Q is the flow rate.

Δp is the change in pressure of the fluid over the pump.

- **Electrical power**: power input (in kW) of the pump.
- **Electricity and primary energy**: energy consumed by the pump. The primary energy includes the losses due to generation and transport of electricity.
- **Efficiency at operating/duty point.** This is a major determinant in lifetime operating costs. It is therefore important that a pump should be chosen which has a high efficiency, and 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.
- **Part load behaviour.** Throttled down to around half flow, a fixed speed pump can become noisy (see 'Noise' below) due to recirculation of the flow in the impeller and volute. At lower flows this could reduce bearing and seal life. At very low flows a pump can overheat. However, low flows should be avoided as far as possible because of loss of efficiency. It is therefore very important to avoid adding unnecessary margins to the required head and flow, which cause the pump to operate at reduced flow under actual site conditions.

1.2.3 Other relevant parameters

There are several other parameters considered to be relevant, namely noise, expected lifetime of the pump, and general construction.

- **Noise.** A pump of the types covered in this report operating under optimum conditions should be less noisy than its motor. If such a pump is noisy, then it is a fault condition. It could be a mechanical fault, such as failed bearings. However, it is more likely to be an operational fault. It could be running at too low a flow, which causes noisy cavitation in a volute and sometimes in an impeller, or it could be suffering from inadequate NPSHA, which causes noisy cavitation in an impeller.
- **Expected lifetime of the pump.** The lifetime of a water 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. A large water pump operating under ideal conditions should work for 20 years with minimum

maintenance. The variations in the other pumps considered in this study are too large to specify a single expected lifetime. (Lifetimes of various types of pumps in the scope of the ENER Lot 29 study will be discussed in more details in Task 3).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. It is not unusual to lose 10% of the new efficiency in ten years.

- **General construction.** Ease of maintenance varies with pump type. 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.

1.2.4 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 required by the pump (NPSHR) is defined above. To operate normally the pump will usually be arranged in the system such that the NPSH available at the pump inlet (NPSHA) is greater than the NPSHR throughout the intended flow range.

If the NPSHA is close to or less than the NPSHR, 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. 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.

1.2.5 Improving Efficiency of Pumps

An extract from the 'SAVE Study on Improving the Efficiency of Pumps' is provided in Annex 1. It contains detailed information on the key factors in but design that affects the overall operating efficiency.

In addition to this, a description of the 'House of Efficiency Scheme' used in the ENER Lot 11 preparatory study is provided in Annex 2.

1.2.6 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 29 pumps. They are presented in Table 1-1.

Table 1-1: PRODCOM categories

PRODCOM code	Prodcom category
28.13	**Manufacture of other pumps and compressors**
28.13.14	***Other centrifugal pumps for liquids; other 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
29.29	**Manufacture of other general-purpose machinery n.e.c.**
28.29.12	***Filtering or purifying machinery and apparatus, for liquid***
28.29.12.30	Machinery and apparatus for filtering or purifying water

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

The only pertinent technical standard is the dimensional classification of pumps EN 733:1995 '*End-suction centrifugal pumps, rating with 10 bar with bearing bracket. Nominal duty point, main*

dimensions, designation system'. Whilst the standard is well accepted within the industry, it is limited in scope to this style of pump only.

IEC standard 60335-2-41 '*Household and similar electrical appliances – Particular requirements for pumps*' and IEC 60335-2-55 '*Household and similar electrical appliances – Particular requirements for electrical appliances for use with aquariums and garden ponds*' are both pertinent to aquariums and garden pumps.

1.2.8 Labelling categories (EU Energy Label or Eco-Label)

There are currently no ecolabels at EU or Member State levels that can be used as a basis for pump categorisation. The voluntary circulator scheme (EC) No 641/2009 is a useful reference, 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. This is not the case with many pumps considered in this study because they are used for a very wide range of duties. However, there are certain situations where this 'extended product approach' may be appropriate. A technical note on the extended product approach is located on the ENER Lot 29 website: http://lot29.ecopumps.eu/documents.

1.2.9 Proposed classification scheme for pumps

Given the lack of an existing classification scheme adequate for the study purposes, the following categorisation method is adopted. There are other categorising schemes available from other sources, but none of them has obvious merits over any others.

This section will provide some preliminary definitions of some of the products that could be included within the scope of the ENER Lot 29 study.

For each type of pump, the power ranges are agreed with stakeholders. Pumps may also have additional features from being customised for either mass market (small pumps) or designed for individual applications (large pumps).

Pumps come in a variety of generic types as shown see Figure 1-6.

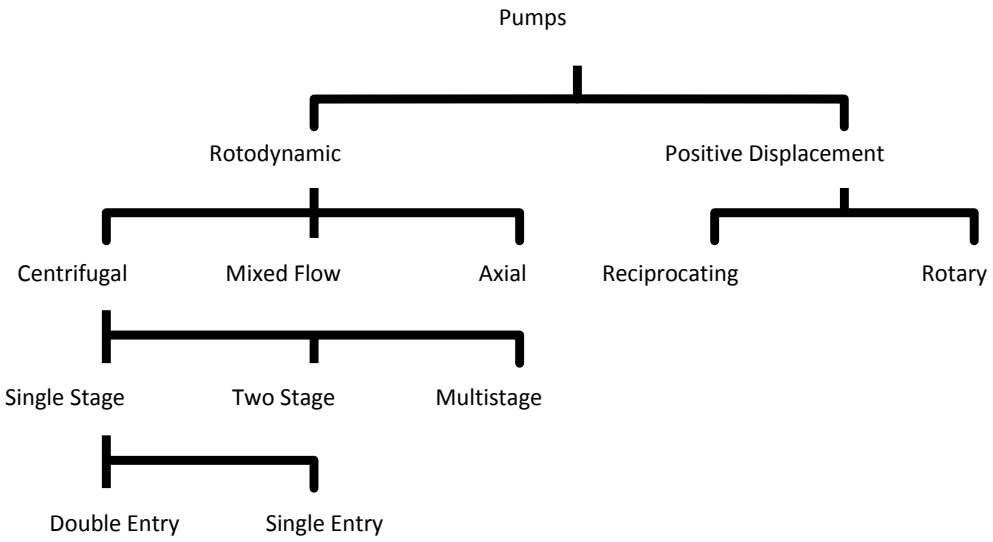


Figure 1-6: Preliminary classification for pumps

1.3 Product screening

This section discusses how the pump categories to be studied are derived from the above classification and presents the rationale for the screening of pump categories. This step is taken due to the large and inhomogeneous product groups. The approach taken is to assume that all pumps are included, unless there are sound reasons why they should be excluded. Care has been taken to try to ensure that no pumps are excluded due to the type of technology rather than the duty/service/function.

The key criteria the project team considers in the screening analysis include:

- Estimated total energy consumption and 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.
- Other environmental aspects – where energy consumption is not a key environmental aspect, other aspects such as material consumption might be of importance and should be taken into account to avoid loopholes.
- Different products available to fulfil the application duty – i.e. could regulations be technology neutral? Regulations under the Ecodesign Directive can only be based on products available on the market; they cannot take account of the application in which they are used. Hence, where more than one product type is available to satisfy an application, great care must be taken to ensure a level playing field between different competing technology options.
- Size of custom / specials market – the existence of alternative products that do not fit definitions can easily lead to loopholes.

1.3.1 Description of pump categories considered

Many of the pumps in this study fall into the category of 'rotodynamic,'. Based on the specification of work, the following types of pump have been considered for inclusion:

- Swimming pool pumps
- Fountain pumps
- Pond pumps
- Aquarium pumps
- Aquarium blowers
- Spa pumps for domestic & commercial spa's
- Counter-Current Pumps
- Large clean water end suction pumps
- Large clean water vertical multistage pumps
- Large clean water submersible multistage pumps

Aquarium blowers are air pumps. Some of them fall into the category of centrifugal pumps, but many aquarium blowers work on a principle similar to a diaphragm pumps. Other than the submersible and vertical multistage pumps, all the other pumps are single stage and single entry pumps. 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. Pumps that are originally designed for use with liquids other than water are not within the scope of this study.

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

1. 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.
2. When collecting data, manufacturers should not offer their 'nearest equivalent' type of pump from a different family that satisfies the required duty, as this would lead to distortions in the results.
3. As pumps are characterised by hydraulic values rather than power (kW) ratings, it is not possible to directly link them to the ranges in the motor study. However, indicatively it is unlikely that any pumps within the scope of the study will require an electrical motor in excess of 1 MW to drive them. However, it should be noted that most pumps beyond 160kW are non-standard engineered items, which are not considered suitable for setting ecodesign requirements.
4. 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. Firm data is

not available on the proportion of the market that is excluded from the study in this way, and it will vary with the different pumps considered, but our best estimate is that it is less than 5% of the total sales of each style, 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.

Table 1-2 shows the selected pump categories/sizes that are to be considered to develop the screening analysis. These were carefully selected to represent the manufacturing features that apply to all pumps within each of the categories. To do this adequately, it was found necessary to select a range of sizes for certain types of model.

Table 1-2: Pump categories and associated duties

Categories	Selected Duties (Q,H,speed)
Swimming Pool pumps (Domestic with built in strainer up to 2.2kW)	Q 5 – 20 m³/h H 8 – 11 m Speed 2,900 rpm
Swimming Pool pumps (Domestic/commercial with built in strainer over 2.2kW)	200 m³/h H 12 – 16 m 2900 – 1450 rpm
Fountain & pond pumps	Q 100 – 15,000 l/h H 0 – 8 m Speed 3,000 rpm
Aquarium pumps	Q 100 – 5,000 l/h H 0 – 4 m Speed 3,000 rpm
Spa pumps	P 0.75-3kW Speed 1,450 and 2,900rpm
Counter current pumps	Q 30,000 - 60,000 l/h H 10-14m Speed 2,900rpm
End Suction pumps (Size > ENER Lot11)	Q 200 - 2,000 m3/h H 10-90m Speed 1,450rpm
Submersible bore-hole pumps (8", 10", 12")	Q 15 - 500 m3/h H 30-500m Speed 2,900rpm
Submersible bore-hole pumps > 12"	Q 300 - 2,500 m3/h H 25-200m Speed 1,450rpm
Vertical Multistage pumps (Size > ENER Lot11)	Q 100 - 700 m3/h H 20-400m Speed 1,450rpm and 2900rpm

Figure 1-7 shows which pump categories, out of the universe of all pumps, have been selected for screening. These pumps for screening are then analysed further in section 1.3.3.

It should be noted that pumps above 1MW are non-standard, engineered products, which are not considered possible to analyse further, therefore the upper limit for pumps in scope for this lot is 1 MW. However, consideration will be given to potential measures for these pumps in Task 8.

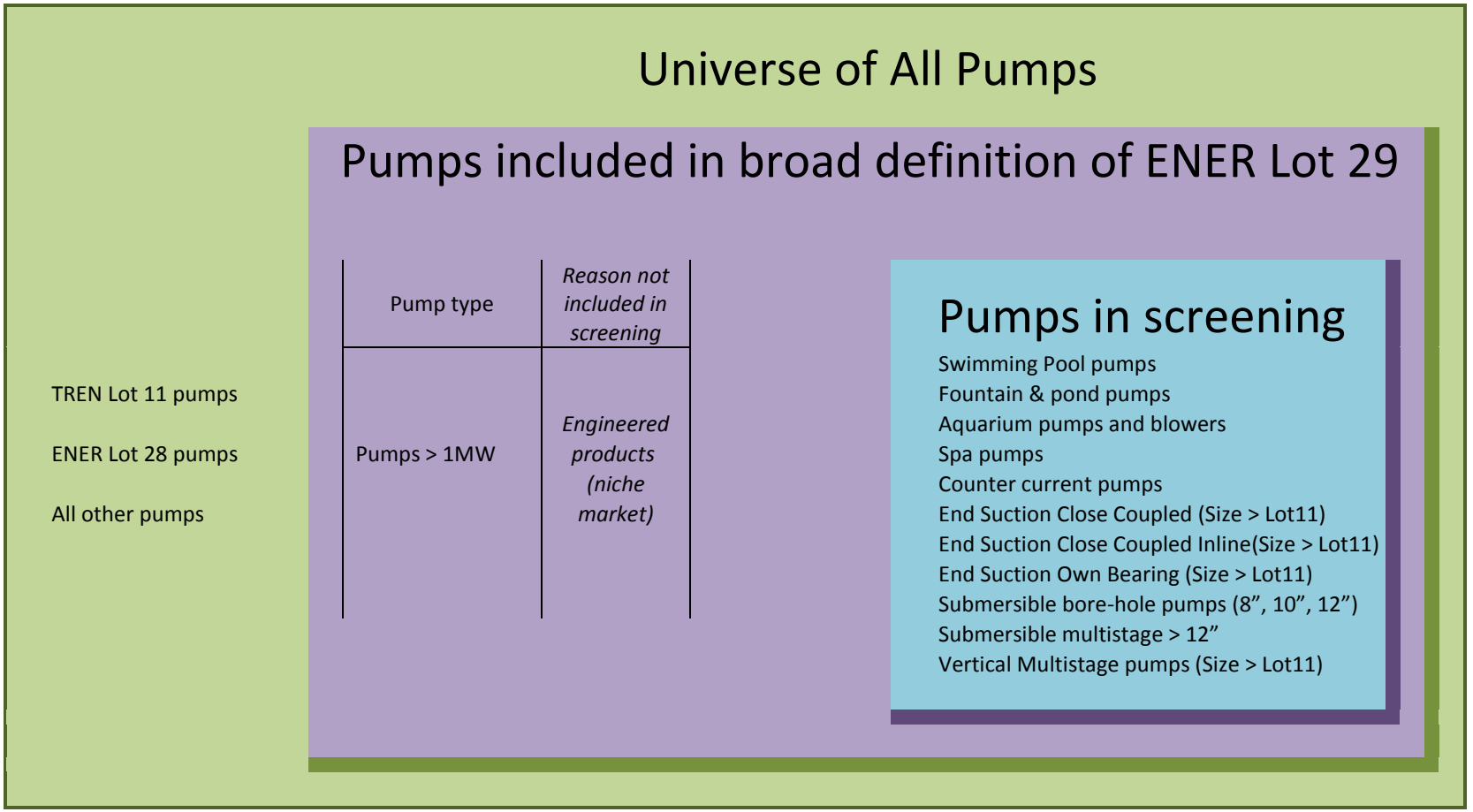


Figure 1-7: Process to define pumps for screening

1.3.2 Details of the key types of pumps considered in this study

A. LARGE WATER PUMPS

For consistency, the same product classification and analysis as in the TREN Lot 11 study that covers pumps up to 150kW (4-pole) is used for these pumps:

- '*End suction water pump*' means a glanded single stage end suction rotodynamic water pump
  - '*End suction own bearing water pump*' (ESOB) is an end suction water pump with own bearings and the suction side in axial and the water pressure outlet in radial direction (Figure 1-9);
  - '*End suction close coupled water pump*' (ESCC) is an end suction water pump of which the motor shaft is extended to become also the pump shaft with the suction side in axial and the water pressure outlet in radial direction;
  - '*End suction close coupled inline water pump*' (ESCCi) means a water pump of which the suction side of the pump is in one line with the water pressure outlet of the pump;
- '*Vertical multistage water pump*' (MS-V) means a glanded multi stage (i > 1) rotodynamic water pump in which the impellers are assembled on a vertically rotating shaft;
- '*Submersible multistage water pump*' (MSS) means a multi stage (i > 1) rotodynamic water pump.

Such pumps have many uses, such as water supply or industrial cooling systems. The analysis will start at the upper size boundary of the proposed regulations, i.e. 1 MW for water pumps, which varies with both the type of pump and the actual duty (see Figure 1-8).

The TREN Lot 11 study upper boundaries were calculated on the basis that these were the approximate limits of the mass produced pumps. Above these sizes, and for the ranges which this new study covers, pumps are so large that they are increasingly tailored or 'engineered' for each application. The efficiencies in these large sizes can already be high, and so there may be little potential for increasing the efficiency. However, given the large annual energy consumption, even a small saving can have a large impact, and so is of particular interest to operators.

For submersible multistage pumps, the minimum power in the ENER Lot 29 study is considerably less than 150kW, due to TREN Lot 11 Pumps being limited to 6" diameter. The upper size considered for the ENER Lot 29 study is 12" diameter. The pumps beyond this size are engineered items, unsuitable for regulation.

End suction close coupled pumps are available in the power range considered in the ENER Lot 29 study, but they are relatively rare.

The upper motor size limits for the vertical multistage pumps, end suction own bear pumps and submersible multistage pumps is 1 MW as this fits with the ENER Lot 30 Motor study size range.

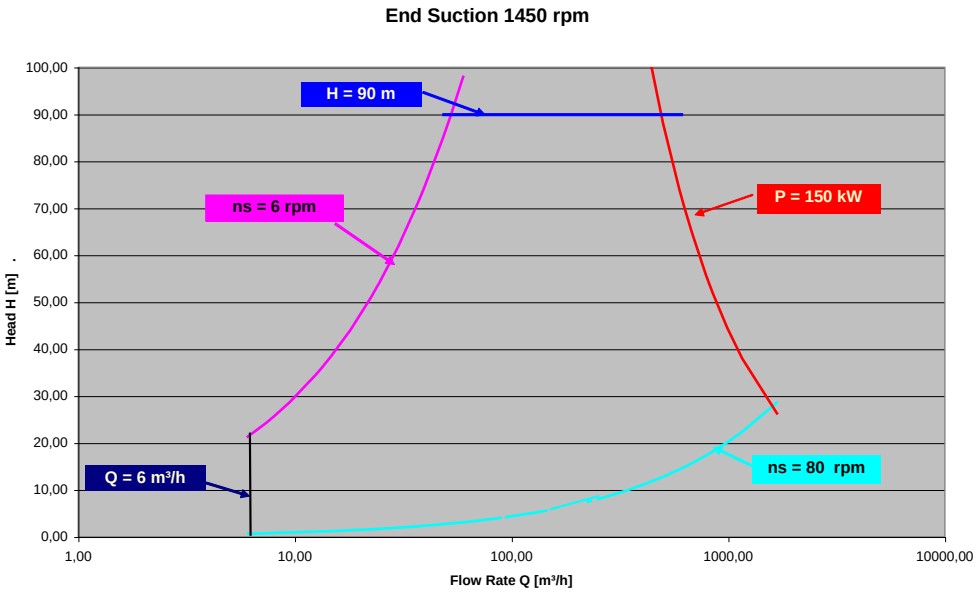


Figure 1-8: Boundaries of TREN Lot 11 preparatory study pumps (4 pole). The ENER Lot 29 study would include pumps to the right of the red maximum power line.

Large clean water pump manufacturers will typically sell pumps with a variety of pump ranges of different sizes in order to attempt to meet the various head and flow requirements of their clients' applications. For each pump range, further variation is possible by impeller trimming, which is important to maintain best efficiency at duties below the optimum.

For each pump, it will have its best efficiency at the top middle of the range. The best achievable efficiency will depend on size and specific speed. Specific speed underpins studies of pump efficiency, and it depends on shaft speed, number of stages, head and flow.



Figure 1-9: Example of an end suction own bearing pump

The other styles are physically similar, with the exception of the Multistage submersible that is designed for operation down deep boreholes (see Figure 1-10).



Figure 1-10: Multistage submersible pump (courtesy of KSB)

For these styles of pumps, the motor is specified separately from the pump, and so the pump will be analysed without the motor.

- **B. SWIMMING POOL PUMPS**

The swimming pool pumps referred to in this Lot are regarded as being the smaller packaged type sold for residential use (see Figure 1-11), with commercial premises using standard water pumps. Older style pumpsets comprising separate motor and pumps now comprise probably <1% of stock, and so can be considered obsolete technology. These domestic swimming pool pumps can also be used for Jacuzzis.

Conterflow pumps, which are used to provide an injection of high pressure flow from outlets on the side of a pool, have too low an energy consumption to be considered in this study (see Figure 1-12). SPA pumps for domestic & commercial spa's where the water is retained and filtered/treated (not those installed into domestic baths which are emptied each time after use) are also considered to have too low an annual energy consumption to be considered for this study.

Public swimming pools may have larger pumps that are driven by a separate motor. Our initial investigations show that these are effectively clean water pumps of the type already analysed within TREN Lot 11.

Domestic swimming pool pumps are typically made from plastic for reasons of efficiency, and of steel in commercial pool pumps for wear resistance and longevity. They are typically rated at around 1kW, and come as packaged units that comprise an integrated motor + pump + controls. They are limited to about 3kW, corresponding to the maximum power that can be drawn from a domestic mains outlet. The ENER Lot 29 study will also include domestic swimming pool pumps with built in strainer up to 3kW and large domestic /commercial swimming pool pumps with built in strainer over 3 kW. Given that pool pumps are a packaged product, and that it should be possible to define typical flow-time profiles, the extended product approach will be readily applicable. There is also much best practice information published on the efficient use of pool pumps, such as that published by swimming pool trade bodies and manufactures, would be a good source of information to be included on or with pumps.



Figure 1-11: Packaged swimming pool pump unit, showing (left to right) prefilter, pump and motor



Figure 1-12: Example of a counter-flow domestic swimming pool pump

C. AQUARIUM PUMPS

An aquarium is a 'living environment' whose health depends on many elements; water parameters involved are numerous (e.g. pH, content of Nitrite, of Nitrate, of Phosphate, temperature, etc.) and they are interrelated and influenced by other factors such as species of living organisms hosted (e.g. fish, shellfish, invertebrates), ratio biomass/water volume, presence of plants, etc..

The pump/filter plays a vital role in the aquarium ecosystem and must operate continuously 24/24. Any control of the rotation speed of the pump, from a ON/OFF option up to a variable speed drive (VSD), can be harmful for the livestock because:

The water flow thru the biological filter needs to be continuous, to guarantee the perfect functioning of the device (risk of inactivation of the filter) and to exclude the risk of Ammonia (NH_3/NH_4+) and Nitrite (NO_2-) accumulation. Nitrite ion is the most dangerous for the stock and can cause its death.

The water turnover could be neap and not able to assure the catabolites disposal. The catabolites are the result of protein metabolism of fish.

Fish excrete a lot of waste, mainly ammonia (NH_3/NH_4+), a toxic compound. Ammonia rapidly accumulates, until enough colonies of bacteria are established in the filter. These bacteria convert ammonia into nitrite (NO_2-), that is even more toxic than ammonia. Nitrite too accumulates in water until it is converted by another type of bacteria, into nitrate, a low toxic compound. This end state, with enough bacteria to convert ammonia and nitrite into nitrate, allows the filter to maintain fish safe. If water flow through the filter is stopped, water cannot be depurated and ammonia and nitrite start to accumulate again.

Ammonia and Nitrite concentration above 0,5 mg/L should be considered highly toxic to aquatic fauna.

Most aquarium pumps are circulating pumps connected to a device that works as a filter. Inside the filter water is forced to flow through different types of filtering materials, in such a way that water is cleared from dirt and detoxified from fish waste. Most Aquarium pumps use the technology of integrated motor with wet rotor. Since the 80's, the aquarium industry has seen a progressive technological shift with the replacement of traditional asynchronous motors with permanent magnet synchronous motors characterized, as known in the literature, by a much higher yield together with lower power consumption than asynchronous motors. Today, aquarium pumps exclusively employ high efficiency permanent magnet motors.

In addition, over the last decade, the industry has made great efforts to optimise the hydraulic design with a view to improving the performance and get further reduction of energy consumption. Today are widely available on the market hydraulic solutions characterized by an high yield such as oriented blades impellers, flexible blades impellers, closed impellers; thanks to the very low hydraulic power the above mentioned design solutions are able to guarantee the correct direction of rotation without using electronics that controls the start-up phase of the pump. On models with higher performance, although they represent a niche market (salt water aquariums), they are also used with electronic controls that ensure the correct direction of rotation of the impeller.

The market is further complicated by some pumps that are connected to additional devices, for example, a heating element, a UV-C lamp or a particular filtering unit. At this stage, it is suggested that any MEPS that might be defined are based on the pump alone, but the test standard will need to take account of the need to remove these other elements (when not necessary to the functionality of the pump itself, for example some aquarium filters as shown in Figure 1-13). While this is a shift from the pure 'extended product approach' that aims to consider as much of the system as possible, it is likely that trying to define 'standard' to fit within regulations would be difficult and give little real benefit.

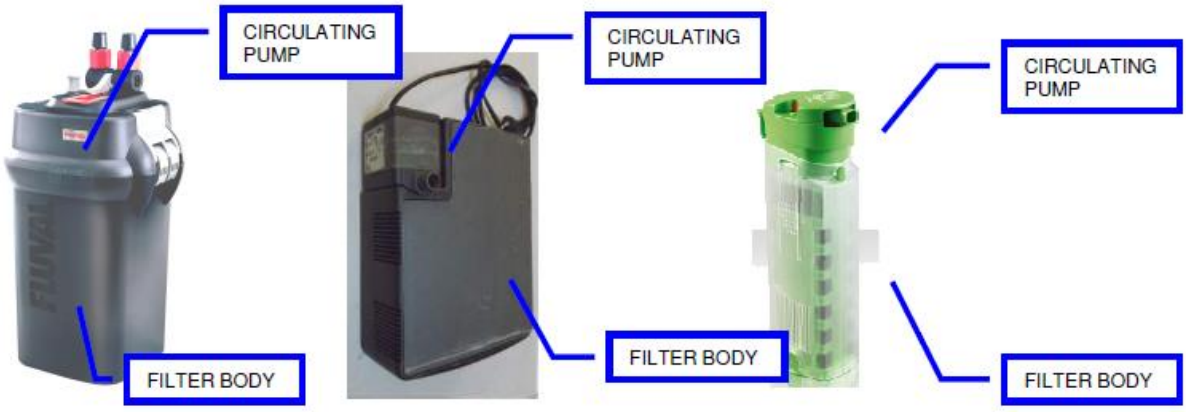


Figure 1-13: Aquarium filters - As described above the circulating pump forces the water through the filter body

Most Aquarium pumps use the technology of integrated motor with wet rotor: the older style pumpset comprising separate motor and pumps can be considered obsolete. Mainly for aquaria applications that need supplementary circulating current, a further circulating pump is also needed Figure 1-14. These are low power units typically <120W although larger pumps are available. The inefficiencies in these pumps cause heating of the water that in some cases may be unwanted.



Figure 1-14: Circulating pumps

D. FOUNTAIN & POND PUMPS

A pond is a living ecosystem and pump intended for the filtration has a vital role must operate continuously throughout the period of use. Also fountains pumps usually play a "filtration role" inside the pond; moreover they guarantee oxygenation of water avoiding the risk of ipoxia in the pond. Pond pumps and fountain pumps are basically built in the same way and differ only for the point of work on the flow/head characteristic curve. Fountain pumps need to work at high head and low flow, while pond pumps need to work at low head and high flow.

Pond pumps drive water through a filter whereas fountain pumps are designed for higher heads for decorative features such as fountains or waterfalls (see Figure 1-15). Fountain pumps will have an internal and possibly satellite inlet filter for protecting the pump.

In pond pumps dirty water will be sourced from a ground filtration unit and often also from a protein skimmer that removes residue from the surface (see Figure 1-16). Most of these types of pump use the technology of integrated motor with wet rotor: the older style pumpset comprising separate motor and pumps can be considered obsolete.

Power ratings vary enormously from <5W to >1kW, with an average power around 40 W. They typically filter up to 25 m³ per hour. They are usually manufactured with a permanent magnet motor.

The upper boundary will need debate in order to ensure no conflict with standalone motors and pumps considered in TREN Lot 11.







Figure 1-15: Typical fountain pump with satellite inlet filter and with internal inlet filter

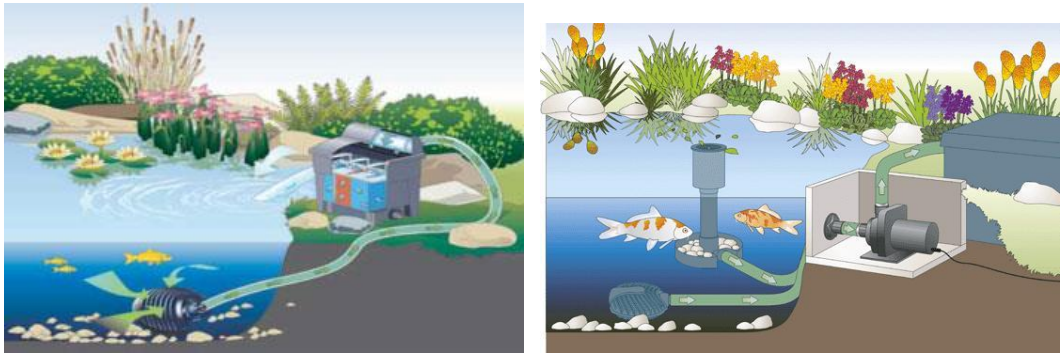


Figure 1-16: Typical pond pump and external filtration unit (left) and Surface – protein – skimmer and dry pond pump (right) from Oase

1.3.3 Evaluation of importance of pump types

Table 1-3 shows an estimation of the annual energy consumption and energy savings potential for the EU stock in 2011 of the pumps considered for the screening analysis. To calculate the annual energy consumption of the pumps, the average hydraulic power is multiplied by the annual operating hours and then added the power absorbed by the motor (assumed as 20%).

Any pump type with significant environmental impact and improvement potential should be kept within the scope. With that reason, the share of total environmental impacts (of the EU stock of pumps considered in the study), per pump type, have been estimated by means of a simplified Life Cycle Assessment (using the EcoReport tool) that includes a simplified bill of materials, the energy consumption, the product life span and the market data. The aim of this exercise is to do a first analysis of the environmental impacts and improvement potential of pumps covered by the definition of the ENER Lot 29 preparatory study. The results are presented in Table 1-4.

Table 1-3: Energy consumption and energy savings potential for the EU stock of pumps considered for the screening analysis (Source: Europump)

	Pump type (and sub-categories)	EU Installed stock 2011	EU Annual sales	Hydraulic pump power	Annual operating hours	Annual energy consumption at EU level* 2011	Improvement potential	Potential savings at EU level 2011	Share of energy consumption	Product level energy savings from EPA	Existing market penetration of EPA	Potential energy savings to overall market from EPA Regulation	Actual savings Potential from EPA Regulation
		Units	Units	kW	Hours	GWh	%	GWh	%	%	%	%	GWh
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	4,800,000	480,000	0.8	1,500	6,912	2.0%	138.2	14.7%	10.0%	0.0%	10.0%	691.20
	Domestic/commercial with built in strainer over 2.2 kW	115,000	11,500	5	3,375	2,329	2.0%	46.6	5.0%	10.0%	0.0%	10.0%	232.88
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	1,845,000	205,000	0.02	6,000	266	2.0%	13.3	1.4%	0.0%	0.0%	0.0%	0.00
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	8,050,000	1,150,000	0.005	8,720	421	2.0%	21.1	2.2%	0.0%	0.0%	0.0%	0.00
	Aquarium power head to 120W	350,000	50,000	0.005	8,720	18	2.0%	0.9	0.1%	0.0%	0.0%	0.0%	0.00
	Spa pumps for domestic & commercial spa's	42,000	4,200	1.1	350	19	2.0%	0.6	0.1%	0.0%	100.0%	0.0%	0.00
	Counter-Current Pumps	1,000,000	100,000	3	20	72	2.0%	1.4	0.2%	0.0%	0.0%	0.0%	0.00
End suction (ES) water pumps (over 150kW-P2)	ES CloseCoupled from 150 kW to 1 MW	1,000	100	150	3,600	648	1.0%	6.5	0.7%	25.0%	50.0%	12.5%	81.00
	ES CloseCoupled Inline from 150 kW to 1 MW	1,000	100	150	3,600	648	1.0%	6.5	0.7%	25.0%	50.0%	12.5%	81.00
	ES Own Bearing from 150 kW to 1 MW	5,500	550	325	3,000	6,435	1.0%	64.4	6.9%	25.0%	50.0%	12.5%	804.38
Submersible bore-hole pumps	8" Submersible bore-hole pumps	73,000	7,300	33	2,565	7,415	2.0%	148.3	15.8%	15.0%	15.0%	12.8%	945.40
	10" Submersible bore-hole pumps	31,670	3,167	65	2,725	6,731	2.0%	134.6	14.3%	15.0%	15.0%	12.8%	858.26
	12" Submersible bore-hole pumps	15,160	1,516	121	3,114	6,855	2.0%	137.1	14.6%	15.0%	15.0%	12.8%	873.97
	Submersible bore-hole pumps larger than 12"	4,500	450	288	3,352	5,213	1.3%	69.3	7.4%	15.0%	15.0%	12.8%	664.66
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar	29,000	2,900	68	2,700	6,389	2.0%	127.8	13.6%	25.0%	50.0%	12.5%	798.66

	Pump type (and sub-categories)	EU Installed stock 2011	EU Annual sales	Hydraulic pump power	Annual operating hours	Annual energy consumption at EU level* 2011	Improvement potential	Potential savings at EU level 2011	Share of energy consumption	Product level energy savings from EPA	Existing market penetration of EPA	Potential energy savings to overall market from EPA Regulation	Actual savings Potential from EPA Regulation
		Units	Units	kW	Hours	GWh	%	GWh	%	%	%	%	GWh
	and/or 100 to 180 m3/hr)												
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	2,875	275	125	3,450	1,488	1.5%	22.3	2.4%	25.0%	50.0%	12.5%	185.98
Totals		16,365,705	2,017,058			51,859		939					6,217

* Calculated as: ((Hydraulic pump power * Annual operating hours) +20%) * EU Installed stock

Table 1-4: Contribution (in %) of each of the pumps covered in the screening analysis to the overall environmental impacts at EU level

	SPPS	SPPL	FPP	AP	APH	SPA	CCP	ESCC	ESCCI	ESOB	SBHP08	SBHP10	SBHP12	SBHP12+	VMSPS	VMSPL	Total
Total Energy (GER)	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
of which, electricity (in primary PJ)	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Water (process)	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Water (cooling)	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Waste, non-haz./ landfill	22,6%	3,8%	0,4%	0,6%	0,0%	0,0%	0,4%	1,3%	1,3%	13,1%	11,3%	10,4%	10,5%	8,0%	13,1%	3,0%	100%
Waste, hazardous/ incinerated	22,7%	3,8%	0,4%	0,8%	0,0%	0,0%	0,3%	1,3%	1,3%	13,1%	11,3%	10,3%	10,5%	8,0%	13,0%	3,0%	100%
Greenhouse Gases in GWP100	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Acidification, emissions	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Volatile Organic Compounds (VOC)	22,4%	3,8%	0,4%	0,6%	0,0%	0,0%	0,3%	1,3%	1,3%	13,2%	11,4%	10,4%	10,6%	8,0%	13,1%	3,1%	100%
Persistent Organic Pollutants (POP)	23,6%	3,8%	0,5%	0,7%	0,0%	0,1%	1,1%	1,3%	1,3%	12,7%	10,9%	10,3%	10,3%	7,7%	12,7%	3,0%	100%
Heavy Metals	22,4%	3,8%	0,4%	0,6%	0,0%	0,0%	0,3%	1,3%	1,3%	13,2%	11,4%	10,4%	10,6%	8,0%	13,1%	3,1%	100%
PAHs	23,3%	3,8%	0,5%	0,7%	0,0%	0,1%	0,6%	1,3%	1,3%	12,9%	11,2%	10,2%	10,4%	7,9%	12,9%	3,0%	100%
Particulate Matter (PM, dust)	23,8%	3,6%	0,8%	1,4%	0,0%	0,1%	1,3%	1,3%	1,3%	12,3%	10,5%	10,6%	10,2%	7,5%	12,4%	3,0%	100%
Heavy Metals	22,5%	3,8%	0,4%	0,6%	0,0%	0,0%	0,3%	1,3%	1,3%	13,2%	11,4%	10,4%	10,6%	8,0%	13,1%	3,1%	100%
Eutrophication	23,1%	3,8%	0,5%	0,8%	0,0%	0,1%	1,0%	1,3%	1,3%	12,8%	10,9%	10,5%	10,4%	7,8%	12,8%	3,0%	100%

* NOTE: Acronyms are presented on the next page

List of acronyms:

SPPS	Domestic with built in strainer up to 2.2 kW
SPPL	Domestic/commercial with built in strainer over 2.2 kW
FPP	Fountain and pond pumps to 1 kW
AP	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W
APH	Aquarium power head to 120W
SPA	Spa pumps for domestic & commercial spa's
CCP	Counter-Current Pumps
ESCC	End Suction Close Coupled from 150 kW to 1 MW
ESCCI	End Suction Close Coupled Inline from 150 kW to 1 MW
ESOB	End Suction Own Bearing from 150 kW to 1 MW
SBHP08	8" Submersible bore-hole pumps
SBHP10	10" Submersible bore-hole pumps
SBHP12	12" Submersible bore-hole pumps
SBHP12+	Submersible bore-hole pumps larger than 12"
VMSPS	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)
VMSPL	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)

As seen in Table 1-3 and Table 1-4, there are big differences in energy consumption and environmental impacts of the pumps in the scope. However, the definition of the product groups to be included in the preparatory study is clear and includes all these types of pumps. Therefore, all pump types in the definition of the preparatory study will be considered for analysis in the following Tasks:

- Swimming Pool pumps (integrated motor+pump)
  - Domestic with built in strainer up to 2.2 kW
  - Domestic/commercial with built in strainer over 2.2 kW
- Fountain and pond pumps to 1 kW
- Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W[2]
- Aquarium power head to 120W
- Spa pumps for domestic & commercial spa's
- Counter-Current Pumps
- End Suction Close Coupled from 150 kW to 1 MW
- End Suction Close Coupled Inline from 150 kW to 1 MW

[2] The upper limit of 120W was chosen as the vast majority of aquarium pumps are below this figure and the motors are not covered by other regulations

- End Suction Own Bearing from 150 kW to 1 MW
- 8" Submersible bore-hole pumps
- 10" Submersible bore-hole pumps
- 12" Submersible bore-hole pumps
- Submersible bore-hole pumps larger than 12"
- Vertical multi-stage pump (> 40 bar and > 180 m3/hr)
- Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)

1.4 Test Standards

This section presents the relevant test standards and procedures identified to date.

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.

The definition of product performance is restrictive in that it would not permit changes in physical design of the product, which is in contravention of Article 15 5(e) of the Ecodesign Directive: *'in principle, the setting of an ecodesign requirement shall not have the consequence of imposing proprietary technology on manufacturers.'* Given the large number of pump types in existence, this single standard (which corresponds to some of the 'Centrifugal – Single entry volute conventional' pumps in Figure 1-6), is inadequate as a means of classifying pump types, and it would certainly be inappropriate to use EN 733:1995 as the basis for any efficiency standards.

1.4.1 Clean water classification

Clean water is defined in Regulation 547/2012. Some EU Directives, such as the Abstraction of Surface Water for Drinking water (74/440/EC) clearly elaborate water quality standards while others like the Nitrate Directive (91/676/EEC) do not. Standards exist for drinking water quality, bathing waters excluding swimming pools and spas, and fishery waters but do not exist for groundwater and clean water in the scope study. There are different levels of pool water quality (pH, Cl content, etc) in different Member States in the EU. There is some standardisation work ongoing on the homogenisation of swimming pool definitions, sizes, pumps, etc, However, this work is not available at the time of writing.

1.4.2 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. They will test typically to ISO 9906:1999 Grade 2, which allows for a - 5% tolerance on quoted efficiency. (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. Verification of efficiency levels are clearly defined in Commission communication (2012/C 402/07) ECO design requirements for water pumps.

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

If an independent testing body is asked to measure the performance of a pump, it is in their interests to use a test method with a small uncertainty. This will not only give a more accurate indication of the true efficiency, but will also minimise the efficiency 'allowance' to take account of measurement uncertainties that needs to be given to the pump being tested (see Figure 1-17). Nonetheless, too much allowance given by independent testing body can lead to false efficacy claims, which could be used as loopholes by manufacturers.

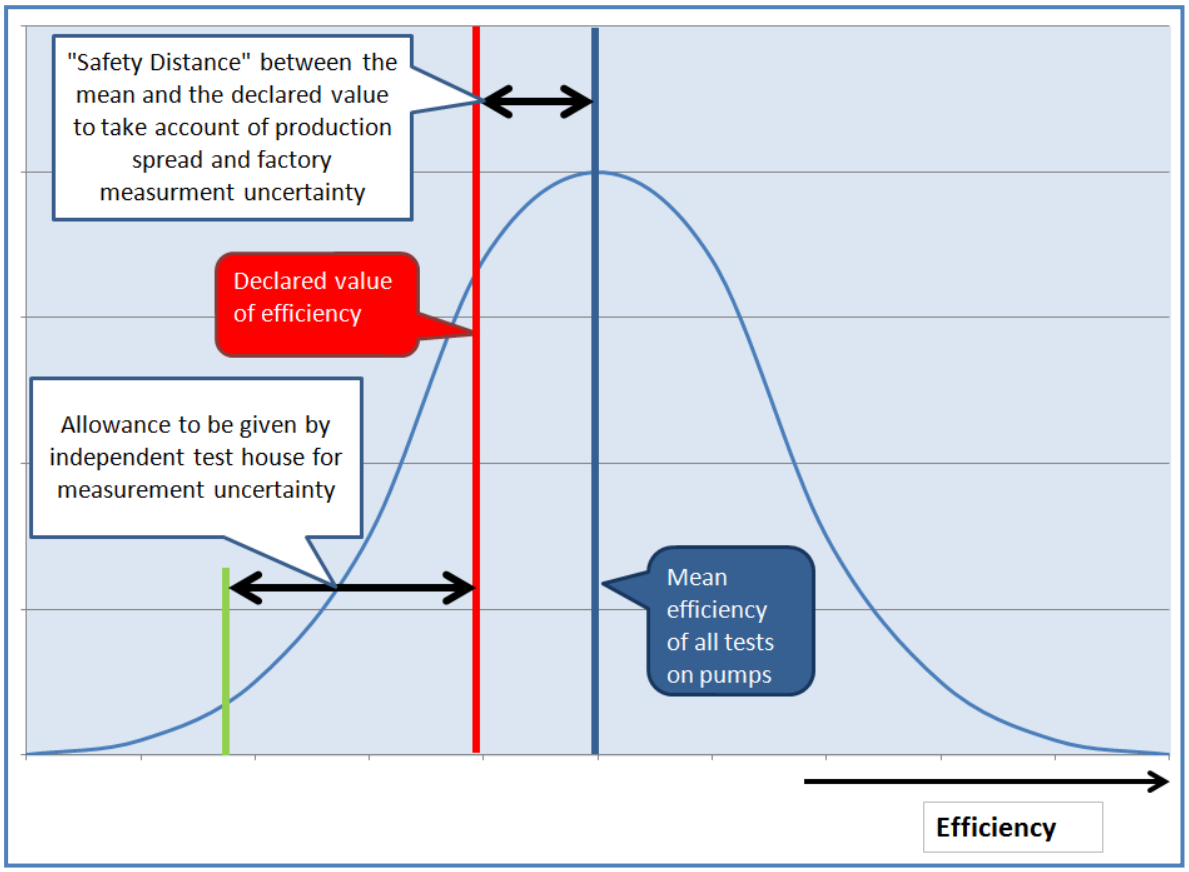


Figure 1-17: Testing and verification of pumps (only relevant to testing of products by an external test house)

1.4.3 Standards at European Union level

There are no energy related standards, which the consortium is aware of for any of the pump categories within ENER Lot 29. However, there are many technical standards governing the construction and design of these pumps, as presented in Table 1-5.

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 1-5: Non-energy related EU standards relevant for pumps within study scope

Reference	Title
EN 733:1995	End-suction centrifugal pumps, rating with 10 bar with bearing bracket. Nominal duty point, main dimensions, designation system
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.

Reference	Title
EN 13463-1	Non-electrical equipment for potentially explosive atmospheres. Basic method and requirements.
EN 60034	Rotating electrical machines
EN 60335-2-41	Household and similar electrical appliances – Safety – Part 2-41: Particular requirements for pumps
EN 60335-2-55	Household and similar electrical appliances - Safety - Part 2-55: Particular requirements for electrical appliances for use with aquariums and garden ponds

1.4.4 Standards at Member State level

Water quality standards and filtration practices change from Member State to Member State. This seriously affects the functionality of the pump. There are very different levels of pool water quality (pH, Cl content, etc) in different Member States, and standardisation work is currently being done in that sense. Some aspects of the whole pool water treatment (water quality, installation, equipment) will affect the choice of the pump size. Hence, regulating energy efficiency in swimming pool pumps without considering this issue could have negative effects on pool water quality.

In the UK there is the Publically Available Standard (PAS) 39 '*Management of public swimming pools. Water treatment systems, water treatment plant and heating and ventilation systems. Code of practice*'

In France there is Circulaire DGS/EA4 2008-65 '*La Direction Générale de la Santé à publié en février une circulaire relative aux dispositions réglementaires applicables aux piscines ouvertes au public, à l'utilisation des produits et procédés de traitement de l'eau (PHMB) et notamment à ceux mettant en oeuvre des lampes à rayonnement ultraviolet (UV) pour la déchloramination des eaux.*'

In Germany there is the DIN 19.643—'*treatment and disinfection of swimming pool and bathing tub water*' standard.

1.4.5 International Standards

Table 1-6 presents the international standards relevant for ENER Lot 29 pumps.

Table 1-6: International standards relevant for pumps within study scope

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 and 2.

Clean water pumps test typically to ISO 9906:1999 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.

Voluntary standards do exist for swimming pools in the US. For instance, the ANSI/APSP-11 2009, which is an standard for water quality in public pools and spas that was adopted in 2009 by the American National Standards Institute (ANSI).

1.4.6 Conclusions on test standards

A. Large Water Pumps

For large water pumps, the project team will adopt the same ISO 9906 test standard as used in the TREN Lot 11 study. This defines how pump performance and hence efficiency is measured. In addition, the project team will use the MEPS calculation methodology as described in the TREN ENER Lot 11 Regulation (currently at working draft stage). However, it should be noted that these TREN Lot11 Ecodesign Regulations are based on full diameter impellers, and will not directly influence the optimum selection of impeller diameter.

B. Swimming pool pumps

From initial investigation, it appears that there is insufficient consistency in test standards vary between EU Member States, which is a major problem that needs to be resolved. There are no performance tests standards that apply specifically to swimming pool pumps, and so the project team suggests the use of ISO 9906. The energy performance methodology for End Suction Close Coupled pumps in the draft Ecodesign Pump Regulation could be applied, although the actual MEPS (Minimum Energy Performance Standard) levels will obviously be different because the TREN Lot 11 pumps do not include the motor or filter.

Some pumpsets use an alternative motor, such as one fed by an inverter, but the project team will look to the ENER Lot 30 study for performance data on these products.

Further, pool pump safety is a critical issue, and so there are many relevant standards, especially relating to the design of the suction inlet.

Suction Entrapment poses severe risks from:

- Hair entrapment if the flow rating of the cover is too small for the pump or pumps.
- Limb entrapment where a limb is sucked into an opening, for instance if the cover flow rating is insufficient for the pump, or the drain cover missing or broken.
- Body entrapment where the body is sucked against the drain cover.
- Disembowelment where a person sits on or against the suction. This may occur when a drain cover is missing, loose, cracked, or not properly secured.

- Mechanical entrapment when a finger, toe or item of jewellery is caught in the suction. This hazard is present when the drain cover is missing, broken, loose, cracked, or not properly serviced.

EN 13451-3: '*Swimming pool equipment — Part 3: Additional specific safety requirements and test methods for inlets and outlets and water/air based water leisure features*', provides guidance on these measures.

The US Virginia Graeme Baker pool and Spa Safety Act imposes specific requirements on owners and operators of swimming pools[3].

ASME/ANSI A112.19.17 describes safety equipment that might include Safety vacuum Release, suction limiting, automatic shut-off Systems for use on residential and commercial swimming pools, Spas, Hot Tubs and Paddling pools.

ANSI/ASME A112.19.8 specifies anti-entrapment covers. Pools and spas should have a minimum of two drains to reduce maximum suction. ANSI/IAF-7 gives detailed information on suction design.

The pool installations shall comply the applicable existing standard HD 60 364-7-702.

Table 1-7 presents some relevant standards on performance and safety for swimming pools and their components.

Table 1-7: Preliminary list of available standards applying to swimming pool pumps

Standard	Scope
A112.19.8-2007	Suction Fittings for use in Swimming Pools, Wading Pools, Spas, Hot Tubs, and Whirlpool Bathtub Appliances
ASTM F1346	Standard Performance Specification for Safety Covers and Labelling Requirements for All Covers for Swimming Pools, Spas and Hot Tubs
AS5102 – 2009	Performance of Household Electrical Appliance – Swimming Pool Pumps-Units. Part1: Energy consumption and performance Part2: Energy Labelling and minimum energy performance standard requirements
CSA C222 No 68-92	Motor-Operated Appliances (Household and Commercial)
CSA C222 No 108-01	Liquid Pumps
NSF/ANSI 50	Circulation System Components and Related Materials for Swimming Pools, Spas/Hot Tubs
UL 778	Motor-Operated Water Pumps
UL 1081	Swimming Pool Pumps, Filters, and Chlorinators
UL 1241	Junction Boxes for Swimming Pool Luminaires
UL Subject 379	Outline of Investigation for Transformers for Fountain, Swimming Pool, and Spa Luminaires

[3] www.cpsc.gov

Standard	Scope
UL Subject 676A	Outline of Investigation for Potting Compounds for Swimming Pool, Fountain, and Spa Equipment
UL 2452	Outline of Investigation for Electric Swimming Pool and Spa Cover Operators
EN 13451-1 part 1:	Pool with public use / swimming pool equipment: general safety requirements and test methods
EN 13451-3 part 3:	Pool with public use / additional specific safety requirements and test methods for pool fittings for water treatment purposes
HD 60 364-7-702	Low-voltage electrical installations - Requirements for special installations or locations –Swimming pools and fountains

C. AQUARIUM PUMPS

For aquarium pumps, there is no specific standard. To this pump type, the following standards will also apply:

- EN 60335-2-41: Household and similar electrical appliances – Safety – Part 2-41: Particular requirements for pumps
- EN 60335-2-55: Household and similar electrical appliances - Safety - Part 2-55: Particular requirements for electrical appliances for use with aquariums and garden ponds
- UL 1018: Standard for Safety for Electric Aquarium Equipment.

D. FOUNTAIN & POND PUMPS

For the fountain pumps, there is no specific standard. To this pump type, the following standards will also apply:

- EN 60335-2-41: Household and similar electrical appliances – Safety – Part 2-41: Particular requirements for pumps
- EN 60335-2-55: Household and similar electrical appliances - Safety - Part 2-55: Particular requirements for electrical appliances for use with aquariums and garden ponds
- UL 788:Motor operated Water Pumps
- CSA C22.2 No. 108-1 Liquid Pumps Fountain pumps will have integral filters to protect the hydraulics, and so a protocol on how or if these are included in the test methodology will need to be established.

1.5 Existing Legislation

1.5.1 Legislation and Agreements at European Union Level

1.5.1.1 *Health and Safety*

ISO EN 809:1998: 'Pumps and pump units for liquids. Common safety requirements' establishes safety requirements for the construction, assembly, erection, operation and servicing of:

- Rotodynamic pumps
- Rotary positive displacement pumps
- Reciprocating displacement pumps
- Pump units

The Pressure Equipment Directive (PED) 1997/23/EC applies to the design, manufacture and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure PS greater than 0.5 bars. The pumps in the scope of this study are exempt from the PED as they are covered under the machinery directive (EN809).

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

The WEEE Directive implements the principle of 'extended producer responsibility': 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 lifecycle of EEE, especially those dealing with waste 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.

The product must meet the following three criteria to be affected by the WEEE Directive:

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

It must be one of the categories of EEE / WEEE specified in Annex A1 of the WEEE Directive[4].

Even if a pump is sold without a motor, it will usually be powered by an electric motor. The power range of the pumps considered in this study is very broad, from small aquarium pumps to large water pumps. Aquarium and pond pumps are household appliances that meet the three criteria for WEEE directive, although they are not explicitly mentioned in the regulation. It is recommended that future revisions of the WEEE Directive Annex A1 include aquarium and pond pumps.

Swimming pool pumps, counter-current pumps and spa pumps could be considered household appliances, if they are meant to be used in domestic installations. However, these products usually require installation and therefore are not likely to be part of the Municipal Solid Waste (MSW) stream, but recovered and disposed by professional installers. However, there is a growing market for smaller domestic above ground pools, and these pumps for these installations will most likely be handled by householders. Therefore it is recommended that these are also included in future revisions of the WEEE Directive Annex A1.

The rest of larger pumps (borehole, vertical submersible and end suction pumps) are not household appliances and therefore it is clear that the WEEE Directive does not affect them.

1.5.1.1 *RoHS 2 (Restriction of Hazardous Substance Directive) Directive 2011/65/EU*

The RoHS Directive was firstly implement in 2006, restricting the use of certain Hazardous Substances in electrical and electronic equipment. It bans the putting on the EU market of new Electrical and Electronic Equipment (EEE) containing more than the permitted levels of certain materials[5].

The RoHS Directive covers the same products as the WEEE Directive. The control-systems and printed circuit-boards of aquarium and pond pumps covered by this Directive need to be accounted for in the ENER Lot 29 preparatory study. Other pumps tend to be controlled and driven by external units, which are considered under separate lots.

1.5.2 Third Country 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 29 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

[4] 1.Large household appliances; 2.Small household appliances; 3.IT & telecommunications equipment; 4.Consumer equipment; 5.Lighting equipment; 6.Electrical and electronic tools; 7.Toys leisure and sports equipment; 8.Medical devices; 9.Monitoring and control instruments; 10.Automatic dispensers.

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

demanding for instance larger clearances. It is understood that these standards do not impact on the design of water pumps for the European market.

1.6 Product performance assessment

1.6.1 Boundaries of the system

The boundaries for each pump category are decided on a product-by-product basis. A fundamental consideration is whether the product includes or excludes the motor.

To be consistent with the Ecodesign Directive (2009/125/EC), the approach adopted is as follows:

- Where the motor can be removed and tested separately, the motor and pump shall be considered as separate products.
- Where the motor cannot be easily removed from the assembly, it shall be considered as an integral product, and the combined pump+motor combination shall be regulated as a product.
- Exceptions may be made for products that have a motor that can be separated, but where the motor is not subject to existing regulations (ref 2009/125/EC) or possible future regulations as part of Ecodesign ENER Lot 30.

Pump performance data and subsequent analysis considers the pump shaft power only, (known sometimes as P2). It is only converted into electrical power (P1) in order to estimate the environmental impact of the pumps. This is done by assuming that the motor is on the IE3 efficiency class border, where $P1 = P2 / \eta_{mot}$, where η_{mot} is the assumed motor efficiency (at full load).

However, some pumps considered in this study, namely the aquarium, pond and swimming pool pumps, have integrated motors. Therefore, it may be more appropriate to regulate these pumps with the pump, motor and controls together. This approach has been successfully implemented in the past with heating system circulator pumps which resulted in the voluntary circulator scheme (EC) No 641/2009.

1.6.2 The Extended Product Approach

- **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)[6] it also takes into consideration efficiency related factors from load profiles and control methods.

Extended Products (EP): consists of physical components

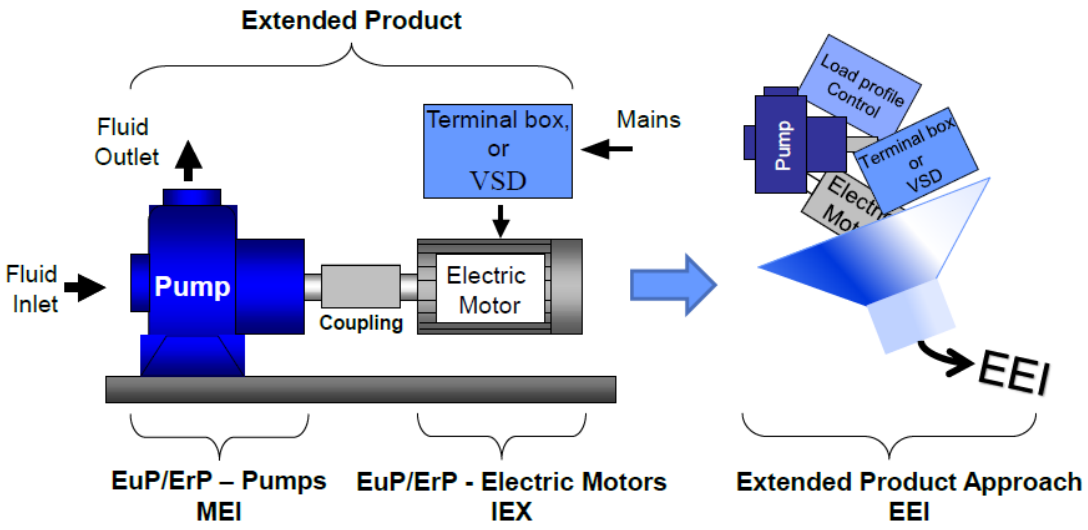


Figure 1-18 Definition of Extended Product Approach – (Source Europump)

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[7].

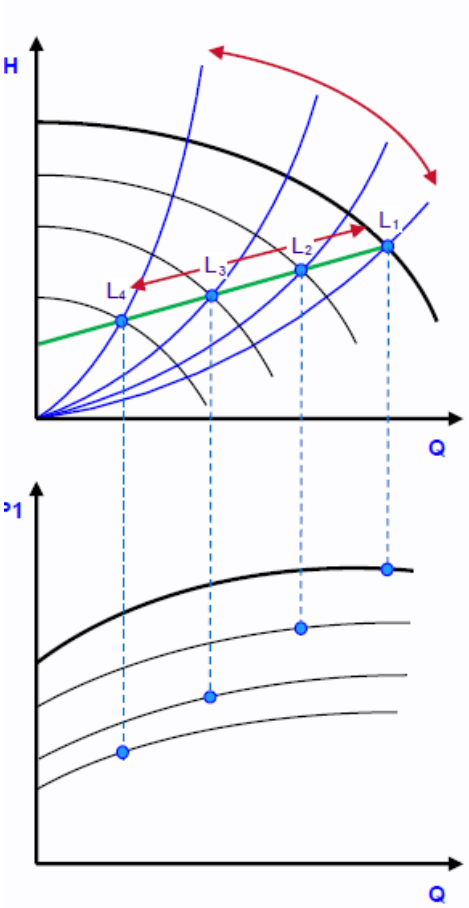
- **Extended Product Approach System Types**

The EPA can be used with both closed loop systems, such as swimming pool pump systems, and open loop systems, such as many clean water transfer 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 in 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.

[6] 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.

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

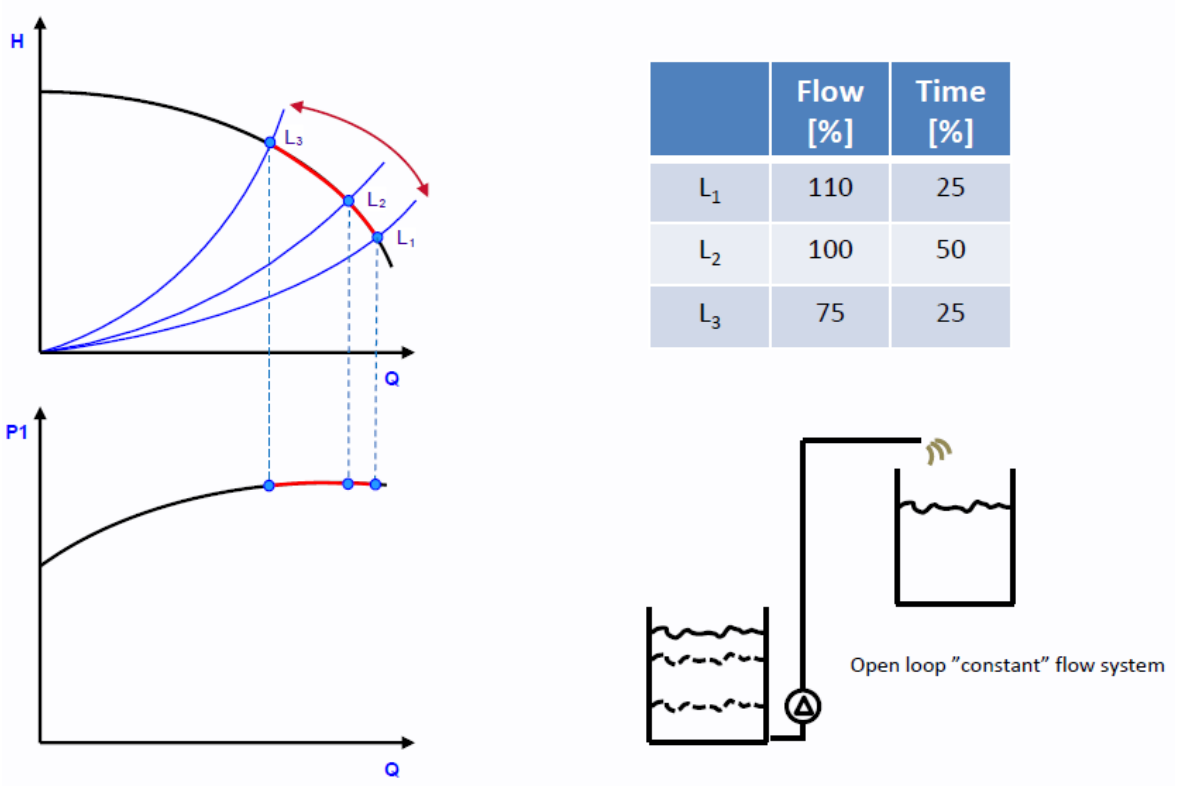


	Flow [%]	Time [%]
L_1	100	6
L_2	75	15
L_3	50	35
L_4	25	44

Figure 1-19 Load profile for a typical variable flow system such as found in HVAC systems (Source Europump)

Some of the larger clean water pumps could be used in a variable slow system. There are some domestic swimming pool pumps that are also used with variable flow systems but these are the exception rather than the norm.

