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

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

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Task 1: Definition

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

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

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

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

The report is structured as follows:

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

1.1 Introduction

1.1.1 Wastewater

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

- **Urban WW**

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

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

- **Domestic WW**

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

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

- **Industrial WW**

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

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

- **WW treatment**

There are three fundamental steps for treatment of WW.

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

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

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

More advanced treatment process steps can be used for:

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

The need for a scientific definition of WW

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

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

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

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

- Viscosity
- Rag
- Grit
- Chemical properties

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

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

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

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

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

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

1.1.2 What are pumps?

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

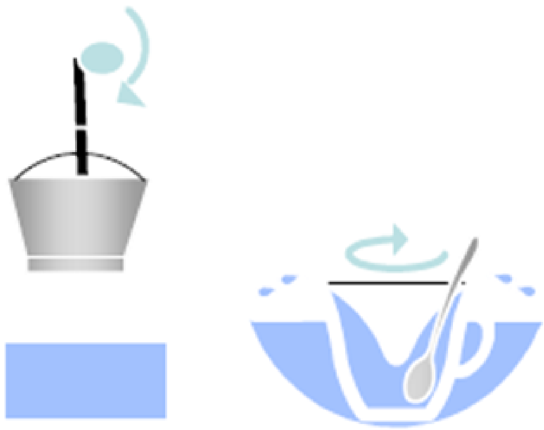


Figure 1-1: Operating principles of positive displacement pumps (pump on left side) and rotodynamic water pumps (pump on the right side)

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

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

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

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

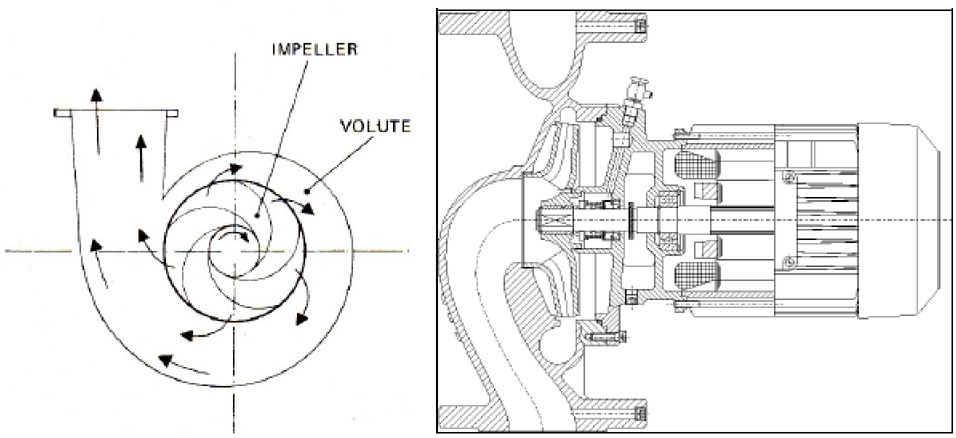


Figure 1-2: How rotodynamic pumps work: flow paths (left) and cutaway of motor coupled pump (right)