In constant flow system the change of flow can be due to a change in the static head, such as occurs when filters become blocked. An example of load profile for a constant flow system is shown in Figure 1-20



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

Figure 1-20: Load profile for a typical constant flow system

Some of the pumps considered within the scope of this study, such as swimming pool pumps, aquarium and pond pumps, are typically used in constant flow applications. As such they potentially could have load profiles similar to that shown in Figure 1-20. Each individual pump type requires its own load profile.

1.7 Conclusions

Task 1 presents an overview of the pumps that are included within this study. These pumps vary in scale from very large clean water pumps to small pumps used in swimming pools and gardens. Although aquarium blowers may fit into the very broadest interpretation of the scope of this study, they were excluded after an initial screening process due to the fact that they pump air rather than water. The final list of pumps included in the study are:

- Domestic swimming pool pumps with built in strainer up to 2.2 kW
- Domestic/commercial swimming pool pumps with built in strainer over 2.2 kW
- Fountain and pond pumps to 1 kW
- Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W
- Aquarium power head to 120W
- Spa pumps for domestic & commercial spa's

- Counter-Current Pumps
- ES Close Coupled from 150 kW to 1 MW
- ES Close Coupled Inline from 150 kW to 1 MW
- ES Own Bearing from 150 kW to 1 MW
- 8" Submersible bore-hole pumps
- 10" Submersible bore-hole pumps
- 12" Submersible bore-hole pumps
- Submersible bore-hole pumps larger than 12"
- Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)
- Vertical multi-stage pump (>40 bar and/or >180 m3/hr)

The primary functional parameters of the pumps are defined as 'Rated flow', 'Head' and 'Fluid properties'. The fluid properties will be less relevant to the large clean water and swimming pool pumps, however further investigations are required as to what the appropriate fluid properties would be for fountain and pond pumps which are likely to involve an element of solids handling.

In common with other clean water pumps, it is recommended that the larger pumps are tested to ISO 9906:1999 Grade 2.

Although there are a currently a number of standards at EU level relating to the safety requirements of pumps, no energy related standards were found. Regarding legislation, only the electronic parts such as printed circuit boards are affected by the RoHS Directive, and small household pumps such as aquarium and pond pumps are affected by the WEEE Directive.

The boundaries of the systems are defined depending on how the pump and motor are manufactured. Where the motor can be removed and tested separately, the pump and motor are considered as separate products. Where they cannot be easily separated they shall be considered as an integral product and should be regulated as such. Exceptions may be made for products that have a motor that can be separated and where the motor is not subject to existing regulations.

There may be the opportunity to regulate all the pumps in the study using the extended product approach.

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

This section is included for reference, and is an extract from the Study on Improving the Energy Efficiency of Pumps[8]

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

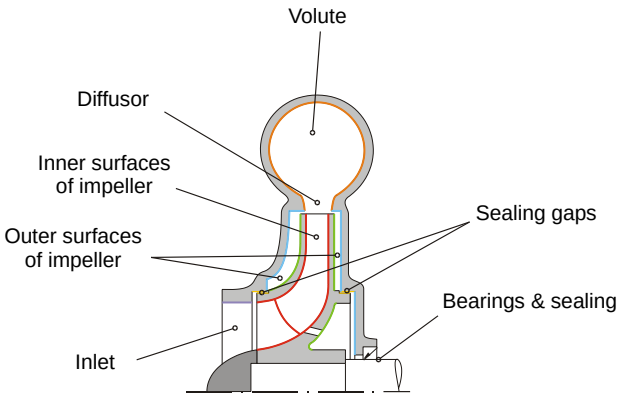
The specific speeds of the considered pumps covered the range from ns = 10 min-1 up to ns = 100 min-1 (corresponding to values from 520 min-1 up to 5200 min-1 in US-units) and represents the typical field of application of standard centrifugal pumps. By the aid of the similarity laws it is possible to 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 A1 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

[8] ETSU, AEAT PLC (2001) Study on Improving the Energy Efficiency of Pumps. Prepared for the European Commission

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)

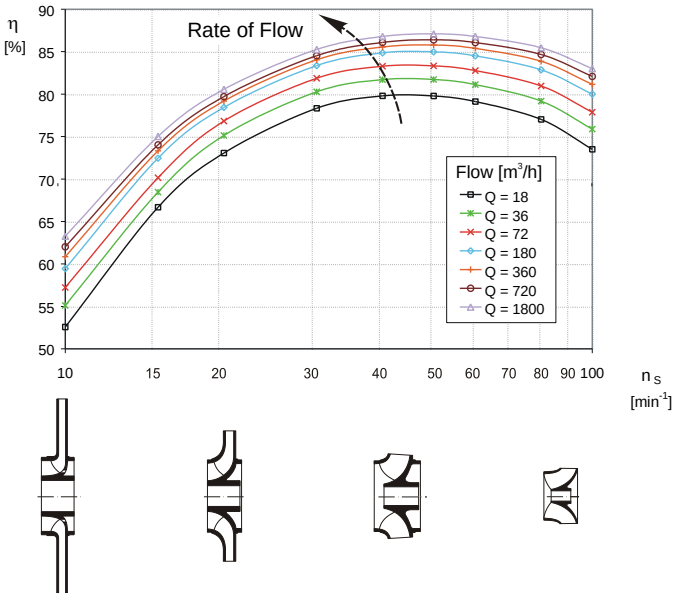
- mechanical losses

Figure 1-21: 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 1-20 (where n is the speed of rotation, Q the rate of flow and H the pump head).



Specific speed:

$$n_s = n \cdot \frac{Q^{1/2}}{H^{3/4}}$$

$n_s\,[\mathrm{min}^{-1}]$, $n\,[\mathrm{min}^{-1}]$, $Q\,[\frac{\mathrm{m}^3}{s}]$, $H\,[\mathrm{m}]$

$$n_{s,US-units} = 51.64 \cdot n_s$$

In the following:

$n = 1450\,\mathrm{min}^{-1}$
$Q = 180\,m^3/h$

Figure 1-22: The influence of rate of flow

As shown in Figure 1-20 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 A2 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 (Figure 1-20) were generated for operating conditions characterized by a flow rate of 180 m3/h and a speed of rotation n = 1450 min-1.

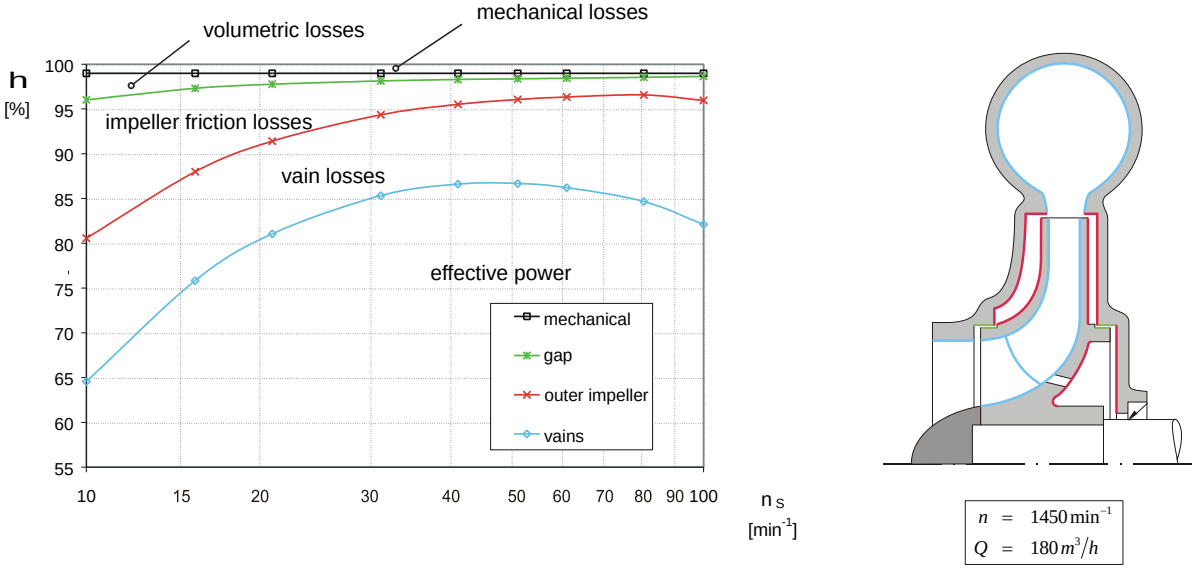


Figure 1-23: Partial losses within a centrifugal pump

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

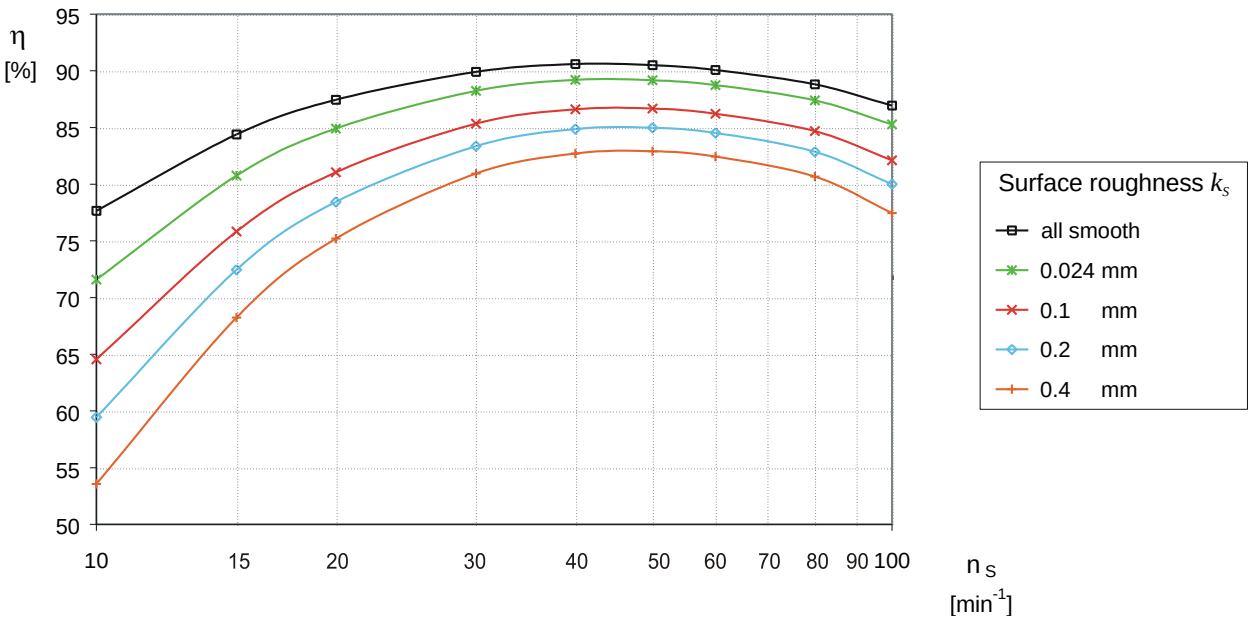


Figure 1-24: The influence of surface roughness

Figure 1-20 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.q. 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 1-20 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.

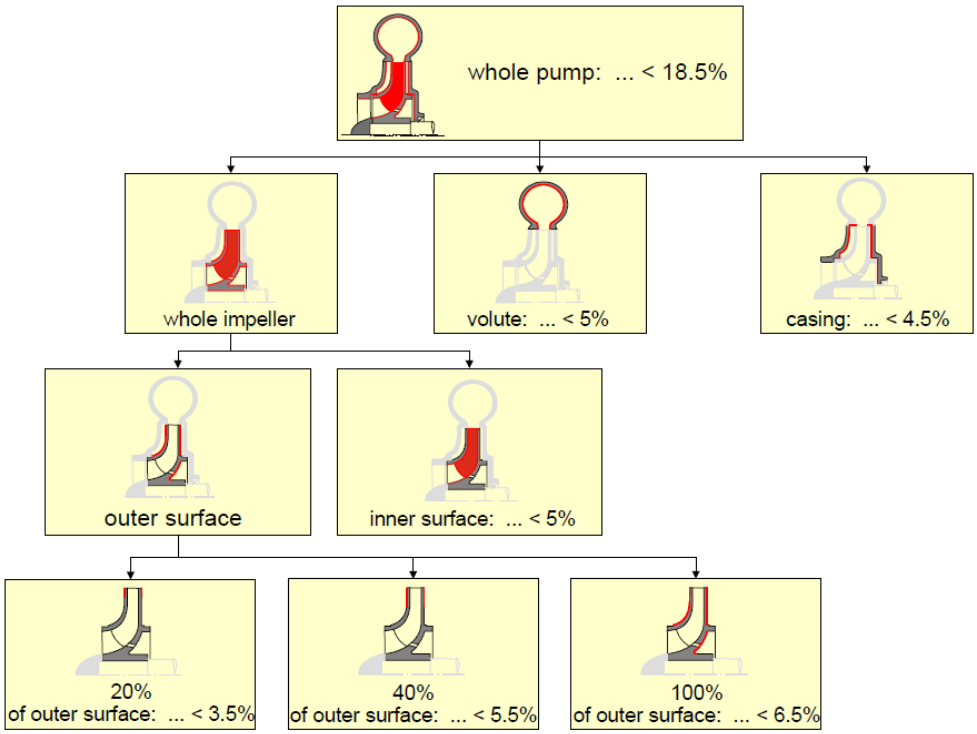


Figure 1-25: Maximum improvement of efficiency for several smoothing steps (estimated by theoretical calculations for medium size pump of 180 m3/h)

Annex 2: Extract from the ENER Lot 11 Preparatory study - The 'House of Efficiency' scheme

This section is included for reference, and is an extract from the ENER Lot11 Preparatory study report, section 8.1.12.3).

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:

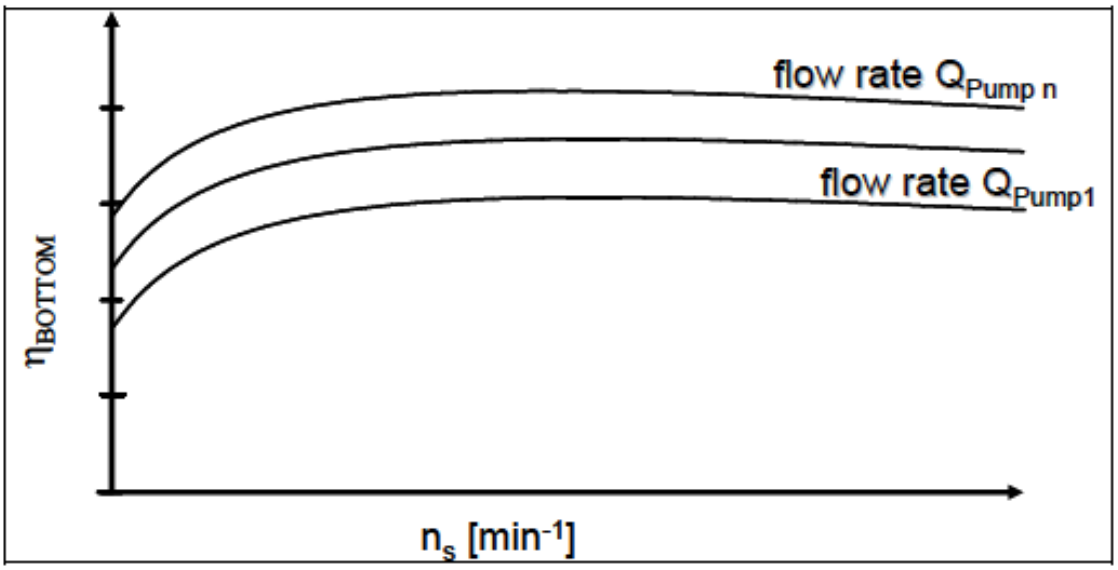


Figure 1-26: Bottom lines for different geometrical pump sizes (defined for nominal flow rate Qn > Q1) within one pump type

That leads to bottom lines specific to each pump type at a certain flow (see Figure 1-20) which have to be defined, based on statistical data.

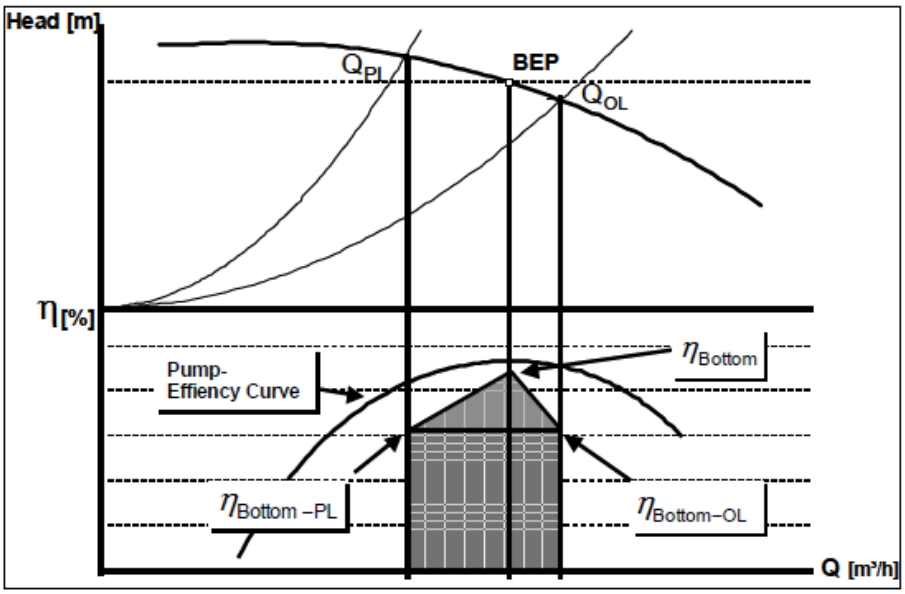


Figure 1-27: 'House of Efficiency' - explanatory representation of the scheme in a η (Q): flow-Plot

In Figure 1-20 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.



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

ENER Lot 29 – Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under ENER Lot 11) – Task 2: Economic and Market Analysis

Final report to the European Commission, DG ENER
28 March 2014



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Task 2: Economic and market analysis

The purpose of this task is to present the economic and market analysis of the products covered in the scope of ENER Lot 29 preparatory study on pumps for private and public swimming pools, ponds, fountains and aquariums, and clean water pumps larger than those regulated under ENER Lot 11. A clear picture of the product sales and installed stock available on the EU market is provided together with growth and replacement rate forecasts, product trends, and economic data.

There are four main objectives of this chapter, which include:

1. To place the ENER Lot 29 product group within the total context of EU industry and trade.
2. To provide market (sales and installed stock) and energy consumption inputs for the assessment of EU-wide environmental impacts of the ENER Lot 29 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 in Tasks 5 and 7.

From Task 1 of this study it could be seen that clean water pumps for swimming pools, ponds, fountains and aquariums cover a broad range of applications and power capacities.

As the screening exercise and project scoping is presented in Task 1, this report sets out the structure for gathering further information, as well as providing stakeholders an opportunity to review and comment on the data collected so far.

2.1 Generic economic data

The PRODCOM statistics have the advantage of being the official European Union (EU) source. It is based on products whose definitions are standardised across the European Union thus guaranteeing comparability between Member States. It is used and referenced in other EU policy documents regarding trade and economic policy.

However, the PRODCOM statistics have some limitations, some data points are unknown or confidential, and therefore not available. As shown in Task 1 of the present preparatory study, PRODCOM classifies numerous water pump products within the category NACE 28.13:

- 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
- 28.29.12.30 Machinery and apparatus for filtering or purifying water

These categories include a wide range of pump products, and as seen in Task 1, these product groups do not match exactly the classification proposed for pumps in ENER Lot 29. Hence, PRODCOM can only serve as a broad overview of the market size. Figure 2-1 to Figure 2-4 show the market volume and value derived from PRODCOM[1,2]. Figure 2-5 also shows the evolution of sales from 2008 to 2010 in the EU-27.

[1] Available at: epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database. Accessed on 04/06/2012

[2] Apparent consumption = Production + Imports – Exports

For some Member States, data are not provided either due to confidentiality or to lack of availability

Figure 2-1: Market size of rotodynamic pumps and machinery for filtering water in the EU-27 in 2010, PRODCOM (in number of units)

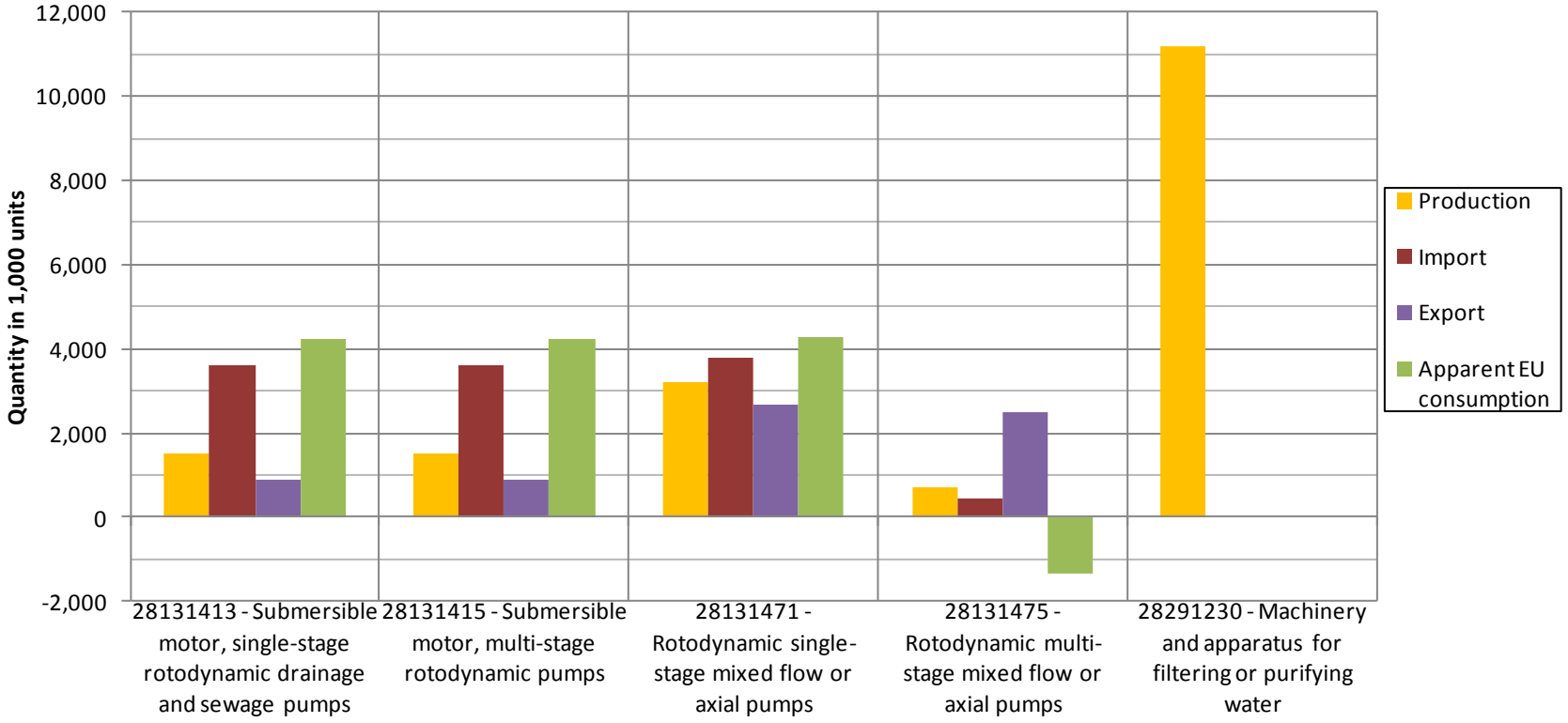


Figure 2-2: Market size of centrifugal pumps in the EU-27 in 2010, PRODCOM (in number of units)

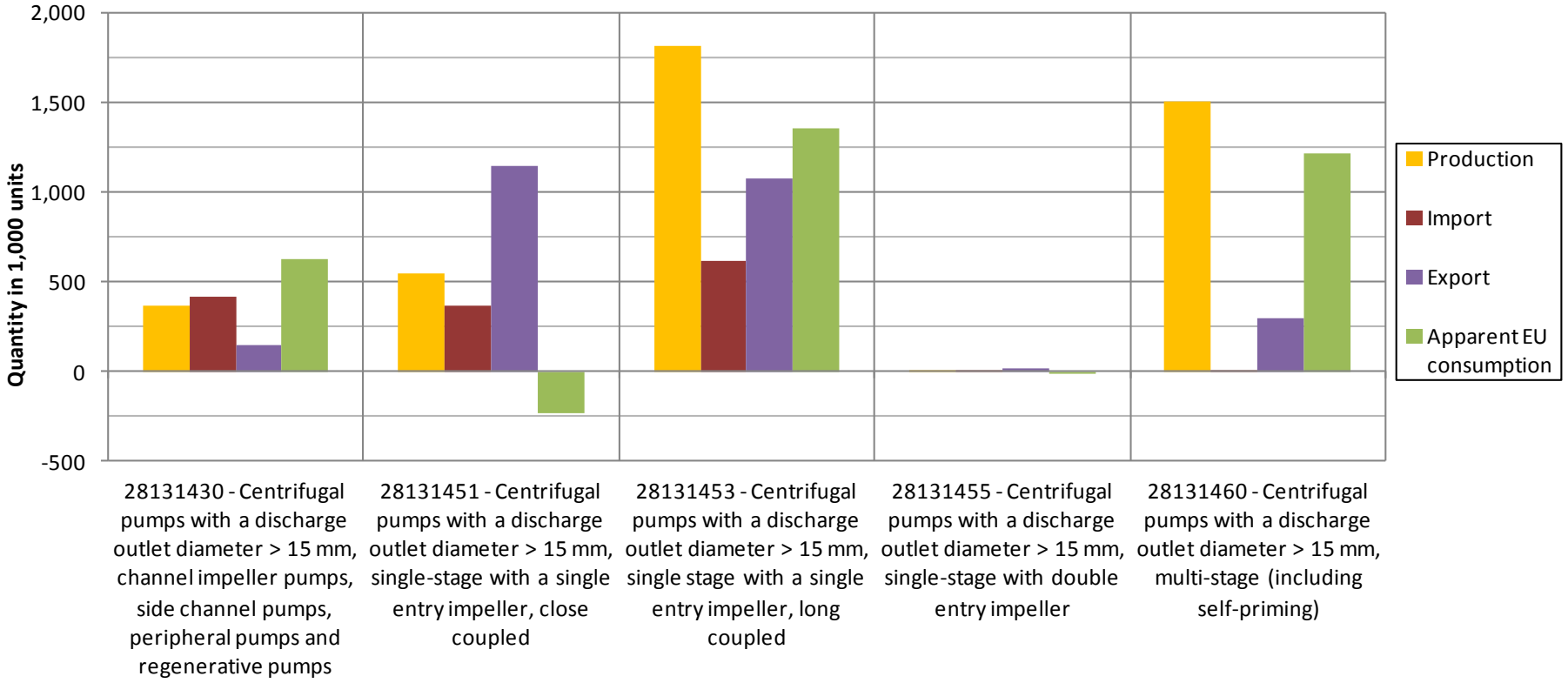


Figure 2-3: Market value rotodynamic pumps in the EU-27 in 2010, PRODCOM (in number of units)

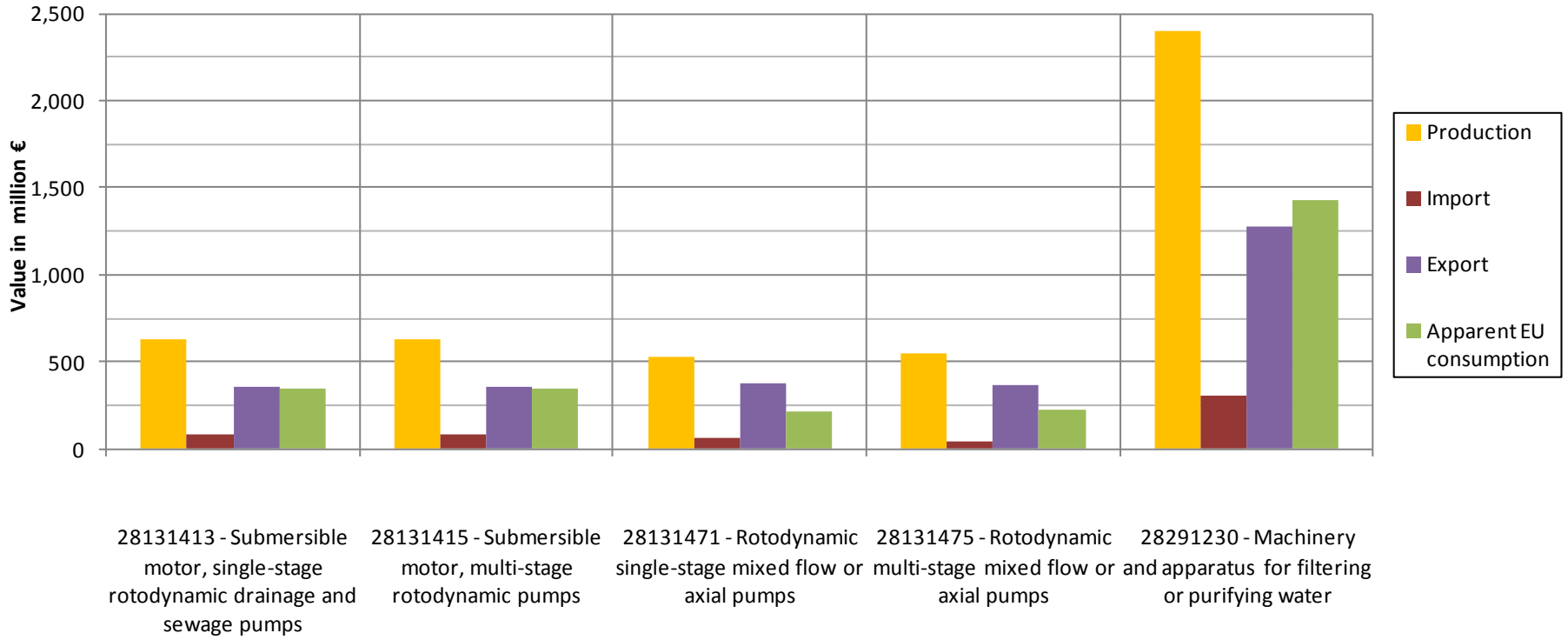


Figure 2-4: Market value of centrifugal pumps in the EU-27 in 2010, PRODCOM (in number of units)

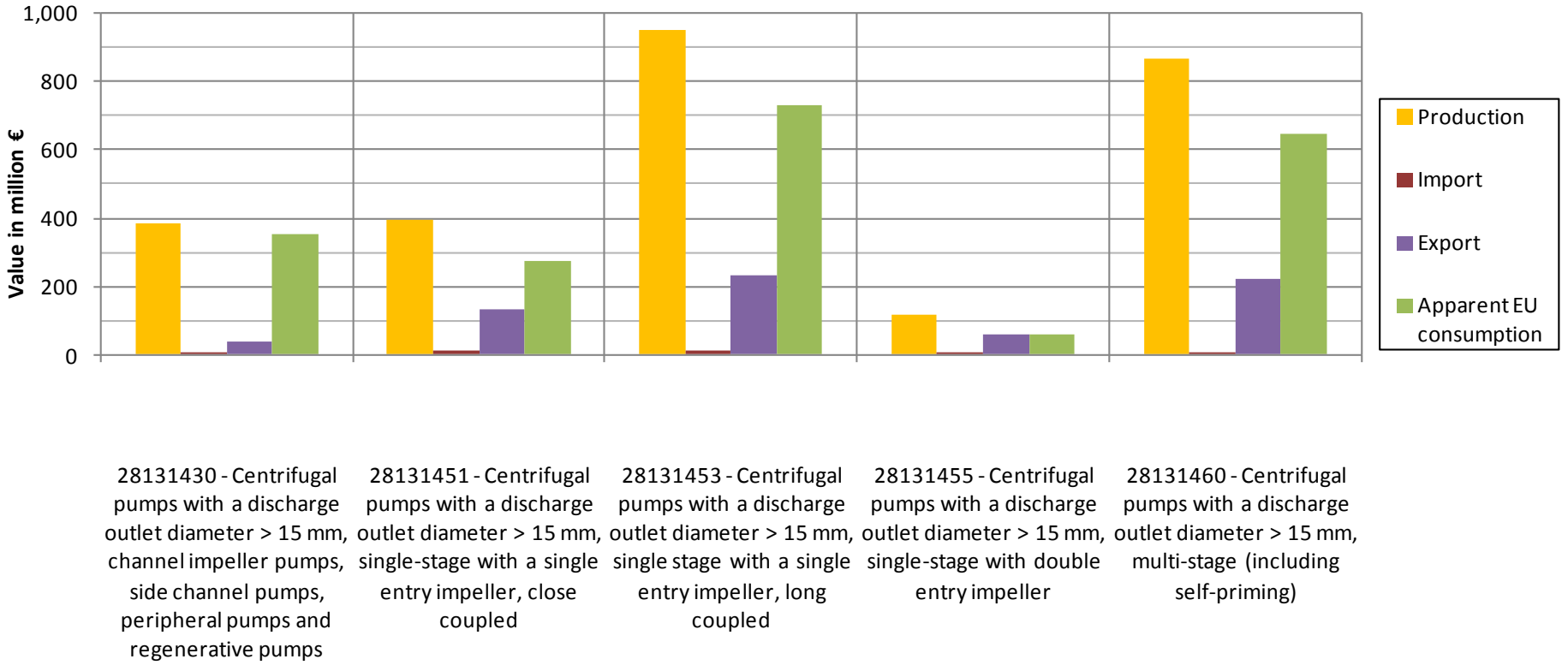
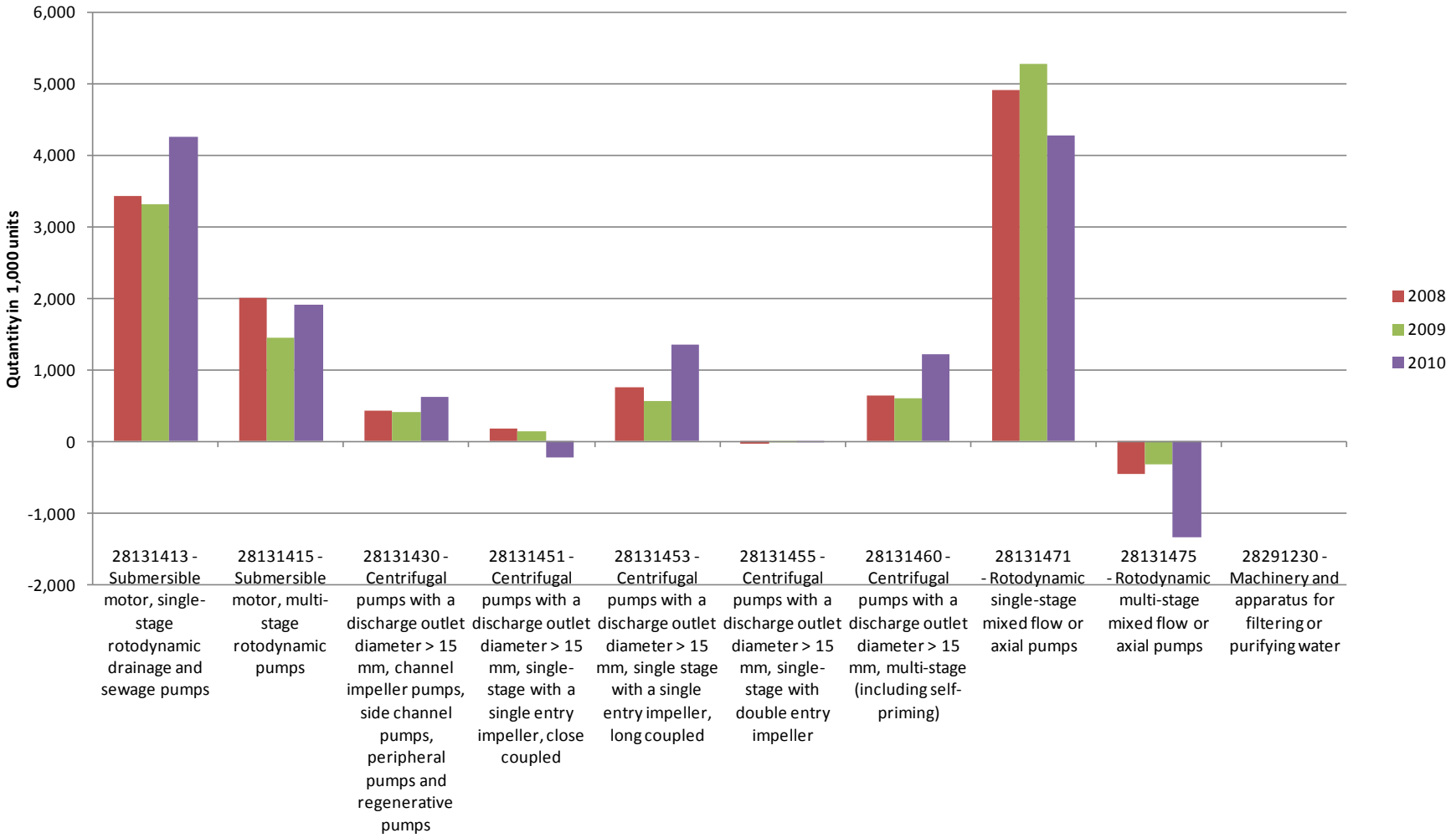


Figure 2-5: Apparent consumption of water pumps in the EU-27 from 2008 to 2010, PRODCOM (in number of units)



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 water pumps covered in ENER Lot 29 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 industry.

The figures provided by Europump Association 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 is about 21 %. However, the countries represent only approximately 7.6 % of the pump marked. When Europump preformed the data collection member companies had the total European market in view and reported accordingly.

2.2.1 Sales data

Table 2—1 provides market data for the water pumps covered in ENER Lot 29 following Europump classification sold in 2005 and in 2011.

Table 2—1: Estimated sales per year of pumps in the EU-27

Pump type (and sub-categories)		Estimate of sales per year (units)	
		2005[3]	2011[4]
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	374,060	480,000
	Domestic/commercial with built in strainer over 2.2 kW	8,970	11,500
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	159,760	205,000
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	896,170	1,150,000
	Aquarium power head to 120W	38,970	50,000
	Spa pumps for domestic & commercial spa's	3,280	4,200
	Counter-Current Pumps	77,930	100,000
End Suction water pumps (over 150kW-P2)	ES Close Coupled from 150 kW to 1 MW	80	100
	ES Close Coupled Inline from 150 kW to 1 MW	80	100

[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.

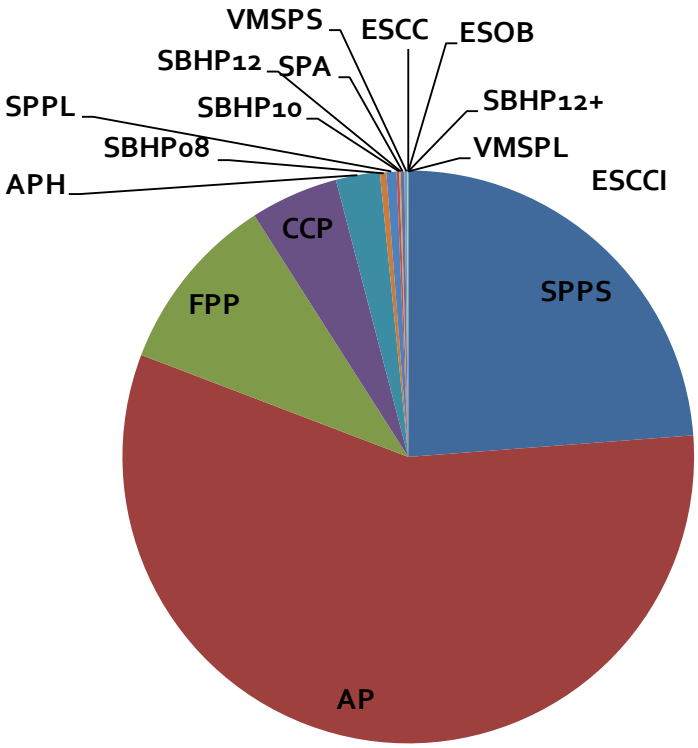
Europump is the European Association of Pump Manufacturers. It represents 18 National Associations in 15 EU Member States, Turkey, Russia & Switzerland. Europump members represent more than 450 companies with a collective production worth more than €10 billion and employing 100 000 people in Europe.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

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

Pump type (and sub-categories)		Estimate of sales per year (units)	
		2005[3]	2011[4]
	ES Own Bearing from 150 kW to 1 MW	430	550
Submersible bore-hole pumps	8" Submersible bore-hole pumps	5,738	7,300
	10" Submersible bore-hole pumps	2,489	3,167
	12" Submersible bore-hole pumps	1,192	1,516
	Submersible bore-hole pumps larger than 12"	360	450
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)	2,260	2,900
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	220	275

Figure 2-6 presents the share of different pump types in the overall EU sales of ENER Lot 29 pumps in 2011. *"Aquarium pumps"* dominates the overall pump market (market share of 56%) followed by *"swimming pool pumps"* (market share of 23%), *"fountain and pond pumps"* (market share of 10%) and counter-current pumps (5%). Other remaining pumps account for 2% or less of the overall market of ENER Lot 29 pumps in EU in 2011.

Figure 2-6: Sales distribution of ENER Lot 29 pumps in EU in 2011



SPPS	Domestic with built in strainer up to 2.2 kW
SPPL	Domestic/commercial with built in strainer over 2.2 kW
FPP	Fountain and pond pumps to 1 kW
AP	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W
APH	Aquarium power head to 120W
SPA	Spa pumps for domestic & commercial spa's
CCP	Counter-Current Pumps
ESCC	ES Close Coupled from 150 kW to 1 MW
ESCCI	ES Close Coupled Inline from 150 kW to 1 MW
ESOB	ES Own Bearing from 150 kW to 1 MW
SBHP08	8" Submersible bore-hole pumps
SBHP10	10" Submersible bore-hole pumps
SBHP12	12" Submersible bore-hole pumps
SBHP12+	Submersible bore-hole pumps larger than 12"
VMSPS	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)
VMSPL	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)

2.2.2 Stock data

Stock is the installed base of existing appliances, i.e. the number of units in operation in EU. 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 as shown in Table 2—2.

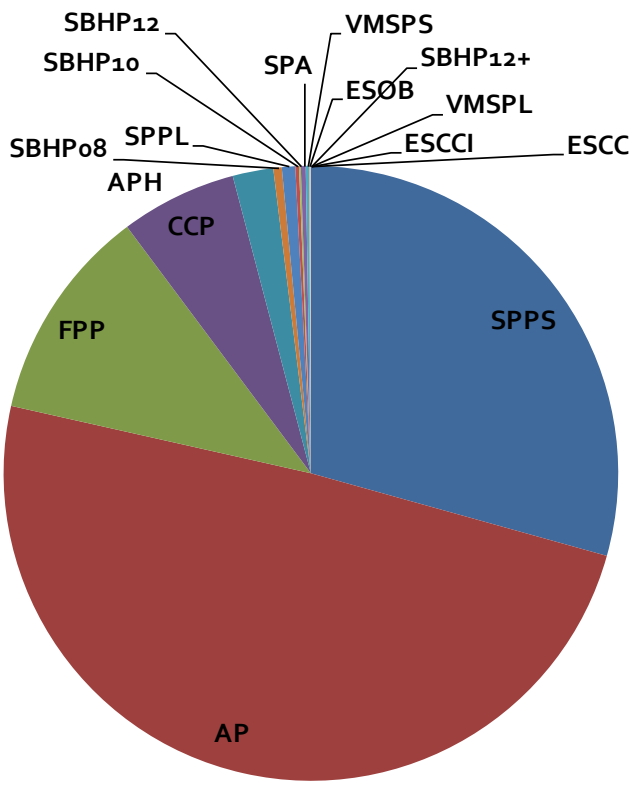
Table 2—2: Estimated installed stock of pumps in the EU-27

Pump type (and sub-categories)		Estimate of installed stock (units)	
		2005[5]	2011
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	4,241,990	4,800,000
	Domestic/commercial with built in strainer over 2.2 kW	101,640	115,000
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	1,630,520	1,845,000
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	7,114,170	8,050,000
	Aquarium power head to 120W	309,320	350,000
	Spa pumps for domestic & commercial spa's	37,120	42,000
	Counter-Current Pumps	883,750	1,000,000
End Suction water pumps (over 150kW-P2)	ES Close Coupled from 150 kW to 1 MW	890	1,000
	ES Close Coupled Inline from 150 kW to 1 MW	890	1,000
	ES Own Bearing from 150 kW to 1 MW	4,870	5,500
Submersible bore-hole pumps	8" Submersible bore-hole pumps	64,532	73,000
	10" Submersible bore-hole pumps	27,996	31,670
	12" Submersible bore-hole pumps	13,401	15,160
	Submersible bore-hole pumps larger than 12"	3,980	4,500
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)	25,630	29,000
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	2,550	2,875

Figure 2-7 presents the share of different pump types in the overall EU installed stock of ENER Lot 29 pumps in 2011. "*Aquarium pumps"* dominates the overall installed stock of pumps (market share of around 48%) in 2011 followed by "*swimming pool pumps*" (29%), "*fountain and pond pumps"* (market share of 11%) and "*counter-current pumps*" (6%). Other remaining pumps account for 2% or less of the overall installed stock of ENER Lot 29 pumps in EU in 2011.

[5] 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

Figure 2-7: Stock distribution of ENER Lot 29 pumps in EU in 2011



SPPS	Domestic with built in strainer up to 2.2 kW
SPPL	Domestic/commercial with built in strainer over 2.2 kW
FPP	Fountain and pond pumps to 1 kW
AP	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W
APH	Aquarium power head to 120W
SPA	Spa pumps for domestic & commercial spa's
CCP	Counter-Current Pumps
ESCC	ES Close Coupled from 150 kW to 1 MW
ESCCI	ES Close Coupled Inline from 150 kW to 1 MW
ESOB	ES Own Bearing from 150 kW to 1 MW
SBHP08	8" Submersible bore-hole pumps
SBHP10	10" Submersible bore-hole pumps
SBHP12	12" Submersible bore-hole pumps
SBHP12+	Submersible bore-hole pumps larger than 12"
VMSPS	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)
VMSPL	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)

2.2.3 Sales growth rate

The sales growth rates data will be used to assess the future evolution of EU market of pumps covered in ENER Lot 29 study. This is useful for development of various scenarios in Task 8.

The sales growth for the years, from 2013 to 2040, is expected to be at a rate of 3%[6].

2.2.4 Product lifetime

Lifetime can be used to estimate the stock data based on sales. In the context of this study, the focus is on "active lifetime" or the so-called "economical life", i.e. the duration that the product is in service. This is usually less than its technical life (time until which the pump functions sustaining minimum acceptable performance criteria).

Some preliminary estimates on average technical and economical product life are presented in Table 2—3. It should be taken into account however that product lifetime can vary greatly depending on use patterns across Member States. Furthermore it should be noted that there have been some discrepancies concerning the data received for the lifetimes of the pumps

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

discussed in this study, which can have an important impact on the policy recommendations resulting from this study in task 8. Therefore a sensitivity analysis will be performed in task 8 assesing the impact of the diverging data on lifetime received.

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 2—3: Product technical lifetime and average lifetime in service of pumps in the EU-27

Pump type (and sub-categories)		Technical life	Average economical life[7]
		Years	Years
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	20	20
	Domestic/commercial with built in strainer over 2.2 kW	20	20
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	9	9
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	7	7
	Aquarium power head to 120W	7	7
	Spa pumps for domestic & commercial spa's	20	20
	Counter-Current Pumps	20	20
End Suction water pumps (over 150kW-P2)	ES Close Coupled from 150 kW to 1 MW	20	20
	ES Close Coupled Inline from 150 kW to 1 MW	20	20
	ES Own Bearing from 150 kW to 1 MW	20	20
Submersible bore-hole pumps	8" Submersible bore-hole pumps	11	11
	10" Submersible bore-hole pumps	11	11
	12" Submersible bore-hole pumps	11	11
	Submersible bore-hole pumps larger than 12"	11	11
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)	12	12
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	12	12

[7] The pump technical lifetime and average lifetime in service of pumps in the EU-27 are estimated by Europump

2.2.5 Replacement sales and new sales

In order to estimate the future installed stock of pumps covered in ENER Lot 29 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, which do not.

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

2.3 Market trends

This section presents recent evolution and expected orientation of the market, as well as a review of the parameters, which are likely to influence appliances sales and design in the future. It is important to understand such trends to identify products, which might represent a significant or marginal market in the near future.

2.3.1 Market production structures

The pumps industry in the EU is a growing and SME-driven sector. The European pump industry is.mainly comprised of few large manufacturers and a number of SMEs. These manufacturers are well represented by industry associations at Member State and EU level. These mainly include Europump and BPMA[8].

Very large pumps tend to be engineered and produced in the EU. This is the case for some End suction water pumps, Submersible multistage pumps and Vertical multistage pumps. Small pumps for fountains, ponds and aquariums are likely to be cheaper and many of them are manufactured outside the EU. Medium-sized water pumps for swimming pools might be either EU-produced or imported.

[8] BPMA is British Pump Manufacturers Association.

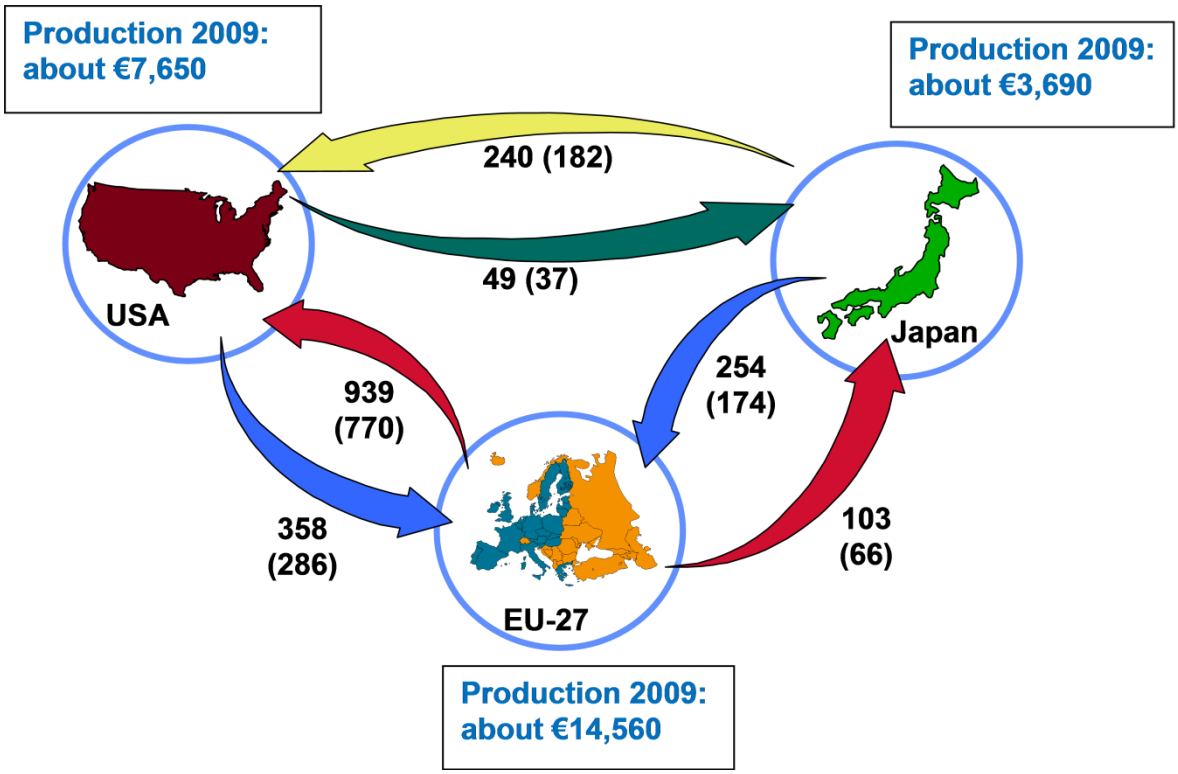
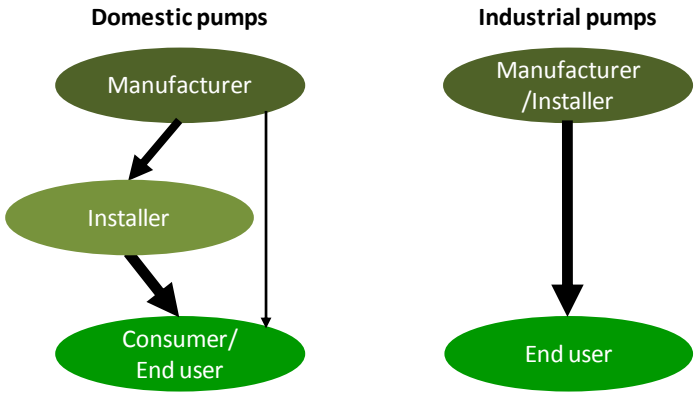


Figure 2-8: Production, imports and exports of European, Japanese and US pump manufacturers in 2009 and 2010, in billion €[9]

The product distribution channels of water pumps are mostly business-to-business, as these products usually need professional installation, with the exception of some aquarium pumps, or are included within other products. The market of water pumps directly sold to the consumer is likely to be very small, mostly for DIY or amateur sectors. Figure 2-9 presents the overview of the market distribution channels of water pumps in ENER Lot 29.

Figure 2-9: Market distribution channels of water pumps in ENER Lot 29



[9] *Source: VDMA Fachgemeinschaft fuer Pumpen*

2.3.2 Trends in product design and features

The main developments in this area concern advances in VSD motors and controls for regulation of the water flow. However, this feature is not applicable to all the water pumps considered within this preparatory study.

For vertical multistage and end suction – the larger end of the market are engineered to high specification (e.g. used in power plants for cooling). Often there are financial penalties set out in contracts if these pumps do not meet their pre-specified efficiencies.

For aquarium pumps and pond pumps, the pump must operate continuously 24/24 and any control of the rotation speed of the pump, from a ON/OFF option up to a variable speed drive (VSD), can be harmful for the livestock see Task 1 Section 1.3.2.

2.3.3 Redesign cycle of water 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 redesign cycle of pumps covered in ENER Lot 29 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 29 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[10].

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 noncompliant.

2.4 Consumer expenditure base data

Average EU consumer purchase prices, incl. VAT (in €), as well as installation costs, maintenance costs, 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 tasks 5.4 and 5.5 where Life Cycle Costs of pumps will be calculated.

[10] 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

2.4.1 Purchase price

Table 2—4 presents the range and average purchase price of ENER lot 29 pumps in Euros/unit.

Table 2—4: Estimated product price (including VAT) for pumps in the EU-27

Pump type (and sub-categories)		Purchase price range	Average purchase price	Source*
		€	€	
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	295 - 715	330	Public price list
	Domestic/commercial with built in strainer over 2.2 kW	1,000 – 3,000	1,500	Team estimate
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	23 – 1,000	100	Public price list
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	22 - 465	50	Public price list
	Aquarium power head to 120W	20 - 100	45	Public price list
	Spa pumps for domestic & commercial spa's	230 - 350	275	Public price list
	Counter-Current Pumps	620 – 3,500	1,325	Public price list
End Suction water pumps (over 150kW-P2)	ES Close Coupled from 150 kW to 1 MW	5,500 – 250,000	8,000	Team estimate
	ES Close Coupled Inline from 150 kW to 1 MW	5,500 – 250,000	8,000	Team estimate
	ES Own Bearing from 150 kW to 1 MW	5,500 – 250,000	8,000	Team estimate
Submersible bore-hole pumps	8" Submersible bore-hole pumps	€ 3,150 – 8,800	6,135	Public price list
	10" Submersible bore-hole pumps	6,000 - 13,000	8,000	Team estimate
	12" Submersible bore-hole pumps	7,000 – 15,000	10,000	Team estimate
	Submersible bore-hole pumps larger than 12"	8,000 – 17,000	12,000	Team estimate
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)	10,000	10,000	Public price list
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	33,000	33,000	Team estimate

* The prices presented are team estimates, confirmed by manufacturers

2.4.2 Installation costs

The installation costs of ENER Lot 29 pumps vary depending on their technology, size, site and application type. Table 2—5 presents the estimated cost of installation for pumps in the EU-27.

Table 2—5: Estimated installation costs (including VAT) for pumps in the EU-27

Pump type (and sub-categories)		Installation costs range	Average installation costs	Source
		€	€	
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	100 – 400	250	Team estimate
	Domestic/commercial with built in strainer over 2.2 kW	200 - 600	500	Team estimate
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	0 - 100	0	Team estimate
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	0 – 50	0	Team estimate
	Aquarium power head to 120W	0 – 50	0	Team estimate
	Spa pumps for domestic & commercial spa's	100 - 600	450	Team estimate
	Counter-Current Pumps	100 - 600	500	Team estimate
End Suction water pumps (over 150kW-P2)	ES Close Coupled from 150 kW to 1 MW	750 – 4,000	2,000	Team estimate
	ES Close Coupled Inline from 150 kW to 1 MW	750 – 4,000	2,000	Team estimate
	ES Own Bearing from 150 kW to 1 MW	750 – 4,000	2,000	Team estimate
Submersible bore-hole pumps	8" Submersible bore-hole pumps	1,000 – 4,000	3,000	Team estimate
	10" Submersible bore-hole pumps	1,000 – 4,500	3,000	Team estimate
	12" Submersible bore-hole pumps	1,000 – 5,000	3,000	Team estimate
	Submersible bore-hole pumps larger than 12"	1,000 – 6,000	4,000	Team estimate
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)	750 – 4,000	2,000	Team estimate
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	750 – 4,000	2,000	Team estimate

* The prices presented are team estimates, confirmed by manufacturers

2.4.3 Running costs

Maintenance and repair costs can be very significant depending upon the type impellers used, the use pattern and the presence or not of solids suspended in the water. For example, during 'real-life' use, swimming pool pumps and pond pumps might be blocked due to solid (hair, leaves, etc.) contained in the water. Table 2—6 presents the maintenance cost per year of water pumps in the EU-27.

The scope of repair costs mainly concerns expenses related to cost of basic consumables and replacement parts, including:

- Lubricant for bearings
- Replacement seals
- New bearings and new wear rings
- Coatings may also be applied to reduce friction
- Worn hydraulic parts

The scope of maintenance costs presented in this section mainly concerns the visit of pump for:

- Condition inspections
- Security checks
- Electrical tests and jetting

Table 2—6: Maintenance costs per year of water pumps in the EU-27

Pump type (and sub-categories)		Average maintenance costs	Source
		€/year	
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	0	Team estimate
	Domestic/commercial with built in strainer over 2.2 kW	50	Team estimate
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	0	Team estimate
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	0	Team estimate
	Aquarium power head to 120W	0	Team estimate
	Spa pumps for domestic & commercial spa's	0	Team estimate
	Counter-Current Pumps	0	Team estimate
End Suction water pumps (over 150kW-P2)	ES Close Coupled from 150 kW to 1 MW	500	Team estimate
	ES Close Coupled Inline from 150 kW to 1 MW	500	Team estimate
	ES Own Bearing from 150 kW to 1 MW	500	Team estimate
Submersible bore-hole pumps	8" Submersible bore-hole pumps	2,000	Team estimate
	10" Submersible bore-hole pumps	2,000	Team estimate
	12" Submersible bore-hole pumps	2,500	Team estimate
	Submersible bore-hole pumps larger than 12"	3,000	Team estimate
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)	1,000	Team estimate
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	1,000	Team estimate

The electricity and water prices as listed in the MEErP methodology[11] are used in this subsection. Table 2—7 presents the generic economic data of EU-27 listed in the MEErP methodology.

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

Table 2—7: Generic economic data in the EU-27[12]

	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	2.50%	
Energy escalation rate	%	4%		
VAT	%	20%		

2.4.4 Interest and inflation rates

Table 2—8 presents the generic interest and inflation rates in the EU-27. A default value of 4% is suggested as the EU average discount rate in the MEErP methodology which is proposed to be used in this subsection.

Table 2—8: Generic interest and inflation rates in the EU-27[12]

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

2.4.5 Disposal costs

ENER Lot 29 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.

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.

2.5 Conclusions

The data presented in Task 2 will help analyse the total environmental impacts of the EU-stock of pumps in the scope of ENER lot 29 and the improvement potential of these products, and will form the basis for selecting the most representative products on the European market and eventually formulating the Base-Cases in Task 5.

Economic data and energy prices are also presented in this task and will be used as inputs to the Life Cycle Costing (LCC) analysis to be carried out in Tasks 5 and 7.

[12] VHK, MEErP 2011 METHODOLOGY PART 1.

This report presents a first draft of the best estimates based on inputs from the industry. The official statistics based on PRODCOM have been also analysed but they can only provide a broad overview and are not sufficiently detailed for the purposes of further analysis in this preparatory study.

Regarding the stock numbers of ENER Lot 29 products when compared to other pumps covered in ENER Lot 28 and ENER Lot 11, it can be said that they represent 1/3 of the market, in terms of units in stock, similar to those of ENER Lot 11 and ENER Lot 28.

Table 2—9: EU installed stock of pumps

Study	Stock (million units)	Year	Geographical scope
ENER Lot 11[13]	17.1	2007	EU-25
ENER Lot 28[14]	15.7	2011	EU-27
ENER Lot 29	16.6	2011	EU-27

As indicated in Table 2—9, the pumps covered within ENER Lot 28 and ENER Lot 11 comprise each almost 1/3 of the market (in terms of units in stock); the ENER Lot 29 products representing 33% of the pumps market.

It is important to note that the information presented in the table only regards the number of pumps installed in the EU. The different sizes, functions and energy consumptions of the pumps are addressed in task 4 and 5. The following tasks of this preparatory study will also determine the energy consumption, the environmental impacts and the potential for improvement of this product sector.

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.

[13] Only refers to pumps covered within ENER Lot 11.

[14] ENER lot 28 covers pumps for private and public wastewater and for fluids with high solids content.

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

ENER LotENER Lot 29 – Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under ENER Lot 11) – Task 3: Consumer Behaviour and Local Infrastructure

Final report to the European Commission, DG ENER
28 March 2014



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Task 3: Consumer Behaviour and Local Infrastructure

Consumer behaviour has a significant direct effect on the use of pumps for clean water pumps, during the use phase of the product. It also has some influence on the End-of-Life phase, depending on the type of product. To some extent, product-design can influence a consumer's behaviour thus regulating 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 pumps for private and public swimming pools, ponds, fountains, and aquariums (and clean water pumps larger than those regulated under ENER Lot 11), and on the influence they can have on the environmental performance of the equipment.

The areas covered in this task are divided into following three main sections:

- Section 3.1: Real life efficiency
- Section 3.2: End-of-life behaviour
- Section 3.3: 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 understand how the real life efficiency of pumps in the ENER Lot 29 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), timer settings; dosage, quality and consumption of auxiliary inputs; 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)

3.1.1 Pump applications

- **A. Large water pumps**

Pumps of this size represent a major capital investment, and so are far more likely to be carefully sized and specified, as is the motor that run them. The running costs are also so large that impellers may be changed to match the pump duty to the actual demand.

Depending on the exact specification of pump agreed, large multi-stage pumps with removable sections may be included. These will see the number of stages increased as for example water levels fall, avoiding running at very low loads.

These represent major investment, and so if they wear are likely to be re-furbished during their lifetime. Condition monitoring that detects a fall off in performance is also more likely with these larger pumps. As pumps will keep working even when in poor condition, this deterioration may not be appreciated until they fail catastrophically, by which time their efficiency may be as much as 20% below the as new performance.

Where a VSD is used in variable flow applications, the pump efficiency will be maintained at a good level at speeds much less than the design point.

- **B. Swimming pool pumps**

Swimming pool pumps can be used to pump water through filters, heaters, and chemical dosing systems. The number of changes of water required per day is the subject of regional regulations, which vary considerably. Harmonisation of these standards would seem to offer the biggest opportunity for saving, but it is beyond the scope of this study. However, in parallel with this study it would be good if the EC was to start discussions with a view to harmonisation.

There are many online tools available for calculating the required pump size as a function of size, number swimmers etc. The theoretical turnover period for the pool water can be calculated from considerations of pump flow rate and volume, and will vary from 5 minutes for a leisure water bubble pool to 6 hours for a private pool. In practice, 7 volume changes are needed to ensure that 99% of water actually passes through the filter.

This variation in duties will dominate energy consumption, and hence it is important that more attention is given to creating regulations based on real requirements.

Pool skimming is also important for removing the bulk of the contamination that is found in the top 15cm of the pool, as it reduces the load on the pump filters. Filters should be backwashed at least once a week, or when the pressure drop exceeds 3psi.

The range of duties, and the flow required, is indicated in Figure 3-1.

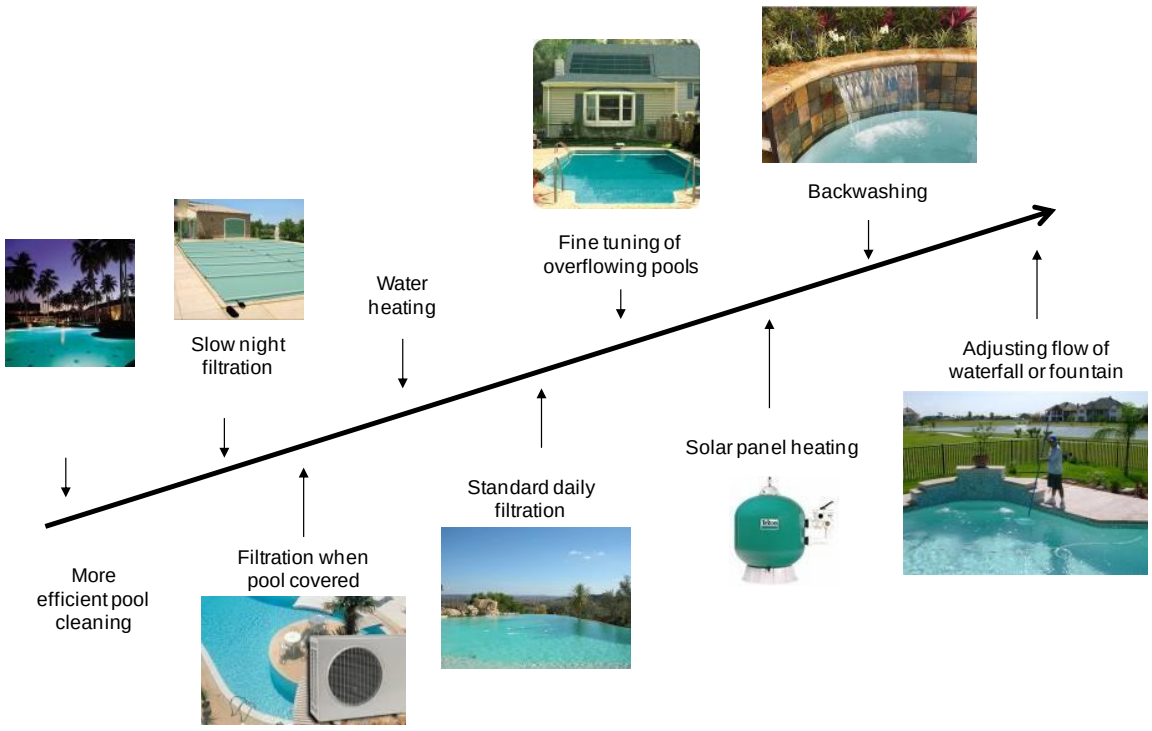


Figure 3-1: Inteliair diagram indicating the variation of duties a pump may be expected to supply – Many domestic pumps will only perform filtration, heating and backwashing

A 0.75hp (0.6kW) pump is generally adequate for standard residential pools, although 1hp (0.75kW) is the most common size in the US.

The economic product life is provisionally estimated to be similar to that shown for the smaller pumps in the EU regulations, i.e. about 10 years.

C. Fountain, pond and aquarium pumps

Pond circulators, aquarium pumps and aquarium powerheads will work on continuous (24/7) duty in order to protect the stock.

Fountains will work for limited hours according to resident requirements, but likely to be limited to warmer/dryer seasons and for hours when they are present.

The load factor for each will be constant in operation, but a nominal load factor for each type will need agreeing.

System Aspects

Because few consumers have the understanding to precisely match the performance to the duty, it is assumed that most pumps work sub-optimally. There are several factors that will lead to poor performance in real life:

- Filters - blocked. As conventional filters block up, the pressure drop increases, putting additional load on the pump.
- Filters – pressurised type. These more compact types are increasing in popularity, but have a higher pressure drop than conventional types.

- Excess flow. Many consumers and retailers are unsure about specifying a pond or aquaria pump, and so will opt for a design which is considerably higher than needed in order "to be on the safe side".

3.1.2 Frequency of use

The range of pumps considered in scope has a wide range of operating hours. Table 3-1 shows the annual number of operating hours of the ENER Lot 29 pumps. Domestic products have lower operating hours per year than commercial and industrial ones, and some specific products such as spa pumps and counter-current pumps have a low number of operating hours per year. 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. 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 3-1: Annual operating hours of the ENER Lot 29 pumps

Pump type (and sub-categories)		Annual operating hours[1]
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	1,500
	Domestic/commercial with built in strainer over 2.2 kW	3,375
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	6,000
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	8,720
	Aquarium power head to 120W	8,720
	Spa pumps for domestic & commercial spa's	350
	Counter-Current Pumps	20
End suction water pumps (over 150kW-P2)	ES CloseCoupled from 150 kW to 1 MW	3,600
	ES CloseCoupled Inline from 150 kW to 1 MW	3,600
	ES Own Bearing from 150 kW to 1 MW	3,000
Submersible bore-hole pumps	8" Submersible bore-hole pumps	2,565
	10" Submersible bore-hole pumps	2,725
	12" Submersible bore-hole pumps	3,114
	Submersible bore-hole pumps larger than 12"	3,352
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)	2,700
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	3,450

3.1.3 Product related eco-information

This section primarily relates to clean water pumps larger than those analysed in ENER Lot 11 preparatory study.

- **Repair and maintenance practices**

[1] The information on the annual operating hours of the ENER Lot 29 pumps are provided by Europump.

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 reduce corrosion, which can be used both from new and for in service refurbishment. For the smaller pumps in this study, it will not be economic to change these parts, and so they will instead be replaced with new pumps. The effect of the wear of pump and the wear trends are presented in Figure 3-2 and Figure 3-3.

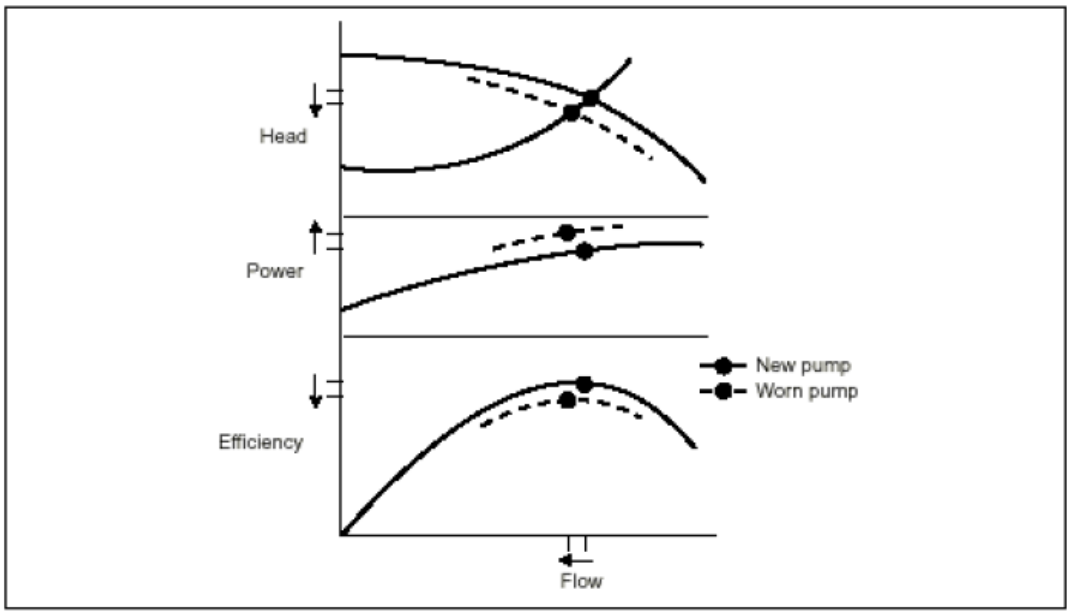


Figure 3-2: Effect of wear on pump characteristics

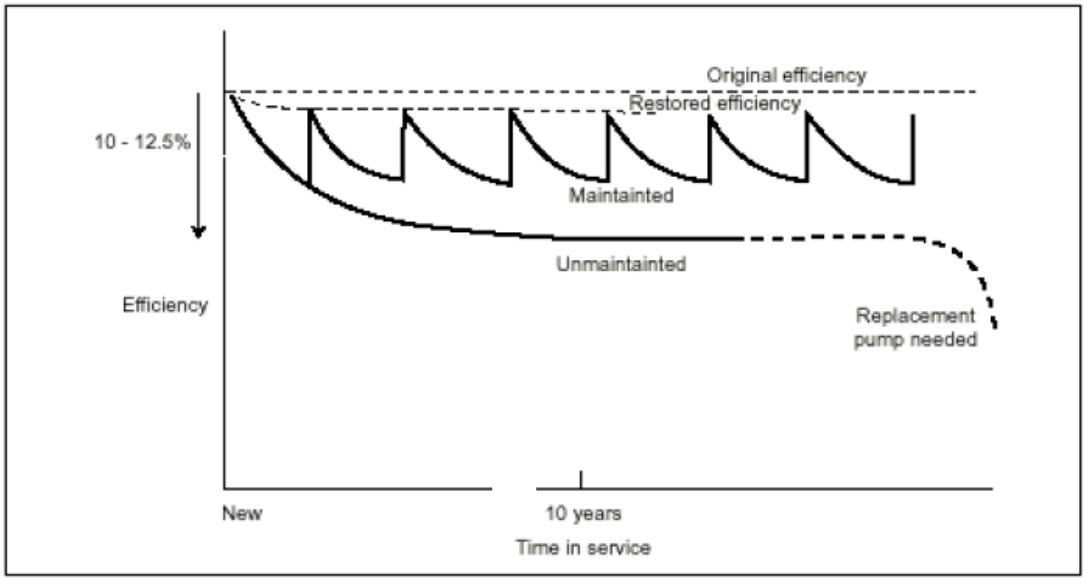


Figure 3-3: Average wear trends for maintained and unmaintained pumps

Large 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 Supervision 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.

- **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. With regards to smaller domestic products such as aquarium and garden pumps the selection process is based on the calculation of the correct turnover of water inside the aquarium tank or inside the pond basin (pump must recirculate the entire volume of water from 3 to 5 times every hour).

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 impact patterns of use.

However, although beyond the scope of this report, measures to reduce water consumption would reduce the operating duties of many of the pumps covered by this study, 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 pumps such as aquarium and pond pumps, water conservation methods are unlikely to have an impact on their usage.

It is clear that the correct selection of pump is at least as important as the selection of pump by 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 their ranges of pumps to cover a range of duties, (Figure 3-4). 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 (Figure 3-5) following makes this clearer.

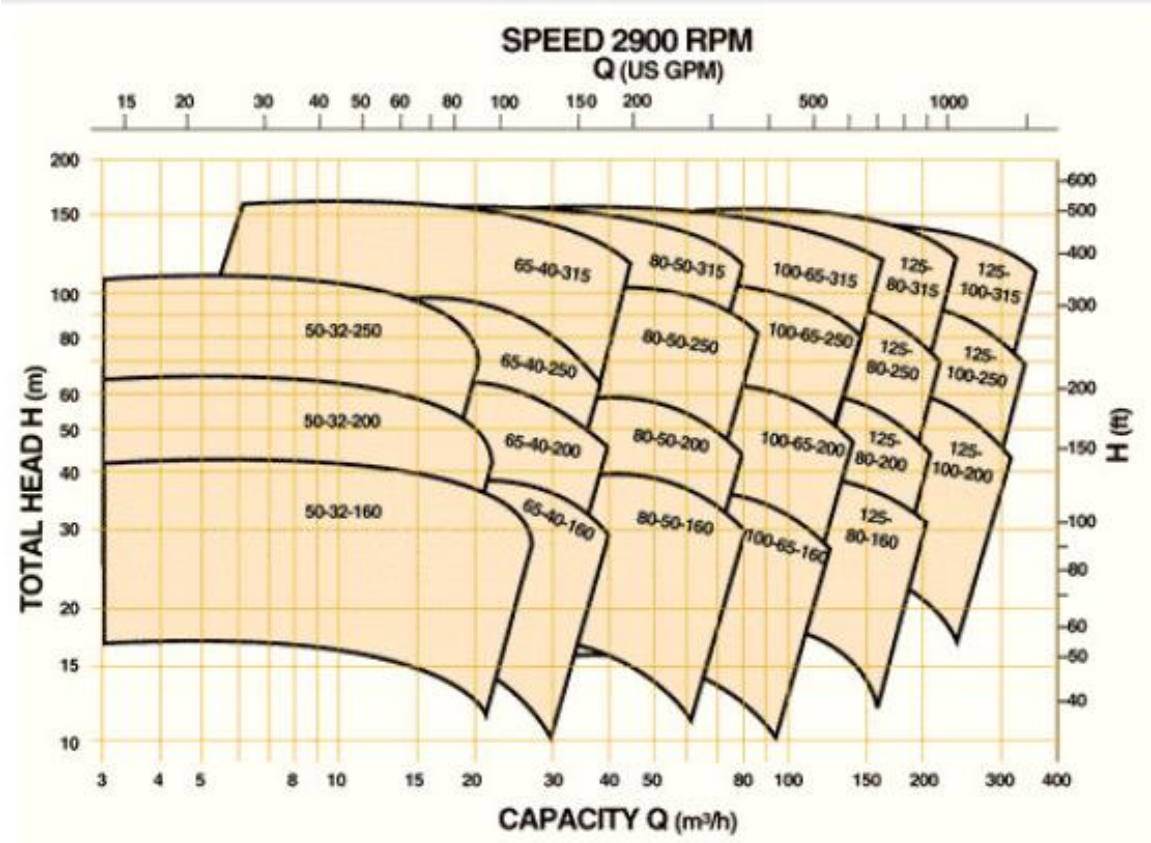
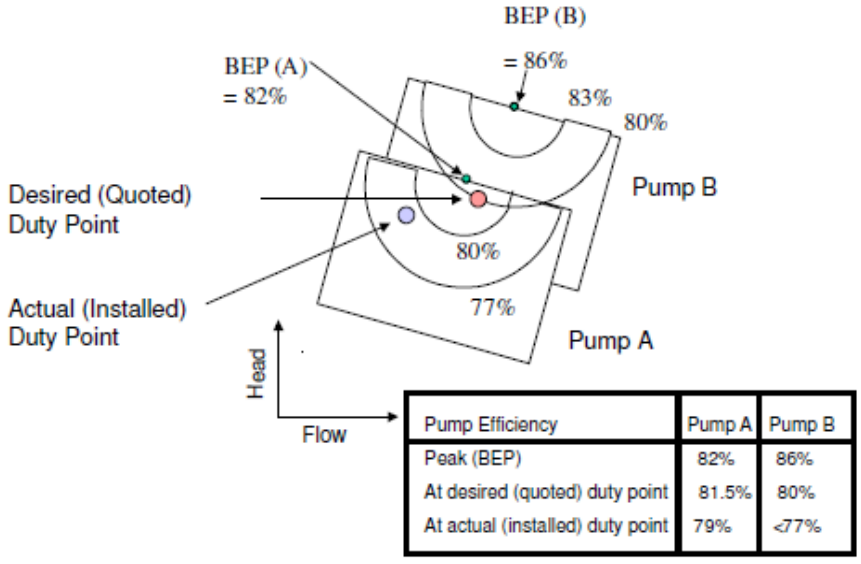


Figure 3-4: "Tombstone" curves for the selection of pumps by duty



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 3-5: Worked example showing the importance of correct selection of a pump

A user requests quotes for a pump at a particular desired duty. 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).

- **System Energy Savings**

This report concerns solely the energy savings that can be achieved by using a more efficient pump – 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 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 whole pumping system. The SAVE study[2] identified energy savings associated with these measures as follows:

- Selecting better sized pump: 4%
- Better installation / maintenance: 3%
- Better System Design: 10%
- Better System Control: 20%

In particular, 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.

- **Part load characteristics of pumps**

Pumps are always defined by the basic Pump characteristics as shown in

Figure 3-6 shows 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. As shown in Figure 3-7, the peak power consumption will not necessarily be at the BEP.

[2] SAVE Study on Improving the Efficiency of Pumps', AEAT for the European Commission, February 2001

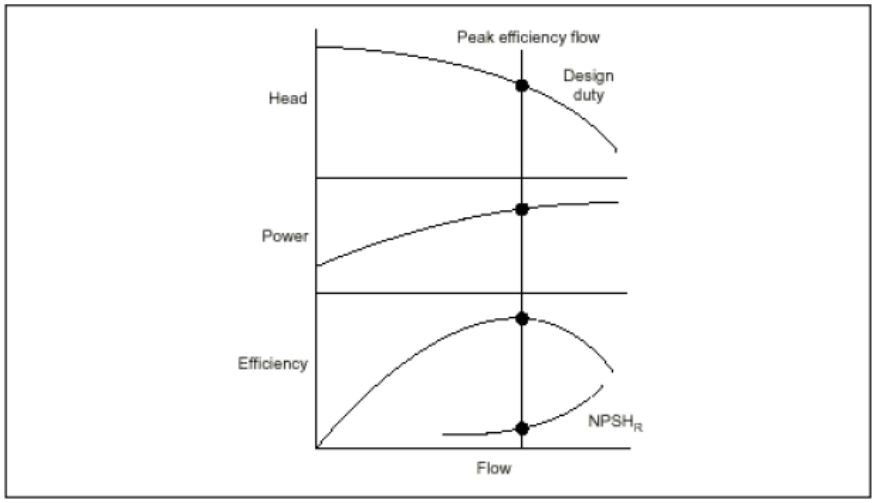


Figure 3-6: Centrifugal pump characteristics

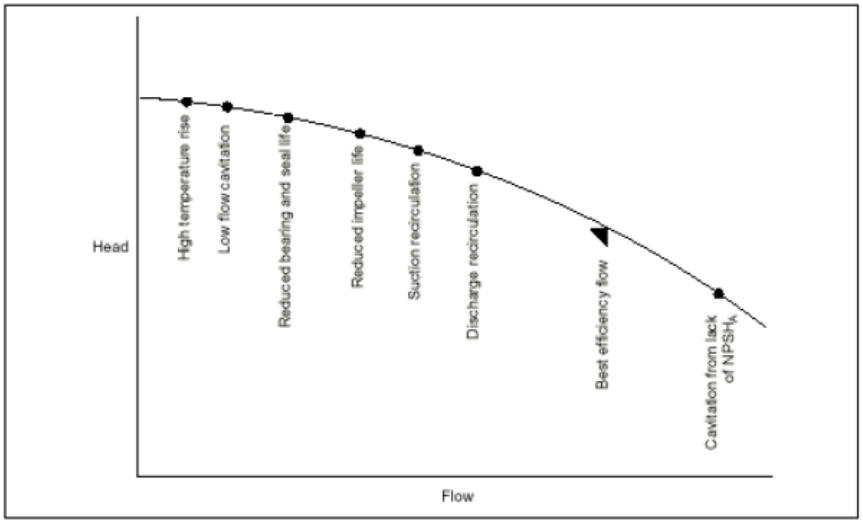


Figure 3-7: Onset of adverse effects when operating a pump away from its peak efficiency flow

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 should be reduced.
- Vibration should be minimised, benefiting other equipment.
- Noise should be minimised, improving the environment.
- Pressure pulsations should also be minimised, reducing the risk of problems in the pumping system as a whole.

Figure 3-8 indicates some of the problems that 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.

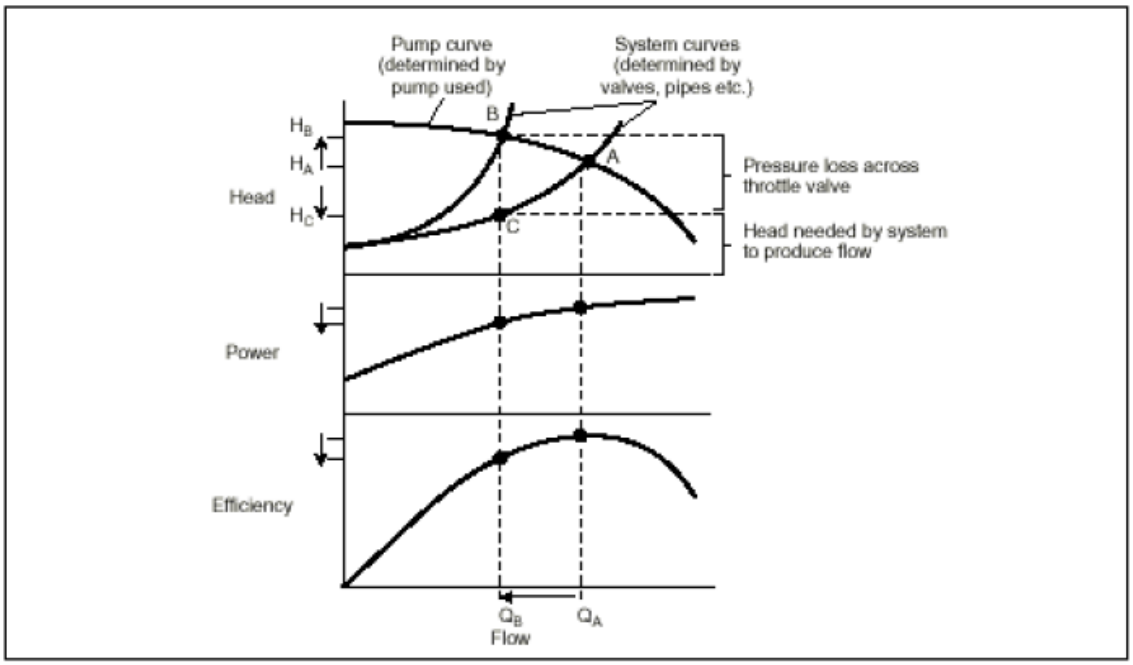


Figure 3-8: Illustration of the effect on the efficiency of throttling a pump

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 catalogue efficiency.

3.2 End-of-life behaviour

- **A. Large water pumps**

These pumps are likely to be returned to factory for refurbishment when their performance deteriorates too far. Pump manufacturer often provide a comprehensive range of spares for these pumps. Routine maintenance will be performed in the field.

When these pumps reach the end of their life, as they are all metal they will be sent for scrap. There is little market for second hand pumps.

- **B. Swimming pool pumps**

Given the cost of these pumps, at failure they are more likely to be replaced than repaired. Spare motors are for example readily advertised. The second hard market is only small, as consumers are unlikely to upgrade unless their pump fails.

- **C. Fountain, pond and aquarium pumps**

Given the low value of these, they are likely to be disposed of when they fail, not repaired. The motor contains valuable metal, but the plastic pump and case is unlikely to be recycled.

3.2.1 Economical Product Life (in practice)

The lifetime of a water 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 estimated technical life and actual time to disposal for pumps in this study is analysed in Task 2 of this preparatory study. The product life in practice is usually equal or shorter than its maximum technical life. In some cases, pumps may be replaced due to an upgrade of the overall system (e.g. aquarium powerheads and pumps), or refurbishing works (e.g. spa pumps and swimming pool pumps), etc. The difference between technical life and economic life is usually small in large pumps with high purchase prices (e.g. end suction pumps, submersible borehole pumps, etc.). In these cases, the high investment cost prevents from replacing the pump before the end of its technical life.

3.2.2 Present fractions to recycling, re-use and disposal

The 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 can be assumed that all of the metallic and none of the non-metallic components are recycled from large pumps. For small and medium-size pumps, segregation of different metal fractions is often not done, leading to the loss of valuable copper and aluminium in iron metal recycling. Table 3-2 shows the weight of pumps split by metallic and non-metallic components:

Table 3-2: Proportion of non-metallic components in the pumps considered in the study

Pump type	Percentage of non-metallic components (%)	Source
Swimming Pool pumps	11-31	Europump
Fountain & pond pumps	47-60	Estimate
Aquarium pumps	50-69	Estimate
Spa pumps	27	Europump
Counter-current pumps	23	Europump
End Suction pumps (ESCC, ESCCI & ESOB) (Size > ENER Lot11)	0	Europump
Submersible bore-hole pumps (8", 10" & 12")	1	Europump
Vertical Multistage pumps (Size > ENER Lot11)	0-1	Europump

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 on pumps. (Motors on pump sets could well be re-used. This is frequently practiced for large pumps but is less common for the smaller pumps in the study. It should be noted that 100% separation of the main metal fractions from the pump is difficult and is not actually achieved during scrap treatment leading to, for example, lower iron recycling quality due to its remaining copper content.

The smaller domestic pumps in the study are typically disposed of in the municipal waste collection and not via separate WEEE collection.

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 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 EcoReport model carried out in the screening in Task 1 showed that materials are not responsible for much of the total environmental impact; this does not represent a significant error, and so is not investigated any further.

3.2.3 Estimated 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, it is rather 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 referred to Task 2, and so this lack of definitive data does not affect the analysis.

3.3 Local infrastructure (energy, water, telecom, physical distribution, etc)

The aim of this subtask is to identify and describe barriers and opportunities relating to local infra-structural factors. It deals with the differences between theory and practice, which is very important for the success of green-design. The benefit of technology only persists if the product is properly used. So there are a variety of very good ideas which are not used, because either, end users do not accept or do not care about them.

The end user is a central player concerning the environmental impacts of energy using 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.

3.3.1 Local infrastructure factors

- **A. Large water pumps**

These pumps will draw a high electrical power, and so may need an appropriate MV electrical connection. In some cases, an engine drive will be used, for example on emergency pumps.

When money is short, the decision may be taken to refurbish rather than replacing pumps, hence delaying the impact of any regulations.

- **B. Swimming pool pumps**

There are not thought to be any significant infrastructure constraints on the adoption of improved products, but this will be tested.

- **C. Fountain, pond and aquarium pumps**

With the exception of dry pond pumps that require a dry space for fitting, there are no local infrastructure requirements for these types.

3.3.2 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. Buyers and product distributors are not in charge of the system operation afterwards and thus do not pay the final electricity bill. Following are some other barriers:

- **Preference for stabilised technologies:** technology changes often generate a temporary increase in breakdown rates due to a necessary learning period.
- **Fear of complexity:** as an example, 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 pumps for in the study.
- Other **non-technical barriers** (lack of internal incentives, e.g. reduction of budget for subsequent years).

In this study, the analysis will be made first for the pump alone, and then for the systems which will have been selected (see Task 4).

3.4 Conclusions

Task 3 has considered consumer behaviour and local infrastructure issues associated with the pumps covered by this study. Large clean water pumps represent major capital investment and therefore tend to be carefully sized and specified to provide highly efficient operation. In variable flow, systems provided with variable speed drives, which allow the supply to match the demand whilst maintaining a high level of efficiency.

Conversely, smaller pumps, such as those found in swimming pools and gardens, tend to be sized through well-accepted rules of thumb rather than after a detailed calculation of the site-specific system losses. The energy savings to be made in these pumps arise from better selection, improved installation and maintenance, better system design and better controls. Of these, better controls, offer the biggest scope for improvement.

There is a significant amount of metal in the large clean water pumps, which may be recovered as scrap at the end of their lives. There is little market for second hand pumps of this kind. Swimming pool pumps are likely to be repaired at failure rather than replaced and there is an established market for spare motors. There is only a small second hand market. Fountain, pond and aquarium pumps are likely to be disposed, if they fail, rather than repaired, as they are low value items. The motors contain metals, which are likely to be recycled. Again, there is not a significant second hand market.

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

ENER Lot 29 – Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under ENER Lot 11) – Task 4: Technical analysis

Final report to the European Commission, DG ENER
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Task 4. Technical Analysis

This chapter presents the technical analysis of pumps for private and public swimming pools, ponds, fountains, and aquariums (and clean water pumps larger than those regulated under ENER Lot 11) covered in the scope of the ENER Lot 29 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[1] 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.

This task is therefore divided into the following subtasks according to the different life-cycle stages of the pumps for pumps for private and public swimming pools, ponds, fountains, and aquariums (and clean water pumps larger than those regulated under ENER Lot 11):

- production phase;
- distribution phase;
- use phase of the product;
- use phase of the extended product; and,
- end-of-life phase

The last sections of this report concern recommendations for possible mandates to be issued by the European Commission and standardisation organisations for ENER Lot 29 products and 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

[1] Available at http://lot29.ecopumps.eu/

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.

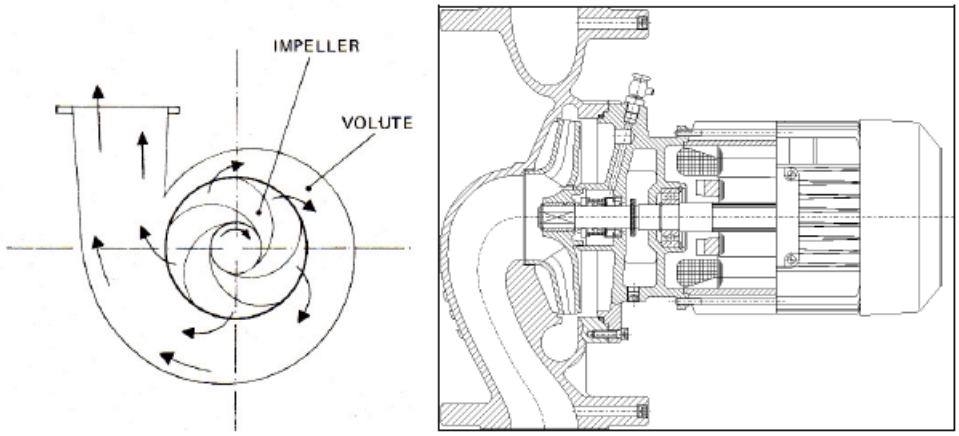


Figure 1 – How rotodynamic pumps work: flow paths (left) and cutaway of motor-coupled pump (right) (Source: ENER Lot 11 preparatory study on ecodesign of motors)

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 the pumps considered in this study 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.

4.1.2 Common products and technologies

The products involved in this study are described in detail in Task 1, section 1.3.1.

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'[2] for the European Commission and issued in February 2001. Task 5 of that study supported 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 main 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.

[2] ETSU, AEAT PLC (2001) Study on Improving the Efficiency of Pumps. Available at http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/files/documents/save_pumps_final_report_june_2003.pdf

Impellers

Impellers have a key role in contributing towards the efficiency and performance of pumps. This is because their primary function is to transfer the energy from the pump to the water, and so a poorly designed impeller can be a significant source of losses in the system. Impellor should be designed to minimise leakage from the discharge side back to the suction side. Wear rings can be provided which assist with minimising leakage.

Pump manufacturers provide pumps with a range a range of impeller sizes to cater for the wide range of duties required. The diameter of an impeller has the following effects on pump performance:

- Flow is directly proportional to impeller diameter
- Head is proportional to the square of the impeller diameter
- Power is proportional to the cube of the impeller diameter

Impellers can be trimmed to ensure that their output matches the required duty. However, users who buy pumps with trimmed impellers should be aware that pumps are designed for maximum efficiency with the impeller at full diameter.

Motors

Many of 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, one set of electromagnets in the form of a rotating magnetic field is formed in the stator when an AC supply 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 at 120 degrees 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.

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

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.

There are two types of three-phase induction motors classified by the type of rotor used: wound or squirrel cage, the latter representing the large majority of them.

Main characteristics:

- Low construction complexity,
- High reliability (no brush wear), even at very high achievable speeds
- Medium efficiency at low power (below 2.2. kW), high efficiency at high power
- Driven directly by the grid or by multi-phase Inverter controllers
- Low Electromagnetic Interference (EMI)
- Sensorless speed control possible
- 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.

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, by motors made by different manufacturers meeting the same requirements. There is a huge variety of special purpose induction motors, generally custom made for specific applications. In some applications, these motors may have to comply with strict requirements (e.g. fireproof motors) 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 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 energized. 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. After starting, a centrifugal switch may be used to disconnect the auxiliary winding.

Main characteristics:

- Medium construction complexity due to extra capacitor and centrifugal switch
- Higher cost than 3-phase induction motors

- High reliability (no brushes)
- Lower efficiency than 3-phase induction motors
- Low EMI
- Driven directly from AC line or from Variable Frequency controllers

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.

- **Brushless Permanent Magnet DC or AC Motor**

Brushless permanent magnet AC motors (BLAC) are used in smaller pumps such as aquarium and fountain pumps. BLAC motors are synchronous motors with use permanent magnets rather than windings in the rotor. The brushless permanent magnet DC motor (BLDC) is a brushless AC motor with integrated inverter and rectifier, sensor and inverter control electronics. They are fed through a DC link with power originating from an AC source. The DC power is then inverted back to AC, which feeds the motor. Strictly speaking, they are AC motors but historically they have been classified as DC.

Brushless Permanent Magnet (BPM) Motors are rapidly becoming one of the most popular motor types. 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 Inverter controllers
- Sensorless speed control possible

These motors are still highly customized without suitable standards (e.g. dimensions, mounting, power, torque specifications, etc.) to allow a commodity market to develop. Because of mass production for specialized applications, their cost has been decreasing and may become a key player particularly in the low power range. They are often used in conjunction with aquarium, pond and swimming pool pumps.

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 types of controls can commonly be found on swimming pool pumps or pond pumps and are based on pre-set on and off operation times.

Time switches are relatively simple to operate and are available as simple once per day timers, to very complex multiple event, multiple day timer that allow the user to specify different times of operation on different days.

Level controls

Level controls are commonly used in wet well type pumping operations. They are used to switch the pumps on when the amount of water in a wet well reaches a pre-set high level, and switch them off once the 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 those pumps used for specific process operations like borehole pumping in water treatment work. 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 water, the pumps will be operated at full speed; however they might be operated at half speed during periods of low demand.

Pressure controls

Pressure controls are used to vary the speed of pumps in order to maintain a constant outlet pressure and flow rate in the pumping system. These types of controls are commonly used in water supply network, and in filtering processes. In water supply networks, these controls ensure that a constant flow rate is supplied to all users of a water network, and in filtering processes ensure that a consistent volume of water is filtered, even when the filter starts to clog.

Sensors

Level and pressure sensors tend to be most commonly used water pumping. Level sensors are typically found in the form of pressure transmitters, ultrasonic sensors, level probes and float switches.

Pressure transmitters

Pressure transmitters are suspended in the water of the wet well, in a protective enclosure, and they use the pressure measured to determine the water level. Pressure transmitters can provide continuous accurate level readings.

- **Ultrasonic sensor**

Ultrasonic sensors are placed in wet wells above the water level. They measure water level by emitting an ultrasonic sound waves at the water 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 water level in the wet well.

A key benefit of these types of sensor is that they are never in contact with the water.

- **Level probes**

The principle of operation of is that there are two electrodes placed within the wet well. One on the well wall and one in the level probe. A low voltage is applied between the wall electrode and the level probe. When the waste water level in the wet well reaches the height of the probe, an electrical connection in made between the two electrodes, and this is used as a signal be the controls to turn the pumps on or off.

- **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 4-2, when the float-switch is submerged in the water it turns upside-down and the switch is turned on and the control system is sent a signal.

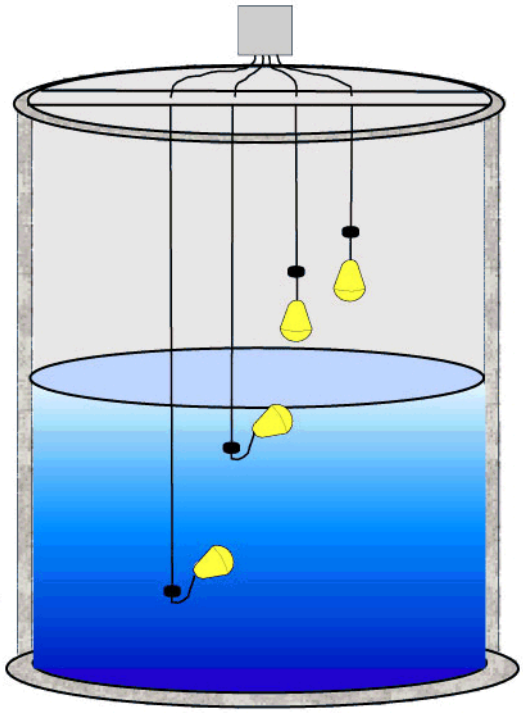


Figure 4-2: Example of a wet well with float switches

- **Pressure sensors**

Pressure sensors are typically made of piezoelectric materials, which convert any force exerted onto it into an electrical signal. The pressure sensor is installed into the pump system and the electrical signal is fed back to the pump controller. Pressure sensors are relatively cheap and easy

to install, and require little maintenance. Table 4-1 listed the components present or available for pumps in the study.

Table 4-1: Components present or included for pumps in the study

		Impellers	Motors			Controls				Sensors				
			Three phase Induction motors	Single-Phase Induction motors	Brushless Permanent Magnet Motor	Time switches	Level controls	Process based controls	Pressure controls	Pressure transmitters	Ultrasonic sensor	Level probes	Float switches	Pressure sensors
Swimming Pool pumps (integrated motor+pump)														
	Domestic with built in strainer up to 2.2 kW	✓	✓	✓	○	○	×	×	×	×	×	×	×	○
	Domestic/commercial with built in strainer over 2.2 kW	✓	✓		○	○	×	×	×	×	×	×	×	○
Fountain and pond pumps to 1 kW		✓			✓	○		×	×	×	×	×	×	×
Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W		✓			✓	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Aquarium power head (separate study for life cycle data only) to 120W		✓			✓	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Spa pumps for domestic & commercial spa's (where the water is retained and filtered)		✓	✓	✓		×	×	×	×	×	×	×	×	×
Counter-Current Pumps		✓	✓	✓		○	×	×	×	×	×	×	×	×
End Suction water pumps (over 150kW-P2)														
	ES Close Coupled from 150 kW to 1 MW	✓	○			×	×	×	×	×	×	×	×	×
	ES Close Coupled Inline from 150 kW to 1 MW	✓	○			×	×	×	×	×	×	×	×	×
	ES Own Bearing from 150 kW to 1 MW	✓	○			×	×	×	×	×	×	×	×	×
8" Submersible bore-hole pumps		✓	○			×	×	×	×	×	×	×	×	×
10" Submersible bore-hole pumps		✓	○			×	×	×	×	×	×	×	×	×
12" Submersible bore-hole pumps		✓	○			×	×	×	×	×	×	×	×	×
Submersible bore-hole pumps larger than 12"		✓	○			×	×	×	×	×	×	×	×	×
Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)		✓	○			×	×	×	×	×	×	×	×	×
Vertical multi-stage pump (>40 bar and/or >180 m3/hr)		✓	○			×	×	×	×	×	×	×	×	×

✓: Included ○: Optional Δ: to be avoided ×: Not commonly included

4.2 Production phase

4.2.1 Bill of Materials (BoM)

In order to calculate the environmental impacts and costs of materials and production processes, 'bill of materials' (BoM) of typical pumps for pumps for private and public swimming pools, ponds, fountains, and aquariums (and clean water pumps larger than those regulated under ENER Lot 11) needs to be gathered from manufacturers. BoMs list all the types and quantities of materials and components used to produce one product unit.

The primarily materials used in pumps depends on their size and use. In the large, clean water pumps steel and non-ferrous metals account for more than 90% of the materials used. This is as expected as they are often used for applications where they need to be robust and withstand high pressures. With the smaller pumps, there is a higher prevalence of plastic materials used, especially for the pump body.

Table 4-2 to Table 4-5 show the BoM for the pumps in the study.

Table 4-2: Detailed bill of materials for VSD

Materials	Rated Power of the pump motor				
	0.37 kW	**1.1 kW**	**11 kW**	**110 kW**	**560 kW**
Steel (kg/kW)	-	0,5	0,16	0,05	0,045
Aluminium (kg/kW)	1,3	1	0,22	0,01	0,009
PVC Plastic (kg/kW)	0,4	0,3	0,05	0,03	0,027
PWB (kg/kW)	0,26	0,2	0,03	0,01	0,009
Electronics small (SMD, IC,…) (kg/kW)	0,26	0,2	0,07	0,04	0,036
Electronics big (IGBT, Thyristors,…) (kg/kW)	0,065	0,05	0,02	0,03	0,027

Table 4-3: Bill of Material for smaller clean water pump – Source: Europump and technical experts

Materials	Swimming pool pumps up to 2.2kW*	Swimming pool pumps over 2.2 kW	Fountain and pond pumps up to 1 kW*	Aquarium pumps to 120W*	Aquarium power head	Spa pumps*	Counter-Current Pumps*
Max. power rating [kW]	2.2	25	1	0.12		25	17
Product weight [kg]	14	24.2	4.5	1.2	0.6	25	27.5
Packaging weight [kg]	1.425	5.575	0.39	0.34	0.2	6.5	4.625
Product	**Content [%]**	**Content [%]**	**Content [%]**	**Content [%]**		**Content [%]**	**Content [%]**
Steel	44	49	-	-	-	44	49
Cast Iron	-	-	-	-	-	-	-
Other ferrous metals	-	23	32	17	17	-	11
Non-ferrous metals	25	17	22	17	17	29	17
Plastics	31	11	2	5	17	27	15
Coatings	-	-	-	-	-	-	-
Electronics	-	-	-	-	-	-	-
Other Materials	-	-	27	25	33	-	8
Packaging	**Content [%]**	**Content [%]**	**Content [%]**	**Content [%]**		**Content [%]**	**Content [%]**
Plastics	18	2	3	-	-	-	8
Cardboard	82	44	82	100	100	100	43
Paper	-	-	10	-	-	-	11
Other (Wood, etc.)	-	54	5	-	-	-	38

* Includes pump and motor

Table 4-4: Bill of Material for large clean water pumps – Source: Europump and technical experts

Materials	End suction close coupled from 150 kW to 1 MW	End suction close coupled inline from 150kW to 1MW	End suction own bearing from 150 kW to 1 MW
Max. power rating [kW]	1,000	1,000	1,000
Product weight [kg]	650	650	650
Packaging weight [kg]	10	10	8
Product	**Content [%]**	**Content [%]**	**Content [%]**
Steel	13	13	13
Cast Iron	-	-	-
Other ferrous metals	85	85	85
Non-ferrous metals	2	2	2
Plastics	-	-	-
Coatings	-	-	-
Electronics	-	-	-
Other Materials	-	-	-
Packaging	**Content [%]**	**Content [%]**	**Content [%]**
Plastics	30	30	12.5
Cardboard	70	70	87.5
Paper	-	-	-
Other (Wood, etc.)	-	-	-

Table 4-5: Bill of Material for bore hole pumps and vertical muti-stage – Source: Europump and technical experts

Materials	8" Submersible bore-hole pumps	10" Submersible bore-hole pumps	12" Submersible bore-hole pumps	Submersible bore-hole pumps larger than 12"	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m³/hr)	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)
Max. power rating [kW]	110	190	250	400	260	750
Product weight [kg]	191.9	515.1	643.4	2626	283	1,175
Packaging weight [kg]	31.25	53.75	75.5	129.75	34.8	69.3
Product	**Content [%]**	**Content [%]**	**Content [%]**	**Content [%]**	**Content [%]**	**Content [%]**
Steel	49	49	49	49	32	10
Cast Iron	-	-	-	-	-	-
Other ferrous metals	50	50	50	50	66	85
Non-ferrous metals	-	-	-	-	1	5
Plastics	1	1	1	1	1	-
Coatings	-	-	-	-	-	-
Electronics	-	-	-	-	-	-
Other Materials	-	-	-	-	-	-
Packaging	**Content [%]**	**Content [%]**	**Content [%]**	**Content [%]**	**Content [%]**	**Content [%]**
Plastics	6	6	5	5	3	1
Cardboard	17	14	13	10	24	36
Paper	-	-	-	-	-	-
Other (Wood, etc.)	77	80	82	86	73	62

4.3 Distribution phase

There can be wide variations in weight and volume of pumps packed for distribution. Table 4-6 show the weights of pumps, which has been derived through consultation with stakeholders.

Table 4-6: Distribution – Source: technical experts

Pump type		Weight of packaged product [kg]
Swimming Pool pumps (integrated motor+pump)		
	Domestic with built in strainer up to 2.2 kW	15.4
	Domestic/commercial with built in strainer over 2.2 kW	29.8
Fountain and pond pumps to 1 kW		4.9
Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W		1.6
Aquarium power head (separate study for life cycle data only) to 120W		0.8
Spa pumps for domestic & commercial spa's (where the water is retained and filtered)		31.5
Counter-Current Pumps		32.1
End Suction water pumps (over 150kW-P2)		
	ES Close Coupled from 150 kW to 1 MW	660
	ES Close Coupled Inline from 150 kW to 1 MW	660
	ES Own Bearing from 150 kW to 1 MW	658
8" Submersible bore-hole pumps		223.2
10" Submersible bore-hole pumps		568.9
12" Submersible bore-hole pumps		718.9
Submersible bore-hole pumps larger than 12"		2755.8
Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)		317.8
Vertical multi-stage pump (>40 bar and/or >180 m3/hr)		1244.3

4.4 Use phase (product)

4.4.1 Calculation of the Energy Used by the ENER Lot 29 Pumps

The MEEuP Ecodesign general methodology states that the annual resource consumption and the direct emissions produced during the product life should be determined in accordance with the test standards. However, there are currently no test standard condition and so in order to derive the ENER Lot 29 pump models, load profiles for each or the pump types are required. Load profiles give an approximation of how the flow from the pump alters over time. This change in flow could be due to controls in variable flow system. In constant flow systems, this change in flow could potentially be due to changes in the static head or system resistance. An example of a load profile is shown in Table 4-7below.

Table 4-7: Flow profile used for pump modelling – Source ENER Lot 11 Study

% of Best Efficiency Point Flow	% of time at this flow
50	25
75	50
100	20
125	5

The energy performance of each pump is calculated by the following method:

- Look up the rated efficiency at the selected flow points. Subtract a nominal amount to allow to for lifetime decrease in efficiency, and then use this as the basis to determine the average "in service" energy consumption over the lifetime of the pump. Calculate the power consumption at each flow point – i.e.

$$\text{Shaft power (kW)} = \frac{\text{Flow (l/s) x Head (m) x Relative density of fluid (kg/l) x Gravity (m/s}^2\text{)}}{\text{Mean lifetime pump efficiency (\%) x 1,000}}$$

- For each flow point, the power is then multiplied by the annual operating hours associated with this point. This is calculated as a percentage of the time spent at that to get the total annual energy consumption.
- This is repeated for the each of the remaining flow points and totalled to give total annual energy consumption for the pump under assumed operating conditions.
- The conversion between electrical and mechanical (shaft) power is calculated by considering the efficiency of an IE3 induction motor to be used for that pump.

$$Electrical\ Power = \frac{Shaft\ Power}{IE3\ Motor\ Efficiency}$$

- In all cases the data relates to total (electrical) energy consumption, which is what the MEEUP model requires in order to calculate environmental emissions from each pump type. Section 4.3.3 makes these distinctions clear.

Table 4-8 shows the power, operating hours and annual energy consumption for the use phase.

4.4.2 Data on Use Phase for Pumps in Scope

Table 4-8 provides the data on the use phase for pumps in ENER Lot 29.

Table 4-8: Data on use phase for pumps in scope – Scope: Europump

Pump Type		Hydraulic Pump Power	Annual operating hours	Annual energy consumption
		kW	Hours	GWh
Swimming Pool pumps (integrated motor + pump)				
	Domestic with built in strainer up to 2.2 kW	0.8	1,500	6,912
	Domestic/commercial with built in strainer > 2.2 kW	5	3,375	2,329
Fountain and pond pumps to 1 kW		0.02	6,000	266
Aquarium pumps to 120 W		0.005	8,720	421
Aquarium power head to 120W		0.005	8,720	18
Spa pumps for domestic & commercial spa's		1.1	350	19
Counter-Current Pumps		3	20	72
End Suction water pumps (over 150kW-P2)				
	ES Close Coupled from 150 kW to 1 MW	150	3,600	648
	ES Close Coupled Inline from 150 kW to 1 MW	150	3,600	648
	ES Own Bearing from 150 kW to 1 MW	325	3,000	6,435
8" Submersible bore-hole pumps		33	2,565	7,415
10" Submersible bore-hole pumps		65	2,725	6,731
12" Submersible bore-hole pumps		121	3,114	6,855
Submersible bore-hole pumps larger than 12"		288	3,352	5,213
Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)		68	2,700	6,389
Vertical multi-stage pump (>40 bar and/or >180 m3/hr)		125	3,450	1,488

4.5 End-of-life phase

- **LARGE WATER PUMPS**

These pumps are likely to be returned to factory for refurbishment when their performance deteriorates too far. Pump manufacturers often make more from spares and maintenance than they do from selling new parts. Routine maintenance will be performed in the field.

When these pumps reach the end of their life, as they are all metal they will be sent for scrap. There is little market for second hand pumps.

- **SWIMMING POOL, SPA AND COUNTER CURRENT PUMPS**

Given the cost of these pumps, at failure they are more likely to be repaired. Spare motors are for example readily advertised. The second hard market is only small, as consumers are unlikely to upgrade unless their pump fails.

- **FOUNTAIN, POND AND AQUARIUM PUMPS**

Given the low value of these, they are likely to be disposed of when they fail, not repaired. The motor contains valuable metal, and the plastic pump and case is can be recycled.

It should be noted that 100% separation of the main metal fractions from the pump is difficult and is not actually achieved during scrap treatment leading to, for example, lower iron recycling quality due to its remaining copper content.

The smaller domestic pumps in the study are typically disposed of in the municipal waste collection and not via separate WEEE collection.

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 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 EcoReport model carried out in the screening in Task 1 showed that materials are not responsible for much of the total environmental impact; this does not represent a significant error, and so is not investigated any further.

4.6 Recommendations on mandates

The pumps in the study may be appropriate for regulating as extended products. To facilitate this methodology for calculating an Energy Efficiency Index such as that used in the regulation of circulator pumps. It is recommended that a standardised methodology for calculation this is mandated.

4.7 Conclusion

All the pumps in this study are centrifugal pumps. These pumps impart energy to the water via a rotating impeller. Pump impellers are available in a range of dimensions to allow a wide range of duties to be achieved. Impellers can be physically trimmed to meet the exact required duty; however, pumps are designed to achieve their maximum efficiency with a full sized impeller.

The efficiency of pumping operation relies on all the components within it, not just the pump. Using the appropriate combination of motors, controls and sensors with a pump can have as much of an impact on the overall efficiency of a pumping operation as the design of the pump itself.

The smallest pump in the study is the aquarium pump up to 120W. Almost half of the components within this pump are made of plastic, with the remained of the components from metals. As the other end of the size range the clean water pumps have almost 100 % of their components made of metal, with 85% of the materials being classified as 'other ferrous metals'. The pumps in the middle, such as swimming pool pumps and spa pumps are predominantly made of metal, with plastic components accounting for between 15 – 31% of the materials.

In terms of the end life, the larger pumps tend to be refurbished as their performance degrades, and are sent for scrap on failure. Their high metal content ensures that they are recycled. The swimming pool, spa and counter-current pumps are frequently repaired at failure, and sent for scrap at the end of life. The smaller pumps tend to be replaced on failure owing to their low cost. The motors in these smaller pumps are often recycled due to their high metal content, however the plastic components may not be.



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

ENER Lot 29 – Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under Lot 11) – Task 5: Definition of Base-Case

Final Report to the European Commission, DG ENER
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Task 5: Definition of Base-Case

This task provides an environmental and economic impact assessment of pumps for private and public swimming pools, ponds, fountains, aquariums, and clean water pumps larger than those regulated under ENER Lot 11 in the EU-27, also known as the "Base-Cases". A Base-Case (BC) is "a conscious abstraction of reality" used to represent a range of similar products on the market.

The aim of the assessment is to quantify:

- The environmental impacts of the product throughout its life cycle
- 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 method used to develop these impacts is 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]. The MEEuP methodology was updated in 2011 by the European Commission in the Methodology for Ecodesign of Energy related products (MEErP)[2]. The present preparatory study uses the MEEuP as required by the contract, although some aspects of the MEErP are used:

- Electricity rates
- Discount rate

While this study has been completed as comprehensively and accurately as possible, it relies on data 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 manipulating 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 pumps for private and public swimming pools, ponds, fountains and aquariums, as well as clean water pumps larger than those regulated under ENER Lot 11 in Europe.

The description of the Base-Cases is the synthesis of the results of Tasks 1 to 4. 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] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/methodology/index_en.htm

[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

5.1 Overview of 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 models that are common on the EU market, bear a large environmental burden, and have the potential to improve their environmental performance. The most appropriate BCs for this study are selected through discussion with the European Commission and the stakeholders, using the above criteria as guidelines. The broad range of products included in the initial scope of this preparatory study makes it difficult to compare and prioritise pumps with so different applications. Therefore, for the purpose of this task, all product groups will be analysed as BC. This will show the environmental and economic stakes of Lot 29 pumps.

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. 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 Base-Cases based on preliminary information gathered during Task 1 of this preparatory study, from industry stakeholders and technical literature. The total energy consumption of the product stock at EU-27 level is estimated for the year 2011. Stakeholders have provided the specific energy saving potentials. This estimate is a first guess and should be treated as such and it is only used for the Base-Case selection and will be refined in Tasks 6 (technical analysis of Best Available Technologies) and 7 (improvement potential) for the purpose of Task 8 (policy and scenario analysis).

Eleven BCs have emerged in this study. Such a high number of BCs is necessary to cover the broad range of ENER Lot 29 water pump products. The main parameters of the selected Base-Cases are presented in Table 5-1

.

Table 5-1: Overview of clean water pumps product Base-Cases (Source: Europump)

	Pump type (and sub-categories)	EU Installed stock 2011	EU Annual sales (2011)	Hydraulic pump power	Annual operating hours	Annual energy consumption at EU level*	Improvement potential (product)	Potential savings at EU level 2011 (product)	Potential energy saving to overall market from EPA Regulation	Actual saving potential from EPA regulation	Base-case
		Units	Units	kW	Hours	GWh	%	GWh	%	GWh	
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	4,800,000	480,000	0.8	1,500	6,912	2.0%	138.2	10%	691.2	BC-1 SPPS
	Domestic/commercial with built in strainer over 2.2 kW	115,000	11,500	5	3,375	2,329	2.0%	46.6	10%	232.9	BC-2 SPPL
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	1,845,000	205,000	0.02	6,000	266	2.0%	13.3	0.0%	0.0	BC-3 FPP
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	8,050,000	1,150,000	0.005	8,720	421	2.0%	21..1	0.0%	0.0	BC-4 & 5 AP
	Aquarium power head to 120W	350,000	50,000	0.005	8,720	18	2.0%	0.9	0.0%	0.0	
	Spa pumps for domestic & commercial spa's	42,000	4,200	1.1	350	19	2.0%	0.6	0.0%	0.0	BC-6 SPA
	Counter-Current Pumps	1,000,000	100,000	3	20	72	2.0%	1.4	0.0%	0.0	BC-7 CCP
End suction (ES) water pumps (over 150kW-P2)	ES CloseCoupled from 150 kW to 1 MW	1,000	100	150	3,600	648	1.0%	6.5	12.5%	81.0	BC-8 ESCC
	ES CloseCoupled Inline from 150 kW to 1 MW	1,000	100	150	3,600	648	1.0%	6.5	12.5%	81.0	BC-9 ESCCIL
	ES Own Bearing from 150 kW to 1 MW	5,500	550	325	3,000	6,435	1.0%	64.4	12.5%	804.4	BC-10 ESOB
Submersible bore-hole pumps	8" Submersible bore-hole pumps	73,000	7,300	33	2,565	7,415	2.0%	148.3	12.8%	945.4	BC-11 SBHP
	10" Submersible bore-hole pumps	31,670	3,167	65	2,725	6,731	2.0%	134.6	12.8%	858.3	
	12" Submersible bore-hole pumps	15,160	1,516	121	3,114	6,855	2.0%	137.1	12.8%	874.0	
	Submersible bore-hole pumps larger than 12"	4,500	450	288	3,352	5,213	1.3%	69.3	12.8%	664.7	
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)	29,000	2,900	68	2,700	6,389	2.0%	127.8	12.5%	798.7	BC-12 VMSP
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	2,875	275	125	3,450	1,488	1.5%	22.3	12.5%	186.0	
Totals		16,365,705	2,017,058			51,859		939		6,217.4	

* Calculated as: ((Hydraulic pump power * Annual operating hours) +20%) * EU Installed stock where 20% is the motor absorbed power, as suggested by stakeholders.