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

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

1.1.3 The principles of pumping

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

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

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

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

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

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

Equation 1

Thus,

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

Equation 2

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

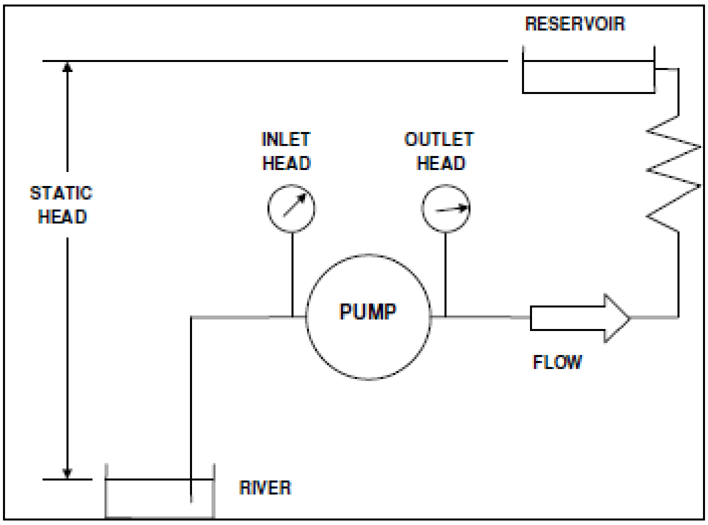


Figure 1-3: Illustration of an open pumping network

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

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

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

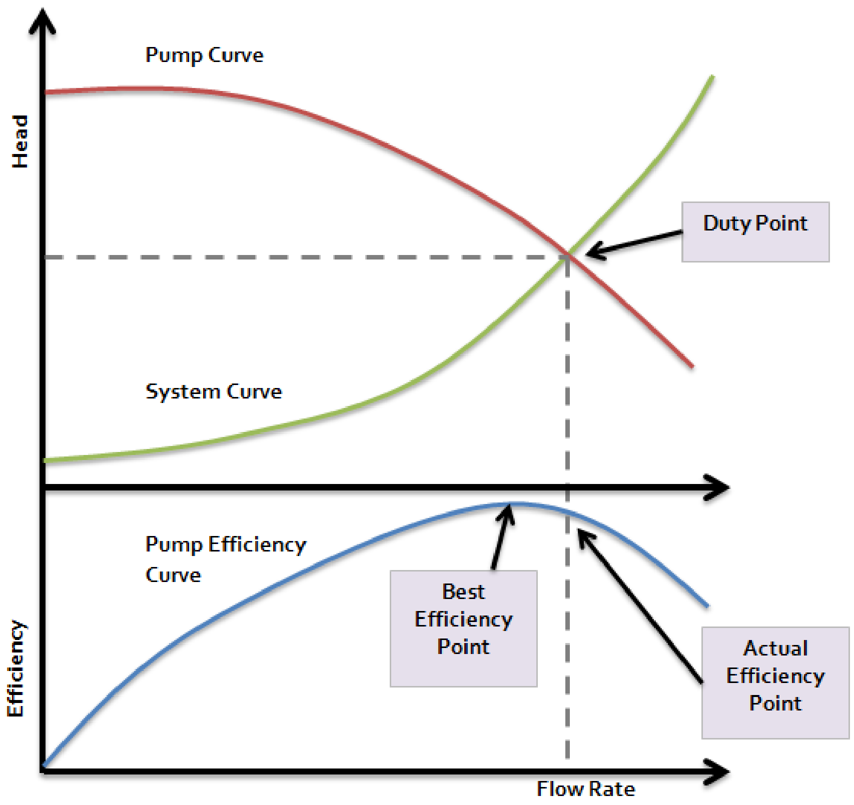


Figure 1-4: Example of a pump system curve showing the difference between the best efficiency point and the actual efficiency point

1.1.4 Basic pump laws for Newtonian fluids

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

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

Equation 3

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

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

Equation 4

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

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

Resolving equation 1 and 2 results in

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

Equation 5

With a Q_{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_{P1})

Specific speed:

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

Equation 6

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

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

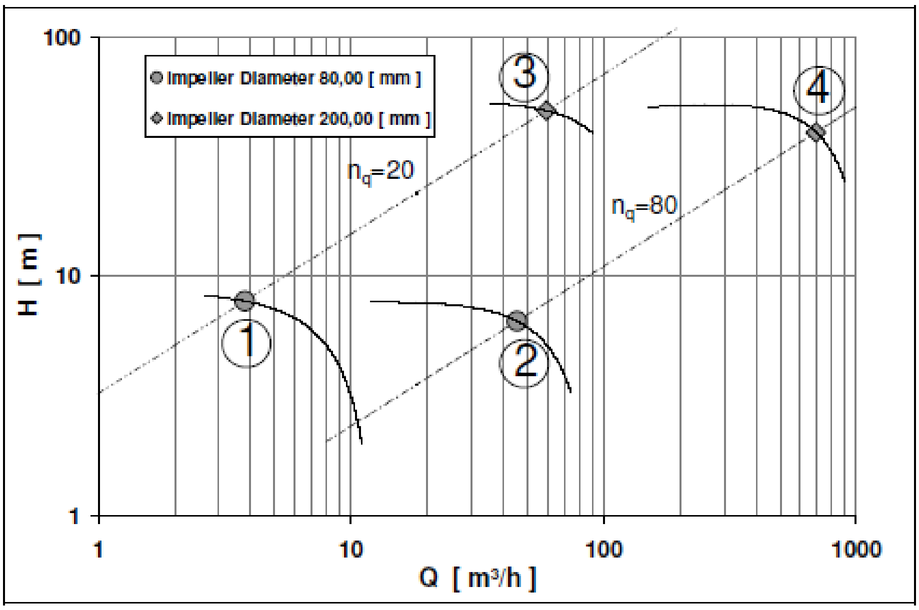


Figure 1-5: Duty points of pumps of different sizes but same specific speed

Figure 1-5 illustrates four different pump cases of two different pump types in a H-Q-Diagram. The two pump types are characterised by the specific speed. Though the pump sizes of for example No.1 and No.3 are completely different (more than a magnitude difference in flow) their geometrical ratio is similar and therefore they have also the same specific speed.

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

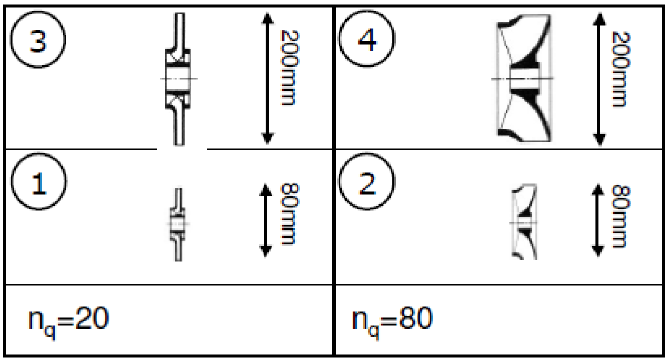


Figure 1-6: Principle impeller designs for typical pump sizes and specific speed

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

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

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

1.1.5 Wider context of pumps covered in ENER Lot 28 study

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

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

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

1.1.6 Functionality

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

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

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

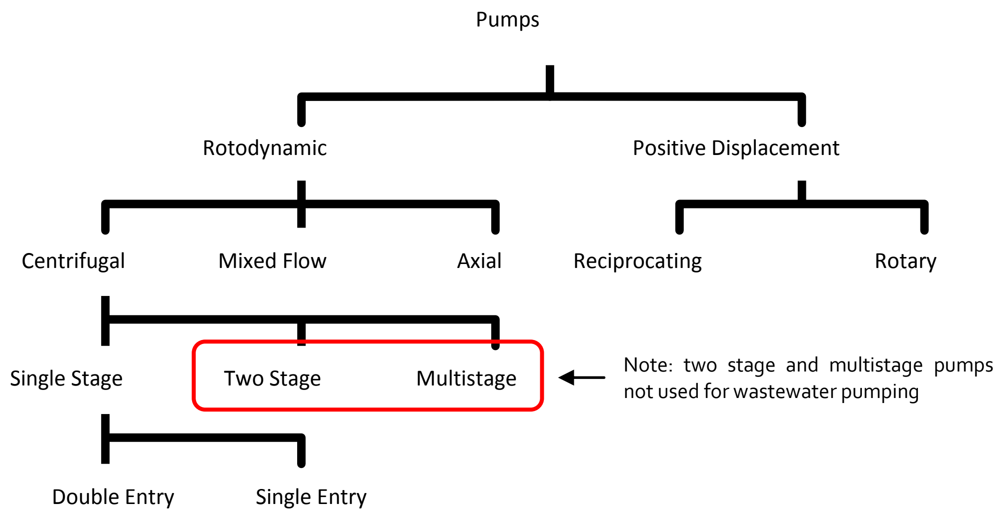


Figure 1-7: Preliminary classification for pumps

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

Table 1: Pump application-type matrix

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

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

This shows that:

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

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

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

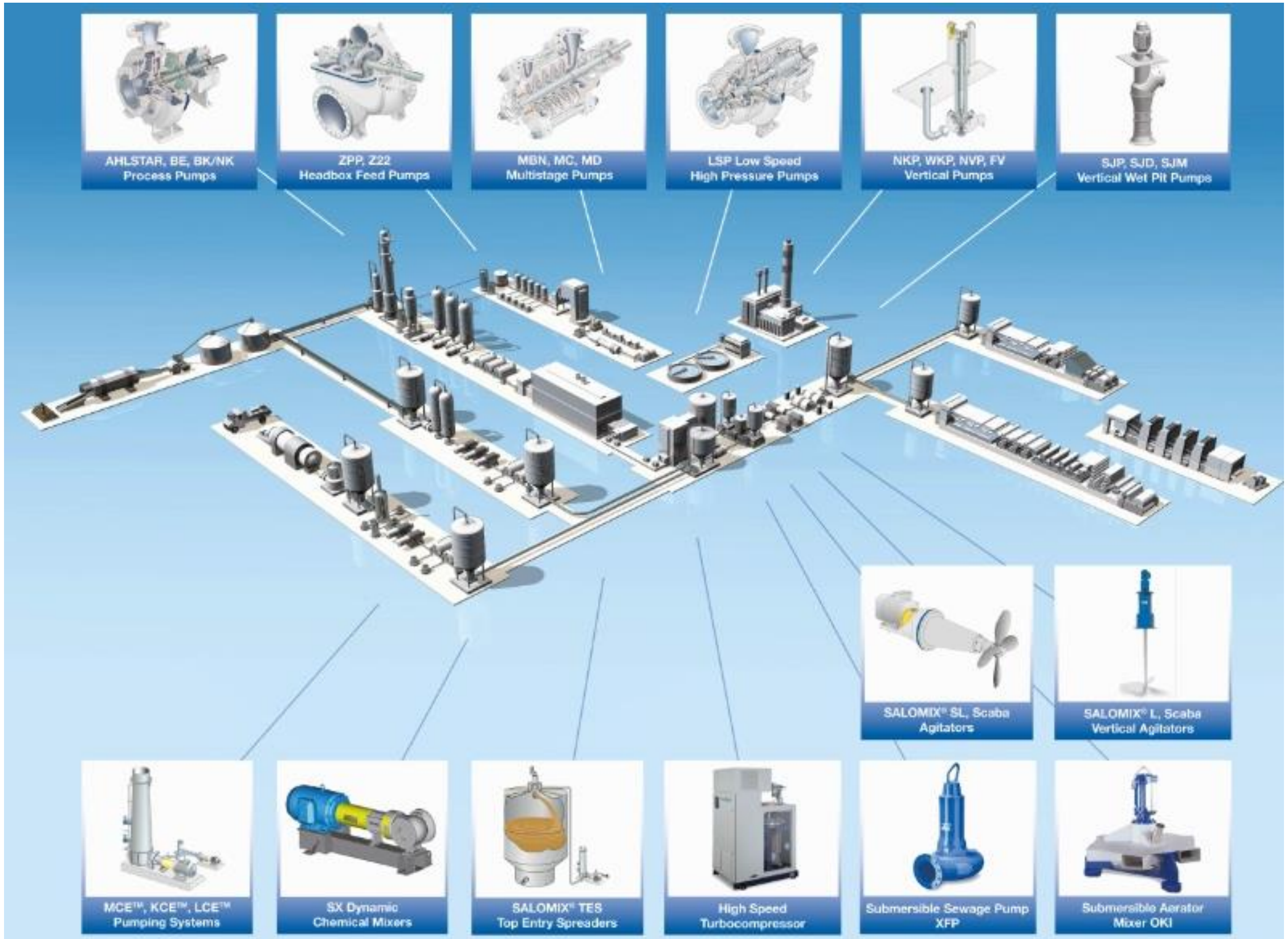


Figure 1-8: Pumps for the Paper and Pulp industry (copyright Sulzer pumps)