5.2 Product Specific Inputs

In this section a description of the characteristics of the selected Base-Cases and the specific inputs used for the environmental and economic analysis are presented, as well as the justification of all the assumptions made.

Average Bills of Materials (BOMs) were received from Europump for each BC. 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.

5.2.1 Swimming pool pumps (integrated motor+pump)

5.2.1.1 Inputs in the production and distribution phase

The average material consumptions including packaging of domestic and commercial swimming pool pumps with built in strainer are included in Table 5-2. The biggest share of materials for both BC-1 and BC-2 is characterised by the manufacturers as "steel". BC-2 also includes a high share of other ferrous and non-ferrous metals, while B-1 presents a higher share of plastic components.

Table 5-2: Bill of materials of BC-1 and BC-2

		BC-1 SPPS	BC-2 SPPL
		kg	kg
Product	Steel	6.16	11.90
	Cast Iron	-	5.66
	Other ferrous metals	-	-
	Non-ferrous metals	3.5	4.07
	Plastics	4.34	2.61
	Coatings	-	-
	Electronics	-	-
	Other Materials	-	-
	Total	**14.00**	**24.24**
Packaging	Plastics	0.250	0.100
	Cardboard	1.175	2.475
	Paper	-	-
	Other (please specify):	-	3.000
	Total	1.425	5.575
		m^3	m^3
	Volume of packaged product	0.1	0.2

5.2.1.2 Inputs in the use phase

Swimming pool pumps do not run continuously therefore their energy consumption were calculated based on the average working hours per year specified in task 3. Energy consumption per year refers to the annual electricity consumption corresponding to a base-case.

Table 5-3: Inputs in the use phase of BC-1 and BC-2

	BC-1 SPPS	BC-2 SPPL
Product life in years	20	20
Energy consumption per year (kWh)*	1,440	20,250

* Calculated as ((Hydraulic pump power * Annual operating hours) +20%)

5.2.1.3 Inputs in the end-of-life phase

For the end of life phase, the same approach as in the ENER Lot 11 preparatory study on pumps is followed. The percentage in weight of the product destined to landfill is estimated in 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). The recycling rate of the metal and miscellaneous fraction is fixed by the MEEuP at 95%[3].

Table 5-4: Inputs in the End-of-life phase of BC-1 and BC-2

Disposal: Environmental Costs per kg final product	BC-1 and BC-2
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%

5.2.1.4 Economic inputs

The market data, product price and user expenditure inputs are estimated based on literature and information provided by stakeholders, and shown in detail in the Task 2 report.

The electricity rates are provided by the MEErP methodology. The discount rate is defined as the interest rate minus the inflation rate. A discount rate of 4% (same for all Base-Cases) obtained from MEErP methodology is used for the Life Cycle Cost (LCC) analysis.

[3] Some stakeholders suggested that the assumption of 95% metal recycling is wrong, as for small pumps only iron/steel content is recycled; the valuable copper part will contaminate the iron recycling and will not be recycled separately. However, the 95% recycling rate for metals is a fixed value in the Methodology for Ecodesign of Energy Using Products (MEEuP) used in all the preparatory studies and it is not in the hand of this project team to question or modify this value. In any case, the project team has studied the influence of the parameters lifetime and metal recycling on the results of the environmental assessment carried out in this Task 5. It was observed that when the recycling rate of metallic parts varies from the default 95% to 50% or to 5% recycling rate, the results of the environmental analysis do not change. This proves that the metals recycling rate does not have much influence in the results of the Ecoreport.

Table 5-5: Inputs to economic analysis in EcoReport for BC-1 and BC-2

	BC-1 SPPS	BC-2 SPPL
Annual sales 2011	480,000	11,500
EU stock 2011	4,800,000	115,000
Average product purchase price (€)	330	1,500
Installation costs (€)	250	500
Electricity rate (€/kWh)	0.11	0.11
Repair & maintenance costs (incl. VAT) (€/yr)	0	50

5.2.2 Fountain, pond, aquarium, spa and counter-current pumps

5.2.2.1 Inputs in the production and distribution phase

The average material consumptions during the production of fountain, pond, aquarium, spa and counter-current pumps are included in Table 5-6. Cast iron characterises the biggest share of materials for BC-3 and BC-4&5. On the other hand, BC-6 and BC-7 are mainly made of steel.

Table 5-6: Bill of materials of BC-3 to BC-7

		BC-3 FPP	BC-4&5			BC-6 SPA	BC-7 CCP
			AP	APH	Weighted average [4]		
		kg	kg	kg	kg	kg	kg
Product	Steel	0.01	-	-	-	11.00	13.5
	Cast Iron	1.42	0.2	0.1	0.2	-	3.0
	Other ferrous metals	-	-	-	-	-	-
	Non-ferrous metals	0.95	0.2	0.1	0.2	7.2	4.7
	Plastics	0.90	0.57	0.1	0.55	6.8	4.1
	Coatings	-	-	-	-	-	-
	Electronics	-	-	-	-	-	-
	Other Materials	1.22	0.26	0.2	0.26	-	2.2
	Total	4.5	1.23	0.6	1.20	25.0	27.5
Packaging	Plastics	0.01	-	-	-	-	0.375
	Cardboard	0.32	0.35	0.2	0.34	3.5	2
	Paper	0.04	-	-	-	1	0.5
	Other (please specify):	0.02	-	-	-	2	1.75
	Total	0.39	0.35	0.2	0.34	6.5	4.625
		m^3	m^3	m^3	m^3	m^3	m^3
	Volume of packaged product	0.02	0.01	0.01	0.01	0.2	0.2

[4] Weighted average refers to the weighted data of the group of pumps in the corresponding base-case, weighted based on the pump sales in year 2011.

5.2.2.2 Inputs in the use phase

The annual energy consumption of BC-3 to BC-7 pumps is given in Table 5-7.

Table 5-7: Inputs in the use phase of BC-3 to BC-7

	BC-3 FPP	BC-4&5			BC-6 SPA	BC-7 CCP
		AP	APH	Weighted average 4		
Product life in years	9	7	7	7	20	20
Energy consumption per year (kWh)*	144	52	52	52	462	72

5.2.2.3 Inputs in the end-of-life phase

For fountain pumps, spa pumps and counter-current pumps, the assumptions in the end-of-life phase are the same as those presented for BC-1 and BC-2 in section 5.2.1.3.

For aquarium pumps and power heads, a different scenario of end-of-life is assumed, since some aquarium equipment (i.e. lighting systems and water heaters) are covered by the WEEE Directive, an equal treatment was given to the aquarium pumps.. Based on WEEE statistics[5], the percentage in weight of the product destined to landfill is estimated in 20%. From the recovered share of plastics, 94% is destined to materials recycling and the rest 6% to thermal recycling (energy recovery).

For all cases, the recycling rate of the metal and miscellaneous fraction is fixed by the MEEuP at 95%.

Table 5-8: Inputs in the End-of-life phase of BC-3, BC-4&5, BC-6 and BC-7

Disposal: Environmental Costs per kg final product	BC-4&5	BC-3, BC-6 & BC-7
Landfill (fraction products not recovered) (%)	20%	8%
Re-use, Recycling Benefit		
Plastics: Re-use, Closed Loop Recycling (%)	0%	1%
Plastics: Materials Recycling (%)	94%	9%
Plastics: Thermal Recycling (%)	6%	90%

5.2.2.4 Economic inputs

The market data, product price and user expenditure inputs are estimated based on literature and information provided by stakeholders. These are shown in detail in the Task 2 report.

As in BC-1 and BC-2, the electricity rates are provided by the MEErP methodology (see section 5.2.1.4).

[5] Eurostat online database

Table 5-9: Inputs to economic analysis in EcoReport for BC-3 to BC-7

	BC-3 FPP	BC-4&5			BC-6 SPA	BC-7 CCP
		AP	APH	Weighted average[6]		
Annual sales 2011	205,000	1,150,000	50,000	1,200,000	4,200	100,000
EU stock 2011	1,845,000	8,050,000	350,000	8,400,000	42,000	1,000,000
Average product purchase price (€)	100	50	45	49.8	275	1,325
Installation costs (€)	0	0	0	0	450	500
Electricity rate (€/kWh)	0.11	0.11	0.11	0.11	0.11	0.11
Repair & maintenance costs (incl. VAT) (€/yr)	0	0	0	0	0	0

5.2.3 End suction (ES) water pumps (over 150kW-P2)

5.2.3.1 Inputs in the production and distribution phase

The average consumption of materials in the production phase including packaging of end-suction water pumps (over 150kW-P2) is included in Table 5-10.

BOMs for packaging of end suction water pumps (over 150kW-P2) were acquired from ENER Lot 11 – Water pumps (in commercial buildings, drinking water pumping, food industry, agriculture). The biggest share of materials for BC-8 to BC-10 is characterised by the manufacturers as cast iron.

Table 5-10: Bill of materials of BC-8 to BC-10

		BC-8 ESCC	BC-9 ESCCI	BC-10 ESOB
		kg	kg	kg
Product	Steel	84.5	84.5	84.5
	Cast Iron	552.5	552.5	552.5
	Other ferrous metals	-	-	-
	Non-ferrous metals	13	13	13
	Plastics	-	-	-
	Coatings	-	-	-
	Electronics	-	-	-
	Other Materials	-	-	-
	Total	650	650	650
Packaging	Plastics	3	3	1
	Cardboard	7	7	7
	Paper	-	-	-
	Other (please specify):	-	-	-
	Total	10	10	8
		m^3	m^3	m^3

[6] Weighted average refers to the weighted data of the group of pumps in the corresponding base-case, weighted based on the pump sales in year 2011

		BC-8 ESCC	BC-9 ESCCI	BC-10 ESOB
		kg	kg	kg
	Volume of packaged product	0.6	0.6	0.6

5.2.3.2 *Inputs in the use phase*

The energy consumption of BC-8 to BC-10 pumps is given for one annual cycle in Table 5-11.

Table 5-11: Inputs in the use phase of BC-8 to BC-10

	BC-8 ESCC	BC-9 ESCCI	BC-10 ESOB
Product life in years	20	20	20
Energy consumption per year (kWh)*	648,000	648,000	1,170,000

* Calculated as ((Hydraulic pump power * Annual operating hours) +20%)

5.2.3.3 *Inputs in the end-of-life phase*

The assumptions in the end-of-life phase are the same as those presented for BC-1 and BC-2 in section 5.2.1.3.

5.2.3.4 *Economic inputs*

The market data, product price and user expenditure inputs are estimated based on literature and information provided by stakeholders, and shown in detail in the Task 2 report.

The electricity rates are provided by the MEErP methodology (see section 5.2.1.4)

Table 5-12: Inputs to economic analysis in EcoReport for BC-8 to BC-10

	BC-8 ESCC	BC-9 ESCCI	BC-10 ESOB
Annual sales 2011	100	100	550
EU stock 2011	1,000	1,000	5,500
Average product purchase price (€)	8,000	8,000	8,000
Installation costs (€)	2,000	2,000	2,000
Electricity rate (€/kWh)	0.11	0.11	0.11
Repair & maintenance costs (incl. VAT) (€/yr)	500	500	500

5.2.4 Submersible borehole pumps and vertical multi-stage pumps

5.2.4.1 *Inputs in the production and distribution phase*

The average consumptions including packaging of vertical multi-stage pumps are included in Table 5-13.

BOMs for BC-12 packaging were acquired from ENER Lot 11 – Water pumps (in commercial buildings, drinking water pumping, food industry, agriculture).

The biggest share of materials for BC-11 and BC-12 is characterised by the manufacturers as cast iron.

Table 5-13: Bill of materials of BC-11 and BC-12

		BC-11 SBHP					BC-12 VMSP		
		8"	10"	12"	>12"	Weighted average[7]	25 to 40 bar and/or 100 to 180 m³/hr	>40 bar and/or >180 m³/hr	Weighted average7
		kg	kg	kg	kg	Kg	kg	kg	kg
Product	Steel	93.1	249.9	313.6	1274	183.32	91.90	117.50	94.12
	Cast Iron	96.9	260.1	323.4	1326	190.37	185.64	998.75	256.07
	Other ferrous metals	-	-	-	-	-	-	-	-
	Non-ferrous metals	-	-	-	-	-	2.73	58.75	7.58
	Plastics	1.9	5.1	6.4	26	3.74	2.73	-	2.49
	Coatings	-	-	-	-	-	-	-	-
	Electronics	-	-	-	-	-	-	-	-
	Other Materials	-	-	-	-	-	-	-	-
	Total	191.9	515.1	643.4	2626	377.43	283.00	1175.00	360.26
Packaging	Plastics	2	3	4	6	2.62	1	1	1
	Cardboard	5.25	7.75	9.5	12.75	6.66	8.3	25	9.75
	Paper	-	-	-	-	-	-	-	-
	Other : Steel wrap	-	-	-	-	-	-	-	-
	Other: Wood	24	43	62	111	35.90	25.5	43.3	27.04
	Total	31.25	53.75	75.5	129.75	45.19	34.8	69.3	37.79
		m³	m³	m³	m³	m³	m³	m³	m³
	Volume of packaged product	0.3	0.6	0.7	0.8	0.4	0.5	0.6	0.5

5.2.4.2 Inputs in the use phase

The energy consumption of BC-11 and BC-12 pumps is given for 1 annual cycle in Table 5-14.

[7] Weighted average refers to the weighted data of the group of pumps in the corresponding base-case, weighted based on the pump sales in year 2011

Table 5-14: Inputs in the use phase of BC-11 and BC-12

	BC-11 SBHP					BC-12 VMSP		
	8"	10"	12"	>12"	Weighted average[8]	25 to 40 bar and/or 100 to 180 m^3/hr	>40 bar and/or >180 m^3/hr	Weighted average
Product life in years[9]	11	11	11	11	11	12	12	12
Energy consumption per year (kWh)*	101,574	212,550	452,153	1,158,451	210,842	220,320	517,500	246,060

* Calculated as ((Hydraulic pump power * Annual operating hours) +20%)

5.2.4.3 *Inputs in the end-of-life phase*

The assumptions in the end-of-life phase are the same as those presented for BC-1 and BC-2 in 5.2.1.3.

5.2.4.4 *Economic inputs*

The market data, product price and user expenditure inputs are estimated based on literature and information provided by stakeholders, and shown in detail in the Task 2 report.

The electricity rates are provided by the MEErP methodology (see section 5.2.1.4)

Table 5-15: Inputs to economic analysis in EcoReport for BC-11 and BC-12

	BC-11 SBHP					BC-12 VMSP		
	8"	10"	12"	>12"	Weighted average4	25 to 40 bar and/or 100 to 180 m3/hr	>40 bar and/or >180 m3/hr	Weighted average 4
Annual sales 2011	7,300	3,167	1,516	450	12,433	2,900	275	3,175
EU stock 2011	73,000	31,670	15,160	4,500	124,330	29,000	2,875	31,875
Average product purchase price (€)	6,135	8,000	10,000	12,000	7,293	10,000	33,000	11,992
Installation costs (€)	3,000	3,000	3,000	4,000	3,036	2,000	2,000	2,000
Electricity rate (€/kWh)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Repair & maintenance costs (incl. VAT) (€/yr)	2,000	2,000	2,500	3,000	2,097	1,000	1,000	1,000

[8] Weighted average refers to the weighted data of the group of pumps in the corresponding base-case, weighted based on the pump sales in year 2011

[9] One stakeholder suggested that the average lifetime of submersible bore-hole pumps and vertical multi stage pumps should be 20 or 25 years, since these big pumps are repaired rather than dismantled. This change in the lifetime of pumps would entail a significant variation in environmental impacts and life cycle costs of the pumps. Thus, the project team will include a sensitivity analysis of this lifetime change in Task 8, and analyse how this would affect the choice of policy scenarios and their economic impacts.

5.3 Base-Case Environmental Impacts

In the following sections, the environmental impacts throughout all the life-cycle stages of the Base-Cases are presented. These results were calculated using the EcoReport tool provided in the MEEuP methodology based on the inputs presented in the previous section. The MEEuP methodology tracks 17 environmental impact categories, classified in three groups:

- 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)

This analysis of the environmental impacts 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 7.

5.3.1 Domestic swimming pool pump with built in strainer up to 2.2 kW

The results of the environmental analysis of BC-1 (domestic swimming pool pump with built in strainer up to 2.2 kW) are shown in Table 5-16 and in Figure 5-1. According to these, the energy consumption during the use phase is the most predominant aspect contributing to the environmental impacts from the product's entire life cycle.. The end-of-life phase and the production phase (material consumption and manufacturing) account for less than 40% of all environmental impacts, and the environmental impacts generated during the distribution phase are negligible except for the contribution to particulate matter. The use phase contributes with more than 90% of the overall environmental impacts for 10 environmental impact categories:

- Total Energy (GER) 99.5%
- of which, electricity (in primary MJ) 99.9%
- Water (process) 99.9%
- Water (cooling) 100.0%
- Greenhouse Gases in GWP100 99.4%
- Acidification, emissions 96.0%
- Volatile Organic Compounds (VOC) 83.8%
- Heavy Metals into air 95.1%
- PAHs 92.3%
- Heavy Metals into water 96.3%

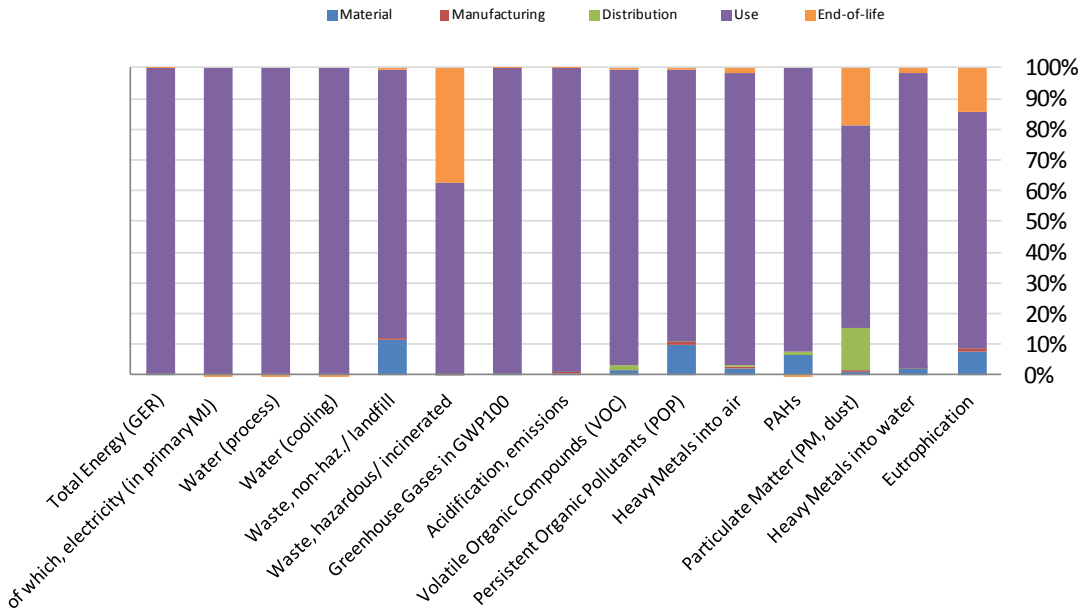


Figure 5-1: Distribution of the BC-1's environmental impacts by life cycle phase

Table 5-16: Life cycle impact (per unit) of BC-1: Domestic swimming pool pump with built in strainer up to 2.2 kW

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	940	311	1,251	163	302,413	365	264	101	303,927
of which, electricity (in primary MJ)	MJ	62	183	245	0	302,402	0	2	-2	302,646
Water (process)	ltr	24	3	27	0	20,160	0	1	-1	20,186
Water (cooling)	ltr	142	83	225	0	806,402	0	10	-10	806,618
Waste, non-haz./ landfill	g	47,225	1,193	48,417	97	351,100	1,514	7	1,508	401,121
Waste, hazardous/ incinerated	g	26	0	27	2	6,968	4,131	1	4,130	11,127
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	46	17	63	11	13,197	27	18	9	13,280
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	634	75	710	32	77,875	55	24	31	78,647
Volatile Organic Compounds (VOC)	g	2	0	2	2	114	1	0	1	119
Persistent Organic Pollutants (POP)	ng i-Teq	226	17	242	1	1,985	11	0	11	2,238
Heavy Metals	mg Ni eq.	122	39	161	5	5,190	100	0	100	5,455
PAHs	mg Ni eq.	43	0	43	7	596	0	0	0	646
Particulate Matter (PM, dust)	g	33	12	45	342	1,664	474	1	473	2,523
Emissions (Water)										
Heavy Metals	mg Hg/20	45	0	45	0	1,950	30	0	30	2,025
Eutrophication	g PO_4	1	0	1	0	9	2	0	2	12
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

5.3.2 Domestic swimming pool pump with built in strainer over 2.2 kW

The results of the environmental analysis of BC-2 (domestic swimming pool pump with built in over 2.2 kW) are shown in Table 5-17 and in Figure 5-2. Similarly to BC-1, the energy consumption during the use phase is the most predominant aspect contributing to the environmental impacts from the product's entire life cycle. The use phase contributes with more than 94% of the overall environmental impacts for 15 environmental impact categories. The environmental impacts generated in the rest of the life cycle phases are negligible.

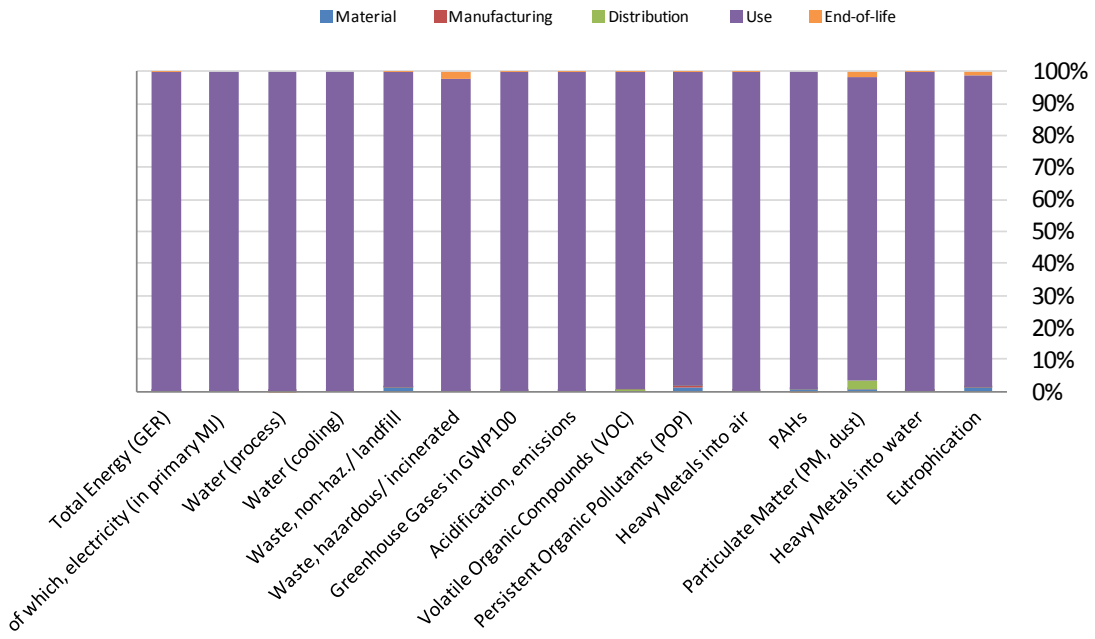


Figure 5-2: Distribution of the BC-2's environmental impacts by life cycle phase

Table 5-17: Life cycle impact (per unit) of BC-2: Domestic swimming pool pump with built in strainer over 2.2 kW

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	1,225	352	1,577	274	4,252,516	329	225	104	4,254,470
of which, electricity (in primary MJ)	MJ	65	205	271	1	4,252,503	0	1	-1	4,252,773
Water (process)	ltr	55	3	58	0	283,501	0	1	-1	283,558
Water (cooling)	ltr	105	90	195	0	11,340,002	0	6	-6	11,340,191
Waste, non-haz./ landfill	g	64,969	1,527	66,496	142	4,931,197	2,925	4	2,921	5,000,757
Waste, hazardous/ incinerated	g	17	0	17	3	97,990	2,439	1	2,438	100,448
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	71	20	91	18	185,578	25	16	8	185,694
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	779	86	866	52	1,095,027	49	21	28	1,095,973
Volatile Organic Compounds (VOC)	g	3	0	3	4	1,602	1	0	1	1,610
Persistent Organic Pollutants (POP)	ng i-Teq	420	32	452	1	27,878	20	0	20	28,351
Heavy Metals	mg Ni eq.	170	75	245	7	72,959	92	0	92	73,304
PAHs	mg Ni eq.	49	0	49	11	8,378	0	0	0	8,438
Particulate Matter (PM, dust)	g	128	13	141	684	23,390	427	0	427	24,642
Emissions (Water)										
Heavy Metals	mg Hg/20	74	0	74	0	27,420	27	0	27	27,521
Eutrophication	g PO_4	2	0	2	0	131	2	0	2	134
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

5.3.3 Fountain and pond pumps up to 1 kW

The results of the environmental analysis of BC-3 (fountain and pond pumps up to 1 kW) are shown in Table 5-18 and in Figure 5-3. According to these, the energy consumption during the use phase is the most predominant aspect contributing to the environmental impacts from the product's entire life cycle. The use phase contributes with more than 50% of the overall environmental impacts for 12 out of the 17 environmental impact categories:

- Total Energy (GER) 97.5%
- of which, electricity (in primary MJ) 99.7%
- Water (process) 97.9%
- Water (cooling) 99.9%
- Waste, non-haz./ landfill 58.8%
- Greenhouse Gases in GWP100 96.9%
- Acidification, emissions 94.7%
- Volatile Organic Compounds (VOC) 83.8%
- Persistent Organic Pollutants (POP) 74.7%
- Heavy Metals into air 80.7%
- PAHs 64.5%
- Heavy Metals into water 85.9%

The end-of-life phase contributes 71.9% to the impacts of hazardous/ incinerated waste. On the other hand, the distribution phase contributes 24.8% for the emissions of Particulate Matter.

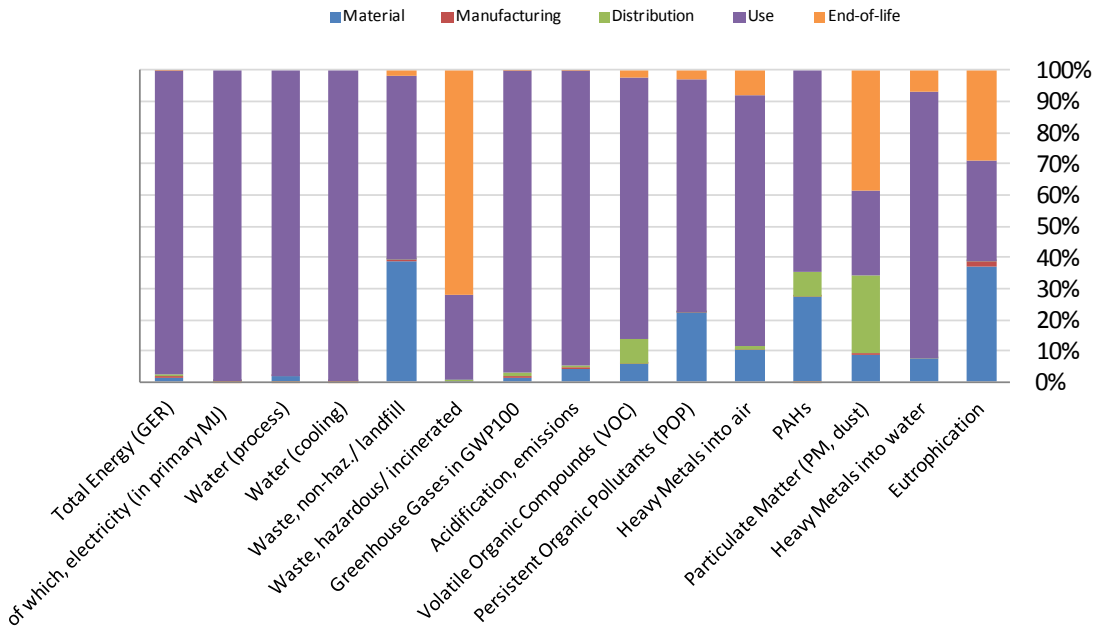


Figure 5-3: Distribution of the BC-3's environmental impacts by life cycle phase

Table 5-18: Life cycle impact (per unit) of BC-3: Fountain and pond pump up to 1 kW

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	223	44	267	74	13,627	82	72	10	13,978
of which, electricity (in primary MJ)	MJ	13	26	39	0	13,625	0	0	0	13,663
Water (process)	ltr	19	0	19	0	908	0	0	0	928
Water (cooling)	ltr	33	12	46	0	36,332	0	2	-2	36,376
Waste, non-haz./ landfill	g	10,459	137	10,596	60	15,903	480	1	479	27,038
Waste, hazardous/ incinerated	g	5	0	5	1	314	819	0	819	1,139
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	9	2	12	6	595	6	5	1	613
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	164	10	174	16	3,510	12	7	6	3,706
Volatile Organic Compounds (VOC)	g	0	0	0	0	5	0	0	0	6
Persistent Organic Pollutants (POP)	ng i-Teq	27	0	27	0	90	3	0	3	120
Heavy Metals	mg Ni eq.	30	0	30	3	234	23	0	23	290
PAHs	mg Ni eq.	11	0	11	3	27	0	0	0	42
Particulate Matter (PM, dust)	g	24	2	26	69	75	107	0	107	276
Emissions (Water)										
Heavy Metals	mg Hg/20	7	0	7	0	88	7	0	7	102
Eutrophication	g PO_4	0	0	1	0	0	0	0	0	1
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

5.3.4 Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W and aquarium power head to 120 W

The results of the environmental analysis of BC-4&5 (aquarium pumps (domestic/small aquarium - non-commercial) to 120 W and aquarium power head to 120 W) are shown in Table 5-19 and in Figure 5-4. According to these, the energy consumption during the use phase is the most predominant aspect contributing to the environmental impacts from the product's entire life cycle. Running aquarium pumps contributes over 60% of total environmental impact during the use-phase for the emissions and resources below:

- Total Energy (GER) 95.9%
- of which, electricity (in primary MJ) 99.5%
- Water (process) 97.9%
- Water (cooling) 99.9%
- Waste, non-haz./ landfill 62.7%
- Waste, hazardous/ incinerated 70.9%
- Greenhouse Gases in GWP100 94.1%
- Acidification, emissions 94.4%
- Volatile Organic Compounds (VOC) 73.0%
- Persistent Organic Pollutants (POP) 76.3%
- Heavy Metals into air 80.0%
- Heavy Metals into water 87.6%

End-of-life disposal contributes 26.6% to hazardous/incinerated waste; 43.3% to particulate matter emissions, and 38.1% to water eutrophication. For the distribution phase, the highest contribution is from the emissions of Particulate Matter which is 32.5%.

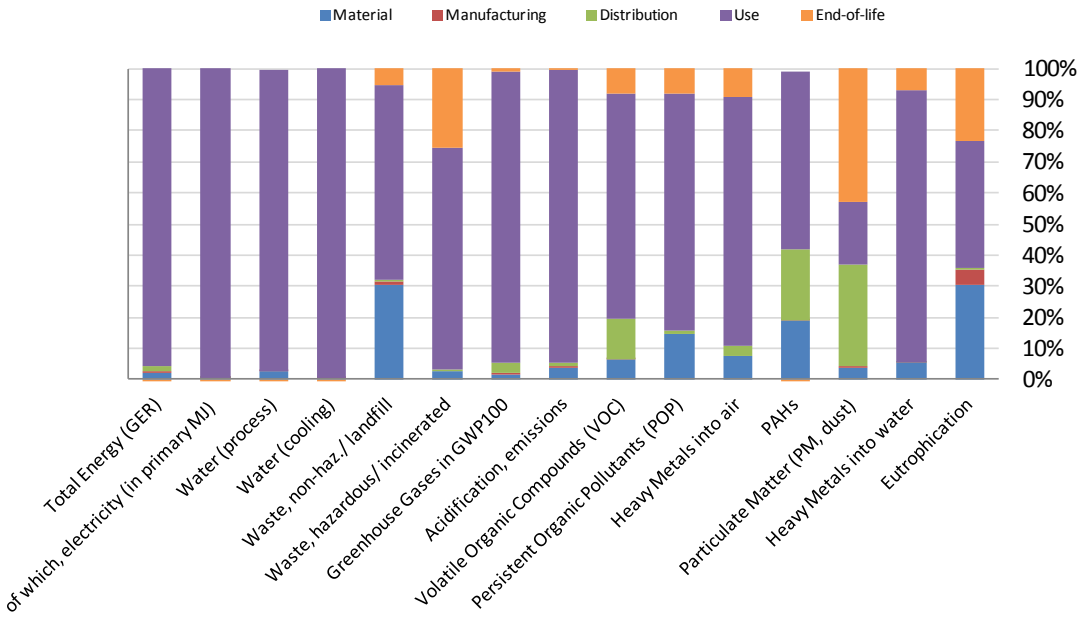


Figure 5-4: Distribution of the BC-4&5's environmental impacts by life cycle phase

Table 5-19: Life cycle impact (per unit) of BC-4&5: Aquarium pumps (domestic/small aquarium non-commercial) pumps up to 120 W and aquarium power head to 120 W

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	80	24	104	63	3,823	27	28	-1	3,988
of which, electricity (in primary MJ)	MJ	7	14	21	0	3,822	0	2	-2	3,841
Water (process)	ltr	6	0	7	0	255	0	1	-1	260
Water (cooling)	ltr	18	7	24	0	10,192	0	10	-10	10,206
Waste, non-haz./ landfill	g	2,150	74	2,224	56	4,454	380	7	373	7,106
Waste, hazardous/ incinerated	g	3	0	3	1	88	33	1	32	124
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	3	1	4	5	167	2	1	1	177
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	36	6	42	14	985	4	2	3	1,043
Volatile Organic Compounds (VOC)	g	0	0	0	0	1	0	0	0	2
Persistent Organic Pollutants (POP)	ng i-Teq	5	0	5	0	25	3	0	3	33
Heavy Metals	mg Ni eq.	6	0	6	3	66	8	0	8	82
PAHs	mg Ni eq.	2	0	2	3	8	0	0	0	13
Particulate Matter (PM, dust)	g	4	1	5	34	21	46	0	46	106
Emissions (Water)										
Heavy Metals	mg Hg/20	1	0	1	0	25	2	0	2	28
Eutrophication	g PO_4	0	0	0	0	0	0	0	0	0
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

5.3.5 Spa pumps for domestic and commercial spas

The results of the environmental analysis of BC-6 (spa pumps for domestic and commercial spas) are shown in Table 5-20 and in Figure 5-5. According to these, the energy consumption during the use phase is the most predominant aspect contributing to the environmental impacts from the product's entire life cycle.

The use phase contributes with more than 50% of the overall environmental impacts for 12 out of 17 environmental impact categories:

- Total Energy (GER) 97.3%
- of which, electricity (in primary MJ) 99.6%
- Water (process) 97.9%
- Water (cooling) 99.9%
- Waste, non-haz./ landfill 53.6%
- Greenhouse Gases in GWP100 96.7%
- Acidification, emissions 94.3%
- Volatile Organic Compounds (VOC) 80.8%
- Persistent Organic Pollutants (POP) 57.5%
- Heavy Metals into air 77.5%
- PAHs 66.2%
- Heavy Metals into water 82.3%

Raw material extraction contributes with more than 25% of the overall environmental impacts for 4 out of 17 environmental impact categories:

- Waste, non hazardous/landfill 44.3%
- POP to air 37.8%
- PAHs 29.9%
- Eutrophication 54.5%

The end-of-life disposal of BC-6 contributes 72.9% hazardous/incinerated waste generation of the overall environmental impact.

Distribution phase contributes 33.2% to the PM emissions to the air.

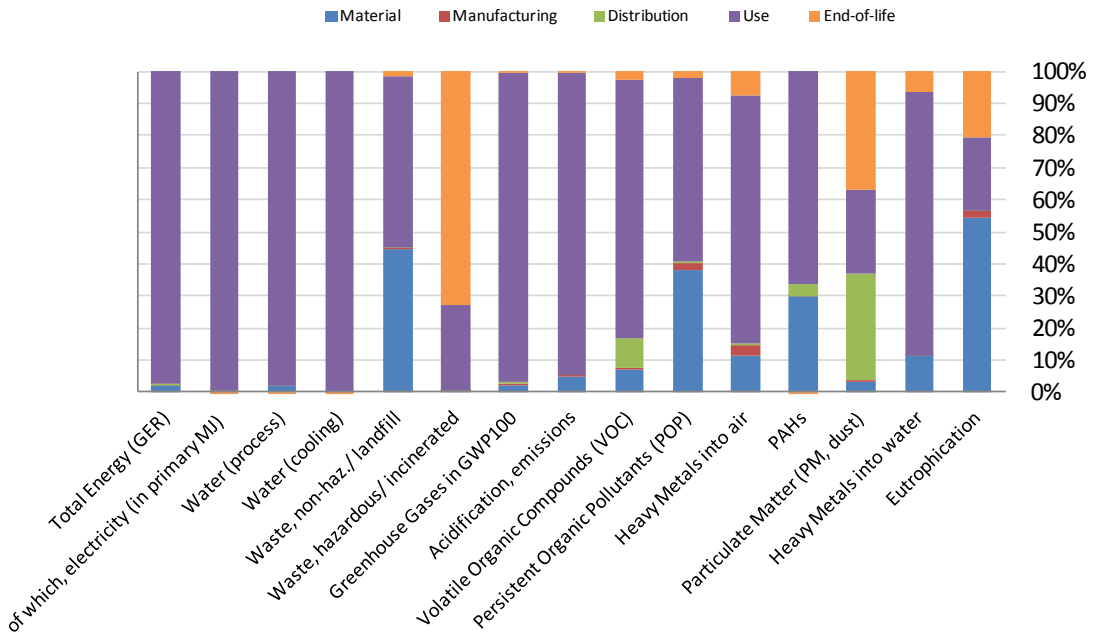


Figure 5-5: Distribution of the BC-6's environmental impacts by life cycle phase

Table 5-20: Life cycle impact (per unit) of BC-6: Spa pumps for domestic and commercial spas

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	1,801	501	2,301	274	97,043	588	470	119	99,737
of which, electricity (in primary MJ)	MJ	109	295	404	1	97,024	0	3	-3	97,426
Water (process)	ltr	138	4	142	0	6,469	0	2	-2	6,610
Water (cooling)	ltr	211	133	344	0	258,723	0	14	-14	259,053
Waste, non-haz./ landfill	g	94,397	1,961	96,357	142	113,453	3,092	10	3,082	213,034
Waste, hazardous/ incinerated	g	40	0	41	3	2,236	6,120	2	6,118	8,398
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	87	28	115	18	4,235	44	33	11	4,379
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	1,284	122	1,406	52	24,997	88	43	45	26,500
Volatile Organic Compounds (VOC)	g	3	0	3	4	37	2	1	1	45
Persistent Organic Pollutants (POP)	ng i-Teq	421	30	451	1	640	21	0	21	1,113
Heavy Metals	mg Ni eq.	246	69	315	7	1,668	162	0	162	2,152
PAHs	mg Ni eq.	87	0	87	11	192	0	0	0	290
Particulate Matter (PM, dust)	g	63	19	81	684	534	763	1	762	2,062
Emissions (Water)										
Heavy Metals	mg Hg/20	86	0	86	0	626	49	0	49	761
Eutrophication	g PO_4	7	0	7	0	3	3	0	3	13
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

5.3.6 Counter-current pumps

The results of the environmental analysis of BC-7 (counter-current pumps) are shown in Table 5-21 and in Figure 5-6. According to these, the energy consumption during the use phase is the most predominant aspect contributing to the environmental impacts from the product's entire life cycle.

The use phase contributes with more than 50% of the overall environmental impacts for 6 out of 17 environmental impact categories.

- Total Energy (GER) 86.7%
- of which, electricity (in primary MJ) 97.7%
- Water (process) 90.8%
- Water (cooling) 99.4%
- Waste, non-haz./ landfill 83.4%
- Greenhouse Gases in GWP100 78.1%

Raw material extraction contributes with more than 50% of the overall environmental impacts for 4 out of 17 environmental impact categories:

- Waste, non-haz./landfill 75.8%
- POP to air 73.7%
- PAHs 57.7%
- Eutrophication 62.1%

The end-of-life disposal of BC-7 contributes 91.4% waste, hazardous/incinerated and 39.8% to emissions of Particulate Matter.

Distribution phase contributes 46.6% to the emissions of particulate matter into the air.

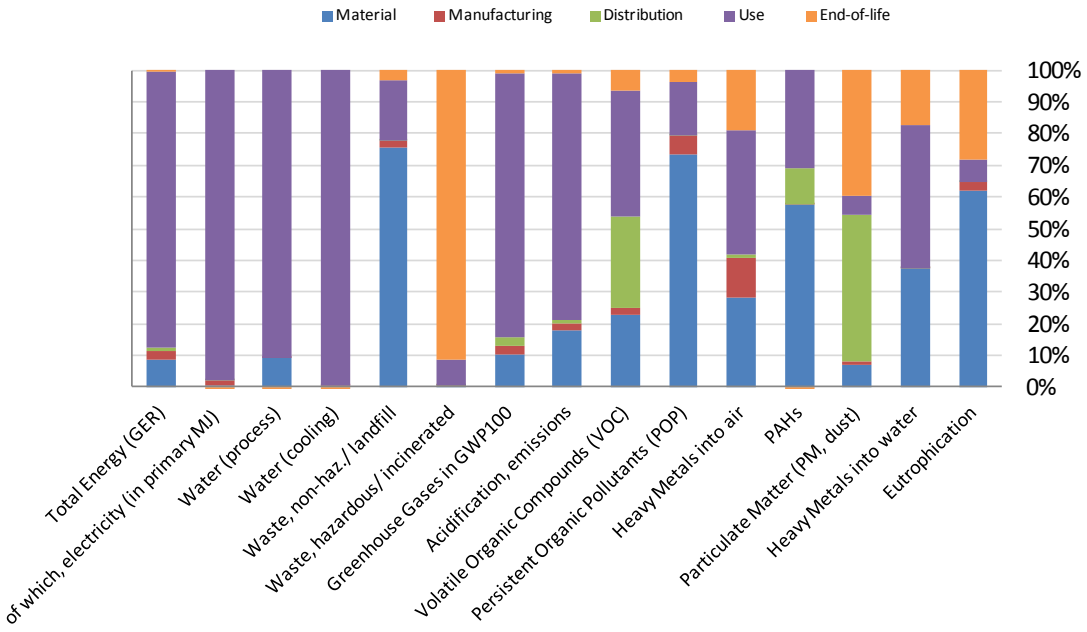


Figure 5-6: Distribution of the BC-7's environmental impacts by life cycle phase

Table 5-21: Life cycle impact (per unit) of BC-7: Counter-current pumps

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	1,483	449	1,933	274	15,139	450	339	111	17,456
of which, electricity (in primary MJ)	MJ	90	263	353	1	15,124	0	2	-2	15,475
Water (process)	ltr	99	4	103	0	1,009	0	1	-1	1,111
Water (cooling)	ltr	150	116	266	0	40,323	0	9	-9	40,579
Waste, non-haz./ landfill	g	73,560	1,889	75,449	142	18,285	3,152	7	3,146	97,022
Waste, hazardous/ incinerated	g	27	0	27	3	349	4,028	1	4,026	4,405
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	80	25	105	18	661	34	24	9	793
Ozone Depletion, emissions	mg R-11 eq.					negligible				
Acidification, emissions	g SO_2 eq.	897	110	1,007	52	3,903	67	31	36	4,999
Volatile Organic Compounds (VOC)	g	3	0	4	4	6	1	0	1	14
Persistent Organic Pollutants (POP)	ng i-Teq	457	36	493	1	104	22	0	22	620
Heavy Metals	mg Ni eq.	189	85	274	7	262	125	0	125	668
PAHs	mg Ni eq.	57	0	57	11	30	0	0	0	99
Particulate Matter (PM, dust)	g	100	17	117	684	84	583	1	583	1,468
Emissions (Water)										
Heavy Metals	mg Hg/20	81	0	81	0	98	37	0	37	217
Eutrophication	g PO_4	5	0	5	0	1	2	0	2	7
Persistent Organic Pollutants (POP)	ng i-Teq					negligible				

5.3.7 End-suction close coupled pumps from 150 kW to 1 MW

The results of the environmental analysis of BC-8 (end-suction close-coupled pumps from 150 kW to 1 MW) are shown in Table 5-22 and in Figure 5-7. According to these, the energy consumption during the use phase is the most predominant aspects contributing to the environmental impacts from the product's entire life cycle. The use phase contributes with more than 98% of the overall environmental impact categories.

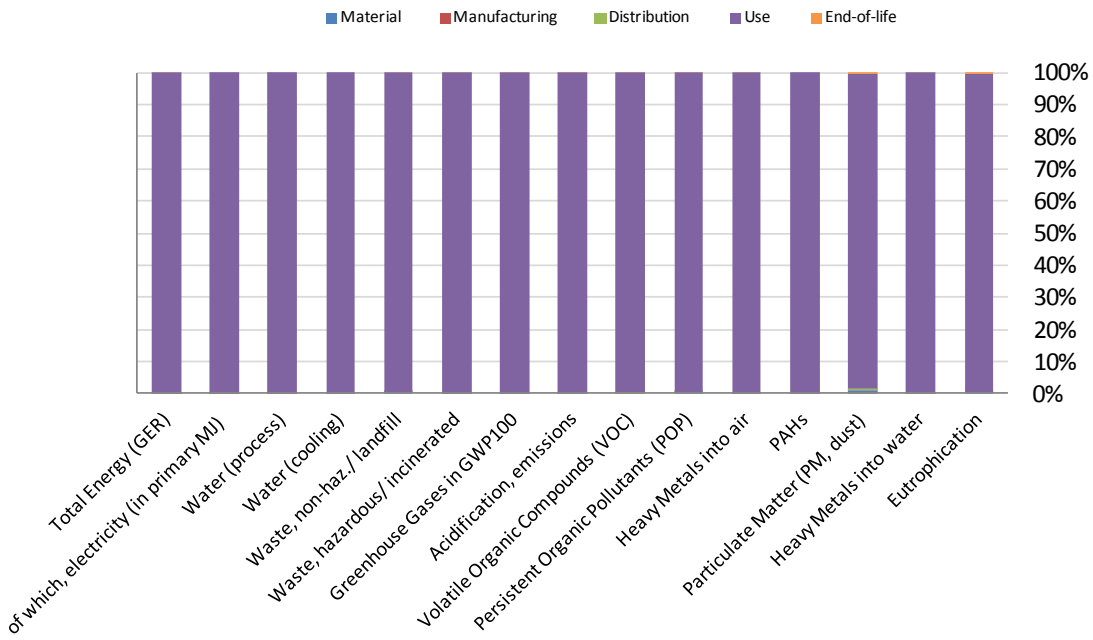


Figure 5-7: Distribution of the BC-8's environmental impacts by life cycle phase

Table 5-22: Life cycle impact (per unit) of BC-8: End-suction close coupled pumps from 150 kW to 1 MW

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	10,110	2,909	13,019	718	136,080,130	3,791	238	3,553	136,097,420
of which, electricity (in primary MJ)	MJ	310	1,703	2,013	2	136,080,020	0	1	-1	136,082,034
Water (process)	ltr	778	24	802	0	9,072,008	0	1	-1	9,072,809
Water (cooling)	ltr	2,115	754	2,869	0	362,880,029	0	6	-6	362,882,892
Waste, non-haz./ landfill	g	455,319	12,130	467,449	324	157,781,712	64,731	4	64,726	158,314,211
Waste, hazardous/ incinerated	g	22	1	23	6	3,135,683	2,700	1	2,699	3,138,412
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	904	164	1,069	44	5,938,466	283	17	266	5,939,844
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	4,519	711	5,230	132	35,040,652	556	22	534	35,046,548
Volatile Organic Compounds (VOC)	g	78	2	80	12	51,252	15	0	15	51,359
Persistent Organic Pollutants (POP)	ng i-Teq	5,756	227	5,983	2	892,008	445	0	445	898,438
Heavy Metals	mg Ni eq.	1,768	533	2,301	16	2,334,643	1,105	0	1,105	2,338,065
PAHs	mg Ni eq.	165	0	165	29	268,081	0	0	0	268,275
Particulate Matter (PM, dust)	g	8,012	109	8,121	2,051	748,521	4,935	0	4,934	763,628
Emissions (Water)										
Heavy Metals	mg Hg/20	886	0	886	1	877,413	315	0	315	878,615
Eutrophication	g PO_4	22	1	23	0	4,184	18	0	18	4,225
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

5.3.8 End-suction close coupled inline pumps from 150 kW to 1 MW

The results of the environmental analysis of BC-9 (end-suction close-coupled inline pumps from 150 kW to 1 MW) are shown in Table 5-23 and in Figure 5-8. According to these, the energy consumption during the use phase is the most predominant aspects contributing to the environmental impacts from the product's entire life cycle. The use phase contributes with more than 98% of the overall environmental impacts for all 15 non-negligible environmental impact categories.

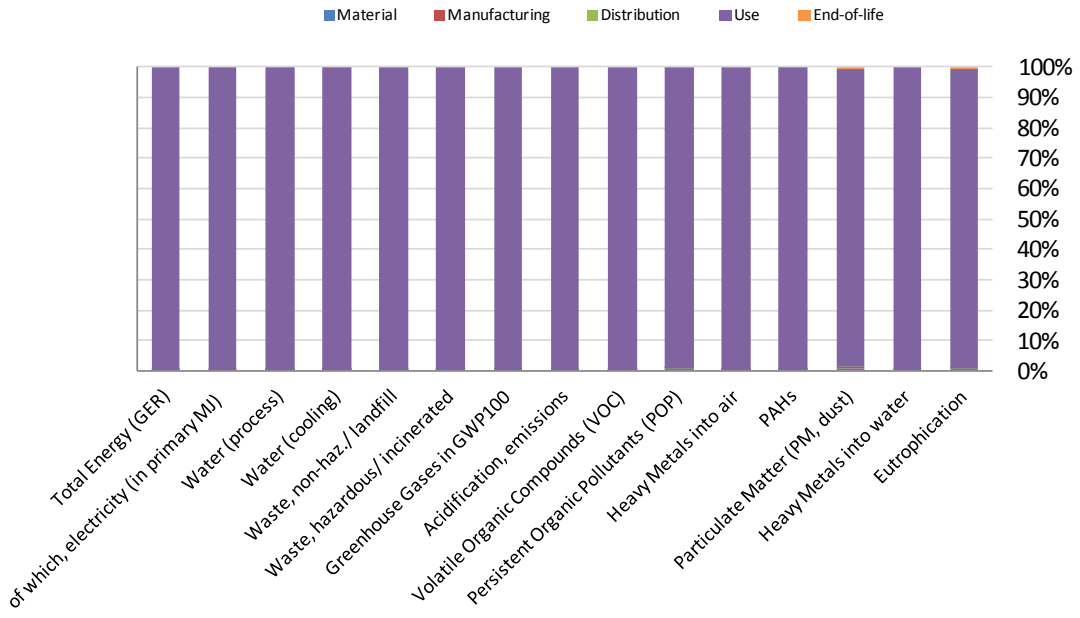


Figure 5-8: Distribution of the BC-9's environmental impacts by life cycle phase

Table 5-23: Life cycle impact (per unit) of BC-9: End-suction close coupled inline pumps from 150 kW to 1 MW

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	10,110	2,909	13,019	718	136,080,130	3,791	238	3,553	136,097,420
of which, electricity (in primary MJ)	MJ	310	1,703	2,013	2	136,080,020	0	1	-1	136,082,034
Water (process)	ltr	778	24	802	0	9,072,008	0	1	-1	9,072,809
Water (cooling)	ltr	2,115	754	2,869	0	362,880,029	0	6	-6	362,882,892
Waste, non-haz./ landfill	g	455,319	12,130	467,449	324	157,781,712	64,731	4	64,726	158,314,211
Waste, hazardous/ incinerated	g	22	1	23	6	3,135,683	2,700	1	2,699	3,138,412
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	904	164	1,069	44	5,938,466	283	17	266	5,939,844
Ozone Depletion, emissions	mg R-11 eq.	negible								
Acidification, emissions	g SO_2 eq.	4,519	711	5,230	132	35,040,652	556	22	534	35,046,548
Volatile Organic Compounds (VOC)	g	78	2	80	12	51,252	15	0	15	51,359
Persistent Organic Pollutants (POP)	ng i-Teq	5,756	227	5,983	2	892,008	445	0	445	898,438
Heavy Metals	mg Ni eq.	1,768	533	2,301	16	2,334,643	1,105	0	1,105	2,338,065
PAHs	mg Ni eq.	165	0	165	29	268,081	0	0	0	268,275
Particulate Matter (PM, dust)	g	8,012	109	8,121	2,051	748,521	4,935	0	4,934	763,628
Emissions (Water)										
Heavy Metals	mg Hg/20	886	0	886	1	877,413	315	0	315	878,615
Eutrophication	g PO_4	22	1	23	0	4,184	18	0	18	4,225
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

5.3.9 End suction own bearing pumps from 150 kW to 1 MW

The results of the environmental analysis of BC-10 (end-suction own bearing water pumps from 150 kW to 1 MW) are shown in Table 5-24 and in Figure 5-9. According to these, the energy consumption during the use phase is the most predominant aspects contributing to the environmental impacts from the product's entire life cycle. The use phase contributes with more than 99% of the overall environmental impacts for all 15 non-negligible impact categories.

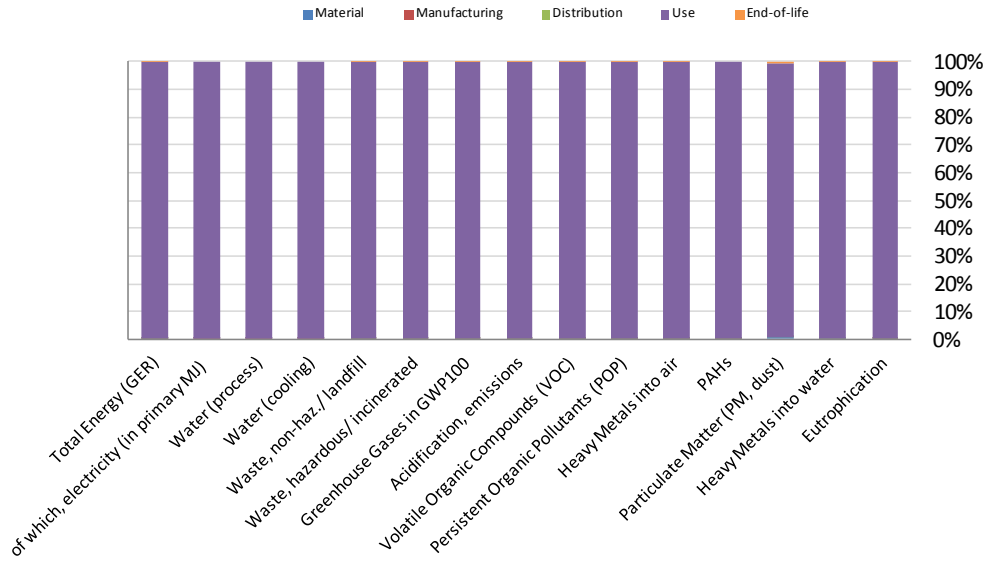


Figure 5-9: Distribution of the BC-10's environmental impacts by life cycle phase

Table 5-24: Life cycle impact (per unit) of BC-10: End suction own bearing water pumps from 150 kW to 1 MW

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	9,957	2,828	12,784	718	245,700,128	3,658	131	3,527	245,717,157
of which, electricity (in primary MJ)	MJ	291	1,654	1,945	2	245,700,019	0	0	0	245,701,965
Water (process)	ltr	771	23	794	0	16,380,008	0	0	0	16,380,802
Water (cooling)	ltr	2,053	731	2,784	0	655,200,028	0	2	-2	655,202,810
Waste, non-haz./ landfill	g	455,242	11,874	467,116	324	284,879,879	64,534	1	64,532	285,411,850
Waste, hazardous/ incinerated	g	11	1	12	6	5,661,650	900	0	900	5,662,568
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	901	160	1,060	44	10,722,221	273	9	264	10,723,589
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	4,506	692	5,198	132	63,267,802	536	12	524	63,273,656
Volatile Organic Compounds (VOC)	g	78	2	80	12	92,538	15	0	15	92,644
Persistent Organic Pollutants (POP)	ng i-Teq	5,756	227	5,983	2	1,610,521	444	0	444	1,616,950
Heavy Metals	mg Ni eq.	1,768	533	2,301	16	4,215,308	1,069	0	1,069	4,218,695
PAHs	mg Ni eq.	164	0	164	29	484,034	0	0	0	484,227
Particulate Matter (PM, dust)	g	8,011	106	8,117	2,051	1,351,431	4,762	0	4,762	1,366,360
Emissions (Water)										
Heavy Metals	mg Hg/20	886	0	886	1	1,584,210	304	0	304	1,585,401
Eutrophication	g PO_4	22	1	23	0	7,554	17	0	17	7,595
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

5.3.10 Submersible borehole pumps

The results of the environmental analysis of BC-11 (submersible borehole pumps) are shown in Table 5-25 and in Figure 5-10. According to these, the energy consumption during the use phase is the most predominant aspects contributing to the environmental impacts from the product's entire life cycle. The use phase contributes the most to the overall environmental impacts all 15 non-negligible environmental impact categories.

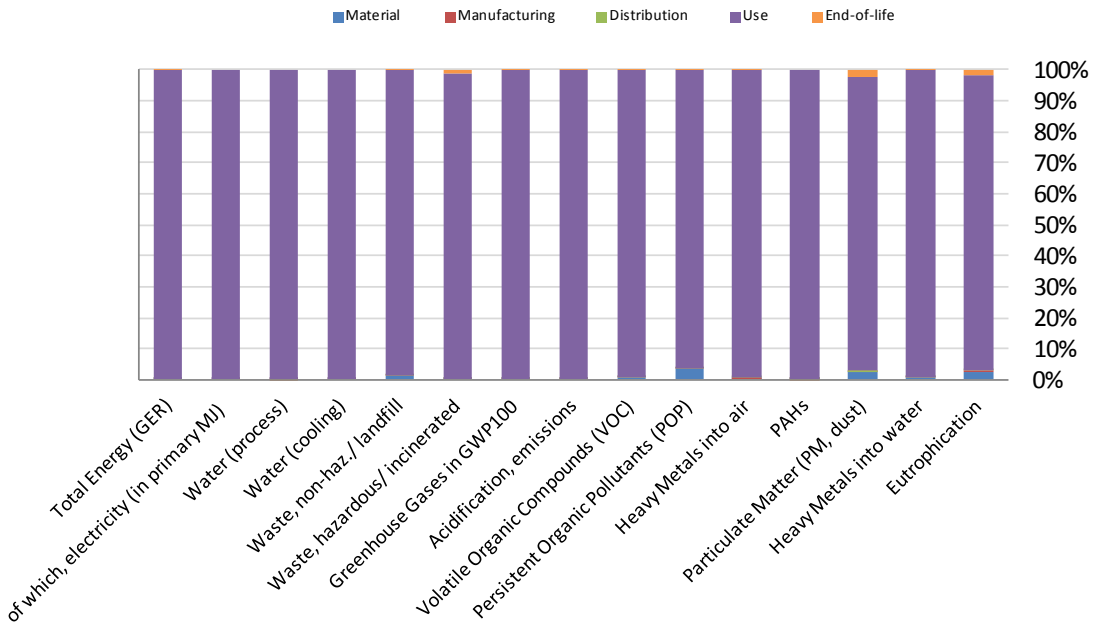


Figure 5-10: Distribution of the BC-11's environmental impacts by life cycle phase

Table 5-25: Life cycle impact (per unit) of BC-11: Submersible borehole pumps

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	9,816	4,000	13,816	496	24,352,389	2,699	957	1,743	24,368,443
of which, electricity (in primary MJ)	MJ	591	2,303	2,894	1	24,352,280	0	2	-2	24,355,172
Water (process)	ltr	569	31	600	0	1,623,489	0	2	-2	1,624,088
Water (cooling)	ltr	894	980	1,874	0	64,939,355	0	13	-13	64,941,215
Waste, non-haz./ landfill	g	378,093	19,072	397,165	233	28,239,025	41,451	9	41,441	28,677,864
Waste, hazardous/ incinerated	g	37	3	39	5	561,148	5,725	1	5,724	566,915
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	761	228	989	31	1,062,729	201	70	132	1,063,880
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	2,067	990	3,057	92	6,270,735	397	88	308	6,274,192
Volatile Organic Compounds (VOC)	g	49	4	53	8	9,172	10	1	9	9,243
Persistent Organic Pollutants (POP)	ng i-Teq	5,909	493	6,403	1	159,683	285	0	285	166,372
Heavy Metals	mg Ni eq.	1,029	1,156	2,185	12	417,815	780	0	780	420,791
PAHs	mg Ni eq.	18	0	18	20	47,974	0	0	0	48,012
Particulate Matter (PM, dust)	g	3,167	151	3,318	1,367	133,971	3,512	2	3,510	142,167
Emissions (Water)										
Heavy Metals	mg Hg/20	824	1	825	0	157,024	224	0	224	158,074
Eutrophication	g PO_4	21	2	22	0	749	13	0	13	784
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

5.3.11 Vertical multistage pumps

The results of the environmental analysis of BC-12 (vertical multistage pumps) are shown in Table 5-26 and in Figure 5-11. According to these, the energy consumption during the use phase is the most predominant aspects contributing to the environmental impacts from the product's entire life cycle. The use phase contributes with more than 95% of the overall environmental impacts for all 15 non-negligible environmental impact categories.

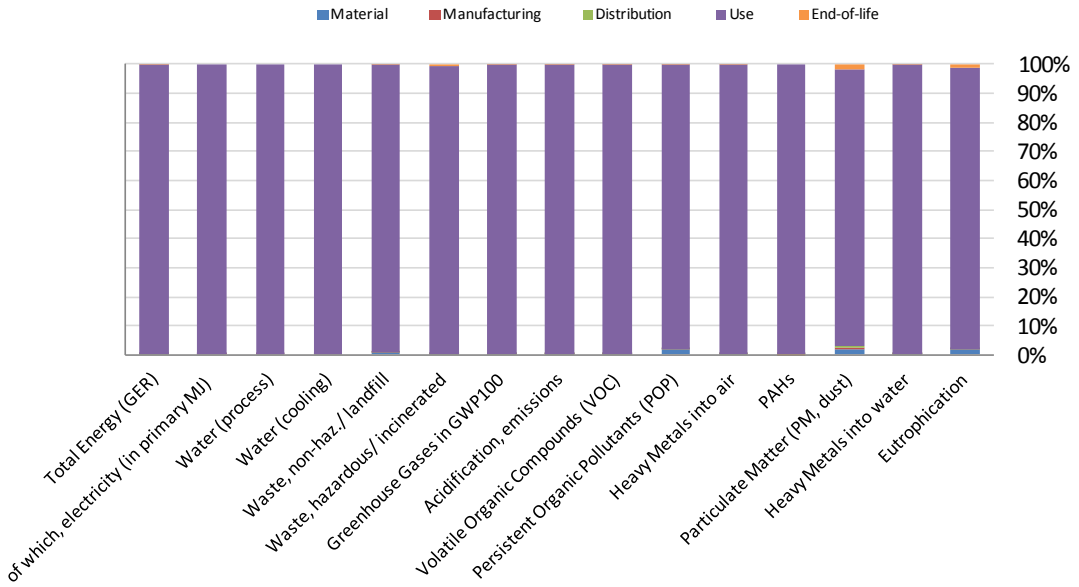


Figure 5-11: Distribution of the BC-12's environmental impacts by life cycle phase

Table 5-26: Life cycle impact (per unit) of BC-12: Vertical multistage pumps

Life Cycle phases -->		Production			Distribution	Use	End-of-life			Total
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	7,808	2,435	10,244	607	31,003,662	2,390	710	1,680	31,016,192
of which, electricity (in primary MJ)	MJ	357	1,412	1,769	1	31,003,578	0	1	-1	31,005,347
Water (process)	ltr	604	20	624	0	2,066,910	0	1	-1	2,067,533
Water (cooling)	ltr	1,046	612	1,657	0	82,676,177	0	7	-7	82,677,826
Waste, non-haz./ landfill	g	323,652	10,987	334,639	278	35,950,215	39,040	5	39,035	36,324,167
Waste, hazardous/ incinerated	g	24	1	25	6	714,413	3,144	1	3,143	717,587
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	610	138	749	37	1,352,986	178	52	126	1,353,898
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	2,801	600	3,400	112	7,983,451	351	66	285	7,987,248
Volatile Organic Compounds (VOC)	g	44	2	46	10	11,677	10	1	9	11,742
Persistent Organic Pollutants (POP)	ng i-Teq	4,126	253	4,379	2	203,259	269	0	269	207,909
Heavy Metals	mg Ni eq.	1,060	593	1,654	14	531,921	694	0	694	534,282
PAHs	mg Ni eq.	99	0	99	25	61,078	0	0	0	61,202
Particulate Matter (PM, dust)	g	3,870	92	3,962	1,709	170,559	3,110	1	3,108	179,338
Emissions (Water)										
Heavy Metals	mg Hg/20	616	0	617	0	199,908	199	0	199	200,724
Eutrophication	g PO_4	17	1	18	0	953	11	0	11	982
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

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 span of the product are considered which include:

- Average sales prices 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 (in kWh)

In the following Tasks, 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:

$$LCC = PP + PWF*OE + EoL$$

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 specified in Task 2.

Table 5-27 presents the EcoReport outcomes of the LCC calculations for all the base-cases in ENER lot 29. It is important to note that both the electricity costs and the maintenance and repair costs are affected by PWF when calculated. There are similarities between BC-1 (domestic swimming pool pumps), BC-2 (domestic and commercial swimming pool pumps), BC-8 (end suction close coupled pumps), BC-9 (end suction close coupled inline pumps), BC-10 (end suction own bearing pumps), BC-11 (submersible borehole pumps) and BC-12 (vertical multi-stage pumps) concerning the life cycle cost. The electricity cost is the main life cycle cost for these base-cases (more than 75% of LCC). Therefore, the improvement in energy efficiency of these pumps would significantly reduce the LCC.

The electricity cost is also the predominant cost for BC-6 (spa pumps) but at the same time, the installation cost is high and accounted for 32% of LCC. For BC-3 (fountain and pond pumps), BC-4&5 (aquarium pumps) and BC-7 (counter current pumps), the product price is also one of the major contributions for the LCC cost. These pumps have low annual energy consumption thus the electricity required is not as high as the other group of pumps. Improvement in energy efficiency in these pumps would not provide much cost savings to consumers.

Table 5-27: Life Cycle Costs per product for all the Base cases

	BC-1 SPPL		BC-2 SPPS		BC-3 FPP		BC-4 & BC-5 APH		BC-6 SPA		BC-7 CCP		BC-8 ESCC		BC-9 ESCCI		BC-10 ESOB		BC-11 SBHP		BC-12 VSP	
	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%	[€]	%
Product price	330	12	1,500	5	100	46	50	59	275	19	1,325	69	8,000	1	8,000	1	8,000	0	7,293	3	11,992	4
Installation/ acquisition costs (if any)	250	9	500	2	-	0	-	0	450	32	500	26	2,000	0	2,000	0	2,000	0	3,036	1	2,000	1
Electricity cost	2,153	79	30,272	92	118	54	34	41	691	49	108	5	968,718	98	968,718	98	1,749,075	99	203,178	88	254,022	92
Repair & maintenance costs	-	0	680	2	-	0	-	0	-	0	-	0	6,795	1	6,795	1	6,795	0	18,371	8	9,385	3
Total	**2,733**	**100**	**32,952**	**100**	**218**	**100**	**84**	**100**	**1,416**	**100**	**1,933**	**100**	**985,513**	**100**	**985,513**	**100**	**1,765,870**	**100**	**231,878**	**100**	**277,399**	**100**

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 life cycle environmental impacts per year corresponding to the EU stock of products are presented in Table 5-28. The total primary energy consumption per year of the EU stock of each of the 11 Base-Cases in 2011 is between 0.2 PJ and 275.4 PJ. The greenhouse gas (GHG) emissions per year are between 0.01 mt CO_2 eq. and 12 mt CO_2 eq. Annual heavy metals emissions into water range 0.002 ton Hg/20 to 1.8 ton Hg/20 while acidification emissions are between 0.1 kt SO_2 eq. and 70.9 kt SO_2 eq. per year.

Submersible borehole pumps present the highest energy consumption per year in the EU-27 and contribute to the highest GHG, acidification, and heavy metals emissions.

Considering the total environmental impact of the installed stock as shown in Table 5-28, the impacts in the different categories show that the following Base-Cases have little to no impacts compared to the overall environmental impacts of Lot 29:

- BC-3: Fountain and pond pumps
- BC-4&5: Aquarium pumps and powerheads
- BC-6: Spa pumps
- BC-7: Counter-current pumps
- BC-8: End suction close coupled pumps
- BC-9: End suction close coupled inline pumps

For this reason, it is thought that the environmental impacts and the improvement potential of these pumps are not relevant enough to require an in-depth analysis in Task 6 (Technical Analysis of Best Available Technologies) and Task 7 (Improvement Potential). The analysis and discussion of policy options in Task 8 will evaluate the possibilities of intervention on all the product groups within the scope of this preparatory study.

Table 5-28: EU-27 total impact of the installed stock (2011) of the 11 Base-Cases

Life Cycle phases -->		BC-1 SPPL	BC-2 SPPS	BC-3 FPP	BC-4 & BC-5 APH	BC-6 SPA	BC-7 CCP	BC-8 ESCC	BC-9 ESCCI	BC-10 ESOB	BC-11 SBHP	BC-12 VSP	TOTAL
Other Resources & Waste													
Total Energy (GER)	PJ	73.3	24.5	2.9	4.8	0.2	1.0	6.8	6.8	67.6	275.4	82.4	532.1
of which, electricity (in primary MJ)	PJ	72.7	24.5	2.8	4.6	0.2	0.8	6.8	6.8	67.6	275.3	82.4	544.5
Water (process)	mln. m3	4.9	1.6	0.2	0.3	0.0	0.1	0.5	0.5	4.5	18.4	5.5	36.5
Water (cooling)	mln. m3	193.6	65.2	7.5	12.2	0.5	2.0	18.1	18.1	180.2	734.0	219.6	1451
Waste, non-haz./ landfill	kt	108.3	29.2	5.5	8.5	0.7	8.8	7.9	7.9	78.6	324.6	96.7	676.7
Waste, hazardous/ incinerated	kt	3.7	0.6	0.2	0.1	0.0	0.4	0.2	0.2	1.6	6.4	1.9	15.3
Emissions (Air)													
Greenhouse Gases in GWP100	mt CO_2 eq.	3.2	1.1	0.1	0.2	0.0	0.0	0.3	0.3	2.9	12.0	3.6	23.7
Ozone Depletion, emissions	t R-11 eq.	negligible	negligible	negligible	negligible	negligible	negligible	negligible	negligible	negligible	negligible	negligible	negligible
Acidification, emissions	kt SO_2 eq.	19.1	6.3	0.8	1.3	0.1	0.3	1.8	1.8	17.4	70.9	21.2	141
Volatile Organic Compounds (VOC)	kt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
Persistent Organic Pollutants (POP)	g i-Teq	0.6	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.4	1.9	0.6	3.8
Heavy Metals	tonNi eq.	1.4	0.4	0.1	0.1	0.0	0.1	0.1	0.1	1.2	4.8	1.4	9.7
PAHs	tonNi eq.	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.2	1
Particulate Matter (PM, dust)	kt	0.8	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.4	1.6	0.5	3.7
Emissions (Water)													
Heavy Metals	ton Hg/20	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.8	0.5	3.4
Eutrophication	kt PO_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Persistent Organic Pollutants (POP)	g i-Teq	negligible	negligible	negligible	negligible	negligible	negligible	negligible	negligible	negligible	negligible	negligible	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 5-29. 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 electricity cost is the predominant of the total annual consumer expenditure at the EU-27, which has a share of 88.7%. These results again point out the importance of studying further the possible improvement options of the energy efficiency of Lot 29 pumps.

Table 5-29: EU-27 total annual consumer expenditure in EU-27 (2011)

	BC-1	BC-2	BC-3	BC-4& BC-5	BC-6	BC-7	BC-8	BC-9	BC-10	BC-11	BC-12	TOTAL EU-27	Share of the annual consumer expenditure by item
Product price (million €)	158	17	21	60	1	133	1	1	4	91	38	525	8%
Installation/ acquisition costs (if any) (million €)	120	6	0	0	2	50	0	0	1	38	6	223	3%
Electricity (million €)	760	256	29	48	2	8	71	71	708	2,884	863	5,700	84%
Repair & maintenance costs (million €)	0	6	0	0	0	0	1	1	3	261	32	304	5%
Total (million €)	**1,038**	**285**	**50**	**108**	**5**	**191**	**73**	**73**	**716**	**3,274**	**939**	**6,752**	**100%**
Share of the annual consumer expenditure by BC	15%	4%	1%	2%	0%	3%	1%	1%	11%	48%	14%	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 over the life cycle of the stock of all products covered within the ENER Lot 29 preparatory study is around 593.3 PJ.

Table 5-30: Annual energy consumption and emissions of EU stock of pump products

	Geographical scope	Energy consumption per year (PJ)	Energy consumption per year (TWh)	Emissions mtCO2eq per year	Emissions ktSO2eq per year
ENER Lot 11	EU-25	1,496	415.5	64	386
ENER Lot 28	EU-27	273	75.8	12	71
ENER Lot 29	EU-27	532.1	148.9	23.7	141

From Table 5-30 above, it is evident that the energy consumptions emissions of CO_2 and of SO_2 per year are significantly higher than those for ENER Lot 28 and similar to those for ENER Lot 11.

5.6 Conclusions

This Task 5 report presents the results of the analysis of the environmental impacts and economic costs of eleven Base-Cases that are thought to represent the clean water pump products most relevant for proposing ecodesign requirements. The selection of Base-Cases and subsequent analysis was based upon the market analysis presented in Task 2, the consumer behaviour 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 market representing a wide range of products considered in this ENER Lot 29 preparatory study. The Base-Cases are used to estimate the environmental impacts of pumps for private and public swimming pools, ponds, fountains, and aquariums (and clean water pumps larger than those regulated under ENER Lot 11) products in the EU.

The results of the analysis show that energy consumption during the use phase is the most important environmental aspect. The manufacturing, distribution and end-of-life phases are less significant to the overall environmental impacts. However, the environmental impacts of the end-of-life phase are significant for the counter-current pumps, spa pumps for domestic and commercial spas, aquarium pumps (domestic/small aquarium - non-commercial) and fountain and pond pumps notably because of particulate matter emissions, incinerated hazardous waste and water Eutrophication. At the same time, the distribution phase of these pumps contributes to PAHs, volatile organic compounds and particulate matter emissions to the air.

The results of the economic analysis are in line with the environmental impacts. Energy consumption (electricity) is the largest single component of the overall Life Cycle Costs. Purchase costs and maintenance costs also represent significant shares of the total consumer expenditure.

The environmental and economic analysis of the Base-Cases will serve as point of reference for Tasks 6&7. As most of the environmental impacts are caused by the energy consumption during the use phase, the improvement options will be focused mainly on this aspect.



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

ENER Lot 29 – Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under ENER Lot 11) – Task 6: Technical Analysis BAT

Final report to the European Commission, DG ENER

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Task 6: Technical analysis of best available technology (BAT)

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 clean water pumps. Note that this report covers the BAT and BNAT available around the world and not just in Europe.

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.

6.1 State-of-the-art at component level

6.1.1 Motors

Only the smaller pump motors (<120W), used in swimming pool/spa pumps, fountain & pond pumps and aquarium pumps, are considered in this study. The motors used on the other pumps are regulated under the Lot 11 or the upcoming Lot 30 motor regulations. The limit of the scope for the Lot 30 motor regulations is 120W

Brushless Permanent Magnet (BPM) Motors are rapidly becoming one of the most popular motor types. 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. They are often used in conjunction with aquarium, pond and swimming pool pumps.

The motor sector is constantly developing and new, more efficient motor types are being brought to the market. Currently around 80% of all pump installations are fixed speed applications, and 20% are VSD-controlled because of the requirement of speed control. There is a possibility of additional reduction of power losses through speed control in some applications. According to EN 50598-2 Chapter 6 the motor starters have an efficiency of 99.9 %.

6.1.2 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.

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, and so are regarded as being beyond the scope of this study.

6.2 State-of-the-art for the product level

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).

6.2.1 Improvements in Centrifugal Pumps

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 efficiencies of 80% were achieved. Today, efficiencies well over 90% are achieved in larger clean water pumps. 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.

Increasing the pipe diameters used on pump systems can reduce the overall system losses and therefore reduce energy consumption. Although this is not something that can be directly affected by pump manufacturers, they can provide guidance to purchasers on this front.

6.2.2 BC-1 & BC-2: Domestic swimming pool pumps with built in strainer

Domestic swimming pool pumps are produced by a variety of companies, but the overall design of a centrifugal pump with an integral inlet strainer is common to them all. The inlet strainers are responsible for a significant proportion of all the inefficiency associated with swimming pool pumps. The losses associated with the strainer will depend on the type of strainer being utilised, with those with the largest open area being the most efficient. This has to be balanced against the fact that strainers with larger open areas, may not be able to filter smaller solids or may be structurally weaker.

Swimming pool pumps generally have good hydraulic performance as the body is made from plastic materials, which are smooth and can be made with tight tolerances. The impellers are typically closed, multi-channel types to provide maximum efficiency.

Most domestic swimming pool pumps are physically located above the water level in the pool for ease of access and maintenance. This means that they need to have a self-priming function. Self-priming pumps are inherently less efficient than standard centrifugal pumps. Removing the need for self-priming pumps would necessitate a significant redesign of the way pumps are installed in domestic settings, including the provision of a pump sump, which would introduce an unnecessary health and safety risk. Therefore, it is felt that maintaining a self-priming function is worth the addition inefficiency caused.

- **Controls**

Significant energy savings can be made in swimming pool pump systems that use variable speed drives to match the flow rate to the requirements of the various water treatment systems within the pool. This allows finer controls allowing the heating, filter backwashing, disinfection and general circulation all to have different operating flow speeds. The theory is that each process is operated as efficiently as possible. This allows flexibility in the sizing of the components, for example, the heating system does not have to be sized for the peak flow conditions, allowing it to be undertaken at lower speeds. This has the effect of reducing pump power consumption and improving filtration efficacy. It should be noted however that in new European standards for domestic pools the minimum backwashing flow rate is the same as the filtration rate for all pumps. The savings are only expected to be possible in 35% on the in ground pool market and 0% of the above ground market.

The running time of domestic swimming pool pumps is often dictated by the need to turn over the pool volume in a fixed period of time, for example there may be a requirement to turn over

the pool volume in 8 hours. Pool pumps have to operate against different head conditions depending on how clean the filter is. The head difference between a clean and dirty filter can be in the region of 5 – 8 metres. Pool pumps are often sized to provide the duty flow rate at high head conditions, when the filters are dirty. When the pumps are working against a clean filter the actual flow rate may be significantly higher than is needed to achieve the stated turn over requirement. In this case, the potential exists to use variable speed drives to reduce the flow rate and benefit from the associated reduction in power consumption and friction losses.

Friction loss in domestic swimming pool pipework system can be relatively high due to the limited pipe sizes available for use. The pipe sizes used tend to be 40 – 50 mm (1½" – 2"), and the flow rates typically varying between 5 m³/h and 20 m³/h, during filtration condition. This can result in some pipework flow velocities being as high a 3 m/s. Friction losses in pipework are proportional to the square of the flow velocity. For example, the friction loss at a flow velocity of 3 m/s are 9 times greater than the losses at 1 m/s therefore there are significant savings to be made from reducing pump speeds (not lower than 0.5m/s). Savings in friction could also be done by fixing the maximal speed in pipe as proposed in CEN-TC402-WG2_N0096_WI_00402005.

It is important to note that many manufacturers believe that the market for domestic variable speed pool pumps is small, as it is perceived the savings potential is small. Variable speed pool pumps are certainly not appropriate for all domestic pool pumps, for example there is a growing market for 'hobby pools' which are small, above ground pools which retail for approximately 500€. Adding a variable speed drive to these pools may not provide any tangible energy savings and could increase the overall price to the point where market is adversely affected.

Variable speed drives are by no means the only option available for altering. For example, two speed (full speed and half speed) controllers are available which operate the pumps at half speed when there is not a demand for full speed operation from the heating or filter backwash systems. These, tend to schedule the high and low speed periods based on assumed operation patterns for the heater and filter. An issue to be aware of with two speed pumps is that in some systems, running pumps at half speed does not provide sufficient head to overcome the system losses, resulting to very low flow conditions. This in turn may result in insufficient filtration occurring and an unacceptable reduction in water quality, along with an increase in operational power consumption.

6.2.3 BC-3: Fountain and pond pumps up to 1 kW

Fountain and pond pump are composed of integral pump, motor combined in a single unit. The filter is sometimes integrated into the pump casing or is provided as a separate satellite unit connected via a hose. The pumps with integral filters have a higher efficiency as they avoid losses associated with the connector hose, however they do not provide as reliable circulation of the entire pumped volume. As with swimming pool pumps, the losses associated with the filter will depend on the size of the filter being utilised being those with the largest open area the most efficient. This has to be balanced against the fact that strainers with larger open areas, may not be able to filter smaller solids or may be structurally weaker. Filters with large surface areas are used to reduce losses and minimise the chance of filters blocking.

Most pond pumps are made with plastic bodies and impellers with help to reduce the losses associated with surface friction. Some pumps have integral UV filters to assist with the treatment of the water without the need for chemicals. The UV lamps are typically in the range of 5W.

6.2.4 BC-4 & BC-5: Aquarium pumps (domestic/small aquarium non-commercial) pumps up to 120W and aquarium power head to 120W

The pump/filter plays a vital role in the aquarium ecosystem and must operate continuously 24 hours per day, 7 days per week. Any control of the rotation speed of the pump, from a ON/OFF option up to a variable speed drive (VSD), can be harmful for the livestock, therefore the pumps are designed to be operated full time.

Most aquarium pumps are circulating pumps connected to a device that works as a filter. Inside the filter water is forced to flow through different types of filtering materials, in such a way that water is cleared from dirt and detoxified from fish waste. Most Aquarium pumps use the technology of integrated motor with wet rotor. Since the 80's, the aquarium industry has seen a progressive technological shift with the replacement of traditional asynchronous motors with permanent magnet synchronous motors characterized by a much higher yield together with lower power consumption than asynchronous motors. Today, aquarium pumps exclusively employ high efficiency permanent magnet motors.

In addition, over the last decade, the industry has made great efforts to optimise the hydraulic design with a view to improving the performance and get further reduction of energy consumption. Today are widely available on the market hydraulic solutions characterized by an high yield such as oriented blades impellers, flexible blades impellers, closed impellers; thanks to the very low hydraulic power the above mentioned design solutions are able to guarantee the correct direction of rotation without using electronics that controls the start-up phase of the pump. On models with higher performance, although they represent a niche market (salt-water aquariums), they are also used with electronic controls that ensure the correct direction of rotation of the impeller.

The market is further complicated by some pumps that are connected to additional devices, for example, a heating element, a UV-C lamp or a particular filtering unit. At this stage, it is suggested that any Minimum Efficiency Performance Standards that might be defined are based on the pump alone, but the test standard will need to take account of the need to remove these other elements (when not necessary to the functionality of the pump itself, for example some aquarium filters as shown in Figure 6-1). While this is a shift from the pure 'extended product approach' that aims to consider as much of the system as possible, it is likely that trying to define 'standard' to fit within regulations would be difficult and give little real benefit.

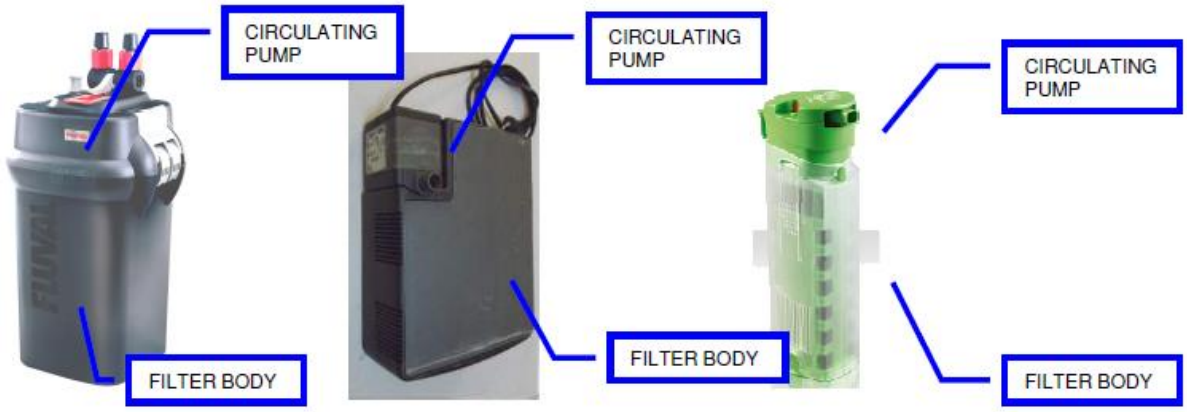


Figure 6-1: Aquarium filters - As described above the circulating pump forces the water through the filter body

Most Aquarium pumps use the technology of integrated motor with wet rotor: the older style pump set comprising separate motor and pumps can be considered obsolete.

6.2.5 BC-6 & BC-7 Countercurrent pumps and spa pumps

Countercurrent pumps and spa pump are essentially the same as swimming pool pumps and therefore have the same hydraulic performance. Countercurrent pumps are generally not provided with an inlet filter basket, however they do have strainers on the upstream end of the water inlet pipework, which does reduce the overall efficiency of the pumps. Countercurrent pumps are generally bigger and more powerful than the pumps used for domestic pools – typically domestic pool pumps are less than 1kW and countercurrent pumps are typically around 2kW.

Spas could have three or four pumps. Often the circulation pump is a fractional HP pump and the booster are considerably larger. These pumps have relatively low running hours.

6.2.6 BC-8 & BC-9: End Suction Close Coupled Pumps

The mechanical loss in the seal will be well below 1% for larger pumps, but for the smaller ones of the sizes considered in this study this loss might be much higher. The remaining power losses are considered 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, efficiency, and Net Positive Suction Head Required (NPSHR) against flow.

However, in most cases efficiency could be improved by sacrificing one or both of the ideals of head stability at low flows (e.g. by using a smaller diameter impeller), or NPSHR at best efficiency

flow (e.g. by using a smaller impeller inlet diameter). The increased sales resulting from higher efficiency would have to be balanced against the loss in sales due to the reductions in performance in the other areas.

- **Surface friction**
  - **Impeller**

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 this is not possible with cast iron. Cast iron should not be used on cold water pumps unless precautions are taken against corrosion, due to the formation of rough corrosion products. Where good access is possible, a cast iron impeller can be coated with a smooth resin. This is costly and is rarely, if ever, done on pumps of this size. For a good finish, the impeller could be made from plastic or pressed sheet steel is viable for smaller pumps, although it is rarely, if ever, done.

  - **Casing**

The side walls should be fully machined to a hydraulically smooth finish. This is, at best, only partially done at present. The whole casing interior can then be coated with a smooth resin. This is very rarely done on pumps of this size and tends to only offer a benefit in the first years of operation. The theory behind the use of resins is the not only does this improve efficiency appreciably, but, more importantly, it enables the improvement to be maintained by avoiding the build up of corrosion products. (There have been objections in the past to the use of resin coatings on drinking water pumps, but coatings do now exist, which satisfy the regulations. However, a coating is only as good as the operator who applies it, so a reputable supplier is essential.) For an indication, based on many real pump tests, of the effect of coating the inside of a new cast iron pump casing, see Figure 6-1 below. It can be seen that, for the small pumps involved here, the efficiency improvement can be quite substantial.

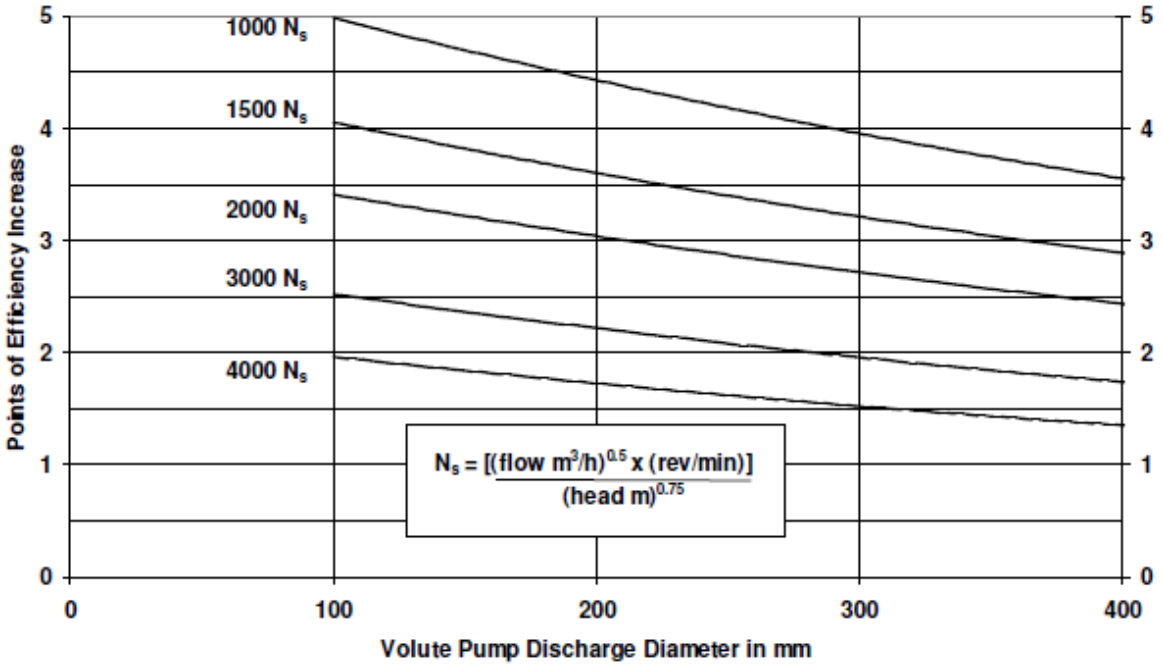


Figure 6-2: Effect on efficiency of coating the inside of a pump casing

- **Leakage**

Pump efficiency could be improved by reducing the leakage at the wear rings, by reducing the clearance.

This would require most or all of the following, all of which would increase cost:

- Tighter manufacturing tolerances
- Increased shaft diameter to minimise contact and wear at reduced or increased flow, which would also require the fitting of larger bearings and seals
- Very hard but compatible wear ring materials (e.g. Tungsten carbide).

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 centering force.

The back wear ring and the associated 'balance holes' could rarely be eliminated to reduce leakage, since this could overload the motor thrust bearing.

The bleeding of water from the casing to cool the mechanical seal could be eliminated by using a large conical housing for the seal (already done on some pumps).

6.2.7 BC-10: End Suction Own Bearings Pumps

The mechanical losses in the two anti-friction bearings and the mechanical seal will be between 2% and 10% of the input power to the pump, depending on the pump size. These are not capable of significant reduction without resorting to very sophisticated (and expensive) solutions, such as water lubricated journal and thrust bearings.

The remaining power losses are looked at theoretically for a specific pump in Task 4. These can be viewed as the hydraulic losses due to turbulence and surface friction, plus the leakage losses. These are considered below.

- **Hydraulic design**

The same comments apply as the previous section. Indeed manufacturers who make both types of pumps will use the same impeller and casing geometries.

- **Surface friction**
  - Impeller - As for End Suction Close Coupled Pumps.
  - Casing - As for End Suction Close Coupled Pumps.
- **Leakage**
  - As for End Suction Close Coupled Pumps.

6.2.8 BC-11:Submersible Multistage Pumps

In some pumps the axial thrust from the pump is normally accommodated in the motor. There is a considerable portion of pumps where the axial thrust cannot be accommodated by the motor or an external ball thrust bearing, but where a balancing device is necessary. The losses in the water lubricated journal bearings can be neglected. There are no seal losses.

- **Hydraulic design**

The pump outside diameter is usually restricted by the diameter of the hole it is intended to work in. To reduce cost, for a given duty, the number of pump stages tends to be minimised and the stage length reduced. This results in relatively narrow impellers and diffusers. By increasing the number of stages and increasing the stage width, it would be possible to increase stage efficiency and, in many cases, increase the pump efficiency for a given duty. However it is important to note that the impeller geometry will play an important role in this context.

Some pumps use inward flow diffusers. Stage efficiency could be improved by using outward flow (or outward/inward flow) diffusers, but again stage numbers would increase.

- **Surface friction**

The pump hydraulic components are normally made from bronze or cast iron. Precision casting is an option where bronze impellers are used.

- **Leakage**

Wear ring (and interstage bush) clearance is mainly dictated by journal bearing clearance. However, very hard but compatible wear ring materials (e.g. Tungsten carbide) may allow reduced clearance. More importantly, hard materials would better resist the wear caused by the abrasive materials found in most wells, which increase leakage. By the same token, hard bearing materials would reduce the risk of wear causing wear ring contact. Rubber bushes and casing wear rings are resistant to wear but to be really effective they need to be run in conjunction with inner hard surfaces.

6.2.9 BC-12: Vertical Multistage Pumps

The axial thrust from the pump on some pumps is accommodated in the motor or an external ball thrust bearing. There is little that can be done to reduce these small thrust bearing losses or the small losses in the water-lubricated journal bearings. The loss in the single mechanical seal is negligible.

- **Hydraulic design**

In the smaller pump sizes, for a given duty the number of pump stages tends to be minimised and the stage length reduced. This results in relatively narrow impellers and diffusers. By increasing the number of stages and increasing stage width it would be possible to increase stage efficiency and, in many cases, increase the pump efficiency for a given duty. The impeller geometry is important in this context.

Some pumps use inward flow diffusers. Efficiency could be improved by using outward flow (or outward/inward flow) diffusers. Pump diameter would increase and, in some cases, so would stage length. If the pumps become taller, they may need to be made sturdier.

- **Surface friction**

The pump hydraulic components are normally made from bronze or cast iron. Where bronze is used, precision casting is possible.

- **Leakage**

Wear ring (and interstage bush) clearance is mainly dictated by bearing clearance. However, in order to reduce these clearances, very hard but and compatible wear ring materials (e.g. Tungsten carbide) could be used. Alternatively, providing the water is clean, PTFE casing wear rings could be used (and sometimes are).

6.3 Summary of BAT options at component and product level

In this section, the best available technology options at component level are summarised for each Base Case[1]. The improvements presented are generally high cost with relatively small efficiency gains, therefore there is likely to be a cost penalty for their implementation.

Note as stated in section 6.2.1, it is difficult to attribute energy savings to single pump improvement measures and so the 'pump/hydraulic improvements' shown here are indicative of the level of savings achievable when hydraulic, surface friction and impeller improvements are combined together effectively. Also, the improvement percentages shown in the following tables are the average improvements over all the stock for each base case. For example, if applying a VSD to pump in the correct circumstances is likely to make 50% savings, but only 20% of all the pumps are suitable for use with VSDs then the savings show are averaged out across the whole stock (i.e. 50% x 20% = 10% overall).

The tables show the improvements that are possible by moving to the most efficient motors, however it should be noted that all motors above 120W will be covered by the Ecodesign Preparatory Study ENER Lot 30 and so the present study will not explore policy options for these motors.

[1] Please note: all statements on improvement potentials for the different pumps (BC 1 to BC 12) and their BATs are based on estimations and have to be evaluated in combination with assumptions on user behaviour

Table 6-1 Summary of BAT options for BC-1: Swimming pooling pumps (integrated motor+pump with built in strainer up to 2.2kW) (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.5%	-22	1,404	2.0%	7	337	0.0%	0	0.0%	0
Motor improvements	0.5%	-7	1,433	2.0%	7	337	0.0%	0	0.0%	0
VSD	10.0%	-144	1,296	200.0%	660	990	20.0%	50	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

Table 6-2 Summary of BAT options for BC-2: Swimming pooling pumps (integrated motor+pump with built in strainer over 2.2kW) (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.5%	-304	19,946	2.0%	30	1,530	0.0%	0	-1.0%	-1
Motor improvements	0.5%	-101	20,149	2.0%	30	1,530	0.0%	0	-2.0%	-1
VSD	40.0%	-8,100	12,150	100.0%	1,500	3,000	10.0%	50	5.0%	3

It is not expected that the improvements in efficiency will require any changes to the installation.

Table 6-3 Summary of BAT options for BC-3: Fountain and pond pumps to 1kW (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements*	1.5%	-2.2	142	2.0%	2.0	102	0.0%	0	0.0%	0
Motor improvements	0.5%	-0.7	143	2.0%	2.0	102	0.0%	0	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

* 1.0% of Annual energy consumption change [%] are linked to strainer improvements

Table 6-4 Summary of BAT options for BC-4&5: Aquarium pumps and power heads to 120 W (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.5%	-0.8	51.54	2.0%	1.0	51	0.0%	0	0.0%	0
Motor improvements	0.5%	-0.3	52.06	2.0%	1.0	51	0.0%	0	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

Table 6-5 Summary of BAT options for BC-6: Spa pumps for domestic & commercial spas (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.0%	-4.6	457.38	0.0%	0.0	275	0.0%	0	0.0%	0.0
Motor improvements	1.0%	-4.6	457.38	2.0%	5.5	281	0.0%	0	2.5%	0.8

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

Table 6-6 Summary of BAT options for BC-7: Counter-Current Pumps (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.0%	-1	71	0.0%	0	1,325	0.0%	0	0.0%	0
Motor improvements	1.0%	-1	71	2.0%	27	1,352	25.0%	125	2.5%	0.8

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

Table 6-7 Summary of BAT options for BC-8: End-Suction Close Coupled pumps from 150 kW to 1 MW (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-6,480	641,520	2.5%	200	8,200	0.0%	0	-2.0%	-10
VSD	12.5%	-81,000	567,000	200.0%	16,000	24,000	100.0%	2,000	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.

Table 6-8 Summary of BAT options for BC-9: End-Suction Close Coupled Inline from 150 kW to 1 MW (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-6,480	641,520	2.5%	200	8,200	0.0%	0	0.0%	0
VSD	12.5%	-81,000	567,000	200%	16,000	24,000	100.0%	2,000	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.

Table 6-9 Summary of BAT options for BC-10: End-Suction Own Bearing from 150 kW to 1 MW (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-11,700	1,158,300	2.5%	250	10,2500	0.0%	0	0.0%	0
VSD	12.5%	-146,250	1,023,750	200.0%	17,500	28,000	100.0%	2,000	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.

Table 6-10 Summary of BAT options for BC-11: Submersible bore-hole pumps (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-2,108	208,734	1.5%	109	7,403	0.0%	0	0%	0
VSD	12.5%	-26,355.	184,487	50.0%	3647	10,940	20.0%	607	0.0%	0

The figures shown for the cost are based on a weighted average of all the pumps in scope. It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.

Table 6-11 Summary of BAT options for BC-12: Vertical multi-stage pumps (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-2460.6	243,599	2.5%	302	12,376	0.0%	0	0%	0
VSD	12.5%	-30757.5	215,303	35.0%	4226	16,301	30.0%	600	0.0%	0

The figures shown for the cost are based on a weighted average of all the pumps in scope. It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.

6.4 State-of-the-art of best existing product technology outside the EU

The pump products in this study – both residential and non-residential - available in the EU are essentially of similar design to appliances sold outside the EU. Therefore, no different technologies have been identified outside the EU.

6.5 Best next available technology

Pumps are a very well established technology that has been refined for several hundred years, and therefore there is very little in terms of 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 as closer manufacturing tolerances become feasible.

An area where savings are likely to be realised in the future is in optimum control of swimming pool pumps. This is already seen to a limited fashion at the moment through variable speed drives, however in the future the potential exists to combine the pump operation with a greater level of intelligence regarding the water quality, such as through the use of turbidity monitors to detect the suspended solids, or chemical analysis to control the chemical dosing requirements. With more intelligence the VSDs can be used to a greater extent and the savings made will be more significant.

6.6 Conclusions

This report has discussed the many ways in which efficiency of centrifugal pumps can be increased. Each of the design options has an economic cost, and in some cases may impact adversely on pump lifetime. The detailed decisions on what options are most appropriate for a particular pump will vary from design to design, and it is seen that a generic relationship between efficiency and production cost exists.

Beyond improvements to the actual design of the pump itself, the use of electronic speed controls frees the designer from the specific speed constraints of standard fixed speed induction motors. This enables the efficiency of some pump sizes to be improved by being designed to operate at a more favourable speed and hence specific speed. In certain specific swimming pool pump applications where a variety of flow rates can be used at different periods in the operating cycle this may be of particular interest. With close control of the pumps' operation at these different periods, the potential for energy reductions exists.



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ENER Lot 29– Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under Lot 11) – Task 7: Improvement potential

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Task 7 Improvement Potential

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 environmental impacts of each of these options are calculated by using the MEEuP EcoReport tool. The economic impacts of each design are assessed in terms of Life Cycle Cost (LCC). The assessment of LCC is relevant as it indicates whether the design solutions may impact the cost to users over the total lifetime of the product (purchase, operating, end-of-life costs, etc.). The assessment of both environmental and economic impacts allows the identification of the design improvement with the Least Life Cycle Costs (LLCC) and 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 products.

7.1 Identification of design options

This section presents the different improvement options applicable to each Base-Case. The design option(s) should:

- 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 and impacts on the manufacturer.

For each of the improvement options, the modifications implied by their implementation in the Base-Case are quantified by the change in energy consumption. The potential of a particular improvement option or a combination of them is evaluated by using the MEEuP EcoReport tool. 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 annual running costs higher than the original product, the return of the investment would not be possible. In some cases the payback time is longer than the lifetime of the product, which would prevent the implementation of the improvement option.

The following sections show the possible energy savings and cost increase of each of the improvement options presented in Task 6 for the pumps in Lot 29. The energy savings and costs estimated in Task 6 serve to calculate the payback time as per the formula shown above. The environmental impacts and the economic impacts of each of the improvement options are then calculated by using the EcoReport tool presented in Task 5.

7.1.1 Base-Case 1: Domestic swimming pool pump with built-in strainer up to 2.2 kW

Task 5 identified that reducing total energy consumption during use would be an effective way to also reduce the overall environmental impacts of a domestic swimming pool pump. Task 6 identified the improvement options that aim to reduce the total energy consumption. Each of the improvement options applicable to domestic swimming pool pumps are presented here with their relative impact of their implementation on a real product in the market. These savings are however contested by some EU pumps manufacturers.

Table 7-1 presents the summary of the selected improvement options.

Option 3 and option 4 provide the highest electricity savings of all the individual improvement options compared to the base-case, but also very long payback times. These options involve using Variable Speed Drives (VSD) in order to achieve energy savings via the reduction in friction losses in the system. It also allows finer controls which make the heating, filter backwashing, disinfection and general circulation all to have different operating flow speeds. This has the effect of reducing pump power consumption and improving filtration efficiency. These savings are however contested by some EU pumps manufacturers.

Table 7-1: Identified energy savings potentials for BC-1: Domestic swimming pool pumps with built-in strainer up to 2.2 kW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulic improvements	-22	7	0	0	2.9
Option 2 (OP2)	Motor improvements	-7	7	0	0	9.1
Option 3 (OP3)	VSD	-144	660	50	0	44.8
Options 4 (OP1+OP2+OP3)	Pump/hydraulic, motor and VSD improvements	-173	674	50	0	38.0

7.1.2 Base-Case 2: Domestic/Commercial swimming pool pumps with built-in strainer over 2.2 kW

The selected improvement options for domestic/commercial swimming pool pumps with built-in strainer over 2.2 kW do not differ from those analysed in the previous section for domestic swimming pool pumps. The use of VSD is also in this case the option that offers the biggest savings in energy consumption of all the other options. In this case, the energy savings are higher and therefore the payback time is lower. Another possible alteration is the inclusion of two speed controllers, which operate the pumps at half-speed when there is not a demand for full speed operation from the heating or filter backwash systems. However, some systems running pumps at half speed do not provide sufficient head to overcome the system losses, resulting to very low flow conditions. Table 7-2 shows the potential electricity savings, price increase and payback times for each of the design options selected.

Table 7-2: Identified energy savings potentials for BC-2: Domestic/commercial swimming pool pumps with built-in strainer over 2.2 kW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulics improvements	-304	30	0	-1	0.9
Option 2 (OP2)	Motor improvements	-101	30	0	-1	2.5
Option 3 (OP3)	VSD	-8 100	1500	50	3	1.7
Option 4 (OP1+OP2+OP3)	Pump/hydraulic, motor and VSD improvements	-8 505	1560	50	1	1.7

7.1.3 Base-Case 3: Fountain and pond pumps up to 1 kW

The summary of potential design improvements for Fountain and Pond pumps up to 1kW can be seen in Table 7-3. As seen in the table, the option that provides the highest savings in energy consumption within a feasible payback time is option 1. The pumps with integral filters have a higher efficiency as they avoid losses associated with the connector hose. However, as with swimming pool pumps, the losses associated with the filter will depend on the size of the filter being used; being those with the largest open area the most efficient This has to be balanced against the fact that strainers with larger open areas, may not be able to filter smaller solids or may be structurally weaker.

Table 7-3: Identified energy savings potentials for BC-3: Fountain and pond pump up to 1 kW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulics improvements	-2.2	2	0	0	8.3
Option 2 (OP2)	Motor improvements	-0.7	2	0	0	26.0
Option 3 (OP1+OP2)	Pump/hydraulic and Motor improvements	-2.9	4	0	0	12.5

7.1.4 Base-Case 4&5: Aquarium pumps (domestic/small aquarium non-commercial) up to 120 W and aquarium pumps power head to 120 W

Looking at the improvement potentials of the various options for aquarium pumps in Table 7-4, the pump/hydraulic improvements seem to give the highest savings in energy consumption of all the other not-combined options. The pump/filter plays a vital role in the aquarium ecosystem and must operate continuously 24/7, which means that improvement modifications made to this component will result in reducing energy consumption. However, the payback time of the improvement options for aquarium pumps are long.

Over the last decade, there have been great efforts to optimise the hydraulic design with the view to improving the performance and get further reduction of energy consumption. These modifications are able to guarantee the correct direction of rotation without using electronics that controls the start-up phase of the pump.

Table 7-4: Identified energy savings potentials for BC-4&5: Aquarium pumps (domestic/small aquarium non-commercial) up to 120 W and aquarium power head to 120 W

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulic improvements	-0.8	1	0	0	11.4
Option 2 (OP2)	Motor improvements	-0.3	1	0	0	30.3
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	-1.1	2	0	0	16.5

7.1.5 Base-Case 6: Spa pumps for domestic & commercial spas

Looking at the improvement potentials of the various options for spa pumps in Table 7-5, similar performance enhancements to the hydraulic performance could be achieved as those for swimming pool pumps. These pumps are generally smaller than the pumps used for domestic swimming pools and therefore, have a slightly lower overall efficiency. As in swimming pool pumps, spa pumps have good hydraulic performance as the body is made from plastic materials, which are smooth and can be made with tight tolerances. Improvements on the motor would entail an increase of the maintenance costs without much energy savings, which means that it would not be possible to get a return of the investment.

Table 7-5: Identified energy savings potentials for BC-6: Spa pumps for domestic and commercial spas

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulic improvements	-4.6	0	0	0	0.0
Option 2 (OP2)	Motor improvements	-4.6	6	0	1	No return of investment possible
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	-9.2	6	0	1	25.9

7.1.6 Base-Case 7: Counter-current pumps

The selected improvement options for counter-current pumps do functions in the same way as those analysed in the previous section on spa pumps. As said before, counter-current pumps work as swimming pool pumps and have the same hydraulic performance. However, they are generally not provided with an inlet filter basket, but they do have strainers on the upstream end of the water inlet pipe-work, which does reduce the overall efficiency of the pumps.

Table 7-6 shows the potential electricity savings, price increase and payback times for each of the design options selected. The improvements achieved are insignificant and would not justify the cost increase.

Table 7-6: Identified energy savings potentials for BC-7: Counter-current pumps

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulic improvements	-1	0	0	0	0.0
Option 2 (OP2)	Motor improvements	-1	27	125	1	No return of investment possible
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	-2	27	125	1	No return of investment possible

7.1.7 Base-Case 8: End-Suction Close Coupled pumps from 150 kW to 1 MW

The summary of potential design improvements for End-Suction close coupled pumps from 150 kW to 1 MW pumps can be seen in Table 7-7.

As can be seen in the table, the VSD option offers the highest energy savings but the improvements of the hydraulic efficiency offers the shortest payback time. For example, modifications in the geometry of the impeller and the casing will increase the efficiency and will result in electricity savings but the head stability would have to be sacrificed. Nevertheless, it is expected that the increase in sales due to the higher efficiency will balance out the decrease in sales, due to the lower performance in other areas.

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 7-7: Identified energy savings potentials for BC-8: End-Suction Close Coupled pumps from 150 kW to 1 MW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-6 480	200	0	-10	0.3
Option 2 (OP2)	VSD	-81 000	16 000	2 000	0	2.0
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-87 480	16 200	2 000	-10	1.9

7.1.8 Base-Case 9: End-Suction Close Coupled Inline from 150 kW to 1 MW

The selected improvement options for End-Suction close coupled inline from 150 kW to 1 MW pumps do not differ from those analysed in the previous section. As mentioned before, for example, modifications in the geometry of the impeller and the casing will increase the efficiency and will result in electricity savings. As in end-suction close-coupled pumps, 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 7-8: Identified energy savings potentials for BC-9: End-Suction Close Coupled Inline from 150 kW to 1 MW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-6 480	200	0	0	0.3
Option 2 (OP2)	VSD	-81 000	16 000	2 000	0	2.0
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-87 480	16 200	2 000	0	1.9

7.1.9 Base-Case 10: End-suction own bearing water pumps from 150 kW to 1 MW

The summary of potential design improvements for End-Suction own bearing water pumps from 150 kW to 1 MW can be seen in Table 7-9. As can be seen in the table, the VSD option offers the largest potential energy savings.

In terms of surface friction reduction, the inner surfaces should be as smooth as possible, but the mechanical, methods of smoothing the rough cast interiors of impellers in iron or bronze are time-consuming and not entirely effective due to inaccessibility. Where good access is possible, a cast iron impeller can be coated with a smooth resin, although this is costly and rarely implemented.

Table 7-9: Identified energy savings potentials for BC-10: End-Suction Own Bearing from 150 kW to 1 MW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-11 700	250	0	0	0.2
Option 2 (OP2)	VSD	-146 250	17 500	2 000	0	1.2
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-157 950	17 750	2 000	0	1.1

7.1.10 Base-Case 11: Submersible borehole pumps

The summary of potential design improvements for submersible borehole pumps can be seen in Table 7-10.

As can be seen in the table, the VSD option is the largest potential energy saving option, but the longest payback time. Option 1 offers the possibility of improving the hydraulics, this way, by increasing the number of stages and increasing the stage width it would be possible to increase the stage efficiency and in many cases, increase the pump efficiency for a given duty. Another example is the use of plastic and sheet metal hydraulic components to reduce the surface friction and this way to improve the efficiency of the pump.

Table 7-10: Identified energy savings potentials for BC-11: Submersible borehole pumps

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-2 108	109	0	0	0.5
Option 2 (OP2)	VSD	-42 168	5 835	972	0	1.5
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-44 276	5 944	972	0	1.4

7.1.11 Base-Case 12: Vertical multistage pumps

The summary of potential design improvements for vertical multistage pumps can be seen in Table 7-11.

As can be seen in the table and the section before, the VSD option offers the largest potential energy savings but the longer payback time. Option 1 achieves improvement modification in the Hydraulic design. This modification requires for a given duty that the number of pump stages is minimised and the stage length reduced. Another way to improve the efficiency would be by using outward flow diffusers (pumps use inward flow diffusers, usually). The pump diameter would increase and, in some cases, so would the stage length. However, if the pumps become taller they may need to be made sturdier.

Table 7-11: Identified energy savings potentials for BC-12: Vertical multistage pumps

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-2 461	302	0	0	1.1
Option 2 (OP2)	VSD	-49 212	6 762	960	0	1.4
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-51 673	7 064	960	0	1.4

7.2 Analysis BAT and LLCC

The design option(s) identified in the technical, environmental and economic analyses in Task 6 are ranked to identify the design improvement option with the least cycle environmental impacts and the least Life Cycle Costs (LLCC). Constructing an energy-LCC-curve (Y-axis= energy consumed and LCC, X-axis=options) allows the LLCC and BATs to be identified[1].

The performance of each improvement option will be compared using the Base-Case presented in Task 5 as reference. The comparison is made in terms of primary energy consumption and LCC.

LLC is the sum of the product price, costs of energy, and the costs of installation and maintenance as described in Task 5 and Task 6.

7.2.1 Base-Case 1: Domestic swimming pool pump with built-in strainer up to 2.2 kW

An environmental and economic assessment was carried out for each improvement option relevant for Domestic swimming pool pumps with built-in strainers up to 2.2 kW using the EcoReport tool. Outcomes of this, taking into account the whole life cycle, are provided in Table 7-12 with absolute values (in units) and variations (in %) compared with the Base-Case.

Design improvement options

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

[1] This is usually the last data point of the curve showing the product design with the lowest environmental impact, irrespective of the price.

Table 7-12: Environmental impacts of the BC-1 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 1	Option 1	Option 2	Option 3	Option 4
Total Energy (GER)	GJ	303.9	299.3	302.5	273.7	264.6
	% change with BC	0%	-2%	0%	-10%	-13%
Of which, electricity	Primary GJ	302.6	298.0	301.2	272.4	263.3
	Final MWh	28.8	28.4	28.7	25.9	25.1
	% change with BC	0%	-2%	0%	-10%	-13%
Water (process)	kL	20.2	19.9	20.1	18.2	17.6
	% change with BC	0%	-2%	0%	-10%	-13%
Water (cooling)	kL	806.6	794.3	802.7	726.0	701.8
	% change with BC	0%	-2%	0%	-10%	-13%
Waste, non-haz./ landfill	kg	401.1	395.8	399.4	366.1	355.5
	% change with BC	0%	-1%	0%	-9%	-11%
Waste, hazardous/ incinerated	kg	11.1	11.0	11.1	10.4	10.2
	% change with BC	0%	-1%	0%	-6%	-8%
Greenhouse Gases in GWP100	t CO_2 eq.	13.3	13.1	13.2	12.0	11.6
	% change with BC	0%	-2%	0%	-10%	-13%
Acidification, emissions	Kg SO_2 eq.	78.6	77.5	78.3	70.9	68.5
	% change with BC	0%	-2%	0%	-10%	-13%
Volatile Organic Compounds (VOC)	kg	0.1	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-10%	-12%
Persistent Organic Pollutants (POP)	µg i-Teq	2.2	2.2	2.2	2.0	2.0
	% change with BC	0%	-1%	0%	-9%	-12%
Heavy Metals to air	g Ni eq.	5.5	5.4	5.4	4.9	4.8
	% change with BC	0%	-1%	0%	-10%	-12%
PAHs	g Ni eq.	0.6	0.6	0.6	0.6	0.6
	% change with BC	0%	-1%	0%	-9%	-12%
Particulate Matter (PM, dust)	kg	2.5	2.5	2.5	2.4	2.3
	% change with BC	0%	-1%	0%	-7%	-9%
Heavy Metals to water	g Hg/20	2.0	2.0	2.0	1.8	1.8
	% change with BC	0%	-1%	0%	-10%	-13%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-8%	-10%
Life-cycle cost	€	2,732.7	2,713.6	2,736.0	3,234.2	2,671.4
	% change with BC	0%	-1%	0%	18%	-2%

The analysis of these figures shows that option 4 achieves the lowest environmental impacts when compared to the Base-Case. This option achieves the lowest primary consumption of all the options presented. Options 3 is the second to achieve the highest energy consumption reduction.

The share of LCC for the Base-Case and the improvements options is shown in Figure 7-1. The electricity costs are the highest share of the LCC, and the second greatest expenses are the purchase price of the pump.

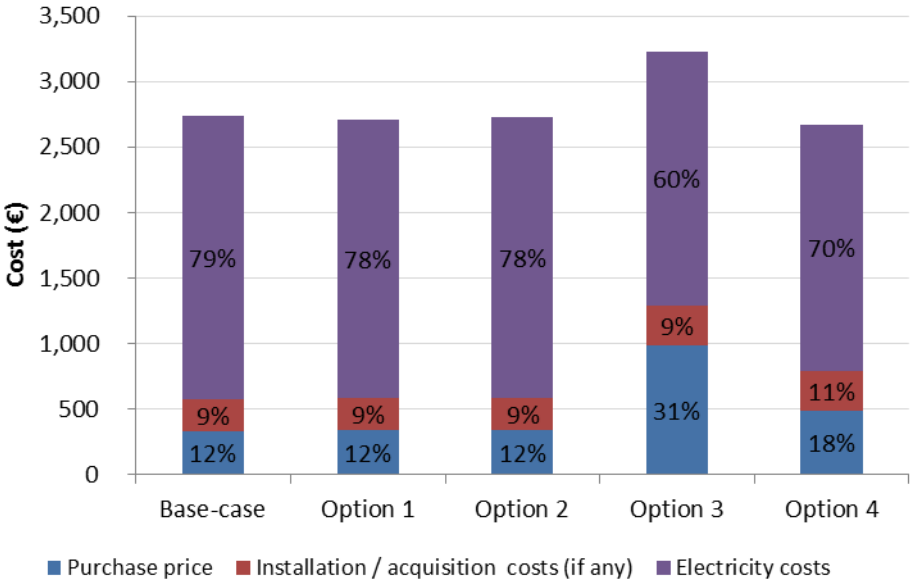


Figure 7-1: Life cycle costs of the improvement options for BC-1

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

Figure 7-2 presents the comparison between primary energy consumption and life cycle costs of the Base-Case and its design options. The least cycle cost option is option 4, which is also the BAT option. This option allows 12% of energy savings.

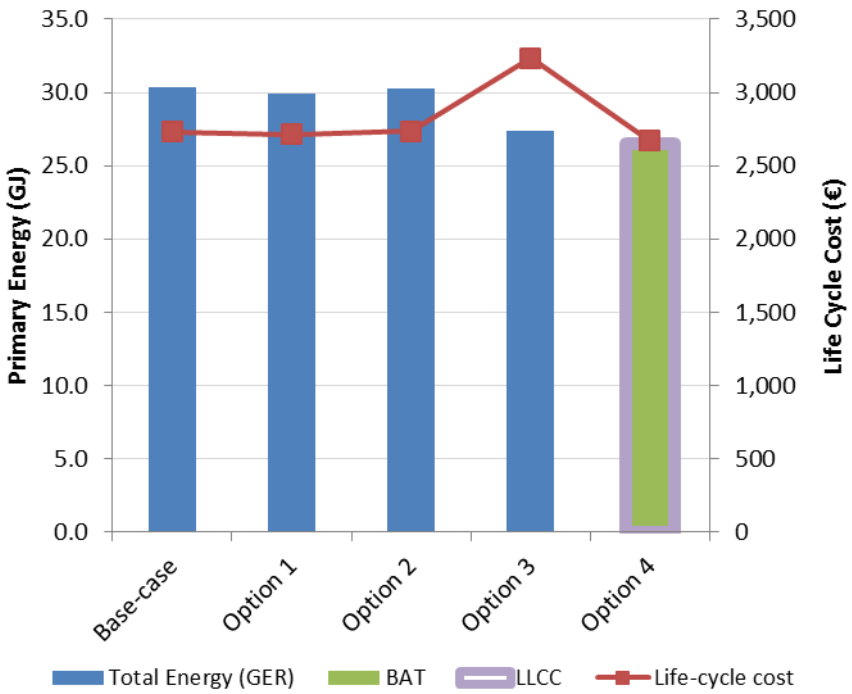


Figure 7-2: Identification of design improvement options with the least energy consumption and LLCC for BC-1

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

7.2.2 Base-Case 2: Domestic/Commercial swimming pool pumps with built-in strainer over 2.2 kW

Table 7-13 shows the environmental and economic impacts of the improvement options selected for BC2. Option 3 achieves a significant reduction in primary energy consumption, but is the Option 4 (i.e. the combination of options 1+2+3), which achieves the highest reduction in environmental impacts related to the Base-Case. The option with lower environmental impacts is option 2. The lowest life cycle cost is also achieved with the combination of options 1 to 3.