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

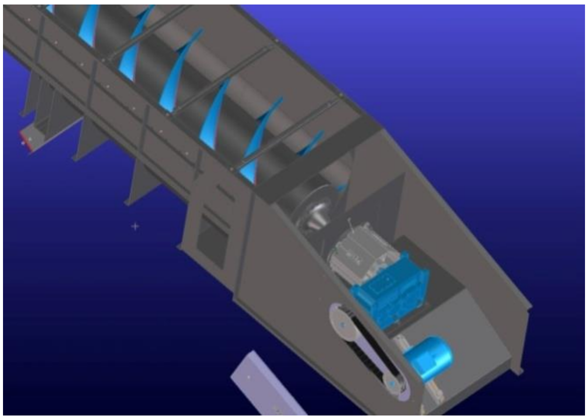


Figure 1-9: Detail of 185 kW system showing drive belt gearbox and bearings

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

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

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

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

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

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

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

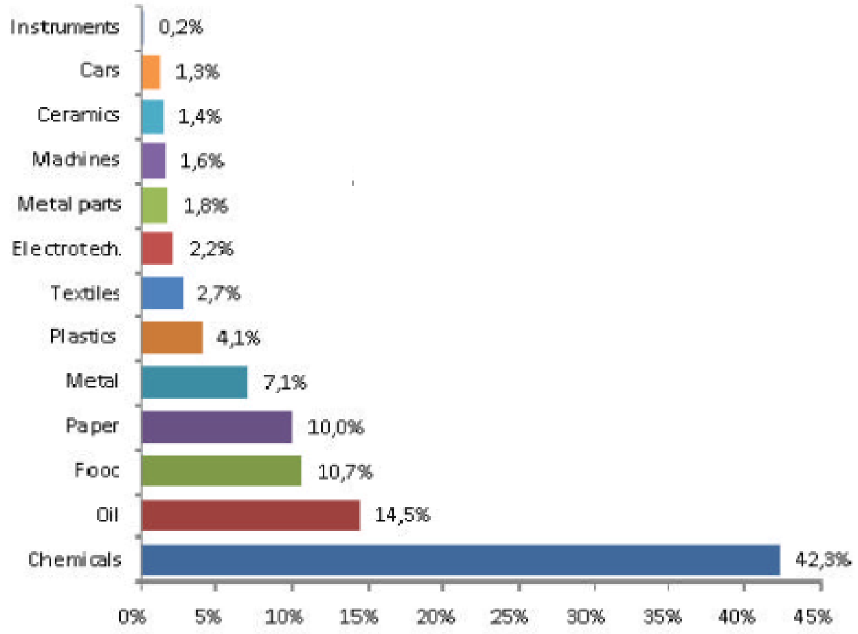


Figure 1-11: Share of annual energy consumption of positive displacement pumps by their application types (Source: Final report of 2nd Ecodesign Working plan)

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

1.1.7 WW pump characteristics

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

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

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

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

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

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

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

1.1.8 Importance of inlet pressure

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

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

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

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

1.1.9 PRODCOM categories

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

Table 2: PRODCOM categories

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

[9] Grundfos Industry (2004) Pump Handbook

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

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

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

Within the norm EN 12050 "Wastewater lifting plants for buildings and sites – principles of construction and testing" the related minimum free solid passages is listed as well as the minimum discharge requirements in relation to the application/use in fluids containing faecal matters or being faecal-free. BS EN 12056-2:2000 "Gravity drainage systems inside buildings" covers wastewater drainage systems that operate under gravity. It is applicable for drainage systems inside dwellings, commercial, institutional and industrial buildings. This standard sets out principles to be followed for both layout and calculation. It makes limited provision for drainage systems conveying trade effluent and makes limited provision for fluids removed by pumps.

1.1.11 Labelling categories (EU Energy Label or EcoLabel)

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

1.2 Proposed categorisation scheme for pumps

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

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

1.2.1 Description of ENER Lot 28 pumps

- **Centrifugal submersible pumps**

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

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

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

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

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

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

There are different types of impellers that can be used depending on the type of wastewater and solids being pumped. For wastewater containing soft and hard solids there are various designs of open or closed single or multi-vane impellers on the market. In case of raw wastewater containing large solids impeller types with large passages are traditionally used in order to prevent clogging. While for larger pumps multi-channel impellers can provide the desired passages, typical impeller types providing large passages even for small sizes are vortex impellers or open or closed single vane impellers. For small pumps or especially fluids with high contents of soft but large solids, a cutting or grinding device might be used to break down the solids to sizes more suitable for pumping. For abrasive solids chromium iron versions of the above or vortex, impellers are often used. Some manufacturers offer special material options suitable in chemically demanding environments. A selection of impellers is shown Figure 1-13.