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

Table 7-13: Environmental impacts of the BC-2 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	4,254.5	4,190.6	4,233.3	2,553.5	2,043.2
	% change with BC	0%	-2%	0%	-40%	-52%
Of which, electricity	Primary GJ	4,252.8	4,188.9	4,231.6	2,551.8	2,041.5
	Final MWh	405.0	398.9	403.0	243.0	1,94.4
	% change with BC	0%	-2%	0%	-40%	-52%
Water (process)	kL	283.6	279.3	282.1	170.2	136.1
	% change with BC	0%	-2%	0%	-40%	-52%
Water (cooling)	kL	11,340.2	11,170.0	11,283.6	6,804.2	5,443.4
	% change with BC	0%	-2%	0%	-40%	-52%
Waste, non-haz./ landfill	kg	5,000.8	4,926.7	4,976.2	3,028.5	2,436.9
	% change with BC	0%	-1%	0%	-39%	-51%
Waste, hazardous/ incinerated	kg	100.4	99.0	100.0	61.3	49.5
	% change with BC	0%	-1%	0%	-39%	-51%
Greenhouse Gases in GWP100	t CO_2 eq.	185.7	182.9	184.8	111.5	89.2
	% change with BC	0%	-2%	0%	-40%	-52%
Acidification, emissions	Kg SO_2 eq.	1,096.0	1,079.5	1,090.5	658.0	526.6
	% change with BC	0%	-1%	0%	-40%	-52%
Volatile Organic Compounds (VOC)	kg	1.6	1.6	1.6	1.0	0.8
	% change with BC	0%	-1%	0%	-40%	-52%
Persistent Organic Pollutants (POP)	µg i-Teq	28.4	27.9	28.2	17.2	13.9
	% change with BC	0%	-1%	0%	-39%	-51%
Heavy Metals to air	g Ni eq.	73.3	72.2	72.9	44.1	35.4
	% change with BC	0%	-1%	0%	-40%	-52%
PAHs	g Ni eq.	8.4	8.3	8.4	5.1	4.1
	% change with BC	0%	-1%	0%	-40%	-52%
Particulate Matter (PM, dust)	kg	24.6	24.3	24.5	15.3	12.5
	% change with BC	0%	-1%	0%	-38%	-49%
Heavy Metals to water	g Hg/20	27.5	27.1	27.4	16.6	13.3
	% change with BC	0%	-1%	0%	-40%	-52%
Eutrophication	Kg PO_4	0.1	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-39%	-51%
Life-cycle cost	€	32,952.0	32,526.8	32,830.3	22,395.0	17,633.9
	% change with BC	0%	-1%	0%	-32%	-46%

Figure 7-3 shows the different shares of consumer expenditure throughout the life cycle of BC2 and the design options. For all the cases, the electricity costs have the highest share (between 81% and 92% of the total).

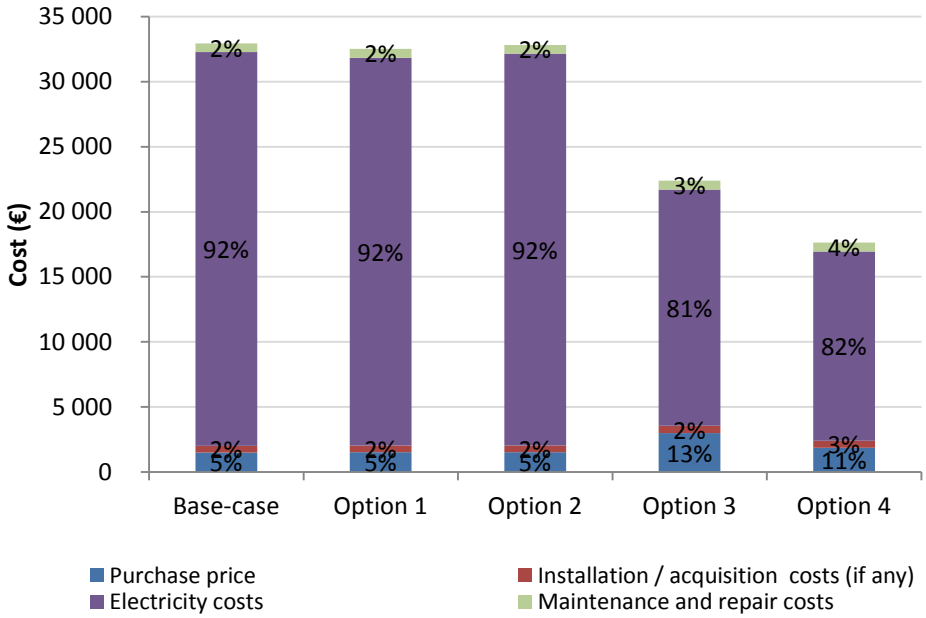


Figure 7-3: Life cycle costs of the improvement options for BC-2

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

Figure 7-4 presents the comparison between LCC and primary energy consumption of BC2 and its design options. The Option 4 is the option with the lowest energy consumption and LLCC. This combination of options presents the LCC 44% lower than the Base-Case and the primary energy consumption as 52% lower than the Base-Case.

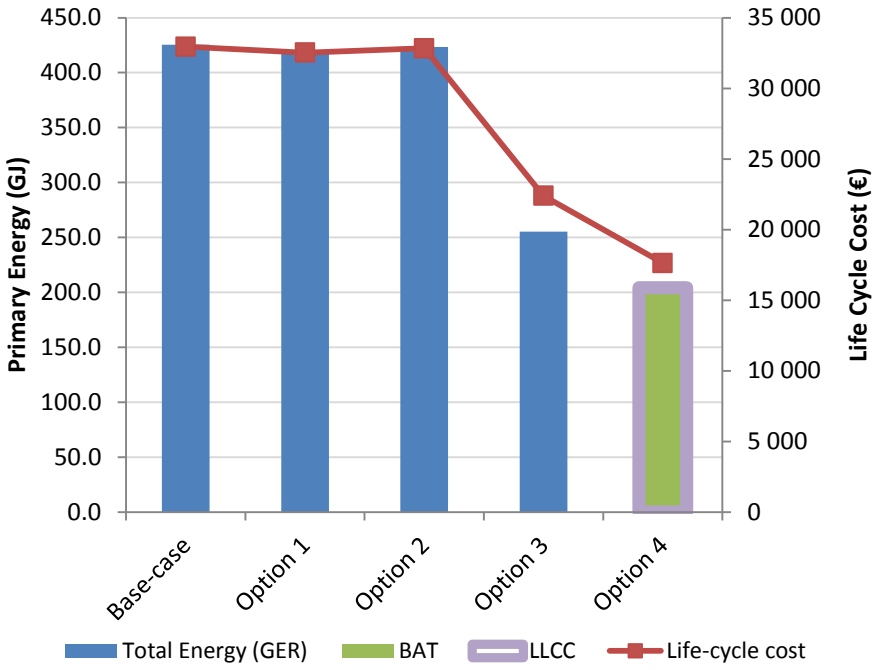


Figure 7-4: Identification of design improvement options with the least energy consumption and LLCC for BC-2

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

7.2.3 Base-Case 3: Fountain and pond pumps up to 1 kW

The results of the environmental analysis of the different designs options for BC_3 are presented in Table 7-14. Option 1 shows to have reductions in the environmental impacts compare to the Base-Case but is the combination option 3 that shows the most optimal results regarding environmental impacts.

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

Table 7-14: Environmental impacts of the BC-3 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 3	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	14.0	13.8	13.9	13.7
	% change with BC	0%	-1%	0%	-2%
Of which, electricity	Primary GJ	13.7	13.5	13.6	13.4
	Final MWh	1.3	1.3	1.3	1.3
	% change with BC	0%	-2%	0%	-2%
Water (process)	kL	0.9	0.9	0.9	0.9
	% change with BC	0%	-1%	0%	-2%
Water (cooling)	kL	36.4	35.8	36.2	35.6
	% change with BC	0%	-2%	0%	-2%
Waste, non-haz./ landfill	kg	27.0	26.8	27.0	26.7
	% change with BC	0%	-1%	0%	-1%
Waste, hazardous/ incinerated	kg	1.1	1.1	1.1	1.1
	% change with BC	0%	0%	0%	-1%
Greenhouse Gases in GWP100	t CO_2 eq.	0.6	0.6	0.6	0.6
	% change with BC	0%	-1%	0%	-2%
Acidification, emissions	Kg SO_2 eq.	3.7	3.7	3.7	3.6
	% change with BC	0%	-1%	0%	-2%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-2%
Persistent Organic Pollutants (POP)	µg i-Teq	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-1%
Heavy Metals to air	g Ni eq.	0.3	0.3	0.3	0.3
	% change with BC	0%	-1%	0%	-2%
PAHs	g Ni eq.	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-1%
Particulate Matter (PM, dust)	kg	0.3	0.3	0.3	0.3
	% change with BC	0%	0%	0%	-1%
Heavy Metals to water	g Hg/20	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-2%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	-1%
Life-cycle cost	€	217.9	218.1	219.3	219.6
	% change with BC	0%	0%	1%	1%

Figure 7-5 shows the different shares of life cycle costs throughout the life cycle of BC3 and the design options. For all the cases, the electricity costs have the highest share (between 53% and 54% of the total). The purchase price has the second highest share (between 46% and 47% of the total).

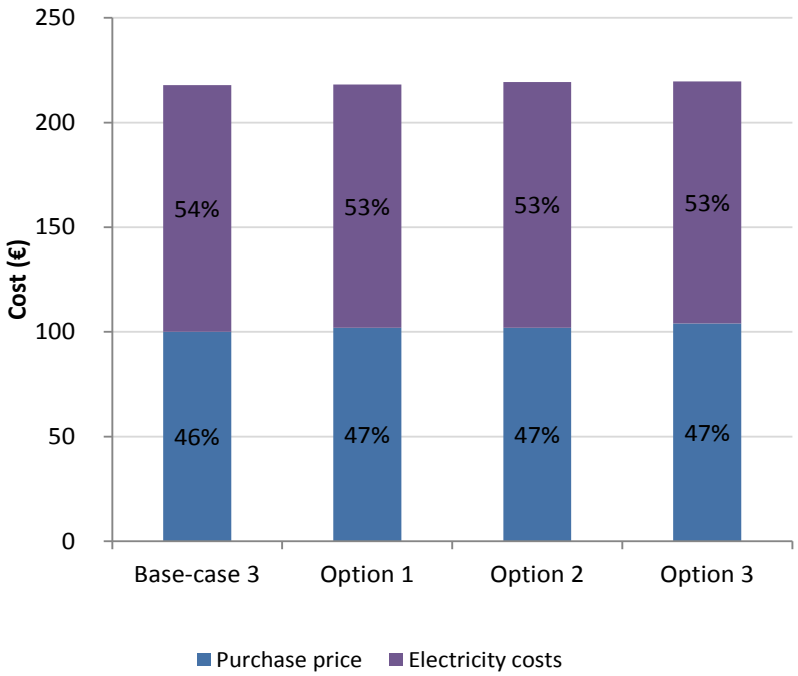


Figure 7-5: Life cycle costs of the improvement options for BC-3

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

Figure 7-6 presents the comparison between LCC and the primary energy consumption for BC3 and the design options. For this Base-Case, the Option 3 (i.e. combination of options 1+2) is the BAT, achieving 2% energy savings but has an increase of 1% in life cycle costs. The LLCC is the base case although the cost savings are only 1%.

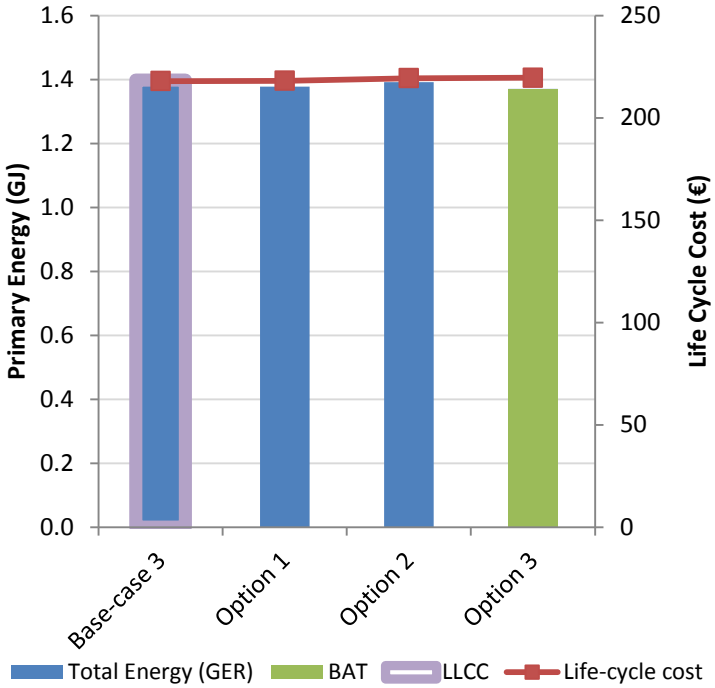


Figure 7-6: Identification of design improvement options with the least energy consumption and LLCC for BC-3

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

7.2.4 Base-Case 4&5: Aquarium pumps (domestic/small aquarium non-commercial) up to 120 W and aquarium pumps power head to 120 W

The results of the environmental analysis of the different designs options for BC4&5 are presented in Table 7-15. Option 1 shows to have reductions in the environmental impacts compared to the Base-Case but is the combination of options 1+2 that shows the most optimal results regarding environmental impacts.

As in BC3, the combination of options 1+2 allows primary energy reductions of 2% and a decrease of 3% on the LCC. On the other hand, the contributions of options 1 and 3 to the reduction of energy consumption and LCC reductions are non-existent.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

Table 7-15: Environmental impacts of the BC-4&5 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 4&5	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	4.0	3.9	4.0	3.9
	% change with BC	0%	-1%	0%	-2%
Of which, electricity	Primary GJ	3.8	3.8	3.8	3.8
	Final MWh	0.4	0.4	0.4	0.4
	% change with BC	0%	-1%	0%	-2%
Water (process)	kL	0.3	0.3	0.3	0.3
	% change with BC	0%	-1%	0%	-2%
Water (cooling)	kL	10.2	10.1	10.2	10.0
	% change with BC	0%	-1%	0%	-2%
Waste, non-haz./ landfill	kg	7.1	7.0	7.1	7.0
	% change with BC	0%	-1%	0%	-1%
Waste, hazardous/ incinerated	kg	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-1%
Greenhouse Gases in GWP100	t CO_2 eq.	0.2	0.2	0.2	0.2
	% change with BC	0%	-1%	0%	-2%
Acidification, emissions	Kg SO_2 eq.	1.0	1.0	1.0	1.0
	% change with BC	0%	-1%	0%	-2%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-1%
Persistent Organic Pollutants (POP)	µg i-Teq	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-2%
Heavy Metals to air	g Ni eq.	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-2%
PAHs	g Ni eq.	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-1%
Particulate Matter (PM, dust)	kg	0.1	0.1	0.1	0.1
	% 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%	-2%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-1%
Life-cycle cost	€	84.1	84.6	85.0	85.4
	% change with BC	0%	1%	1%	2%

In Figure 7-7 we can see the different shares of life cycle costs throughout the life cycle of BC4&5 and the design options. For all the cases, the purchase price has the highest share (between 59% and 61% of the total). The electricity costs have the second highest share of the life cycle costs (between 39% and 41% of the total).

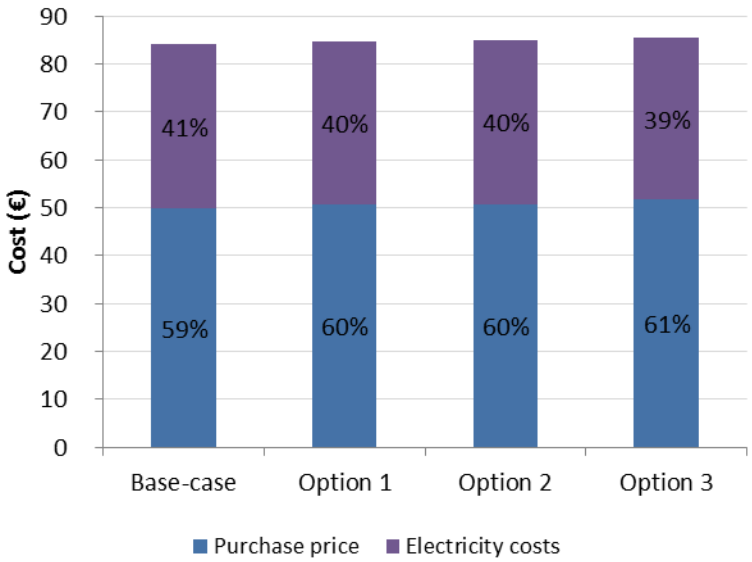


Figure 7-7: Life cycle costs of the improvement options for BC-4&5

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

Figure 7-8 shows the comparison between LCC and the primary energy consumption for BC4&5 and the design options. For this Base-Case, the combination of options 1+2 is the BAT, achieving 2% energy savings but has an increase of 2% in life cycle costs. The LLCC is the Base-Case.

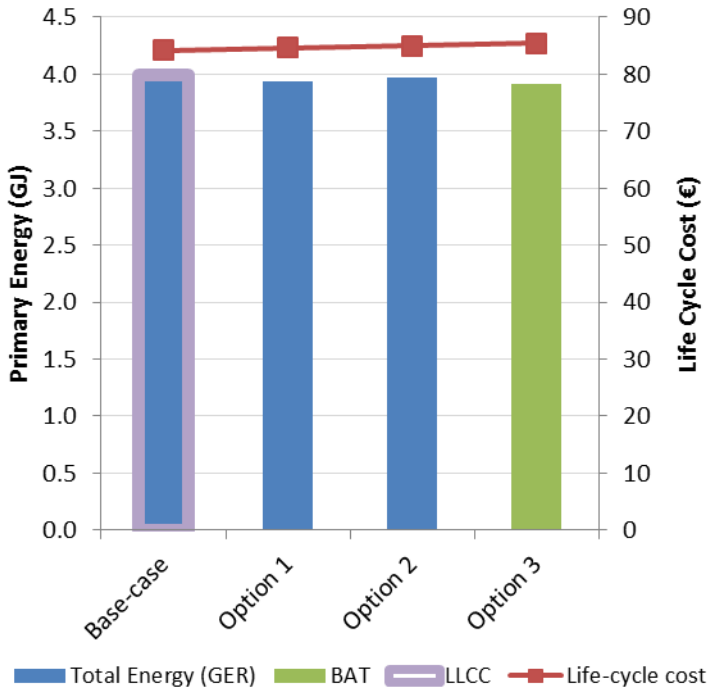


Figure 7-8: Identification of design improvement options with the least energy consumption and LLCC for BC-4&5

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

7.2.5 Base-Case 6: Spa pumps for domestic & commercial spas

The results of the environmental analysis of the different designs options for BC6 are presented in Table 7-16. Options 1 and 2 show to have reductions in the environmental impacts compare to the Base-Case and a primary energy reduction of 1% but it is the combination of these two options that allows the highest reduction of environmental impacts and consumer expenditure over the life cycle.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

Table 7-16: Environmental impacts of the BC-6 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 6	Option 1	Option 2	Options 1+2
Total Energy (GER)	GJ	99.7	98.8	98.8	97.8
	% change with BC	0%	-1%	-1%	-2%
Of which, electricity	Primary GJ	97.4	96.5	96.5	95.5
	Final MWh	9.3	9.2	9.2	9.1
	% change with BC	0%	-1%	-1%	-2%
Water (process)	kL	6.6	6.5	6.5	6.5
	% change with BC	0%	-1%	-1%	-2%
Water (cooling)	kL	259.1	256.5	256.5	253.9
	% change with BC	0%	-1%	-1%	-2%
Waste, non-haz./ landfill	kg	213.0	211.9	211.9	210.8
	% change with BC	0%	-1%	-1%	-1%
Waste, hazardous/ incinerated	kg	8.4	8.4	8.4	8.4
	% change with BC	0%	0%	0%	-1%
Greenhouse Gases in GWP100	t CO_2 eq.	4.4	4.3	4.3	4.3
	% change with BC	0%	-1%	-1%	-2%
Acidification, emissions	Kg SO_2 eq.	26.5	26.3	26.3	26.0
	% change with BC	0%	-1%	-1%	-2%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	-1%	-2%
Persistent Organic Pollutants (POP)	µg i-Teq	1.1	1.1	1.1	1.1
	% change with BC	0%	-1%	-1%	-1%
Heavy Metals to air	g Ni eq.	2.2	2.1	2.1	2.1
	% change with BC	0%	-1%	-1%	-2%
PAHs	g Ni eq.	0.3	0.3	0.3	0.3
	% change with BC	0%	-1%	-1%	-1%
Particulate Matter (PM, dust)	kg	2.1	2.1	2.1	2.1
	% change with BC	0%	0%	0%	-1%
Heavy Metals to water	g Hg/20	0.8	0.8	0.8	0.7
	% 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	€	1,415.7	1,408.8	1,414.3	1,407.3
	% change with BC	0%	0%	0%	-1%

In Figure 7-9 it can be seen the different shares of life cycle costs throughout the life cycle of BC6 and the design options. For all the cases, the electricity costs have the highest share (between 48% and 49% of the total). The installation costs are the second contributor to the LCC. Purchase prices is the third contributor to the LCC

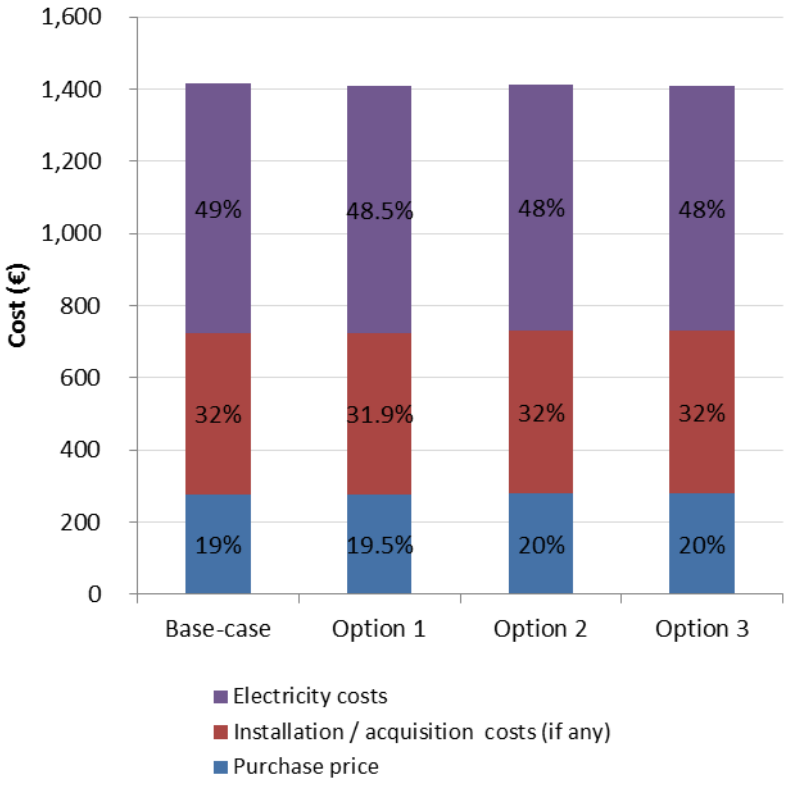


Figure 7-9: Life cycle costs of the improvement options for BC-6

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

Figure 7-10 shows the comparison between LCC and the primary energy consumption for BC6 and the design options. For this Base-Case, the combination of options 1+2 is the BAT as well as the LLCC, achieving 2% energy savings and a reduction of 1% in life cycle costs.

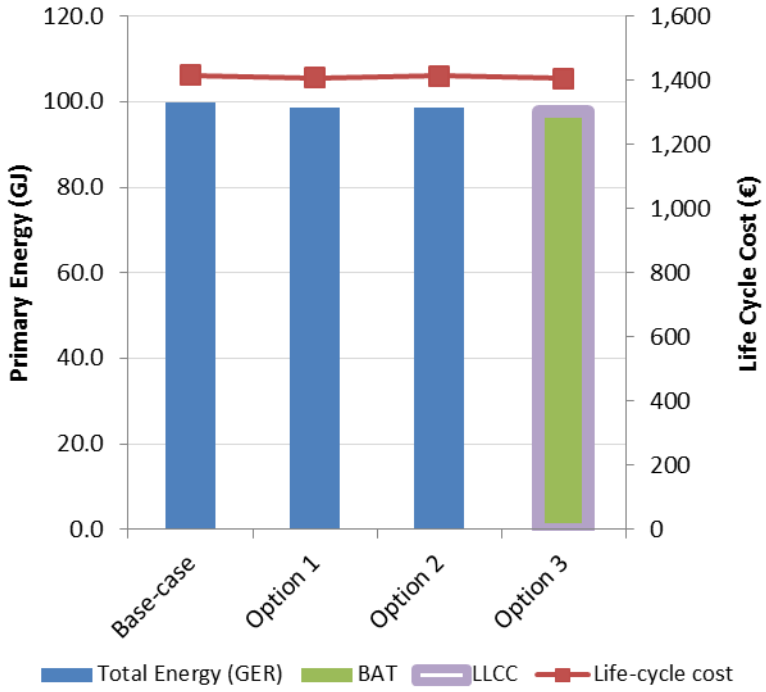


Figure 7-10: Identification of design improvement options with the least energy consumption and LLCC for BC-6

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

7.2.6 Base-Case 7: Counter-current pumps

The results of the environmental analysis of the different designs options for BC7 are presented in Table 7-17. Options 1 and 2 show to have reductions in the environmental impacts compared to the Base-Case and a primary energy reduction of 1% but it is the combination of these options that allows the highest reduction of environmental impacts, but the lowest consumer expenditure over the life cycle is achieved through option 1.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

Table 7-17: Environmental impacts of the BC-7 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 7	Option 1	Option 2	Options 1+2
Total Energy (GER)	GJ	17.5	17.2	17.2	17.2
	% change with BC	0%	-1%	-1%	-2%
Of which, electricity	Primary GJ	15.5	15.3	15.3	15.2
	Final MWh	1.5	1.5	1.5	1.4
	% change with BC	0%	-1%	-1%	-2%
Water (process)	kL	1.1	1.1	1.1	1.1
	% change with BC	0%	-1%	-1%	-2%
Water (cooling)	kL	40.6	40.0	40.0	39.8
	% change with BC	0%	-1%	-1%	-2%
Waste, non-haz./ landfill	kg	97.0	96.8	96.8	96.7
	% change with BC	0%	0%	0%	0%
Waste, hazardous/ incinerated	kg	4.4	4.4	4.4	4.4
	% change with BC	0%	0%	0%	0%
Greenhouse Gases in GWP100	t CO_2 eq.	0.8	0.8	0.8	0.8
	% change with BC	0%	-1%	-1%	-2%
Acidification, emissions	Kg SO_2 eq.	5.0	4.9	4.9	4.9
	% change with BC	0%	-1%	-1%	-2%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	-1%	-1%
Persistent Organic Pollutants (POP)	µg i-Teq	0.6	0.6	0.6	0.6
	% change with BC	0%	0%	0%	0%
Heavy Metals to air	g Ni eq.	0.7	0.7	0.7	0.7
	% change with BC	0%	-1%	-1%	-1%
PAHs	g Ni eq.	0.1	0.1	0.1	0.1
	% change with BC	0%	0%	0%	-1%
Particulate Matter (PM, dust)	kg	1.5	1.5	1.5	1.5
	% 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%	-1%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	0%
Life-cycle cost	€	1,932.6	1,931.1	2,083.7	2,082.0
	% change with BC	0%	0%	8%	8%

Figure 7-11 shows the different shares of life cycle costs throughout the life cycle of BC7 and the design options. For all the cases, purchase price have the highest share (69% of the total). The installation costs are the second contributors to the LCC. Both electricity and maintenance costs have little impacts throughout the life cycle of BC7 and the design options.

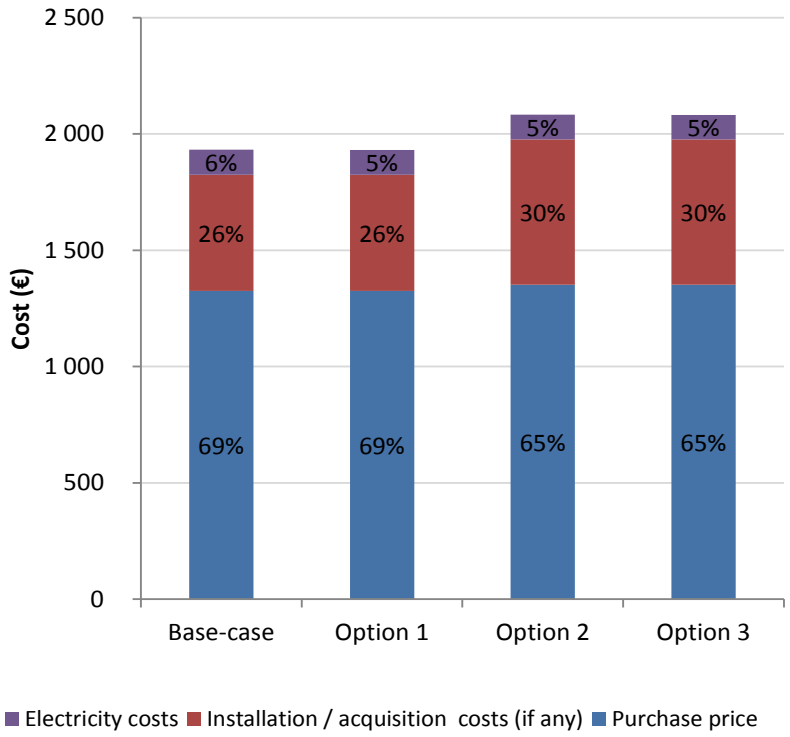


Figure 7-11: Life cycle costs of the improvement options for BC-7

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

Figure 7-12 presents the comparison between LCC and the primary energy consumption for BC7 and the design options. Combination of options 1+2 is the BAT and option 2 is the LLCC, achieving 1% energy savings and a reduction of 1% in life cycle costs.

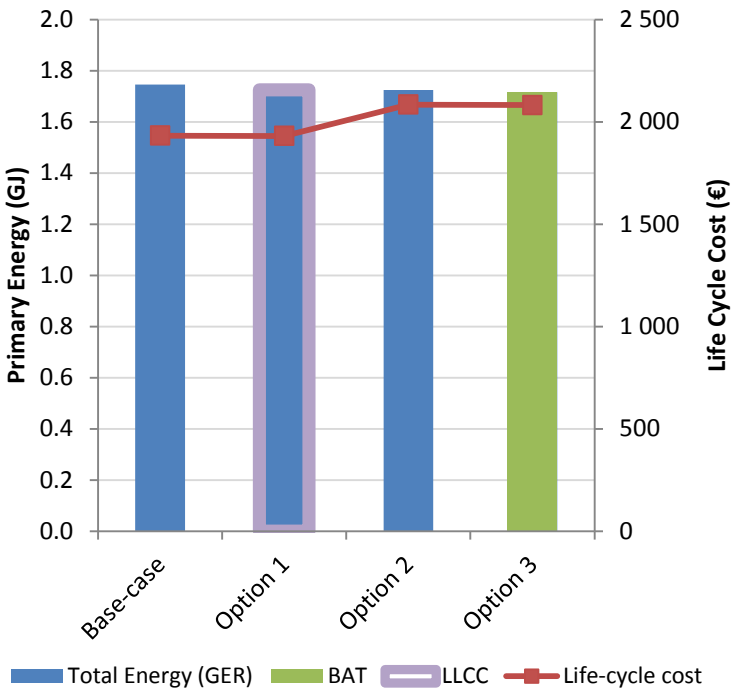


Figure 7-12: Identification of design improvement options with the least energy consumption and LLCC for BC-7

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

7.2.7 Base-Case 8: End-Suction Close Coupled pumps from 150 kW to 1 MW

The results of the environmental analysis of the different designs options for BC8 are presented in Table 7-18. The combination of options 1+2 shows the highest reductions in the environmental impacts and primary energy consumption, compared to the Base-Case. However, it is option 2 has a significantly higher energy savings potential than option 1.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-18: Environmental impacts of the BC-8 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 8	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	136,097.4	134,736.6	119,087.4	117,726.6
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	136,082.0	134,721.2	119,072.0	117,711.2
	Final MWh	12,960.2	12,830.6	11,340.2	11,210.6
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	9,072.8	8,982.1	7,938.8	7,848.1
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	362,882.9	359,254.1	317,522.9	313,894.1
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	158,314.2	156,736.4	138,592.1	137,014.3
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	3,138.4	3,107.1	2,746.5	2,715.1
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	5,939.8	5,880.5	5,197.5	5,138.2
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	35,046.5	34,696.1	30,666.5	30,316.1
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	kg	51.4	50.8	45.0	44.4
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	µg i-Teq	898.4	889.5	786.9	778.0
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	2,338.1	2,314.7	2,046.2	2,022.9
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	268.3	265.6	234.8	232.1
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	Kg	763.6	756.1	670.1	662.6
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	878.6	869.8	768.9	760.2
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	4.2	4.2	3.7	3.7
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	985,513.6	976,019.6	882,423.8	860,200.7
	% change with BC	0%	-1%	-10%	-13%

Figure 7-13 shows the different shares of life cycle costs throughout the life cycle of BC-8 and the design options. For all the cases, the electricity costs have the highest share of almost 100%. The purchase prices, installations and maintenance costs show very little impacts throughout the life cycle of BC8 and the design options.

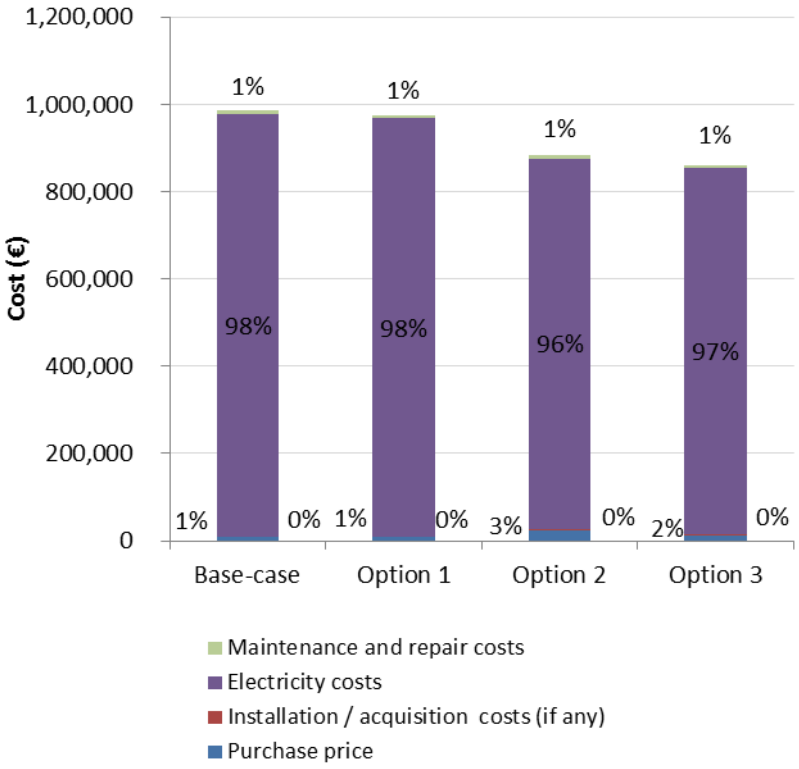


Figure 7-13: Life cycle costs of the improvement options for BC-8

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-14 presents the comparison between LCC and the primary energy consumption for BC8 and the design options. The combination of option 1+2 appears as the BAT and the LLCC, with energy savings of 13% and reduction of the LLC of 13%.

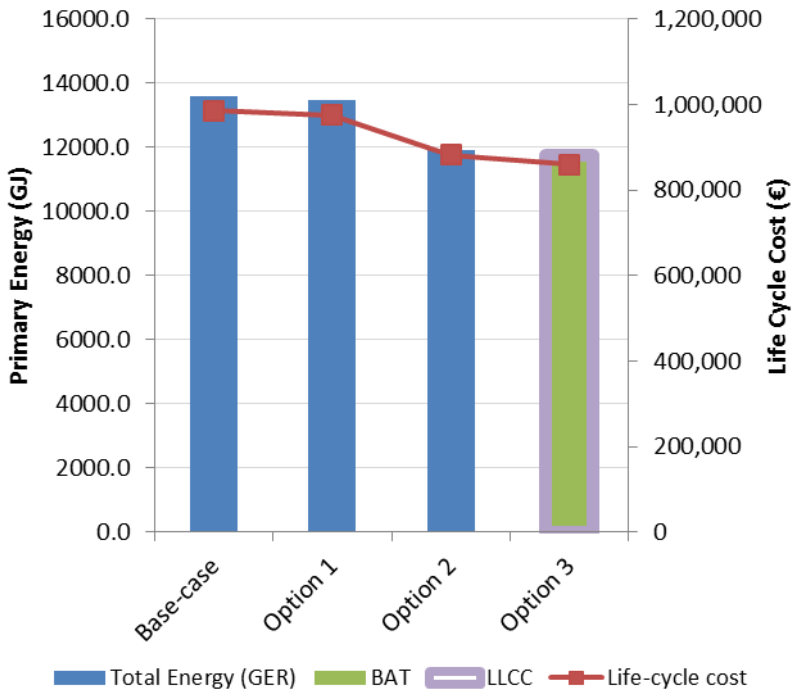


Figure 7-14: Identification of design improvement options with the least energy consumption and LLCC for BC-8

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.2.8 Base-Case 9: End-Suction Close Coupled Inline from 150 kW to 1 MW

The results of the environmental analysis of the different designs options for BC9 are presented in Table 7-19. As seen with BC8, the combination of options 1+2 shows to have the highest reductions in environmental impacts compared to the Base-Case. However, it is option 2 has a significantly higher energy savings potential than option 1.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-19: Environmental impacts of the BC-9 End-Suction Close Coupled Inline from 150 kW to 1 MW

Life-Cycle indicators per unit	Unit	Base-Case 9	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	136,097.4	134,736.6	119,087.4	117,726.6
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	136,082.0	134,721.2	119,072.0	117,711.2
	Final MWh	12,960.2	12,830.6	11,340.2	11,210.6
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	9,072.8	8,982.1	7,938.8	7,848.1
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	362,882.9	359,254.1	317,522.9	313,894.1
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	158,314.2	156,736.4	138,592.1	137,014.3
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	3,138.4	3,107.1	2,746.5	2,715.1
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	5,939.8	5,880.5	5,197.5	5,138.2
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	35,046.5	34,696.1	30,666.5	30,316.1
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	Kg	51.4	50.8	45.0	44.4
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	µg i-Teq	898.4	889.5	786.9	778.0
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	2,338.1	2,314.7	2,046.2	2,022.9
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	268.3	265.6	234.8	232.1
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	Kg	763.6	756.1	670.1	662.6
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	878.6	869.8	768.9	760.2
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	4.2	4.2	3.7	3.7
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	985,513.6	976,026.4	882,423.8	860,436.6
	% change with BC	0%	-1%	-10%	-13%

Figure 7-15 shows the different shares of life cycle costs throughout the life cycle of BC-9 and the design options. For all the cases, the electricity costs have the highest share of almost a 100%. Purchase prices, installations and maintenance show very little impacts throughout the life cycle of BC9 and the design options.

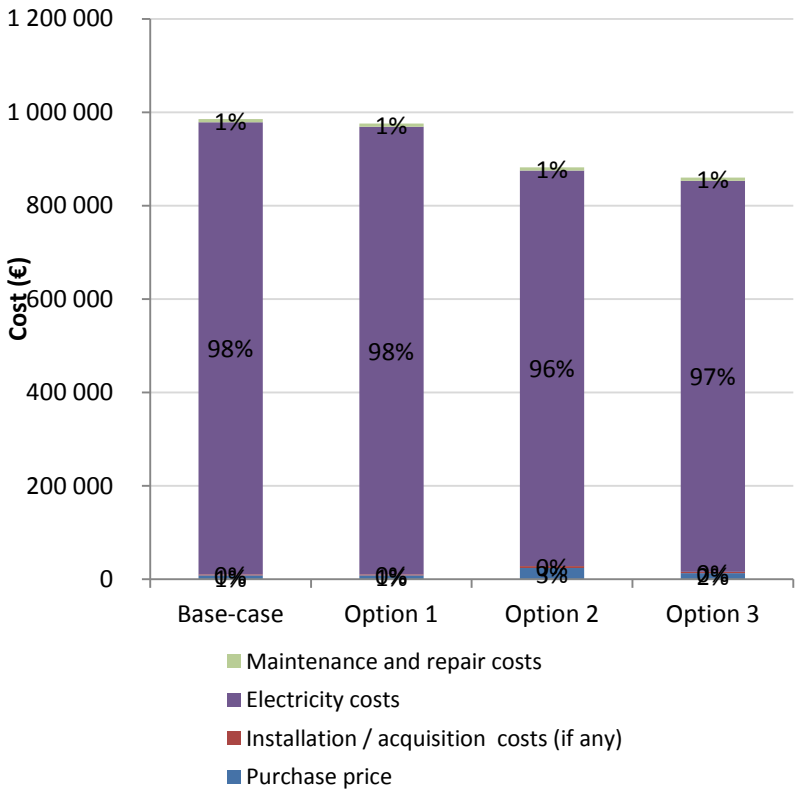


Figure 7-15: Life cycle costs of the improvement options for BC-9

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-16 presents the comparison between LCC and the primary energy consumption for BC-9 and the design options. The combination of option 1+2 appears as the BAT and the LLCC, with energy savings of 13% and reduction of the LLC of 13%.

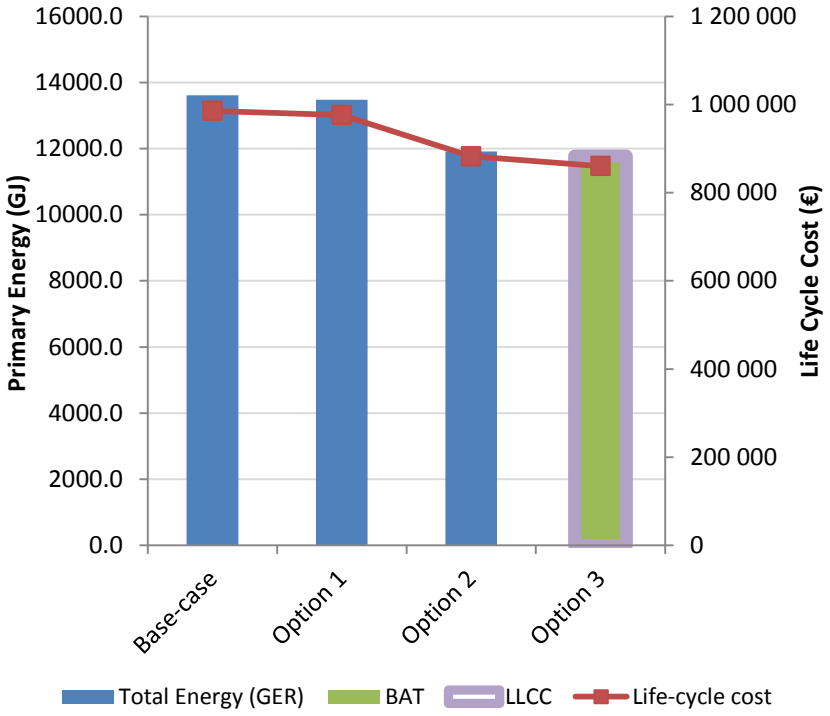


Figure 7-16: Identification of design improvement options with the least energy consumption and LLCC for BC-9

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.2.9 Base-Case 10: End-Suction Own Bearing from 150 kW to 1 MW

The results of the environmental analysis of the different designs options for BC10 are presented in Table 7-20. As seen with BC8 and BC9, the combination of options 1+2 shows to have the highest reductions in environmental impacts compared to the Base-Case. However, it is option 2 has a significantly higher energy savings potential than option 1.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-20: Environmental impacts of BC10: End-Suction Own Bearing from 150 kW to 1 MW

Life-Cycle indicators per unit	Unit	Base-Case 10	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	245,717.2	243,260.2	215,004.7	212,547.7
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	245,702.0	243,245.0	214,989.5	212,532.5
	Final MWh	23,400.2	23,166.2	20,475.2	20,241.2
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	16,380.8	16,217.0	14,333.3	14,169.5
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	655,202.8	648,650.8	573,302.8	566,750.8
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	285,411.9	282,563.1	249,802.4	246,953.7
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	5,662.6	5,606.0	4,954.9	4,898.2
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	10,723.6	10,616.4	9,383.3	9,276.1
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	63,273.7	62,641.0	55,365.2	54,732.5
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	Kg	92.6	91.7	81.1	80.2
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	µg i-Teq	1,616.9	1,600.8	1,415.6	1,399.5
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	4,218.7	4,176.5	3,691.8	3,649.6
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	484.2	479.4	423.7	418.9
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	Kg	1,366.4	1,352.8	1,197.4	1,183.9
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	1,585.4	1,569.6	1,387.4	1,371.5
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	7.6	7.5	6.7	6.6
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	1,765,870.2	1,748,579.4	1,557,235.8	1,538,945.0
	% change with BC	0%	-1%	-12%	-13%

Figure 7-17 shows the different shares of life cycle costs throughout the life cycle of BC-10 and the design options. For all the cases, the electricity costs have the highest share of almost a 100%. Purchase prices, installations and maintenance show very little impacts throughout the life cycle of BC10 and the design options.

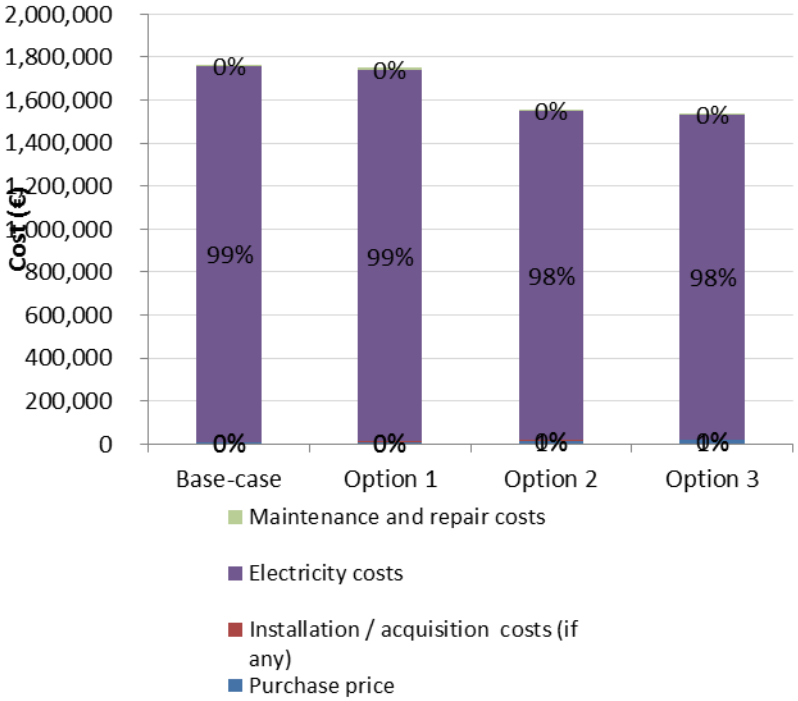


Figure 7-17: Life cycle costs of the improvement options for BC-10

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-18 presents the comparison between LCC and the primary energy consumption for BC10 and the design options. The combination of option 1+2 appears as the BAT the LLCC with a reduction of 13% of the Life cycle cost and a 13% reduction of primary energy consumption .

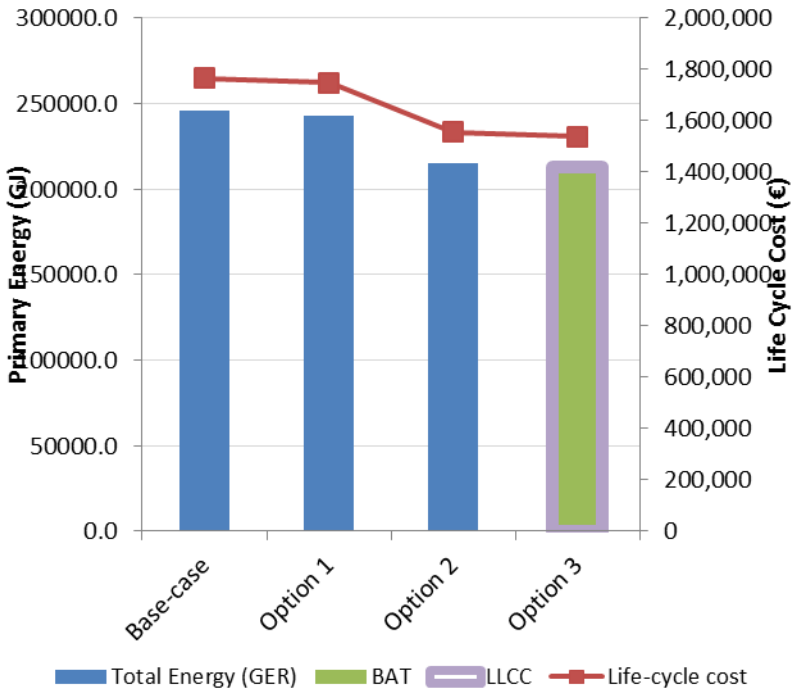


Figure 7-18: Identification of design improvement options with the least energy consumption and LLCC for BC-10

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.2.10 Base-Case 11: Submersible bore-hole pumps

The results of the environmental analysis of the different designs options for BC11 are presented in Table 7-21. As seen with BC8, BC9 and BC10 the combination of options 1+2 shows to have the highest reductions in environmental impacts compared to the Base-Case.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-21: Environmental impacts of the BC-11 Submersible bore-hole pumps

Life-Cycle indicators per unit	Unit	Base-Case 11	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	24,368.4	24,125.0	21,324.4	21,080.9
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	24,355.2	24,111.7	21,311.2	21,067.6
	Final MWh	2,319.5	2,296.4	2,029.6	2,006.4
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	1,624.1	1,607.9	1,421.2	1,404.9
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	64,941.2	64,292.0	56,823.9	56,174.4
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	28,677.9	28,395.6	25,148.5	24,866.1
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	566.9	561.3	496.8	491.2
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	1,063.9	1,053.3	931.0	920.4
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	6,274.2	6,211.5	5,490.4	5,427.6
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	Kg	9.2	9.2	8.1	8.0
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	µg i-Teq	166.4	164.8	146.4	144.8
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	420.8	416.6	368.6	364.4
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	48.0	47.5	42.0	41.5
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	Kg	142.2	140.8	125.4	124.1
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	158.1	156.5	138.4	136.9
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	0.8	0.8	0.7	0.7
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	231,878.1	229,955.7	210,735.3	208,463.1
	% change with BC	0%	-1%	-9%	-10%

Figure 7-19 shows the different shares of life cycle costs throughout the life cycle of BC-11 and the design options. For all the cases, the electricity costs have the highest share (between 84% and 88% of the total). The maintenance and repair are the second contributors to the LCC with 8%-9% of the total. The installation and purchase costs represent 1%-4% of the LCC throughout the life cycle of BC-11 and the design options.

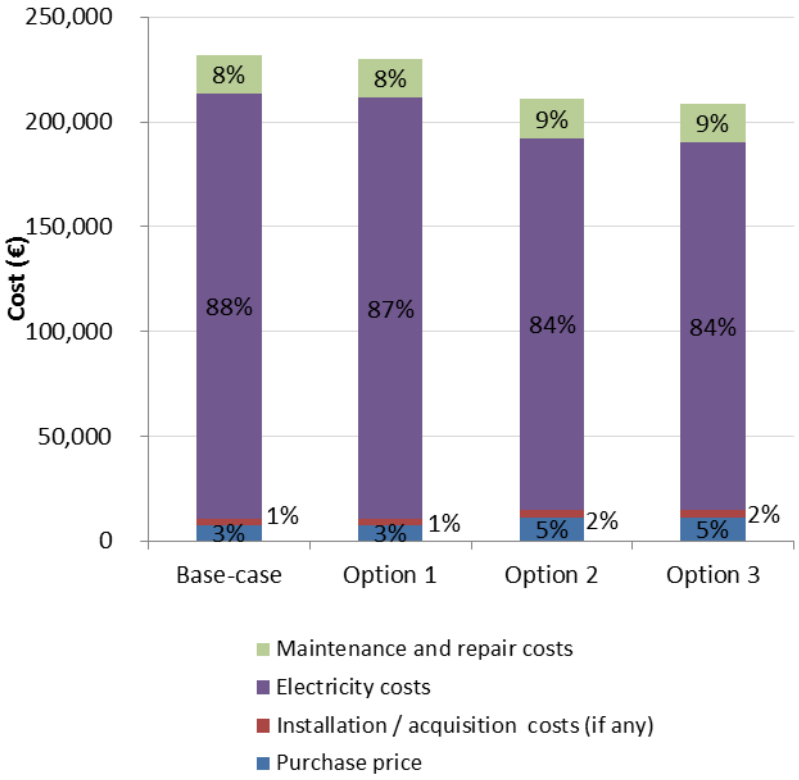


Figure 7-19: Life cycle costs of the improvement options for BC-11

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-20 presents the comparison between LCC and the primary energy consumption for BC-11 and the design options. The option 3 appears as the LLCC with a reduction of 18% of the Life cycle cost. The BAT is alsto option 3 with a 13% reduction in energy consumption.

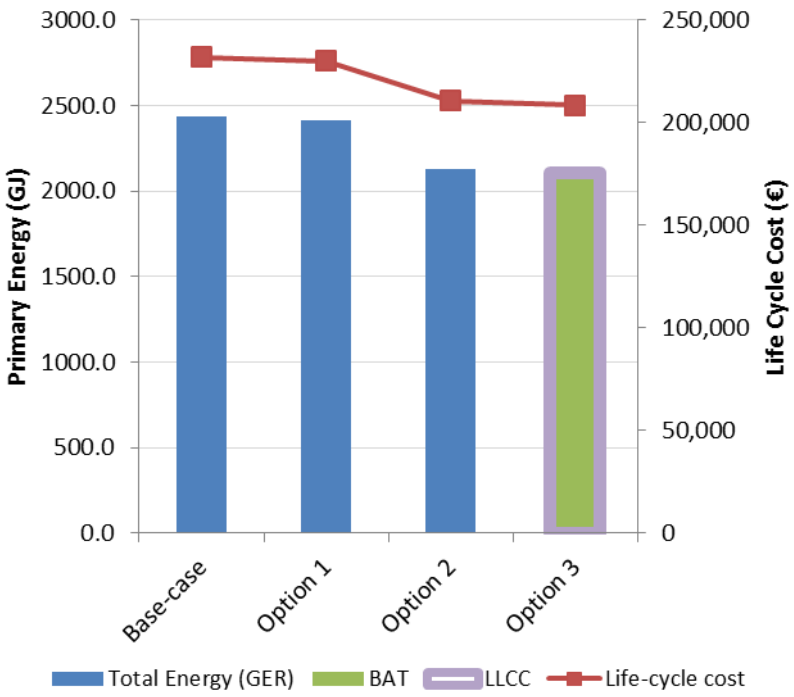


Figure 7-20: Identification of design improvement options with the least energy consumption and LLCC for BC-11

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.2.11 Base-Case 12: Vertical multi-stage pumps

The results of the environmental analysis of the different design options for BC12 are presented in Table 7-22. As seen with BC11, the combination of options 1+2 shows to have the highest reductions in the environmental impacts compared to the Base-Case and a primary energy reduction of 13%.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-22: Environmental impacts of the BC-12 Vertical multi-stage pumps

Life-Cycle indicators per unit	Unit	Base-Case 12	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	31,016.2	30,706.2	27,140.7	26,830.7
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	31,005.3	30,695.3	27,129.9	26,819.9
	Final MWh	2,952.9	2,923.4	2,583.8	2,554.3
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	2,067.5	2,046.9	1,809.2	1,788.5
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	82,677.8	81,851.1	72,343.3	71,516.5
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	36,324.2	35,964.7	31,830.8	31,471.3
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	717.6	710.4	628.3	621.1
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	1,353.9	1,340.4	1,184.8	1,171.2
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	7,987.2	7,907.4	6,989.3	6,909.5
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	kg	11.7	11.6	10.3	10.2
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	µg i-Teq	207.9	205.9	182.5	180.5
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	534.3	529.0	467.8	462.5
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	61.2	60.6	53.6	53.0
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	kg	179.3	177.6	158.0	156.3
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	200.7	198.7	175.7	173.7
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	1.0	1.0	0.9	0.9
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	277,399.1	275,158.7	250,443.6	247,964.9
	% change with BC	0%	-1%	-10%	-11%

Figure 7-21 shows the different shares of life cycle costs throughout the life cycle of BC-12 and the design options. For all the cases, the electricity costs have the highest share (between 89% and 92% of the total). The purchase prices are the second contributors to the LCC with 4% -6% of the total. The installation and maintenance costs represent 1% and 3% respectively of the LCC throughout the life cycle of BC-12 and the design options

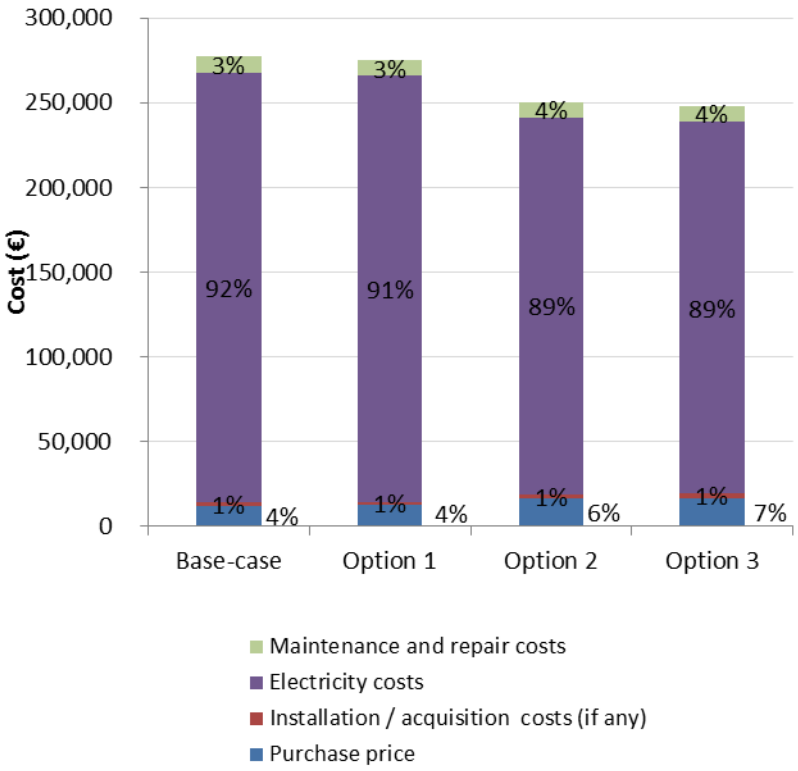


Figure 7-21: Life cycle costs of the improvement options for BC-12

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-22 presents the comparison between LCC and the primary energy consumption for BC11 and the design options. The combination of option 1+2 appears as the LLCC with a reduction of 12% of the Life cycle cost, as well as the BAT with 13% reduction of primary energy consumption.

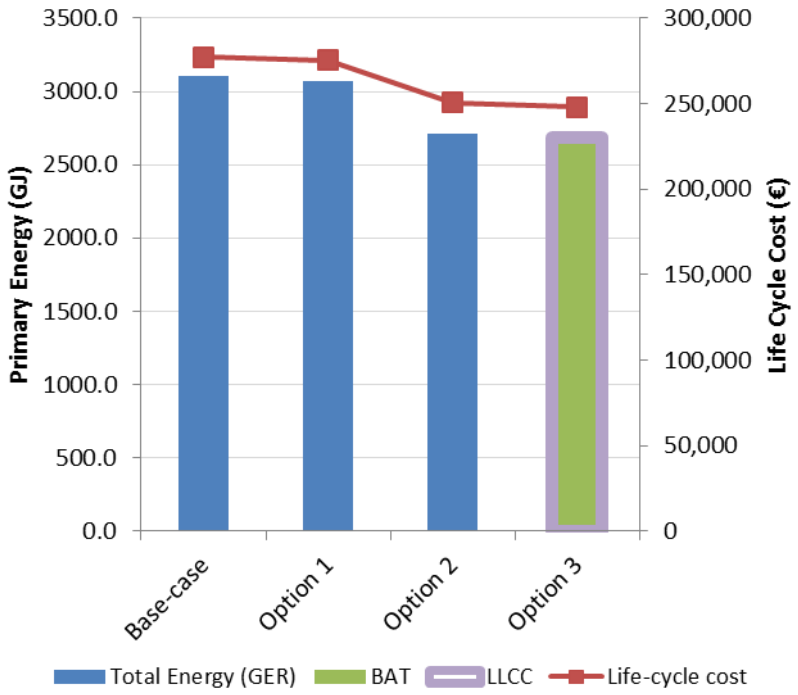


Figure 7-22: Identification of design improvement options with the least energy consumption and LLCC for BC-12

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.3 BNAT and long-term systems analysis

Pumps are a very well established technology that has been refined for several years, and therefore there is very little in terms of 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 as closer manufacturing tolerances become feasible.

An area where savings are likely to be realised in the future is in optimum control of swimming pool pumps. This is already seen to a limited fashion at the moment through variable speed drives, however in the future the potential exists to combine the pump operation with a greater level of intelligence regarding the water quality, such as through the use of turbidity monitors to detect the suspended solids, or chemical analysis to control the chemical dosing requirements. With more intelligence, the VSD and other control units can be used largely and the savings made will be more significant.

7.4 Conclusions

Several improvement options are available for each Base-Case, with different payback periods and in some cases a few constraints. Combinations of these improvement options provide potential for some energy savings, leading to reduction of negative environmental impacts.

In terms of potential energy savings, the option offering the most significant potential savings is VSD. Where applicable, VSD seems to offer the biggest potential energy consumption savings that varies between 10% and 40%. This is the case for swimming pool pumps (BC-1, BC-2), End-suction closed coupled pumps (BC-8, BC-9, BC- 10) and for submersible and vertical pumps (BC-11, BC-12). However, 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.

There are some improvement options that stand out in terms of payback time due to their requirement of little to no investment. As discussed before, VSD is the option that offers the biggest energy savings but also has higher associated costs. The results show that throughout all the Base-Cases, the BAT is always a combination of the different improvement options.

Only in counter-current pumps (BC 7) the option with LLCC is one of the improvement non-combined options. For aquarium pumps the Base-case itself is the LLCC (BC4&5). For the remaining Base-Cases, the LLCC is a combination of all the different improvement options, which is at the same time the BAT. Currently, no available improvement options have a potential to become more affordable over the coming years.

Hence, some increase in the energy efficiency of pumps could be achieved without significant additional environmental impacts, but this varies significantly between pumps types. Fountain, pond, aquarium, spa and counter-current pumps do not present high potential for energy efficiency improvement, and some of the improvement options have long payback times.

Swimming pool pumps, end-suction pumps, submersible borehole pumps and vertical multistage pumps present some potential for energy efficiency improvement, mainly due to VSD. This technology is already implemented in part of end-suction pumps and vertical multistage pumps installed in the EU. However, as discussed above, VSD would not be beneficial for all the pump applications. These results will be further discussed in context of policy options in Task 8.



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

ENER Lot 29– Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under Lot 11) – Task 8: Scenario, policy, impact and sensitivity analysis

Final report to the European Commission, DG ENER
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Chapter 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 would allow achieving reduction of environmental impacts with consideration to Life Cycle Cost and the best available technologies in the market. Some scenarios analyses allow examining and quantifying the potential energy and economic 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 an analysis of various policy options that the authors of the report believe to be of use in order to achieve the desired reduction of the environmental impacts of clean water 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

The purpose of Task 8 is to suggest the most beneficial policy on the products studied. In this section, 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 ENER Lot 29 study are detailed in the following sub-sections.

The pumps covered by Lot 29 use electric motors, which may be subject to specific ecodesign regulation (e.g. 640/2009). All motors over 120 W are studied within the preparatory study ENER Lot 30. Motors used in borehole pumps are also studied in Lot 30.

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 ENER Lot 11 and ENER Lot 28 studies on motors and 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[1], as required by the European Commission to undertake the cost and environmental impact analysis in Ecodesign preparatory studies.

8.2.2 Swimming pools

Swimming pool pumps: devices sold for residential use as well as some commercial use. Domestic swimming pool pumps are typically made from plastic for reasons of efficiency, and of steel in commercial pool pumps for wear resistance and longevity. Domestic swimming pool pumps are typically rated from 40W to around 1kW, depending on the size and design of the pool. Commercial swimming pool pumps are usually above 2.2 kW. Swimming pool pumps come as packaged units that comprise an integrated motor, pump, strainer and controls, and sometimes integrated in a filtering unit. Domestic swimming pool pumps can also be used for jacuzzis.

The final user of swimming pool pumps is normally biased towards the performance and reliability of the pump, and commonly energy efficiency plays a secondary role in the product characteristics. Furthermore, the choice of pumps for swimming pools as per usual goes to the contractors involved with the construction of the swimming pool, rather than to the final user. This implies that the energy efficiency of swimming pool pumps, broadly speaking, may not be a major issue for customers, and therefore, for manufacturers.

The results of Tasks 6 and 7 of this preparatory study show that for swimming pool pumps there is some potential for improvement of the energy efficiency of the products. The payback periods of these improvements depend on the type of pump and its potential for improvement.

The possibilities for regulating swimming pool pumps are several:

A. Information requirements regarding energy efficiency of pumps
B. Energy labelling
C. Mandatory requirement of speed controls
D. Mandatory use of time controls
E. Minimum Energy Performance Standards
F. Voluntary use of correct sized pipes to reduce friction

The following sections present the benefits and drawbacks of each of these policy options.

8.2.2.1 *Information requirements for swimming pool pumps*

The generalisation of a standardised method of communicating the energy performance of swimming pool pumps would be useful to installers and customers to have the right information to make their choice when purchasing a pump.

[1] Available at http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/methodology/index_en.htm

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.

For swimming pool pumps, 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 energy efficiency index of pumps, calculated in accordance with section 8.2.2.4, shall be indicated on the name plate and packaging of the product and in the technical documentation. It could be given as follows: "MEI ≥ 0,[##]". If no MEI calculation method is developed for swimming pool pumps, the energy efficiency information can be given as efficiency (η) at Best Efficiency Point (BEP), at Part Load (PL), and at Over Load (OL)[2].
- The following information shall be provided: "The benchmark for most efficient swimming pool pumps is MEI ≥ 0,[##]". If no MEI is developed for swimming pool pumps, the benchmark can be given as efficiency (η) at Best Efficiency Point (BEP), at Part Load (PL), and at Over Load (OL)[3].

The information listed above shall be visibly displayed on freely accessible websites of the water pump manufacturers.

8.2.2.1 *Energy labelling*

An alternative to the information requirements explained in the previous section is an energy label that would inform consumers and installers of the relative efficiency of the whole pump in relation to the pumps in the EU market. This type of energy label is similar to the existing EU energy label mandatory for some product types, the US Energy Star scheme and a similar voluntary scheme is used in the Australian standard AS 5102.2.

Energy labelling can be an effective policy tool for the consumer market to help consumers make the right choice of best performing product. Therefore, it is proposed that an energy label that gives an indication of the energy consumption of that pump is used on packaging and other

[2] See definition of MEI, ηBEP, ηPL and ηOL in section 8.2.2.4. Although the efficiency (η) and MEI are parameters already used in the EU for water pumps, the development of MEI would require a full market analysis of the swimming pool pumps in the EU. The efficiency (η) at BEP, PL and OL are already in use in the industry and should not pose major problems to implement the information requirements.

[3] No information can be found at the time of writing on the benchmark of swimming pool pumps measured as efficiency at BEP, OL or PL. These parameters are not commonly published by manufacturers.

information. This would be based on the US Energy Star and Australian swimming pool pump labelling information schemes.

Key Product Criteria for ENERGY STAR Qualified Pool Pumps

Version 5.0 Energy Efficiency Requirements: *Effective February 15, 2013*	
Product Type	**Requirements**
Single Speed Pump	**EF** ≥ 3.8 for the single speed Energy Factor (EF) is the volume of water pumped in gallons per watt hour of electric energy consumed by the pump motor (gal/Wh).
Multi-speed, Variable-speed, and Variable-flow pump	**EF** ≥ 3.8 for the most efficient speed Most Efficient Speed: The speed with the highest Energy Factor for a given pump.

Figure 8-1: Energy Star requirements for pool pumps

The US Energy Star criteria for swimming pool pumps are set on Energy Factor (EF), which is the volume of water pumped in gallons per watt-hour of electrical energy consumed by the pump motor (gal/Wh).

The US Energy Star has been adopted by EU Regulation for of office equipment. The EU Energy Star programme was possible thanks to an agreement between the US and the EU to co-ordinate energy labelling of a number of products. The EU Energy Star is managed by the European Commission, with the support of the US EPA, which is the founder and responsible of the US Energy Star.

A similar approach could be taken in the case of swimming pool pumps, which would help homogenise the labelling of these products in the US and EU markets.

The US Energy Star certified pumps are thought to save over $300 per year per pump or $113 million per year[4], which would correspond to around 26 kWh per pump per year[5]. According to a manufacturer, the average swimming pool pumps in the US are slightly more efficient than the average swimming pool pumps in the EU. The entire stock of swimming pool pumps in the EU (i.e. 4,915,000 units, as stated in Task 2 of this preparatory study) is in the same order of magnitude as the US stock of in-ground pool pumps (i.e. 5,000,000 units[4]).

The advantage of the Energy Star is that it is an already existing scheme, which would ease its implementation. The drawbacks are that this scheme is of voluntary application by manufacturers, which does not ensure the penetration of efficient pumps in the market. Furthermore, it differs from already existing EU Regulation for water pumps, which could make it more complex for manufacturers.

Figure 8-2 shows the benchmark of swimming pool pumps as per the Energy Factor used in the US Energy Star scheme.

[4] http://www.energystar.gov/certified-products/detail/pool_pumps?fuseaction=find_a_product.showProductGroup&pgw_code=PP (accessed in March 2014)

[5] Calculated at a retail price of electricity to ultimate customers of $11.65 per kWh. (Source: http://www.eia.gov/electricity/monthly/ accessed in March 2014)

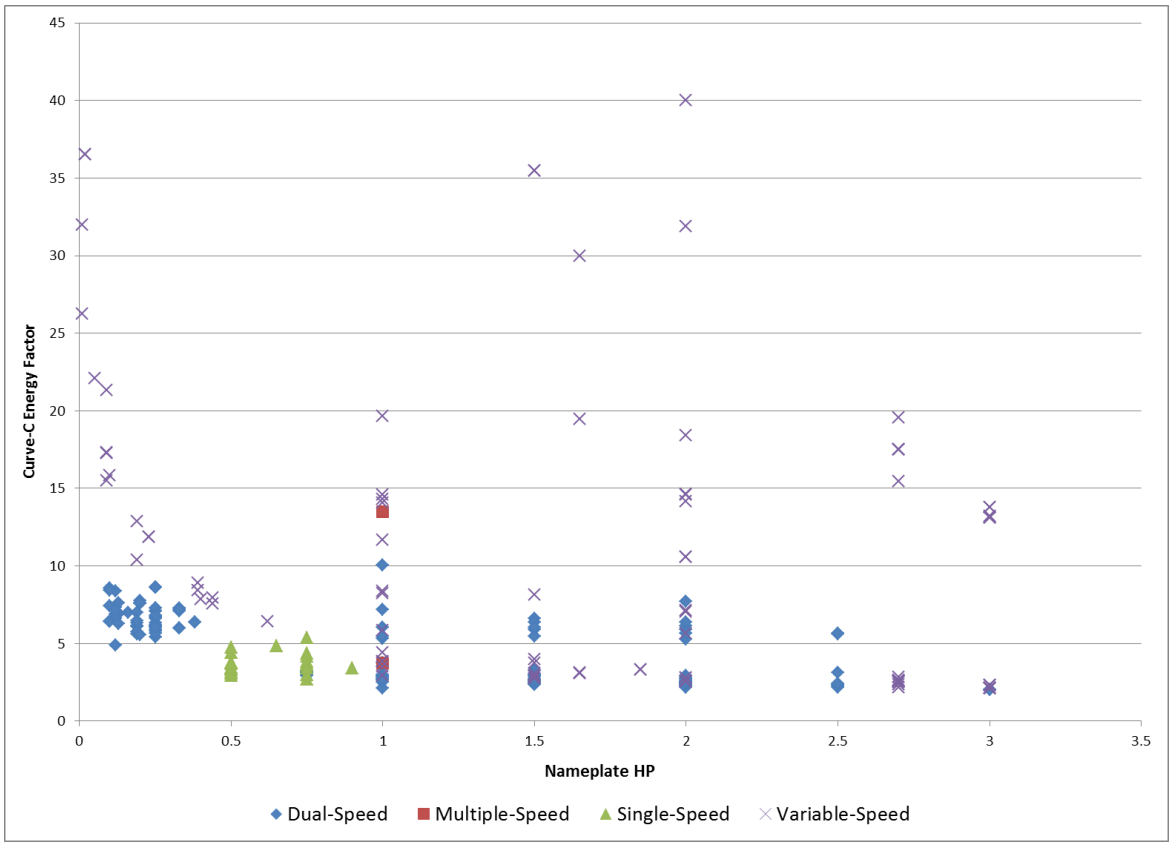


Figure 8-2: Energy Factor of Energy Star-certified swimming pool pumps[6]

8.2.2.2 *Mandatory requirement of speed controls for swimming pool pumps*

Literature sources, legislation and voluntary schemes already in place in the US consistently quote significant energy and economic savings due to the use of variable speed motors instead of single speed in swimming pool pumps. Swimming pool pumps running half-speed for twice the time can theoretically offer 1/8 of the power at 1/4 the energy consumed. The requirement of variable speed or two-speeds is already used in the ANSI/APSP/ICC-15-2011 American National Standard for Residential Swimming Pool and Spa Energy Efficiency. Other states such as California have financial incentives to install variable speed pumps in swimming pools.

The option of implementing two speed drives in swimming pool pumps would not be so precise at setting speeds as VSD, and has much worse energy consumption at low speed than a VSD. Two-speed may be a good regulatory baseline, but is far from the optimum energy saving potential. Two-speed pumps are typically low efficiency operating on low speed, while the motors on variable speed products tend to hold up efficiency at lower speeds. A two-speed pump

[6] Source: http://www.appliances.energy.ca.gov/AdvancedSearch.aspx. Accessed on March 2014. The Energy Factor (Gallons/watt-hr) calculated as per Head Curve-C of a plumbing system, which represents typical pools using 2" pipe size. The plumbing curve crosses the pump's head curve at a single point, called the operating point of the pump/plumbing system. The Energy Factor is standardised in ANSI/APSP/ICC-15a 2013 American National Standard for Residential Swimming Pool and Spa.

operating at half speed can be expected to save up to 55%, while a good variable speed one could save theoretically up to 75%. The variable speed can be set to the lowest speed that works for the pool, while the two-speed offers only 2 choices. The scenario analysis in section 8.4.5 presents an estimation of the potential impacts of this policy option.

However, European swimming pool pump manufacturers represented in Europump association do not fully acknowledge these claims for savings. The key arguments against is that the diversity of swimming pool pumps and their uses in the EU would make it difficult to state that VSD would be a beneficial solution for all swimming pool applications. Not all swimming pool pumps would need a pump at variable speed, some could meet the water pumping needs with two-speed pumps or with fixed-speed pumps controlled by contactors. This would depend much on the load profile and the use pattern of the swimming pool and the pump, and so the implementation of VSD in all pumps in the EU might be counter-productive. However, it is unclear why this situation might be significantly different to that found in the USA.

Facing the lack of agreement on the potential benefits of this policy option, no mandatory requirements of speed controls can be proposed for swimming pool pumps.

8.2.2.3 *Mandatory use of time controls for swimming pool pumps*

In the absence of speed controls, time-switches or other controller with time control function could be added to swimming pool pumps. An appropriate time switch sold together with the pump could limit the operation time of the pumps. This would reduce the energy consumption of the pump in hours where the turnover is not necessary. This requirement is already applied in some states of the US such as Florida[7].

For domestic swimming pools, the turnover time could be estimated as 8 hours in Europe, meaning that the pump should turn over the pool water at least once in this period. This could vary for the time in which any additional equipment such as water heater or water treatment dosing equipment need to work to maintain the water temperature or quality.

The main barrier for this policy option is that the turnover rate for swimming pool pumps is not homogenised across Europe, and usually depend on national health and safety requirements. In any case, the installer or the user, depending on the legal requirements applicable in their country, could adjust the time switch.

It is therefore recommended that mandatory use of time controls is put forward into regulation for swimming pool pumps. The potential energy savings would therefore vary depending on the specific regulation in each Member State. To give an example, if 25% of all the pumps used in the EU are operating for 30% longer than required, then a 7.5% reduction in energy consumption could be expected at EU level.

[7] http://www.floridapoolpro.com/industry/govtrelations/Energy%20Law%20Code%20QA.pdf (accessed on March 2014)

8.2.2.4 *Minimum Energy Performance Standards for swimming pool pumps*

Ecodesign Implementing Measures regarding energy efficiency of products (i.e. Minimum Energy Performance Standards) are already in place for some water pumps and circulators, in the form of Minimum hydraulic Efficiency Index (MEI) and/or Energy Efficiency Index (EEI). [8, 9]

A Regulation on energy efficiency of swimming pool pumps in the form of MEI or EEI, based on parameters and approaches comparable to other pump regulations mentioned before, would help homogenise the regulation affecting water pumps in the EU. It could consist on an extension of the existing MEI and EEI methodologies for pumps and circulators to define the most beneficial energy performance index scheme for swimming pool pumps.

This section presents the possible benefits and downsides of a regulation for swimming pool pumps based on Minimum Energy Performance Standards.

Tasks 6 and 7 of this preparatory study show the potential energy savings and the associated cost increase for swimming pool pumps. Hydraulic improvements and motor improvements for these pumps would allow reductions of around 0.5% to 1.5% of annual energy consumption per pump. The use of speed controls could realise conservative energy savings of 10% to 40% per year, although there is not yet stakeholder consensus on this claim. In this report, an average energy saving of 10% for domestic swimming pool pumps below 2.2 kW and 40% for swimming pool pumps above 2.2 kW are assumed in all calculations. Assuming these potential savings, the payback times of these improvement options for domestic swimming pool pumps below 2.2 kW are between 3 and 45 years. In the case of domestic and commercial swimming pool pumps over 2.2 kW, the payback times would be between 1 and 2.5 years.

Regarding the potential benefits of speed control, some literature sources quote from 50% to 80% energy savings in swimming pools after the substitution of a single speed pump by a variable speed pump[10]. The US Energy Star scheme estimates that multiple speeds in swimming pool pumps could potentially save over $100 million per year in electricity across the US[11]. European swimming pool pump manufacturers represented in Europump association do not fully acknowledge these potential savings. The potential energy savings of speed control for swimming pool pumps in Europump's opinion would be between 10% to 12.5%.

Furthermore, according to Europump, swimming pool pumps are designed to meet 24 hours water circulation, and therefore there would be little or no scope to vary the speeds. Often these pumps have inverters that allow the exact flow to be achieved, which optimises the energy

[8] Commission Regulation (EC) No 641/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products.

[9] Commission Regulation (EU) No 547/2012 of 25 June 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for water pumps.

[10] Hunt and Easley (2012) Measure guideline: Replacing Single-Speed Pool Pumps with Variable Speed Pumps for Energy Savings.

[11] http://www.energystar.gov/certified-products/detail/pool_pumps

consumed by the pump. Other stakeholder suggested that for domestic swimming pools, the turnover time could be estimated as 8 hours in Europe.

Ideally, any regulation on energy efficiency of pumps should be based on the Extended Product Approach presented in Task 1 of this preparatory study. This would help homogenise the regulation affecting water pumps in the EU. The 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. This would solve the question whether the speed controls are beneficial for all swimming pool pumps or not.

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 fixed speed, variable speed or two speeds.

This EEI index 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 swimming pool pumps to be regulated. More information about the EEI is presented in Annex I

Another efficiency parameter, the Minimum hydraulic Efficiency Index (MEI), is defined in the Commission Regulation 547/2012 on ecodesign regulation for 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 swimming pool 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.

For the aim of this preparatory study, different policy options or scenarios based on MEI are modelled in a scenario analysis in section 8.4. That analysis of different scenarios will help estimate and compare the potential benefits at EU level of regulation on swimming pool pumps with different levels of ambition. Section 8.6 will analyse other possible impacts of those policy options.

The MEI values are estimated based on the energy savings and market data for swimming pool pumps presented previously in Task 7 report of this study.

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 these pumps, 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)[12] from setting the different MEI requirements, the distribution of swimming pool pumps is split into 10 discrete bands from 0% (reference, denoted by WP: Worst pump) to 100% cut off, as presented in Table 8-18-1. The maximum energy savings presented in this table refer to the potential energy savings related to the hydraulic efficiency and motor improvements, since as discussed in Task 7 and previously in this section, the application of Variable Speed Drives might not be beneficial for all swimming pool pumps in the EU market.

An additional scenario is presented in section 8.4 using the maximum energy savings due to VSD as the BAT level, in order to estimate what would be the maximum potential energy savings of speed controls at EU level.

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.

[12] 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.

Table 8-1: Estimation of swimming pool pumps market distribution

	Cut-off value									
Reference product	BAT						BC			WP
Base-case 1: SPPS (Domestic swimming pool pumps up to 2.2 kW)										
Cut-off	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
MEI	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Annual energy consumption per product (kWh)	1,411	1,416	1,421	1,426	1,430	1,435	1,440	1,445	1,450	1,454
Difference in annual energy consumption to Base-Case (%)	-2.0%	-1.7%	-1.3%	-1.0%	-0.7%	-0.3%	0.0%	0.3%	0.7%	1.0%
Difference in purchase cost to Base-Case (%)	4.0%	3.2%	2.4%	1.6%	0.8%	0.0%	0.0%	0.0%	-0.8%	-1.6%
Difference in life cycle cost to Base-Case (%)	-1.6%	-1.4%	-1.1%	-0.8%	-0.6%	-0.3%	0.0%	0.3%	0.6%	0.8%
Base-case 2: SPPL(Domestic and commercial swimming pool pumps above 2.2 kW)										
Cut-off	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
MEI	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Annual energy consumption per product (kWh)	19,845	19,913	19,980	20,048	20,115	20,183	20,250	20,318	20,385	20,453
Difference in annual energy consumption to Base-Case (%)	-2.0%	-1.7%	-1.3%	-1.0%	-0.7%	-0.3%	0.0%	0.3%	0.7%	1.0%
Difference in purchase cost to Base-Case (%)	4.0%	3.2%	2.4%	1.6%	0.8%	0.0%	0.0%	0.0%	-0.8%	-1.6%
Difference in life cycle cost to Base-Case (%)	-1.9%	-1.6%	-1.3%	-1.0%	-0.6%	-0.3%	0.0%	0.3%	0.6%	1.0%

BAT: best energy efficient pump in the market
BC: Base-case
WP: worst energy efficient pump in the market

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) and phrased as follows:

Swimming pumps shall have a minimum efficiency:

— at the best efficiency point (BEP) of at least (η BEP)

— a minimum efficiency at part load (PL) of at least (η PL)

— a minimum efficiency at over load (OL) of at least (η OL):

$$(\eta \text{ BEP}) = F_1 x + F_2 y - F_3 x^2 - F_5 y^2 - F_6 x y - C$$

$$(\eta \text{ PL}) = F_7 \cdot (\eta \text{ BEP})$$

$$(\eta \text{ OL}) = F_8 \cdot (\eta \text{ BEP})$$

Where:

x = ln (n s);

y = ln (Q);

ln = natural logarithm;

Q = flow in [m^3 /h];

n s = specific speed in [min –1]; and

C = specific values calculated for each pump type and MEI.

F_1 to F_8 = specific factors of the formulae calculated for each pump type.

Based on a market data collection, the C-values and function factors will need to be adjusted in the possible regulation so that MEI of 0.1 corresponds to banning 10% of the worst performing pumps of each type. An initial estimation by the study authors of the C-values is presented in Annex II. However, an exhaustive data collection on pumps in the EU market should be carried out in order to calculate the appropriate C-values.

The choice of the optimal cut-off values regarding energy savings and consumer expenditure is described in the scenario analysis, section 8.4. In that section, various possibilities of cut-off values are assessed in order to propose the best options and evaluate the potential energy savings at EU level.

8.2.2.5 *Voluntary use of correct sized pipes for swimming pools*

The size of the water pipes and the design of elbows and turns in them influence highly the friction of the fluid passing through them and therefore the energy consumption of the pump in the system. The SPATA Standards Volume Two (1999) give a Suction Velocity maximum 1.2 m/s and Return Velocity maximum 2.0 m/s. The Pool Water Treatment Advisory Group "Swimming Pool Water – Treatment and Water Quality Standards for Pools and Spas – Second Edition 2009" recommend 1.5 m/s suction and 2-2.5 m/s discharge. In principle, there would be no need for higher flow velocities, and therefore the pipe size could be designed accordingly.

The requirements on pipe design and time controls go beyond the ecodesign of swimming pool pumps, and are mostly responsibility of the designer or installer of the swimming pool system. Even though improvements on the pipe design could lead to optimisation of the energy consumed by swimming pool pumps, the manufacturers of swimming pool pumps do not have influence on the elements of the swimming pool system other than pumps.

It could be possible, however, that pump manufacturers include guidelines on the correct design and installation of elements of the pumping system with influence on the energy efficiency of the pump, such as pipe diameter and pipe elbows, in order to optimise the energy performance of the pump. A clear best practice could be given in printed materials and on the pump box to state the cost to the user of not sizing correctly the pipes.

In this context, installer education is needed. A voluntary agreement with installers for the use of properly sized connecting pipework could also be used to put forward this requirement. Installers would sign up to installer association voluntary agreements.

The following figure shows the difference in head loss between two different pipe sizes for a range of flow rates. For a pump rated at 150 l/m the difference in head loss due to pipe size is approximately 3 m. This is approximately equal to 110W of additional power, or 0.9kWh per day based on an 8-hour day.

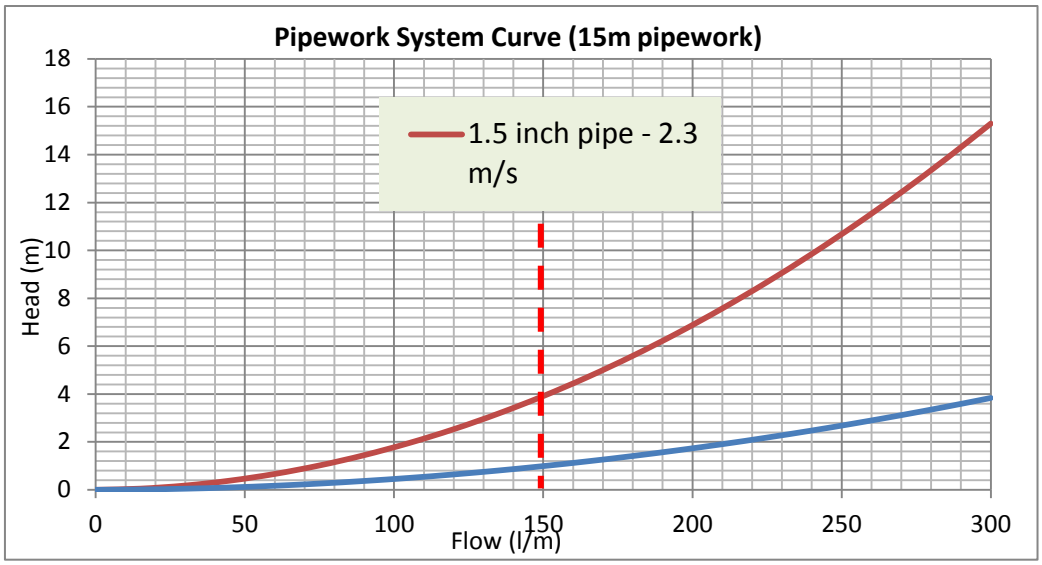


Figure 8-3: Difference in head loss between 2 inch and 1.5 inch pipe for a range of flow rates

Pumps would have to have inlet and outlet fittings sized for the correct sized pipes. A voluntary scheme for installers, through national installer associations, could be used to drive through this requirement, such as a label or certification to installations that respect the recommended pipe size. The real impact that such recommendations would have on pumps energy consumption can be estimated at around 10% savings, although more ambitious claims up to 40% can be found in the literature[13, 14].

8.2.3 Fountain, aquarium, pond, spa and counter current pumps

Fountain and pond pumps: pond pumps and fountain pumps are basically built in the same way and differ only for the point of work on the flow/head characteristic curve. Pond pumps drive water through a filter whereas fountain pumps are designed for higher heads for decorative features such as fountains or waterfalls. In pond pumps dirty water will be sourced from a ground filtration unit and often also from a protein skimmer that removes residue from the surface

Spa pumps: the same technology as swimming pool pumps but lower capacity. These pumps work in the same way as swimming pool pumps.

[13] Residential Swimming Pool Efficiency, 2006. Prepared by Building a Safer Florida and the University of Florida's Program for Resource Efficient Communities

[14] 2008 California Building Energy Efficiency Standards. Residential Swimming Pools. Measure Information Template. Pacific Gas & Electric Company, 2006.

Counter-current pumps: the same technology as swimming pool pumps but bigger capacity. These pumps work in the same way as swimming pool pumps but at a higher fixed speed.

Aquarium pumps: circulation pumps connected to a device that works as a filter. Inside the filter, water is forced to flow through different types of filtering materials, in such a way that water is cleared from dirt and detoxified from fish waste. Most Aquarium pumps use the technology of integrated motor with wet rotor and nowadays aquarium pumps exclusively employ high efficiency permanent magnet motors.

The assessment of environmental impacts of fountain pumps, aquarium pumps, pond pumps, spa pumps and counter-current pumps made in Task 5 of this preparatory study showed that this group of pumps have little impact over the different impact categories, compared to the rest of pumps studied in ENER Lot 29. In Tasks 6 and 7, the technical improvements at a product and component level were studied to evaluate the improvement potential of these options. The result showed that the potential improvements offer very little energy savings per pump (between 0.25% and 1%), which at the end results in very high payback times. This is due to very specific use patterns (for spa, counter-current, fountain and pond pumps) and high efficiency of existing products in the EU market (for aquarium pumps).

Hence, Implementing Measures regarding mandatory requirements on energy efficiency for these pumps would not achieve great energy savings and would connote higher costs to consumers. However, requirements regarding the information that manufacturers offer to customers on energy efficiency can be recommended.

8.2.3.1 Information requirements for fountain, aquarium, pond, spa and counter current pumps

One of the key factors to ensure energy efficient pump systems is the correct dimensioning and use 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 users.

For fountain pumps, pond pumps, aquarium pumps, spa pumps and counter-current pumps, 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 energy efficiency of pumps (η) at Best Efficiency Point (BEP), at Part Load (PL), and at Over Load (OL) shall be indicated on the name plate and technical documentation of the product.

- The following information shall be provided: "The benchmark for most efficient pump is η BEP=##; η PL=##; and η OL= ##".[15]

The information listed above shall be visibly displayed on freely accessible websites of the water pump manufacturers.

8.2.4 End suction, submersible bore-hole and vertical multi-stage pumps

End suction water pumps: glanded single stage end suction rotodynamic water pumps. These pumps could either have own bearings and the suction side in axial and the water pressure outlet in radial direction in the case; the motor shaft is extended to become also the pump shaft with the suction side in axial and the water pressure outlet in radial direction or the suction side of the pump is in one line with the water pressure outlet of the pump. Such pumps have many uses, such as water supply or industrial cooling systems.

Submersible bore-hole water pumps: multi stage (i > 1)[16] rotodynamic water pumps designed to be operated in a borehole.

Vertical multistage water pumps: pumps with a glanded multi stage (i > 1) rotodynamic water pump in which the impellers are assembled on a vertically rotating shaft

The results of Task 7 of this preparatory study show that the potential energy savings of this kind of pumps is around 15% to 25% per year. This is mainly due to variable speed drives in the motors, but these technologies are already implemented in some existing pumps in the market. This means that many of the installed pumps in the EU are high efficient (i.e. 50% of end suction pumps and vertical multi-stage pumps; 15% of submersible bore-hole pumps[17]) and so the possibilities of improvement by application of Extended Product Approach at EU level would be lower for end suction and vertical multi-stage pumps than for submersible bore-hole pumps. However, the uptake of speed controls in these types of pumps would depend highly on the needs of the pump application for which they are designed. The hydraulic efficiency of end suction pumps, submersible bore-hole pumps and vertical multi stage pumps sold in the EU is thought to be high, as this is usually a requirement of the client.

The end suction, submersible bore-hole and vertical multi-stage pumps analysed in this preparatory study are commonly tailor-made and build especially to fit the customer's needs. These pumps have very specific functions and requirements, and as a rule, these pumps are not produced in mass. Some of these pumps are also large machines that consume big quantities of energy, so energy efficiency of the pump frequently plays an important role in the purchase decision. For these reasons, Ecodesign Implementing Measures regarding energy performance

[15] No information can be found at the time of writing on the benchmark of fountain, aquarium, pond, spa and counter current pumps measured as efficiency at BEP, OL or PL. These parameters are not commonly published by manufacturers.

[16] Multi stage pumps are designed with multiple impellers in the same shaft.

[17] See Task 1 of the present study.

requirements would not accomplish a big shift in the EU market for end suction pumps, submersible bore-hole pumps and vertical multi-stage pumps.

The mandatory inclusion of Variable Speed Drives and controls or the recommendation of the minimum pipe size would not apply to these engineered pumps, since the load profile is much related to the specific need of the pump application, and the pump is usually designed accordingly.

Other options for EU product policy are energy labelling or specific design requirements, as in swimming pool pumps. No energy labelling requirements are proposed for end suction, submersible bore-hole and vertical multi-stage pumps, since the EU market of these pumps is mostly within business-to-business. Energy labelling is an effective policy tool for the consumer market to help consumers make the right choice of best performing product. However, energy labelling would not be effective as professional pump engineers and designers are capable of correctly dimensioning and designing pumping systems if they are provided with the relevant information from manufacturers. Furthermore, after observation of the maximum efficiency improvement potential of existing pumps, it can be said that there is not a large range between least and best performing products in the EU for creating different efficiency bands within the energy label. Still, information requirements could be recommended for these pump types, and thus this option will be discussed in the following section.

8.2.4.1 Information requirements for end suction, submersible bore-hole and vertical multi-stage pumps

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 users.

For end suction, submersible bore-hole and vertical multi-stage pumps, 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 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 energy efficiency of pumps (η) at Best Efficiency Point (BEP), at Part Load (PL), and at Over Load (OL) shall be indicated on the name plate and technical documentation of the product.

- The following information shall be provided: "The benchmark for most efficient pump is η BEP=##; η PL=##; and η OL= ##".[18]

8.3 Recommendations on standardisation mandates

As stated in the previous section, the method for calculation of the MEI and corresponding C-values and function factors for the swimming pool pumps covered in this study should be standardised. This can be done by means of a CEN standard or in the regulation issued in the framework of the Ecodesign Directive.

At the time of writing, the University of Darmstadt and Europump are carrying out research work in this context that would contribute to the development of a CEN standard for EEI calculation. This work is expected to continue over 2015. Standardisation of EEI calculation methods and generalisation in the EU market of EEI values could facilitate the correct selection of sizing of water pumps depending on the load profile of the application and therefore provide energy savings for pump applications with variable load.

It would also be necessary to standardise across EU Member States the minimum water quality requirements for swimming pools and therefore a minimum turnover rate for domestic and commercial swimming pool pumps. This influences the load profile of the pumps and thus their energy consumption. A working group at CEN (CEN/TC 164) is working on how to standardise drinking water across the EU, including swimming pool water within their work since it can enter the mouth when bathing. On the other hand, some Member States have less exigent requirements for swimming pool water. A common quality standard and minimum turnover rate across the EU would ease the calculation of the energy consumption of pumps and the definition of the optimum load profiles.

8.4 Scenario analysis

8.4.1 Timeline of specific ecodesign measures

The Ecodesign requirements discussed hereafter are proposed in a provisional timetable consisting in one or several progressive steps. Either option has benefits and drawbacks: 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 could be possible for the pumps in ENER Lot 29 proposed for regulation since the available improvement

[18] No information can be found at the time of writing on the benchmark of end suction, submersible bore-hole and vertical multi-stage pumps measured as efficiency at BEP, OL or PL. These parameters are not commonly published by manufacturers.

options are already implemented in some pumps in the market and the redesign cycle of these pumps is relatively short.

Additional tiers would allow setting several progressive levels of ambition and introducing new standards developed (i.e. EEI calculation method). These steps allow implementing ambitious requirements in a long term, so that the benefits obtained are optimised with respect to the redesign efforts to be done by manufacturers.

The implementation of Ecodesign requirements in the form of tiers takes into account the redesign cycles of around 2 to 4 years[19], as stated in the report of Task 2 of this preparatory study, 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. For this reason, it can be thought that a tiered approach in 2-year steps could be beneficial in terms of energy and economic savings. A maximum of three tiers is considered sufficient to introduce ambitious requirements and provide a long-term roadmap to the manufacturers. In order to simplify the assessment, the scenario analysis has been carried out by using tiers at 2-year steps, but the timeline for the entry into force of the first tier would depend on the level of ambition of the policy. It would be possible to make a first tier mandatory after one year of the entry into force of the regulation, if this first tier does not require high investment and redesign efforts from the manufacturers. Following tiers could introduce more ambitious requirements 3 and 5 years after the regulation.

The potential benefits in terms of energy savings and the related consumer expenditure estimated for each of the approaches proposed of one, two and three tiers will be 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 proposed Implementing Measures;
- **Second tier**: 2018 or four years after the approval of the proposed Implementing Measures; and
- **Third tier**: 2020 or six years after the approval of the proposed Implementing Measures.

8.4.2 Type of scenarios considered

Based on the policy options proposed in the previous section, different scenarios were drawn up to illustrate quantitatively the improvements that each possible MEPS could achieve.

[19] One manufacturer stated that the redesign cycles of end suction pumps, submersible bore-hole pumps and vertical multi-stage pumps is of around 10 years.

The implementation of different sets of improvements options at EU level by 2040 was compared to a reference scenario of no additional policy. In this scenario, the current situation and trends are extended to the future and policy does not influence their evolution. This scenario is also called the "Business-as-usual" (BaU) scenario. This situation may be recommended in cases where intervention from policy is not expected to provide significant gains, or when these gains would entail too high costs for customers, too much burden to manufacturers, or thwart innovation. This scenario reflects the natural evolution of the market assuming no further changes in energy performance of the new pumps manufactured if no new policy is adopted. In other words, the BaU can therefore also be represented by MEI cut-off value as zero (0).

An Excel tool was created to allow the impacts of the different scenarios to be modelled from 2013 to 2040. The time duration (28 years) of the scenario analysis is more than the longest lifetime of the Base-Cases considered (i.e. 20 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 EU stock of 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 (see Table 8-28-2) 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 recommended earlier, which include:

- Base-Case 1: Domestic swimming pool pumps up to 2.2 kW; and
- Base-Case 2: Domestic/commercial swimming pool pumps over 2.2 kW.

Four policy scenarios are analysed, in order to compare the potential 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 preparatory study ENER Lot 11 (Commission Regulation (EU) No 547/2012). The Scenario 2 achieves the same level of ambition than Scenario 1 in a shorter time frame. 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 EU average would be banned for sale at short term, and the 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 swimming pool pumps at EU level.

Table 8-2: 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 least 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 20% 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 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)[20].

Therefore, in total twelve scenarios are compared with the BaU scenario in order to estimate the overall potential of the four options of MEPS.

The assumptions about consumer response to the MEI requirements, banning the share of swimming pool and submersible bore-hole pumps below the MEI cut-off value for the four policy option scenarios across the three different possibilities (sub-scenarios) are presented in Table 8-3. 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

[20] This sub-scenario is unlikely but allow estimating the maximum energy savings.

four policy options. This allows to in turn calculate the energy and economic inputs for the policy option scenarios.

Table 8-3: 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	-

8.4.3 Inputs to scenario analysis tool

An Excel tool was created to allow the impacts of the different scenarios to be modelled (2013-2040). The tool was 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 and stock forecast detailed in Task 2 report were used as input. The annual growth rate has been estimated as 3% from 2011 until 2040.
- 70% of the annual sales are replacement sales (for replacement of the existing installed stock, meaning that 30% of the annual sales are for new installations). The pumps that arrive to their end of lifetime are subtracted from the stock.
- 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.
- Due to the growth of the market explained above, by 2040 the total electricity consumption in the use phase by swimming pool pumps at EU level is estimated as 16.4 TWh for swimming pool pumps below 2.2 kW, and 5.5 TWh for swimming pool pumps above 2.2 kW (i.e. 2.4 times higher than in 2011)

- The tool calculates the cost in Euros and electricity in GWh related to water pumps, for the different MEPS scenarios.
- The electricity results are not limited to the use phase but that into account the energy required over the whole lifetime (including the manufacturing distribution and end-of-life phases).
- 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 the product (purchase and installation price, if any), taken into account at the time of purchase, and the operating costs (energy, maintenance and repair costs, if any), which are spread over the lifetime of the machine.

The electricity consumption and economic inputs used for the four policy option scenarios are presented in Table 8-4.

Table 8-4: Electricity consumption in the use phase and economic inputs for the policy option scenarios

	MEI 0.1			MEI 0.4			MEI 0.7			MEI 1.0
	Pessimistic	Pragmatic	Optimistic	Pessimistic	Pragmatic	Optimistic	Pessimistic	Pragmatic	Optimistic	Pessimistic Pragmatic Optimistic
Base-case 1: SPPS										
Annual electricity consumption (kWh)	1,432	1,431	1,429	1,428	1,424	1,418	1,420	1,413	1,413	1,411
Purchase cost (€)	333	334	335	334	336	339	339	342	342	343
Maintenance cost (€/year)	0	0	0	0	0	0	0	0	0	0
Base-case 2: SPPL										
Annual electricity consumption (kWh)	20,142	20,129	20,088	20,082	20,028	19,946	19,960	19,865	19,865	19,845
Purchase cost (€)	1,516	1,517	1,523	1,518	1,528	1,542	1,540	1,556	1,556	1,560
Maintenance cost (€/year)	49	49	49	49	49	49	49	48	48	48

8.4.4 Comparison of scenarios

This section 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 at EU level: this includes the electricity consumed over the life cycle of the product, divided per year of lifetime; and
- Total consumer expenditure at EU level: this includes the life cycle cost of products divided per year of lifetime.

This comparative analysis is carried out for each of the two Base-Cases recommended for specific ecodesign requirements. The comparative analysis for these two indicators is presented for specific years in the period of analysis: 2018, 2020, 2030 and 2040.

The selection of these 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 (2 years after the first tier of requirements). Year 2020 corresponds to the EU 2020 headline target set in the Europe 2020 strategy[21]. Year 2030 corresponds to almost half of the EU installed stock of ENER Lot 29 pumps represented by more energy efficient pumps. Lastly, year

[21] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF

2040 corresponds to the time by when most of the EU installed stock of pumps is replenished by more energy efficient pumps (as required under the 12 policy option scenarios).

The comparison of scenarios is carried out regarding total energy consumption of the stock of pumps in the EU and the associated consumer expenditure per year.

- **Total electricity consumption at EU level**

The savings in annual electricity for each of the two 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 8-4 to Figure 8-6 present the comparison of annual savings in electricity for each of the Base-Cases for the twelve different sub-scenarios[22].

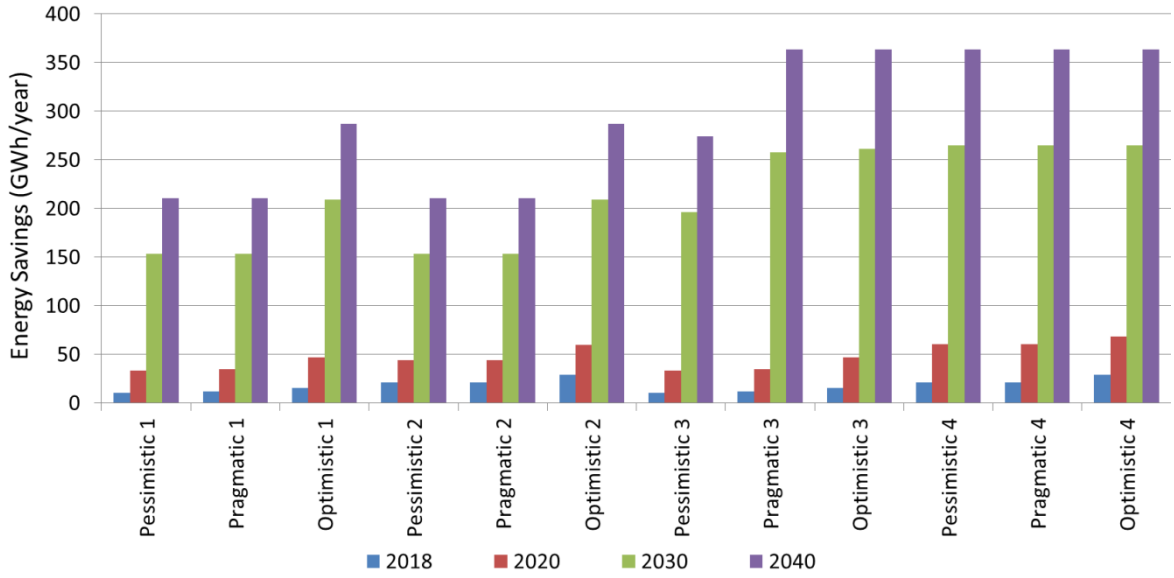


Figure 8-4: Annual electricity savings at EU level (in GWh) for BC 1 across four key years for the 12 policy option scenarios

For Base-Case 1, the most ambitious scenario corresponds to Scenario 4 (cut-offs of 0.4 and 1.0 in 2016 and 2018 respectively), which could save up to around 0.35 TWh per year in 2040 at EU level. If the most pessimistic scenario is considered (i.e. Scenario 1, cut-offs of 0.1 and 0.4 in 2016 and 2018 respectively); the maximum electricity savings at EU level in the same year would be around 0.2 TWh.

In this comparison of scenarios, it can be seen that the Scenario 2 (a single tier at 0.4) could bring savings faster than the Scenario 1 (two tiers at 0.1 and 0.4), but the difference in energy savings potential is negligible.

The difference between the maximum potential energy savings in pragmatic and optimistic scenarios of a cut-off of 0.7 (in Scenario 3) and 1.0 (Scenario 4) is also negligible; except in the

[22] 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.

case of the pessimistic sub-scenario. Scenario 4 would achieve slightly higher electricity savings faster than Scenario 3.

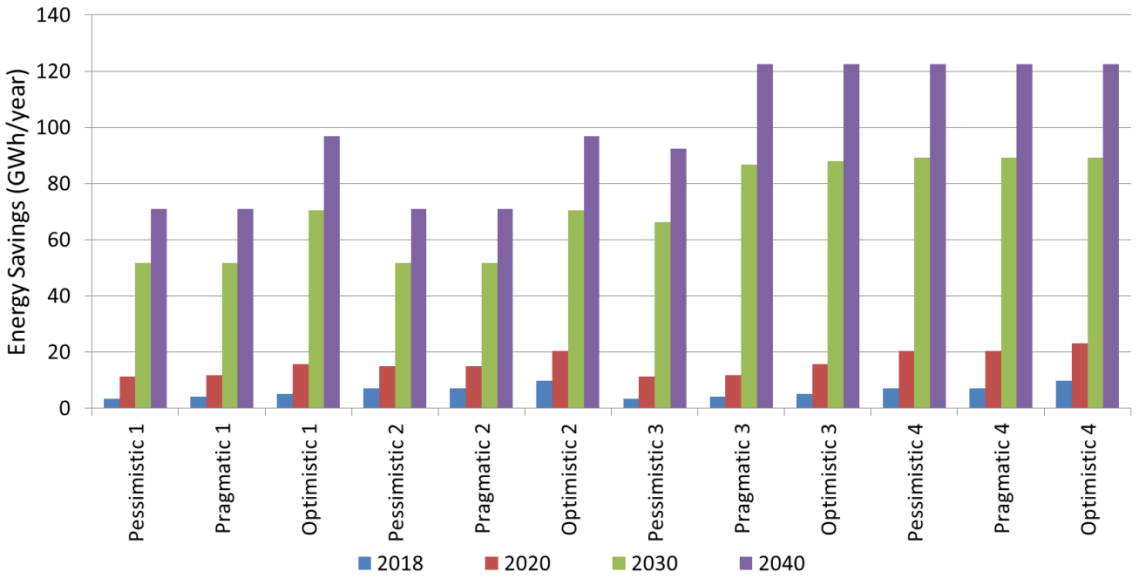


Figure 8-5: Annual electricity savings at EU level (in GWh) for BC 2 across four key years for the 12 policy option scenarios

For Base-Case 2, the most ambitious scenario corresponds to Scenario 4, which could save up to around 0.12 TWh per year in 2040 at EU level. The most pessimistic scenarios are Scenario 1 and 2, which would achieve less than 0.1 TWh 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 savings faster than Scenario 3 (the energy savings for pessimistic sub-scenario 3 are estimated to be 0.09 TWh as compared to 0.12 TWh 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.

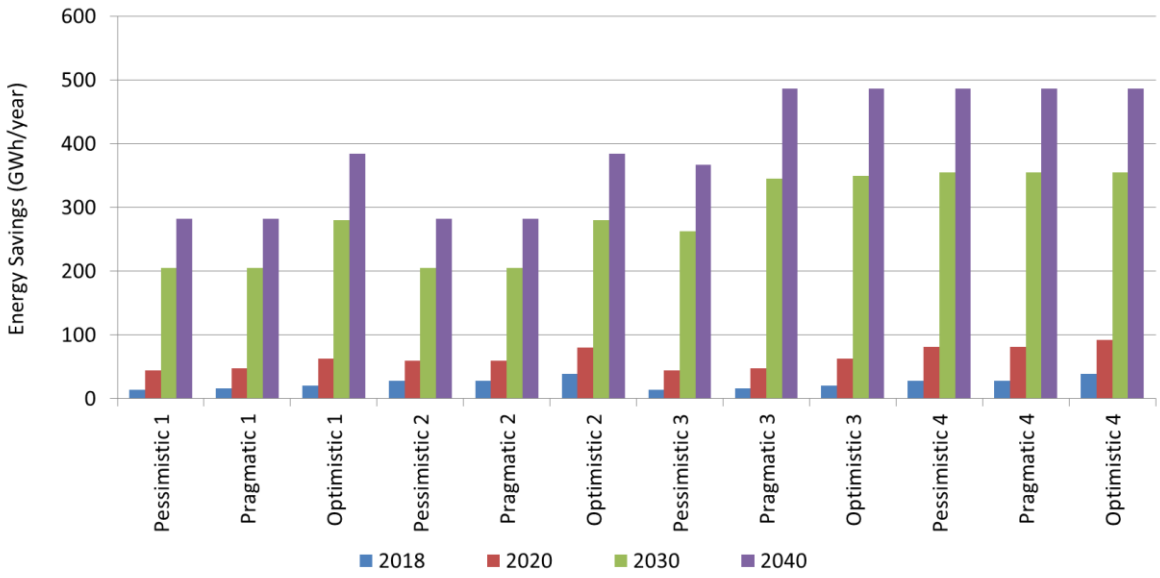


Figure 8-6: Total annual electricity savings at EU level (in GWh) for the selected Base-Cases (BC 1, BC 2) across four key years for the 12 policy option scenarios

The comparison of the total electricity savings achieved by policy implementation on the two Base-Cases included in this analysis shows that the maximum annual savings that could be achieved by 2040 are between 0.29 TWh and 0.49 TWh 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. In a similar way, the potential savings of Scenario 3 and Scenario 4 are similar, although the pessimistic sub-scenario 3 achieves notably lower energy savings.

Total consumer expenditure at EU level

The reduction in annual consumer expenditure for each of the 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 8-7 to Figure 8-9 present the comparison of annual consumer expenditure reduction for each of the Base-Cases (BC 1 and BC 2) for the twelve different (sub-) scenarios[23].

[23] 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.

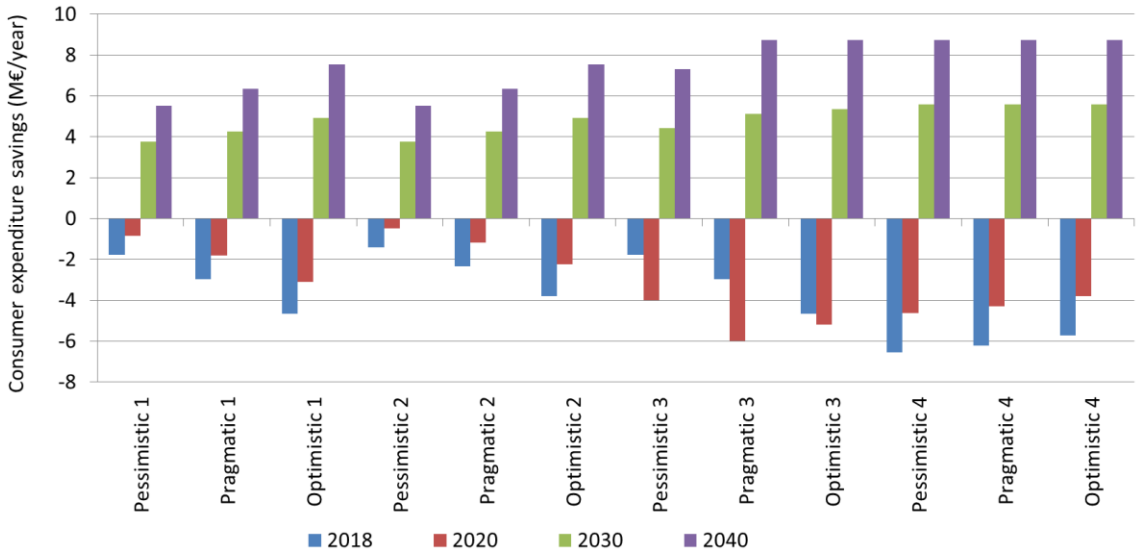


Figure 8-7: Annual consumer expenditure reduction at EU level (in Million Euros) for BC 1 across four key years for the 12 policy option scenarios

For BC 1, the consumer expenditure increases with the enforcement of policy scenarios, up to 6 M€ per year at EU level in 2018 in the pessimistic Scenario 4.

This can be explained on the basis of the very small energy saving potential and high cost increase of the product, which leads to a very long payback time. By 2030, in all the scenarios the consumer expenditure would be lower than in the BaU scenario.

The maximum savings in consumer expenditure at EU level in 2040 would be around 8.5 M€.

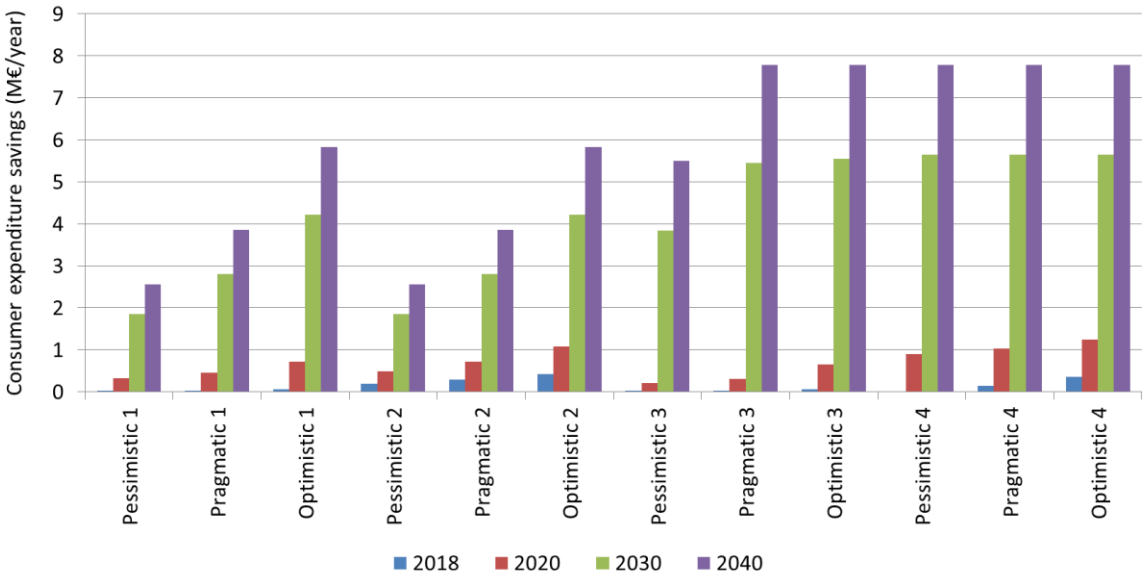


Figure 8-8: Annual consumer expenditure reduction at EU level (in Million Euros) for BC 2 across four key years for the 12 policy option scenarios

There is a reduction in consumer expenditure across all the twelve scenarios considered for BC 2 by as soon as 2018. In one of the most ambitious scenarios (i.e. Scenarios 3 and 4), the maximum reduction in consumer expenditure at EU level in 2040 would be between 5.5 and 7.8 M€.

In the most pessimistic scenario, the total expenditure savings per year at EU level in 2040 would be of 2.5 M€.

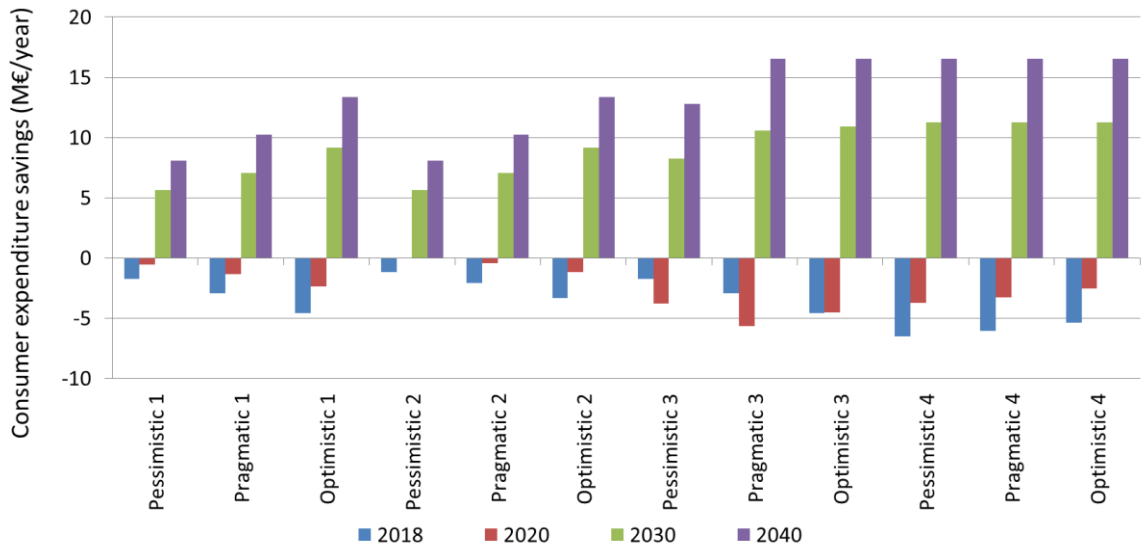


Figure 8-9: Annual consumer expenditure reduction at EU level (in Million Euros) for the selected Base-Cases (BC 1, BC 2) across four key years for the 12 policy option scenarios

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 8 M€ and over 15 M€ at EU level. There is not much difference between Scenario 1 and Scenario 2; and between Scenario 3 and Scenario 4.