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

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

- **Centrifugal dry well pumps**

Figure 1-14: Dry well pump

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

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

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

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

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

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

- **Centrifugal submersible dewatering pumps**

Figure 1-15: A selection of dewatering pumps

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

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

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

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

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

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

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

- **Centrifugal domestic drainage pump**

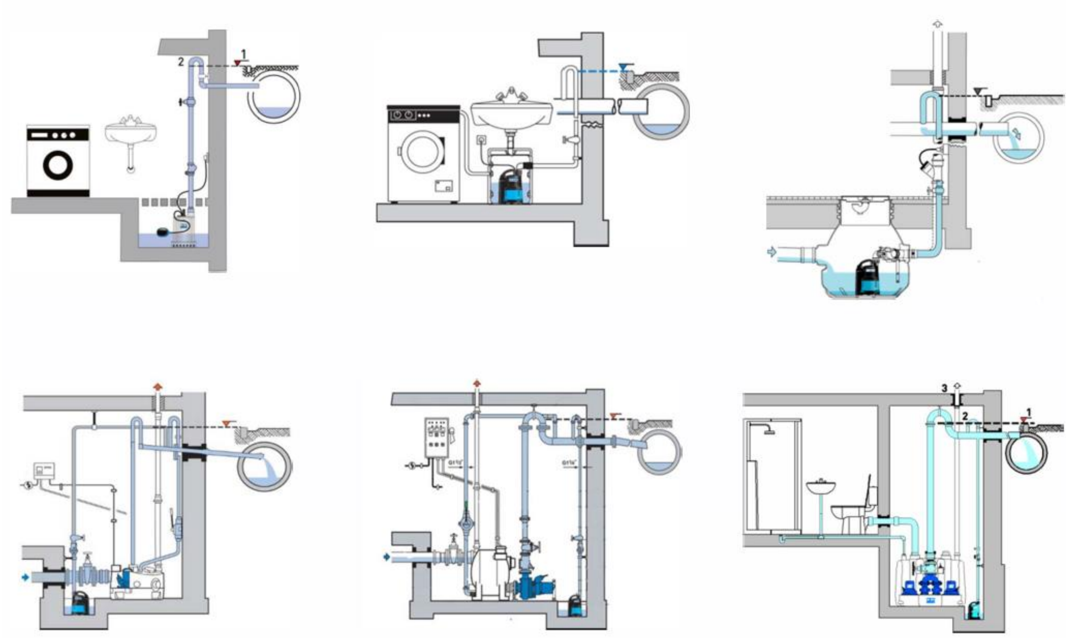


Figure 1-16: Examples of different domestic drainage pump configurations

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

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

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

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

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

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

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

Figure 1-17: Commercial grinding pump

- **Centrifugal domestic shredding/grinding pumps**

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

Figure 1-18: Domestic shredding pump

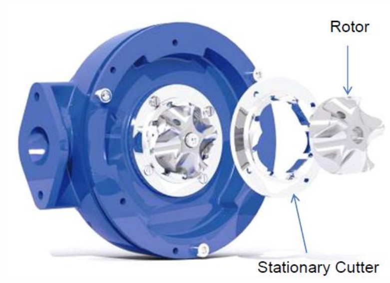


Figure 1-19: Example of a cutting mechanism in a shredding pump

Slurry Pumps

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

Figure 1-20: Slurry Pumps

1.2.2 Screening analysis

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

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

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

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

The key criteria considered in the screening analysis include:

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

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

1.2.3 Energy Saving Estimates of pump types

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

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

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

[12] Source: Europump

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

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

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

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

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

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

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

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

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

Environmental impact category	Units	CS RSP 1 to 10	CS RSP 10 to 25	CS RSP 25 to 1000	CS MFAP	CS1 SG	CS1 RSP 1 to 10	CS1 V	CDWP RSP 1 to 10	CDWP RSP 10 to 25	CDWP RSP 25 to 1000	CDWP MFAP	SP LD	SP HD	Total
Waste, hazardous/ incinerated	kt	14%	8%	32%	3%	0,1%	0,2%	1,0%	3%	3%	6%	0,2%	27,5%	3,1%	100%
Greenhouse Gases in GWP100	mt CO2 eq.	14%	8%	32%	3%	0,1%	0,3%	0,1%	3%	3%	6%	0,2%	27,7%	3,2%	100%
Acidification, emissions	kt SO2 eq.	14%	8%	32%	3%	0,1%	0,3%	0,1%	3%	3%	6%	0,2%	27,6%	3,2%	100%
Volatile Organic Compounds (VOC)	kt	15%	8%	31%	3%	0,4%	1,0%	0,4%	3%	3%	6%	0,2%	26,7%	3,2%	100%
Persistent Organic Pollutants (POP)	g i-Teq	18%	8%	29%	3%	1,4%	3,2%	0,9%	3%	2%	5%	0,2%	23,2%	3,1%	100%

Environmental impact category	Units	CS RSP 1 to 10	CS RSP 10 to 25	CS RSP 25 to 1000	CS MFAP	CS1 SG	CS1 RSP 1 to 10	CS1 V	CDWP RSP 1 to 10	CDWP RSP 10 to 25	CDWP RSP 25 to 1000	CDWP MFAP	SP LD	SP HD	Total
Heavy Metals	ton Ni eq.	15%	8%	31%	3%	0.4%	1.1%	0.4%	3%	2%	6%	0.2%	26.5%	3.1%	100%
PAHs	ton Ni eq.	15%	8%	31%	3%	0.5%	1.3%	0.5%	3%	2%	6%	0.2%	26.1%	3.0%	100%
Particulate Matter (PM, dust)	kt	21%	7%	25%	2%	2.4%	5.7%	2.8%	3%	2%	5%	0.3%	19.6%	3.6%	100%
Heavy Metals	ton Hg/20	15%	8%	31%	3%	0.4%	1.0%	0.3%	3%	2%	6%	0.2%	26.6%	3.1%	100%
Eutrophication	kt PO4	19%	8%	27%	2%	1.9%	4.4%	1.5%	3%	2%	5%	0.3%	21.4%	3.2%	100%

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

Centrifugal submersible pump	
Radial sewage pumps 1 to 10 kW	*(CS RSP 1 to 10)*
Radial sewage pumps >10 to 25 kW	*(CS RSP 10 to 25)*
Radial sewage pumps >25 to 1000 kW	*(CS RSP 25 to 1000)*
Mixed flow & axial pumps	*(CS MFAP)*
Centrifugal submersible pump – once a day operation	
Shredding, grinding pumps	*(CS1 SG)*
Radial sewage pumps 1 to 10 kW	*(CS1 RSP 1 to 10)*
Where volute is part of a tank	*(CS1 V)*
Centrifugal dry well pump	
Radial sewage pumps 1 to 10 kW	*(CDWP 1 to 10)*
Radial sewage pumps >10 to 25 kW	*(CDWP 10 to 25)*
Radial sewage pumps >25 to 1000 kW	*(CDWP 25 to 1000)*
Mixed flow & axial pumps	*(CDWP MFAP)*
Slurry Pumps	
Light duty	*(SP LD)*
Heavy duty	*(SP HD)*

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

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

1.3 Test Standards

This section identifies the relevant test standards and procedures.