8.4.5 Additional scenario: potential benefits of speed controls

As discussed in section 8.2.2.4, there is no clear agreement on the potential benefits of Variable Speed Drives for swimming pool pumps. There might be a big difference in the results of the scenario analysis presented above if the Variable Speed Drive technology is considered as BAT for all swimming pool water pumps. However, this option has not been considered the BAT option for all the pumps under study since it would only lead to energy savings in the case of part load operation. Thus, enforcing VSD to all clean water pumps in the market regardless of their load profiles would entail drawbacks for fixed-speed operation, and at the moment there is no indicator for energy efficiency that can take into account the load profiles of different pump applications. This could be done when the Energy Efficiency Index (EEI) calculation method will be available for clean water pumps studied within this preparatory study.

With the aim of assessing the potential energy savings of VSD technology, an additional scenario including the enforcement of VSD in 2020 is modelled for each of the Base-Cases. Table 8-5 shows the inputs used for this additional scenario. The annual consumption and life cycle cost per product are calculated based on the data presented for the Base-Case in Task 5 and the difference in annual energy consumption and purchase cost presented in Task 6 of this preparatory study.

Table 8-5: Electricity consumption in the use phase and economic inputs for Scenario 5

Reference product	VSD	BC
Base-case 1: SPPS (Domestic swimming pool pumps up to 2.2 kW)		
Annual electricity consumption per product (kWh)	1,267	1,440
Difference in annual electricity consumption to Base-Case (%)	-12.0%	-
Difference in purchase cost to Base-Case (%)	204.0%	-
Difference in life cycle cost to Base-Case (%)	8.4%	-
Base-case 2: SPPL (Domestic and commercial swimming pool pumps above 2.2 kW)		
Annual electricity consumption per product (kWh)	11,745	20,250
Difference in annual electricity consumption to Base-Case (%)	-42.0%	-
Difference in purchase cost to Base-Case (%)	104.0%	-
Difference in life cycle cost to Base-Case (%)	-36.4%	-

As the pragmatic option represents most closely the reality, hence it was chosen for the analysis of this Scenario 5 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.

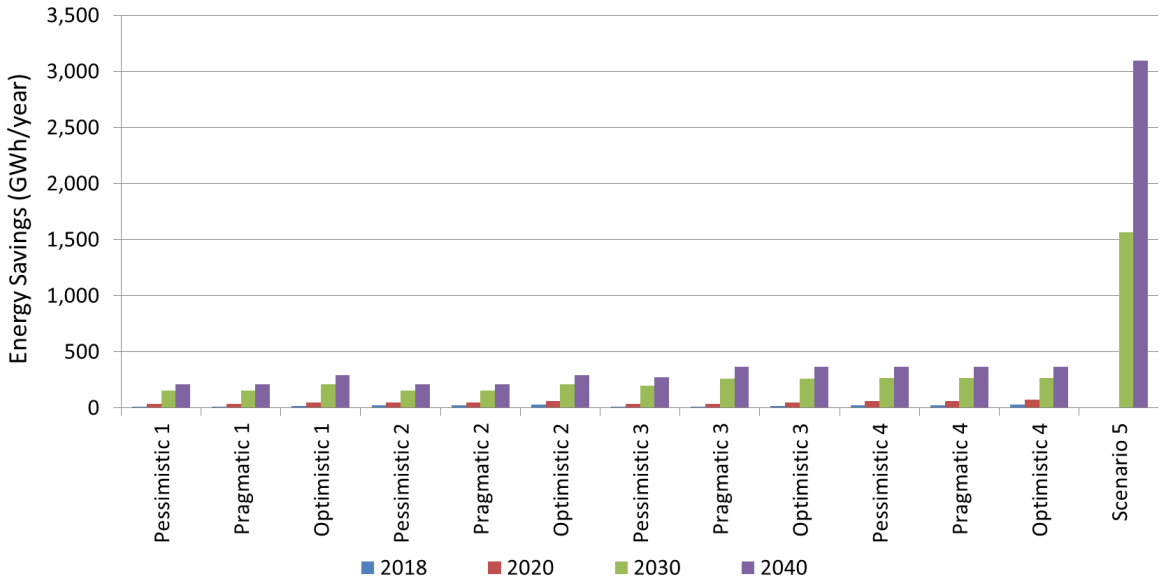


Figure 8-10: Annual electricity savings at EU level (in GWh) for BC 1

For domestic swimming pool pumps under 2.2 kW, the introduction of VSD as the fifth policy scenario would achieve higher electricity savings, around 1.5 TWh per year in 2030 and above 3 TWh per year in 2040.

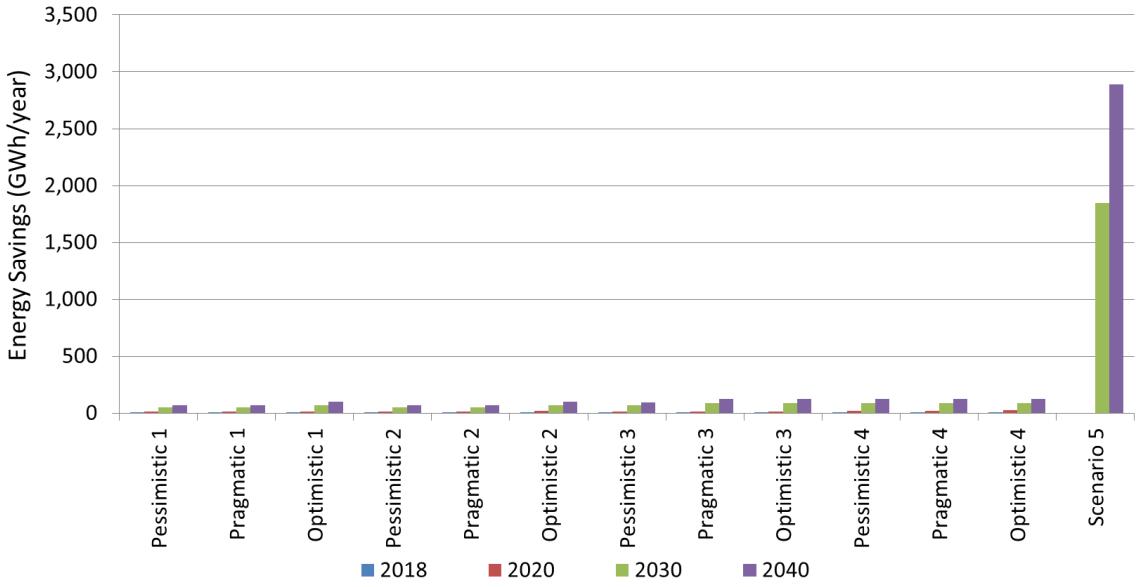


Figure 8-11: Annual electricity savings at EU level (in GWh) for BC 2

The introduction of VSD technology as a policy option in 2020 for swimming pool pumps over 2.2 kW would offer notably higher savings, reaching 2.8 TWh savings per year at EU level in 2040.

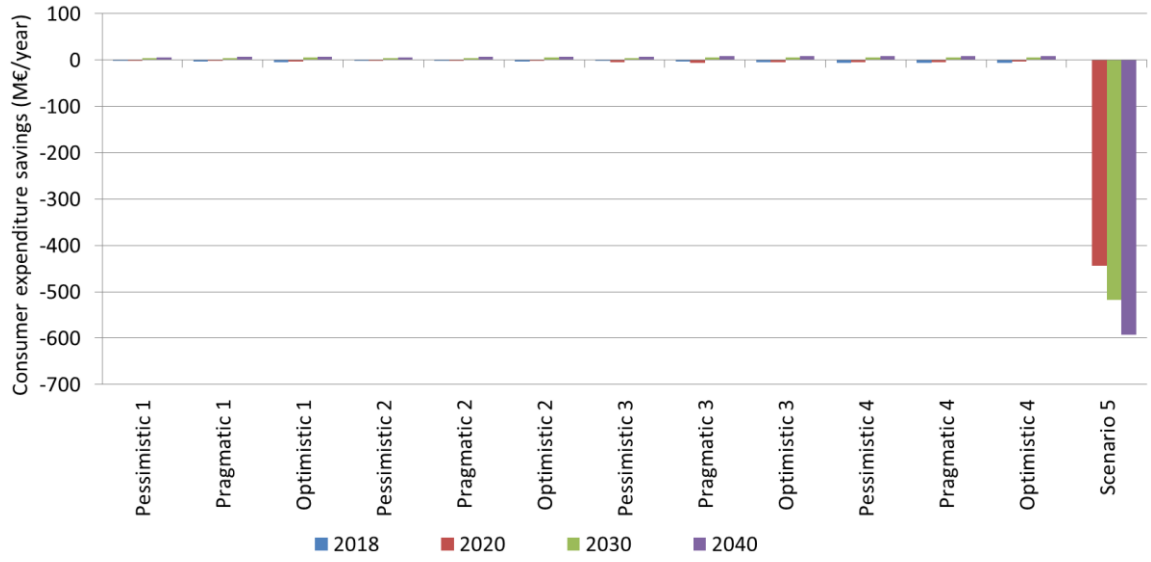


Figure 8-12: Annual consumer expenditure reduction at EU level (in Million €) for BC 1

Regarding the consumer expenditure of domestic swimming pool pumps under 2.2 kW, the introduction of VSD technology as mandatory requirement in 2020 would entail significant increase in expenditure at EU level in 2020, up to 400 M€ higher. This may be due to the high cost increase of this technology (between factor 2 and factor 4 according to some stakeholders), compared to the economic savings achieved by the low reduction in energy consumption.

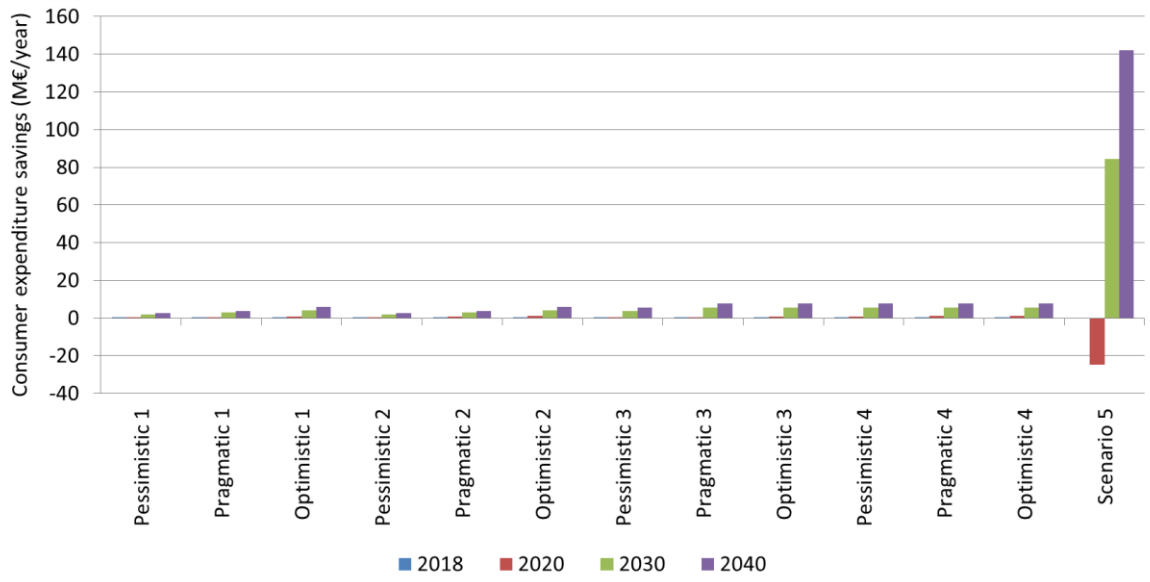


Figure 8-13: Annual consumer expenditure reduction at EU level (in Million €) for BC 2

In the case of swimming pool pumps over 2.2 kW, the introduction of VSD as a fifth scenario policy would lead to a slightly higher consumer expenditure in 2020, but some economic savings in 2030 and 2040, up to 140 M€ per year.

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 uncertainty) in the case of lot 29 pumps are:

- Product lifetime; and
- Annual sales growth rate.

The sensitivity analysis is carried out for each of the two Base-Cases (BC 1, BC 2) around the pragmatic scenarios[24] 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; and

[24] 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.

- 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.

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 two parameters selected, one by one. As an example for BC 1, if:

- BaU EC 2020 = Energy consumption of BC 1 stock in 2020 in Business as Usual scenario;
- PS1 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 1
- PS2 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 2;
- PS3 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 3;
- PS4 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 4;
- LL PS1 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 1 for a Lower value of lifetime;
- LL PS2 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 2 for a Lower value of lifetime;
- LL PS3 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 3 for a Lower value of lifetime;
- LL PS4 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 4 for a Lower value of lifetime;
- UL PS1 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 1 for a Upper value of lifetime;
- UL PS2 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 2 for a Upper value of lifetime;
- UL PS3 EC 2020 = Energy consumption of BC 1 stock in 2020 in pragmatic Scenario 3 for a Upper value of lifetime; and
- UL PS4 EC 2020 = Energy 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

The background data used for the sensitivity analysis graphs presented in this section is presented in Annex III.

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 energy consumption during the use phase.

Variation in product lifetime (in years):

- An increase of 25% (upper limit); and
- A decrease of -25% (lower limit).

This analysis shows the influence of the product lifetime on the total energy consumption (TEC) and life-cycle costs at EU level of the different scenarios analysed in section 8.4.

As seen in Figure 8-13 to Figure 8-18, for all situations, the lifetime of the product has little influence on the total energy consumption (less than 0.25% variation for the total stock of swimming pool pumps). The life cycle costs of swimming pool pumps at EU level varies between -13% and +6% if the lifetime of the pumps is changed.

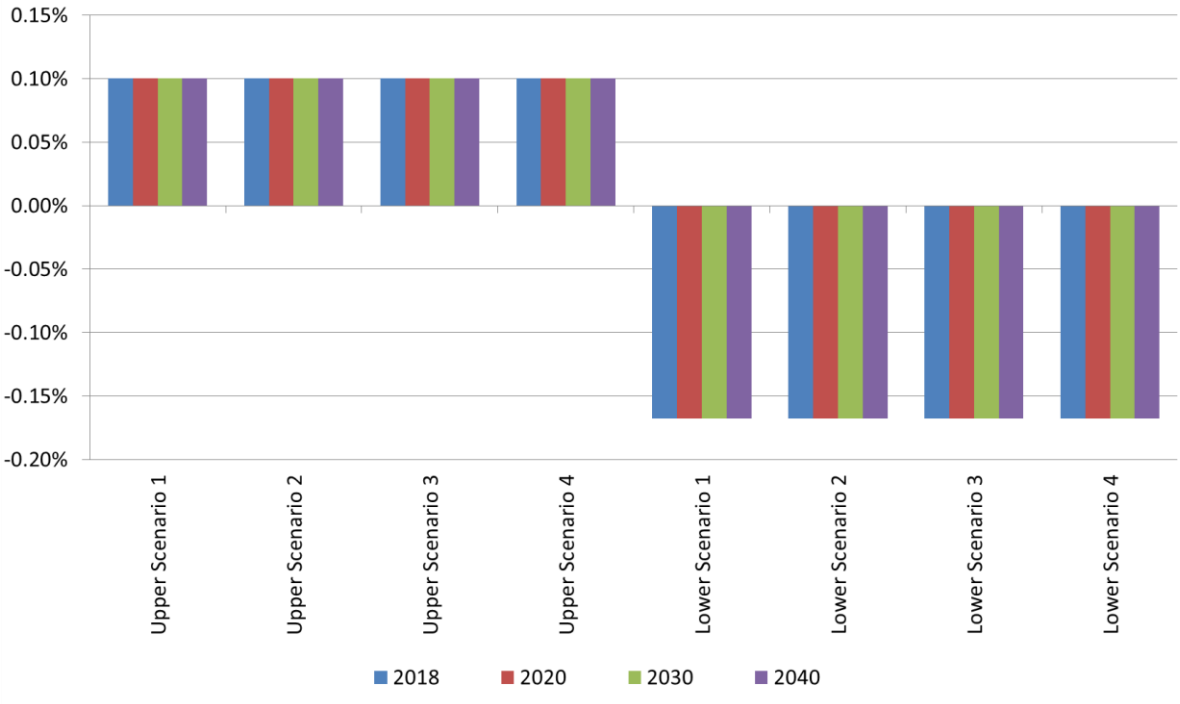


Figure 8-14: Sensitivity to product lifetime for BC 1 Total Energy Consumption

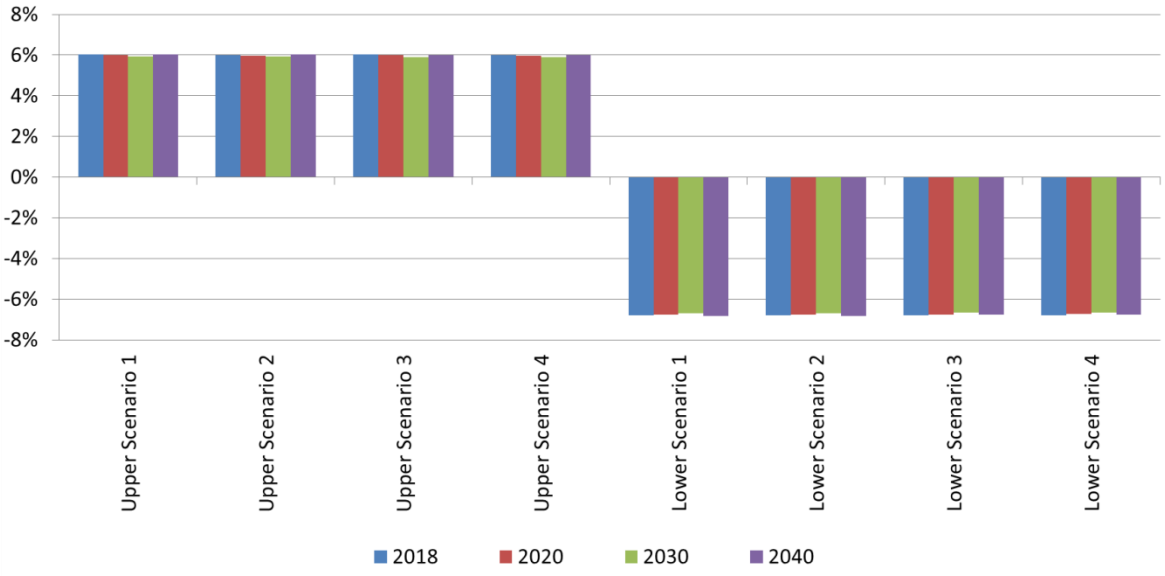


Figure 8-15: Sensitivity to product lifetime for BC 1 Life Cycle Cost

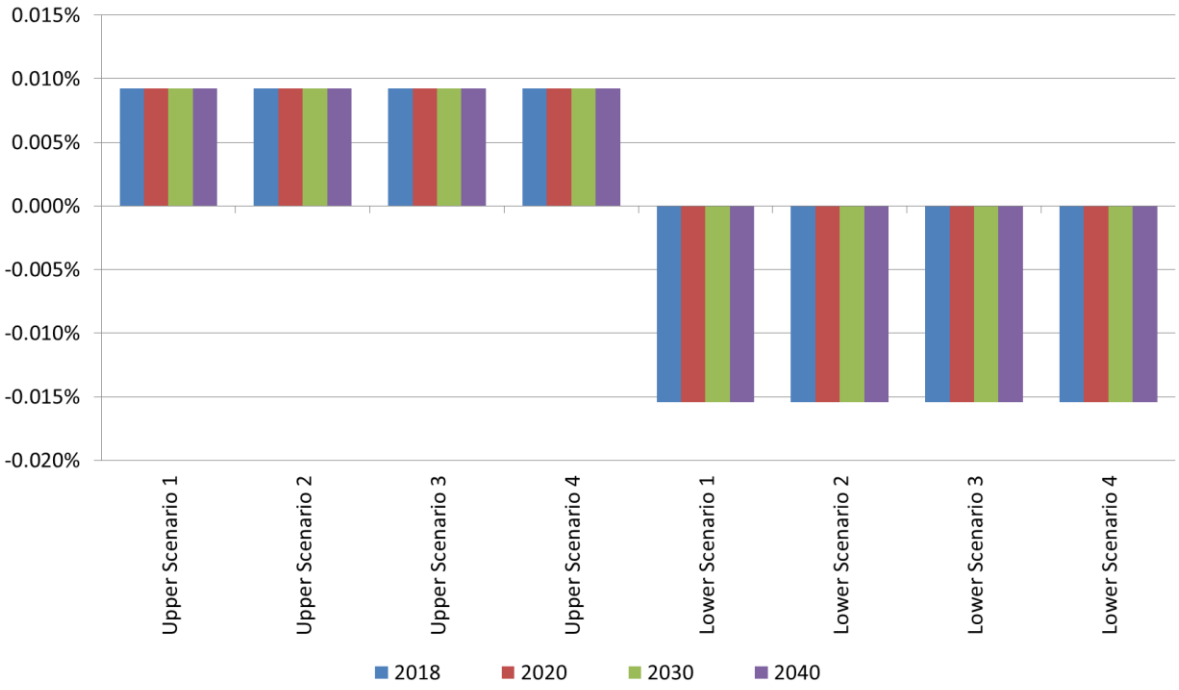


Figure 8-16: Sensitivity to product lifetime for BC 2 Total Energy Consumption

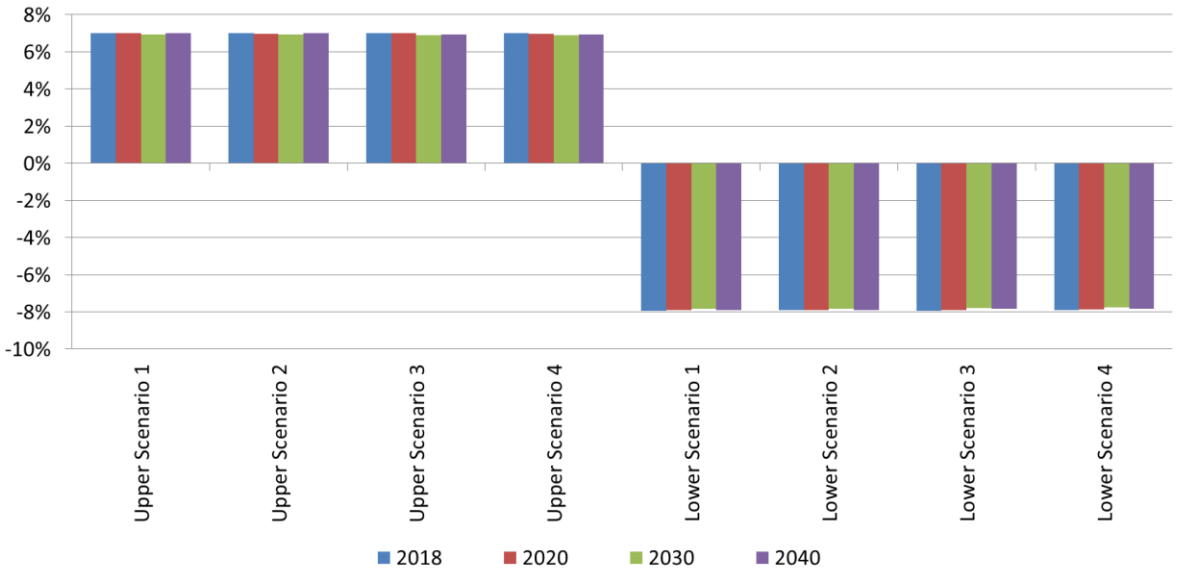


Figure 8-17: Sensitivity to product lifetime for BC 2 Life Cycle Cost

8.5.2 Assumptions related to the annual sales growth rate

Estimating the stock of Lot 29 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 3% until 2017 by industry stakeholders. The same growth rate was assumed by project team to be applicable until 2040.

Variation in sales growth rate:

- An increase to 5%; and
- A decrease to 0%.

The following figures show the influence of the sales growth rate on the total energy consumption (TEC) and life-cycle costs at EU level of the different scenarios analysed in section 8.4.

The sales growth rate influences significantly the potential energy savings of the proposed scenarios (between -35% to +22% variation), and also the consumer expenditure at EU level (between -15% to +7%).

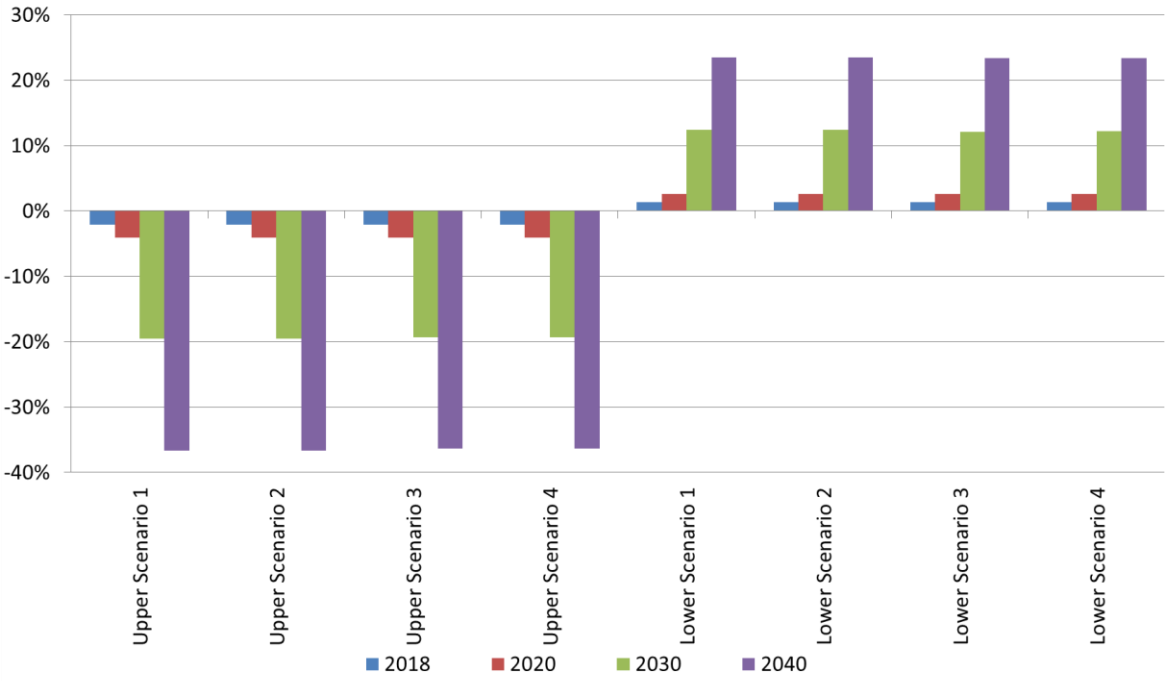


Figure 8-18: Sensitivity to sales growth rate for BC 1 Total Energy Consumption

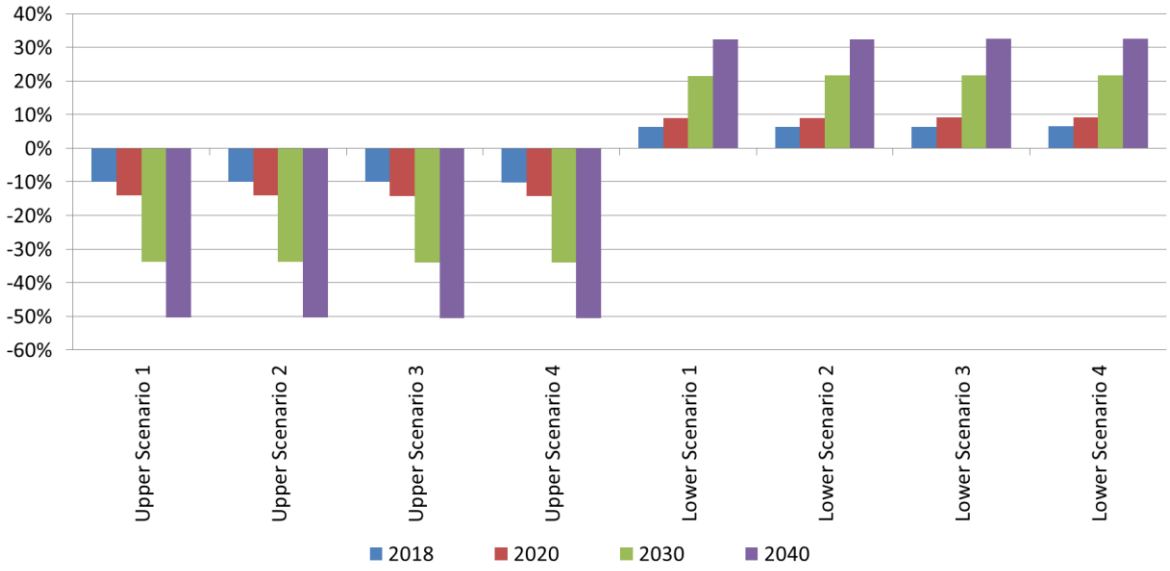


Figure 8-19: Sensitivity to sales growth rate for BC 1 Life Cycle Cost

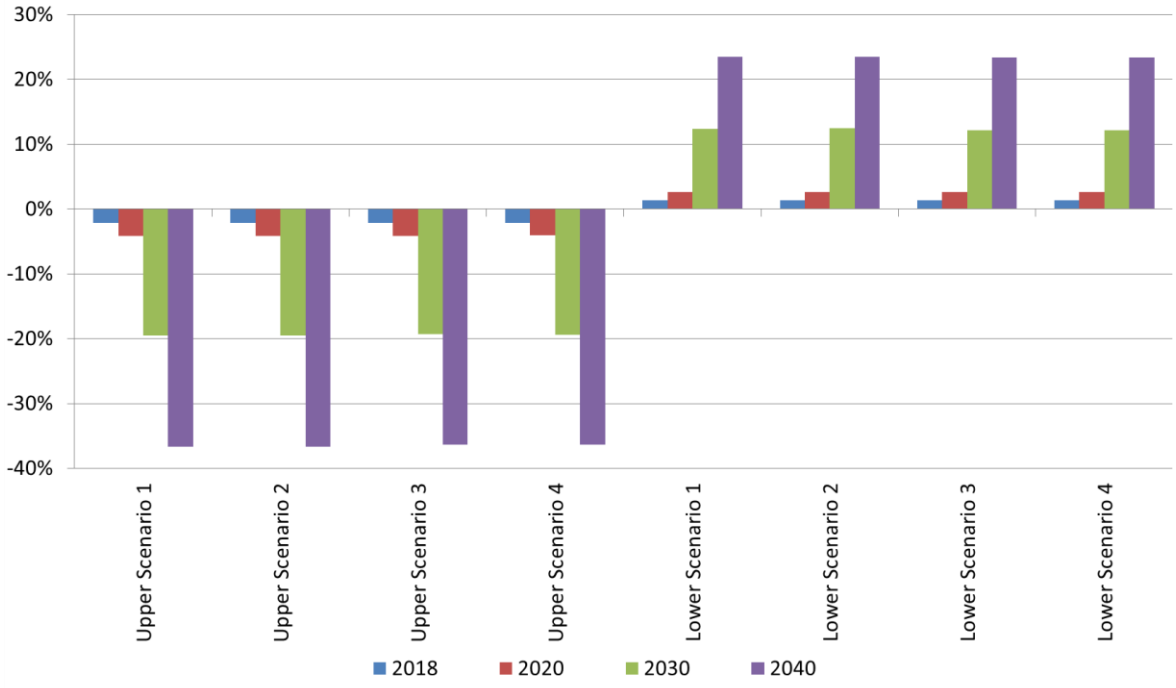


Figure 8-20: Sensitivity to sales growth rate for BC 2 Total Energy Consumption

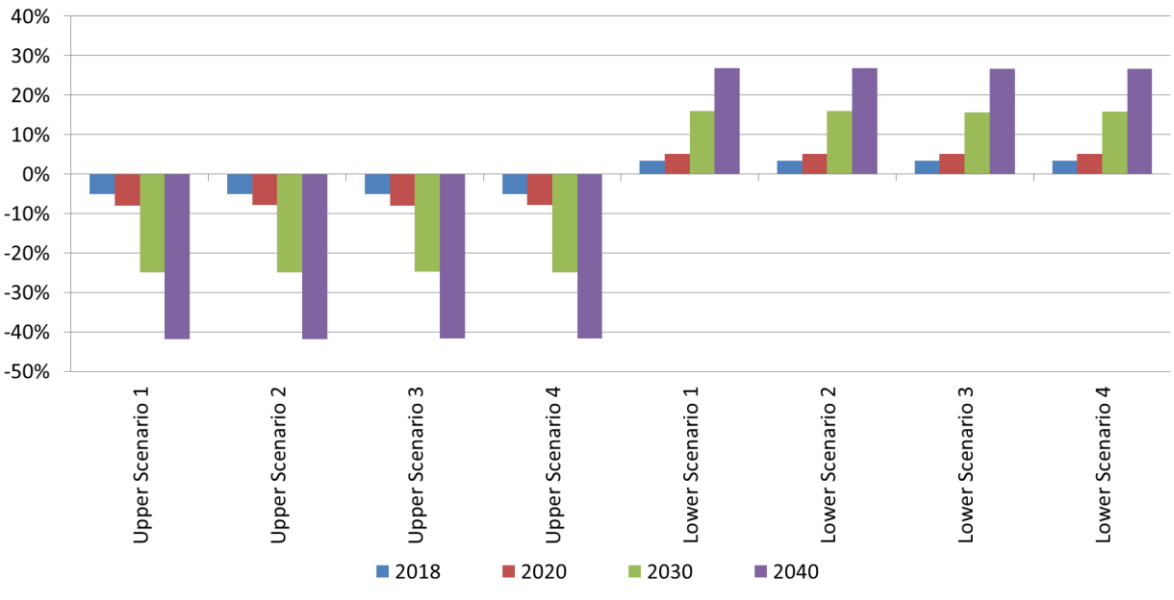


Figure 8-21: Sensitivity to sales growth rate for BC 2 Life Cycle Cost

8.5.3 Conclusions of the sensitivity analysis

The product lifetime and the annual sales growth rate have different influence on the total energy consumption and consumer expenditure at EU level. Whilst the influence of the lifetime on the total energy consumption is negligible, the consumer expenditure can vary from -13 to +6%. This is normal if we take into account that the comparison is made between energy consumption per year and consumer expenditure per year, which are not highly influenced by the lifetime of the product.

On the other hand, the sales growth rate of swimming pool pumps in Europe influences the number of pumps used, and therefore the variations of -35% to +22% potential energy savings are not surprising.

In any case, when varying the input data on the parameters: product lifetime and sales growth rate, the evolution of the four different pragmatic scenarios relative to the business as usual is similar to that presented in section 8.4: 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 sections.

8.6 Impact analysis

The 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. In this section, the following impacts are assessed:

- Impacts on manufacturers and competition;
- Impacts on consumers;
- Impacts on innovation and development; and
- Social impacts.

8.6.1 **Impacts on manufacturers 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 ENER Lot 29. However, the data collected and presented in Task 2 can give a rough economic overview of the sector of clean water 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 pump sales in the EU are replacement of old pumps (around 70%), and only a small part are new pump installations. This means that the 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 measures 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 measures is technically achievable although it will require an economical effort from the manufacturers (e.g. need to invest in new patterns and tooling). The investment needed would vary depending on the ambition of the policies implemented.

While the improvement technologies are already used in some water pumps in the EU, not all the manufacturers include them in their designs, and the launching of new products will require some redesign work. Therefore, the implementation of measures would require investments 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 policies proposed 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 water 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 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[25].

The ongoing work on the development of a methodology for calculating the Energy Efficiency Index of clean water pumps is expected to be continued over 2015. After this task is accomplished, it is recommended that during the next revision of any Ecodesign Regulation for ENER Lot 29 pumps, the European Commission should take into account the EEI approach for ENER Lot 29 MEPS instead of the MEI approach presented in this preparatory study. The standardisation of EEI calculation method would facilitate the benchmark of pumps per application, and therefore the inclusion of the benefits of variable flow for those pumps applications that can benefit from it.

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 pumps. Most of these manufacturers already claim to produce highly efficient pumps. They should all be able to keep up with the market requirements if mandatory policy measures are set. The implementation of MEPS could potentially affect more seriously the medium and small pump manufacturers in the EU.

8.6.2 **Impacts on customers**

For the improvement options presented in Task 6, the functional unit and the quality service given by the improved product remains the same as with the Base-Cases.

In the case of any additional costs to manufacturers, these could be reflected in a higher purchase price for customers. However, 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 11 for most of the policy options considered in this Task whereas for BC 1, reduction in consumer expenditure occurs but only for the most optimistic policy options.

[25] One manufacturer stated that the redesign cycles of end suction pumps, submersible bore-hole pumps and vertical multi-stage pumps is of around 10 years.

8.6.3 Impacts on innovation and development

The proposed policy options will remove inefficient water pumps from the market 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 in the market. However, a shift can be expected towards more efficient models with intelligent controls within the EU. However, such controls have no such big impacts on the design of the pump itself.

The proposed policy measures 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 proposed requirements.

The standardisation of new energy efficiency indexes such as MEI, EEI or the Energy Star scheme 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 clean 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 policy measures 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.

8.6.4 Social impacts

Most of the manufacturers of water 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 performance standards 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.

In addition, the technologies to fulfil the proposed Ecodesign requirements 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 not EU industries disadvantaged.

8.7 Conclusions

This Task report brings together the finding of the previous tasks of the preparatory study for Ecodesign requirements of pumps for public and private swimming pools, ponds, fountains and aquariums. It looked at the possibility for proposing suitable Ecodesign requirements for swimming pool pumps to achieve environmental and economic improvements at EU level.

Due to the diversity of pump types, sizes and uses included in this preparatory study, the policy options are assessed independently for each of the different product groups. The applications and sizes covered within this preparatory study are from <1 kW to engineered pumps of >1000 kW. Any possible regulation would need different methodology, testing, market surveillance and standards.

Swimming pool pumps

For swimming pool pumps, it is recommended to regulate the provision of mandatory information by manufacturers within the pump brochures and technical specifications. This measure would spread the awareness about the energy efficiency of pumps and the possibilities for energy and economic savings.

Manufacturers should also provide with benchmarks, guidance and recommendations on how to design and install the pool water pumping system to optimise the efficiency of the pump. The information on energy efficiency of the pump and the benchmarks could be done in efficiency (η) at Best Efficiency Point, at Part Load and at Over Load.

The US Energy Star can be a quick-win solution to spread awareness between installers and users about the potential energy and cost savings of pumps. The generalisation of this voluntary labelling scheme could drive professional and domestic purchases towards more efficient pumps, and help manufacturers differentiate from competitors in the market.

It is also recommended to implement mandatory use of time controls in all swimming pool pumps in the EU, as this is a simple improvement option that may allow users reduce the energy consumption of pumps at a low cost.

The study team analysed the possible scope to set Minimum Energy Performance Standards (MEPS) for swimming pool pumps, taking the approach of the Minimum Efficiency Index introduced in the Ecodesign Regulation on water pumps[26]. The estimation of MEI values for swimming pool pumps presented in this report has been done as an example, and is based on a linear distribution of the efficiencies of pumps in the EU market. If any regulation is to be set on swimming pool pumps using MEI, a statistical analysis of the EU market of pumps would be necessary in order to calculate the accurate MEI values and potential savings.

Scenarios representing the implementation of MEPS in swimming pool pumps in the EU were projected over the period 2013-2040 to quantify the total potential of improvements that can be achieved with respect to a Business-as-Usual (BAU) scenario if MEPS were enforced from 2017.

[26] Commission Regulation (EU) No 547/2012

For domestic swimming pool pumps up to 2.2 kW, the potential electricity savings vary from 0.20 to 0.36 TWh per year in 2040, but the consumer expenditure at EU level would increase slightly after the introduction of the regulation between 0.5 to 6.5 M€ per year. The consumer expenditure would only decrease to the level before regulation after the year 2030, and would achieve a maximum of 8.5 M€ savings per year in 2040.

For domestic and commercial swimming pool pumps over 2.2 kW, the potential electricity savings at EU level of the policy options studied are between 0.07 and 0.12 TWh per year in 2040, with a consumer expenditure savings of between 2.5 to 7.8 M€ per year.

If Variable Speed Drive technology is considered as a BAT option for policy implementation, the electricity savings of swimming pool pumps would be notably higher (i.e. up to 6 TWh in 2040 for all swimming pool pumps), but the economic impacts on customers would also be affected. The consumer expenditure of swimming pool pumps less than 2.2 kW would increase without possibility of payback during the lifetime of the product. This would definitely prevent from implementing speed controls in small domestic swimming pool pumps. For swimming pool pumps over 2.2 kW, the consumer expenditure would increase up to 20 M€ by 2020, but decrease by in 2030 and 2040, up to 140 M€ per year. This shows the potential of speed control for commercial swimming pool pumps, although it would be necessary to fully develop an Extended Product Approach and EEI calculation method in order to apply any regulation that could achieve these savings across different pump applications.

If Ecodesign Implementing Measures in the form of Minimum Energy Performance Standards are to be set for swimming pool pumps, these should follow the MEI proposed in the intermediate scenario presented in Table 8-6.

Table 8-6: Most beneficial cut-off scenario

	MEI		
	Tier 1: 2016	Tier 2: 2018	Tier 3: 2020
Scenario 3	0.1	0.4	0.7

This policy scenario achieves some energy and economic savings at EU level (e.g. a total of between 0.27 and 0.48 TWh and between 8 to 16 M€ per year in 2040, depending on the consumer market response to the potential Implementing Measures explained in section 8.4.2).

In a future revision of the proposed regulation, the Extended Product Approach and the Energy Efficiency Index method could be included in order to develop a more ambitious regulation for clean water pumps in the EU, which could potentially save up to 6 TWh per year in 2040. The possible drawbacks should be carefully assessed in order to avoid possible economic burden on manufacturers or consumers.

Table 8-7 shows a summary of the potential energy savings of the different policy options analysed for swimming pool pumps.

Table 8-7: Summary of Policy Options considered for Swimming Pool pumps

Policy Option	Average energy savings per product (%)	Estimated annual electricity savings (TWh) in 2040 at EU level		
		Swimming pool pumps <2.2 kW	Swimming pool pumps >2.2 kW	Total
Mandatory Information requirements / Energy labelling[27]	N/A	N/A	N/A	N/A
Mandatory use of speed controls[28]	12% for pumps <2.2 kW 42% for pumps <2.2 kW	3.1	2.9	6.0
Mandatory use of time controls[29]	7.5%	1.2	0.4	1.6
Mandatory MEPS[30]	2%	0.20 to 0.36	0.07 to 0.12	0.27 to 0.48
Voluntary use of correct sized pipes[31]	10%	1.6	0.6	2.2

It should be noted that for VSDs this is the average saving from all swimming pool pumps, savings on individual pumps where good savings can be made will be larger. However, as described in Task 6 and 7 these numbers are best estimates based on little industry data.

The impact of information requirements and energy labelling cannot be estimated due to the difficulty of predicting the purchase decisions of consumers. The US Energy Star present some estimation of potential economic savings if all swimming pool pumps were certified, but it is not clear if those assumptions can be extrapolated to the EU market.

In practice, the total energy savings will be less than the sum of the individual policy options listed in Table 8-7, as some measures are not "mathematically" additive; but because the savings attributable to the individual policy options are if anything understated, this gives a fair idea of the total realistic energy saving potential.

Fountain, pond, aquarium, spa and counter current pumps

The improvement potential of fountain and pond pumps, aquarium pumps, spa pumps and counter current pumps is not very high. These pumps, except some aquarium pumps, usually require professional engineers and technicians to dimension and design the systems. Aquarium pumps may be sold in do-it-yourself markets, but as seen in previous task of this study, the difference in energy efficiency between the best and the worst product is not very big. Thus, relevant product information requirements are thought to be more effective than complex

[27] As described in section 8.2.2.1.

[28] As described in section 8.2.2.2 and calculated in section 8.4.5.

[29] As described in section 8.2.2.3. Calculated as 7.5% of the electricity consumption at EU level in 2040.

[30] As described in section 8.2.2.4 and calculated in section 8.4.

[31] As described in section 8.2.2.5. Calculated as 10% of the electricity consumption at EU level in 2040.

energy labels. The provision of information by manufacturers would make installers and users aware of the energy efficiency of these pumps and the possibilities for energy and cost savings.

End suction, bore-hole and vertical multistage pumps

End suction pumps, bore-hole pumps and vertical multistage pumps usually require professional engineers and technicians to dimension and design the systems. The hydraulic efficiency of these big pumps is usually a major concern of users, and these pumps are usually tailor-made, specifically designed to meet the client's criteria. The use of Variable Speed Drives in these pumps is only beneficial when the pump application in which they are used requires it.

In any case, the provision of information by manufacturers would spread the awareness about the energy efficiency of pumps and the possibilities for optimisation its use and maintenance. Furthermore, the provision of benchmarks, guidance and recommendations on how to design and install the pumping system to optimise the efficiency of the pump may help increasing the energy efficiency of the installed stock in the EU.

Annex I: 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[32], 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.

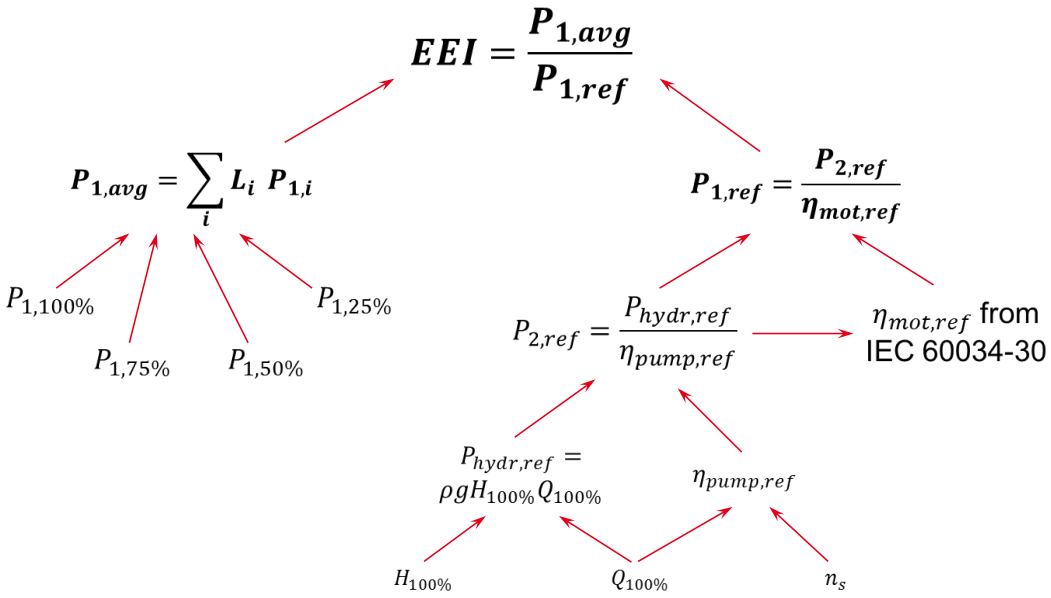
Creating load profiles that are representative of the different types of application that will be powered by the pumps in scope is critical. The load profiles give the proportion of the time that is spent at each load point, with the actual annual operating time for each application being used to establish energy consumption.

The 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:

[32] Commission Regulation (EC) No 641/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products



Where:

P1,i is the electrical power input from the grid in each of the profiles

P2,i is the mechanical power from the motor shaft in each of the profiles

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 II: Estimation of C-values for Lot 29 pumps

This Annex contains a description of the methodology proposed for use to estimate the "C-values" for pumps in ENER Lot 29 preparatory study. This section only covers those pumps for which the project team proposed MEPS based on MEI as part of the possible policy options analysed in Task 8 of this preparatory study (i.e. swimming pool pumps).

The concept of "C-values" was first used in the ENER Lot 11 study for clean water pumps. The intention of the ENER Lot 29 study authors is to use the ENER Lot 11 C-value methodology and adapt it for use with the ENER Lot 29 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). The C-values used in the calculation of EEI and those used in the calculation of MEI are not the same.

Setting the efficiency levels is very complicated, as they will differ by type, speed, flow, head and impeller diameter. Achievable efficiency is dependent on pump size and specific speed as well as pump type. 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 ENER Lot 11 report using data from Technische Universität Darmstadt in 1998 for an earlier SAVE project led by AEAT. This plane is shown in Figure 8-25.

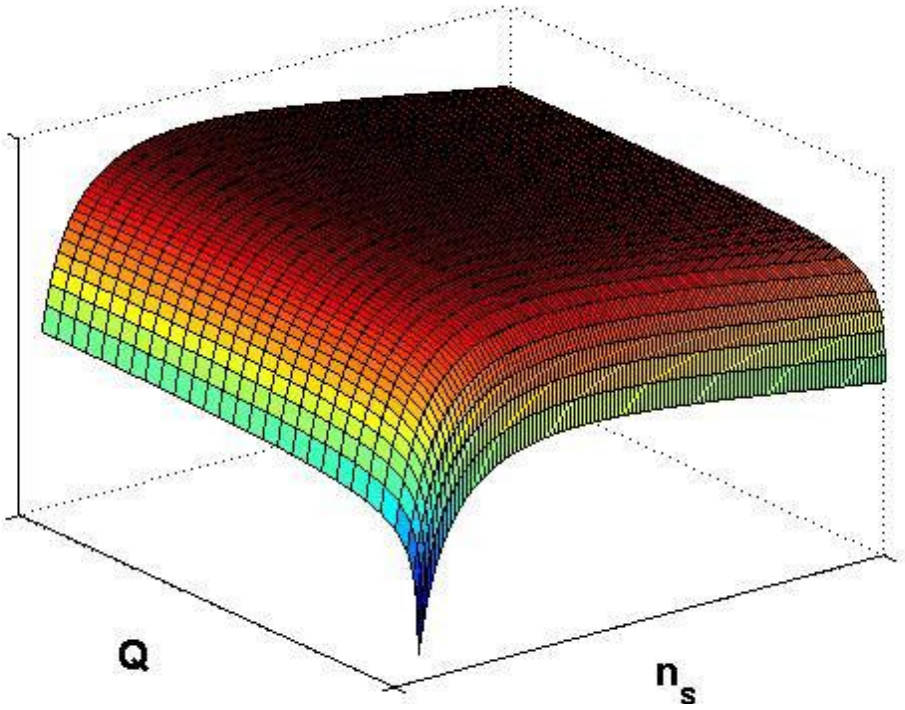


Figure 8-22: 3D plane used in the ENER Lot 11 pump study

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 ENER Lot 11**

In ENER Lot 11, the following C-values were used for the pumps in scope:

Table 8-8: ENER 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 ENER 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 8-9: ENER 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 m^3/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 the table below.

Table 8-10: ENER 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 ENER Lot 11 C-values calculation approach for ENER Lot 29 pumps**

For the ENER Lot 29 pumps, the project team has estimated the following 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.

Table 8-11: Efficiency range for ENER Lot 29 Pumps

Pump type		Hydraulic Power	η_{max} %	η_{min} %	η_{av} %
SPPS	Domestic with built in strainer up to 2.2 kW	0.8	74	55	68
SPPL	Domestic/commercial with built in strainer over 2.2 kW	5	76	65	72

From these values, it is possible to put together the efficiency cut-off bands for the pumps in scope. They have been calculated by evenly apportion the efficiency between the maximum and minimum between the 10 bands.

Table 8-12: Efficiencies at different cut-off values

Pump type	10%	20%	30%	40%	50%	60%	80%	90%	100%
SPPS	56.9	58.8	60.7	62.6	64.5	66.4	70.2	72.1	74
SPPL	66.1	67.2	68.3	69.4	70.5	71.6	73.8	74.9	76

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 to estimate the average head and flow for each pump type[33]. The results are shown in the following table.

Table 8-13: Estimated Average Pump Duties

Pump type	Head (m)	Flow (m³/h)	Specific Speed	ln ns (/min)	ln Q (m3/hr)
SPPS	10	29.65	23.40	3.15	3.39
SPPL	15	123.53	35.24	3.56	4.82

Using the information in Table 8-128-10 and in Table 8-138-11 combination with the formula previously described, the following C-values are estimated as presented in Table 8-148-12.

Table 8-14: Estimated C-values at different MEPS cut-offs

Pump type	10%	20%	30%	40%	50%	60%	80%	90%	100%
SPPS	140.1	138.2	136.3	134.4	132.5	130.6	126.8	124.9	123.0
SPPL	142.4	141.3	140.2	139.1	138.0	136.9	134.7	133.6	132.5

Submersible borehole pumps which already have high efficiency and are on the fringe of the MEI methodology limitations. Swimming pool pumps are unlike others with their integral strainers. Re-evaluation of the methodology is required if regulations on these pumps goes ahead.

[33] 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.

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Annex III: Sensitivity analysis data

This section presents the data on total energy consumption and consumer expenditure at EU level of the variations of the scenarios created in the sensitivity analysis. The data is presented in absolute value at EU level and as variation over the Business as Usual scenario used in section 8.4.

Sensitivity analysis data for lifetime

Table 8-15: Analysis of sensitivity on energy consumption to product lifetime for BC 1

		Pragmatic Upper (25 yr)				Pragmatic lower (15 yr)			
Years		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	9,429	9,420	9,429	9,420	9,454	9,445	9,454	9,445
2020	GWh/year	10,035	10,026	10,035	10,009	10,062	10,053	10,062	10,036
2030	GWh/year	13,845	13,845	13,741	13,733	13,883	13,883	13,778	13,771
2040	GWh/year	19,018	19,018	18,865	18,865	19,070	19,070	18,917	18,917
2018	% over BaU	0.1%	0.1%	0.1%	0.1%	-0.2%	-0.2%	-0.2%	-0.2%
2020	% over BaU	0.1%	0.1%	0.1%	0.1%	-0.2%	-0.2%	-0.2%	-0.2%
2030	% over BaU	0.1%	0.1%	0.1%	0.1%	-0.2%	-0.2%	-0.2%	-0.2%
2040	% over BaU	0.1%	0.1%	0.1%	0.1%	-0.2%	-0.2%	-0.2%	-0.2%

Table 8-16: Analysis of sensitivity on Life Cycle Cost to product lifetime for BC 1

		Pragmatic Upper (25 yr)				Pragmatic lower (15 yr)			
Years		Upper Scenario 1	Upper Scenario 2	Upper Scenari o 3	Upper Scenari o 4	Lower Scenario 1	Lower Scenario 2	Lower Scenario 3	Lower Scenario 4
2018	M€/year	758	757	758	761	861	860	861	864
2020	M€/year	811	810	815	813	920	920	925	923
2030	M€/year	1,121	1,121	1,121	1,120	1,272	1,272	1,271	1,270
2040	M€/year	1,511	1,511	1,509	1,509	1,719	1,719	1,715	1,715
2018	% over BaU	6.0%	6.0%	6.0%	6.0%	-6.8%	-6.8%	-6.8%	-6.8%
2020	% over BaU	6.0%	6.0%	6.0%	6.0%	-6.8%	-6.8%	-6.8%	-6.7%
2030	% over BaU	5.9%	5.9%	5.9%	5.9%	-6.7%	-6.7%	-6.7%	-6.7%
2040	% over BaU	3.4%	3.4%	3.4%	3.4%	-3.8%	-3.8%	-3.8%	-3.8%

Table 8-17: Analysis of sensitivity on energy consumption to product lifetime for BC 2

		Pragmatic Upper (25 yr)				Pragmatic lower (15 yr)			
Years		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	3,165	3,162	3,165	3,162	3,166	3,163	3,166	3,163
2020	GWh/year	3,369	3,366	3,369	3,360	3,370	3,367	3,370	3,361
2030	GWh/year	4,647	4,647	4,612	4,610	4,649	4,649	4,613	4,611
2040	GWh/year	6,384	6,384	6,332	6,332	6,386	6,386	6,334	6,334
2018	% over BaU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2020	% over BaU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2030	% over BaU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2040	% over BaU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 8-18: Analysis of sensitivity on Life Cycle Costs to product lifetime for BC 2

		Pragmatic Upper (25 yr)				Pragmatic lower (15 yr)			
Years		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	216	216	216	216	251	250	251	251
2020	M€/year	230	230	230	230	267	267	267	267
2030	M€/year	318	318	316	316	369	369	366	366
2040	M€/year	434	434	430	430	504	504	500	500
2018	% over BaU	7.0%	7.0%	7.0%	7.0%	-7.9%	-7.9%	-7.9%	-7.9%
2020	% over BaU	7.0%	7.0%	7.0%	7.0%	-7.9%	-7.9%	-7.9%	-7.9%
2030	% over BaU	6.9%	6.9%	6.9%	6.9%	-7.8%	-7.8%	-7.8%	-7.8%
2040	% over BaU	3.9%	3.9%	3.9%	3.9%	-4.4%	-4.4%	-4.4%	-4.4%

Sensitivity analysis data for annual sales growth rate

Table 8-19: Analysis of sensitivity on energy consumption to sales growth for BC 1

		Pragmatic Upper (5% sales growth)				Pragmatic lower (0% sales growth)			
Years		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	9,639	9,628	9,639	9,628	9,310	9,303	9,310	9,303
2020	GWh/year	10,462	10,451	10,462	10,428	9,779	9,771	9,779	9,758
2030	GWh/year	16,596	16,596	16,462	16,462	12,122	12,114	12,057	12,037
2040	GWh/year	26,101	26,101	25,891	25,891	14,509	14,509	14,392	14,392
2018	% over BaU	-2.1%	-2.1%	-2.1%	-2.1%	1.4%	1.3%	1.4%	1.3%
2020	% over BaU	-4.1%	-4.1%	-4.1%	-4.0%	2.6%	2.6%	2.6%	2.6%
2030	% over BaU	-19.5%	-19.5%	-19.3%	-19.4%	12.4%	12.5%	12.1%	12.2%
2040	% over BaU	-36.7%	-36.7%	-36.4%	-36.4%	23.5%	23.5%	23.3%	23.3%

Table 8-20: Analysis of sensitivity on Life Cycle Costs to sales growth for BC 1

		Pragmatic Upper (5% sales growth)				Pragmatic lower (0% sales growth)			
Years		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	887	886	887	891	755	754	755	757
2020	M€/year	983	983	989	987	785	784	788	786
2030	M€/year	1,596	1,596	1,597	1,597	934	933	933	932
2040	M€/year	2,423	2,423	2,424	2,424	1,086	1,086	1,082	1,082
2018	% over BaU	-10.0%	-10.0%	-10.0%	-10.1%	6.4%	6.4%	6.4%	6.5%
2020	% over BaU	-14.1%	-14.0%	-14.3%	-14.2%	9.0%	9.0%	9.2%	9.1%
2030	% over BaU	-33.8%	-33.8%	-34.0%	-34.0%	21.6%	21.6%	21.6%	21.6%
2040	% over BaU	-50.4%	-50.4%	-50.6%	-50.6%	32.3%	32.3%	32.5%	32.5%

Table 8-21: Analysis of sensitivity on energy consumption to sales growth for BC 2

		Pragmatic Upper (5% sales growth)				Pragmatic lower (0% sales growth)			
Years		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	3,233	3,229	3,233	3,229	3,122	3,120	3,122	3,120
2020	GWh/year	3,509	3,505	3,509	3,497	3,280	3,277	3,280	3,273
2030	GWh/year	5,566	5,566	5,521	5,521	4,065	4,063	4,043	4,036
2040	GWh/year	8,753	8,753	8,683	8,683	4,866	4,866	4,826	4,826
2018	% over BaU	-2.1%	-2.1%	-2.1%	-2.1%	1.4%	1.3%	1.4%	1.3%
2020	% over BaU	-4.1%	-4.1%	-4.1%	-4.0%	2.6%	2.6%	2.6%	2.6%
2030	% over BaU	-19.5%	-19.5%	-19.3%	-19.4%	12.4%	12.5%	12.1%	12.2%
2040	% over BaU	-36.7%	-36.7%	-36.4%	-36.4%	23.5%	23.5%	23.3%	23.3%

Table 8-22: Analysis of sensitivity on Life Cycle Costs to sales growth for BC 2

		Pragmatic Upper (5% sales growth)				Pragmatic lower (0% sales growth)			
Years		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	244	244	244	244	225	224	225	224
2020	M€/year	267	267	268	267	235	235	235	235
2030	M€/year	428	428	425	425	287	287	286	285
2040	M€/year	664	664	659	659	340	340	337	337
2018	% over BaU	-5.2%	-5.1%	-5.2%	-5.1%	3.3%	3.3%	3.3%	3.3%
2020	% over BaU	-8.0%	-7.9%	-8.0%	-7.9%	5.1%	5.1%	5.1%	5.1%
2030	% over BaU	-25.0%	-25.0%	-24.8%	-24.9%	15.9%	16.0%	15.6%	15.7%
2040	% over BaU	-41.9%	-41.9%	-41.7%	-41.7%	26.9%	26.9%	26.7%	26.7%

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