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

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

1.3.1 Test Procedure

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

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

1.3.1.1 Verification of efficiency values

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

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

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

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

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

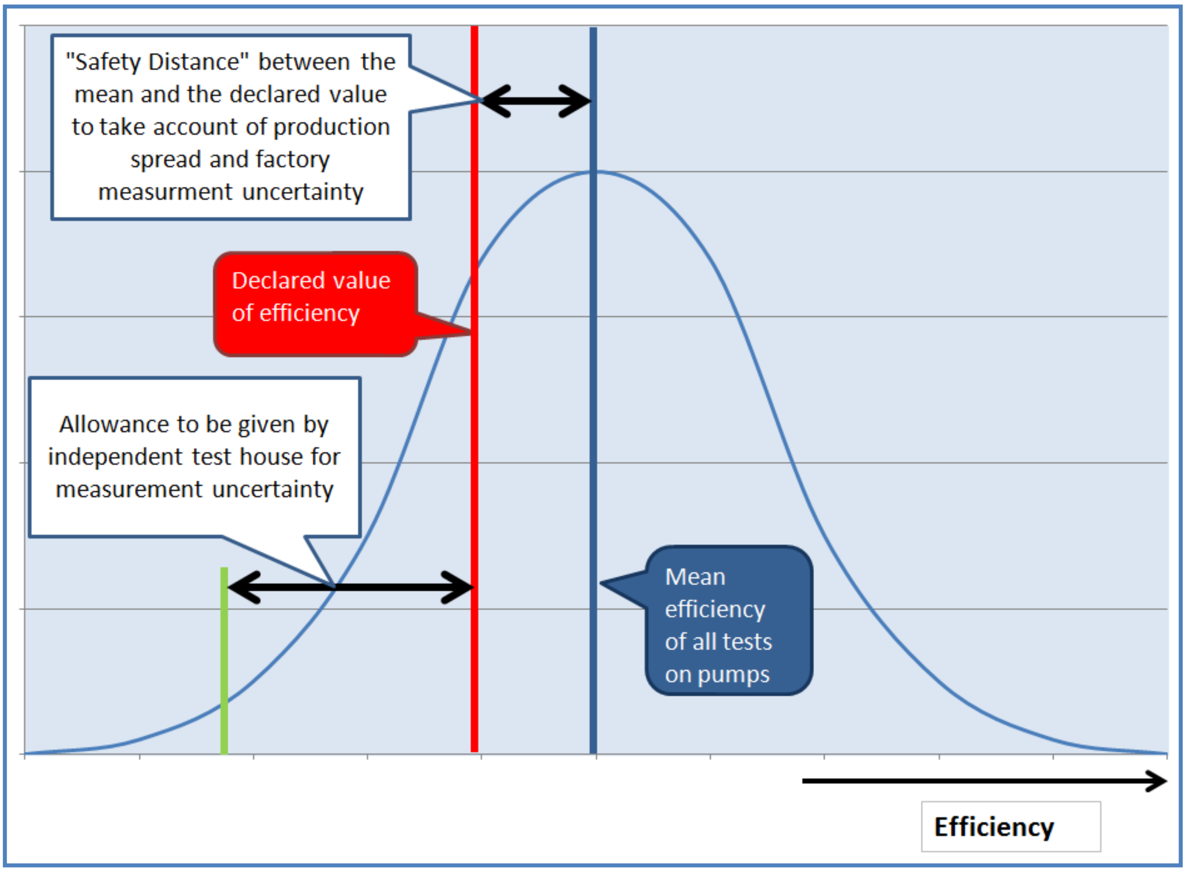


Figure 1-21: Testing and verification of pumps (only relevant to testing of products by an external test house

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

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

1.3.2 Standards at European Union level

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

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

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

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

1.3.3 Standards at Member State level

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

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

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

WIMES 10.6	Positive Displacement Pump Set for Sludge Pumping Duties

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

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

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

1.3.4 International Standards

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

Table 7: International Standards

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

1.3.5 Summary of test standards

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

15 www.wrcplc.co.uk/

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

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

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

1.4 Existing Legislation

1.4.1 Legislation and Agreements at European Union Level

1.4.1.1 Energy related legislation

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

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

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

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

1.4.1.2 Environmental legislation

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

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

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

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

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

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

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

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

.

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

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

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

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

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

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

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

1.4.2 International Legislation

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

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

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

1.5 Product performance assessment

Definition of the Extended Product Approach

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

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

Extended Products (EP): consists of physical components

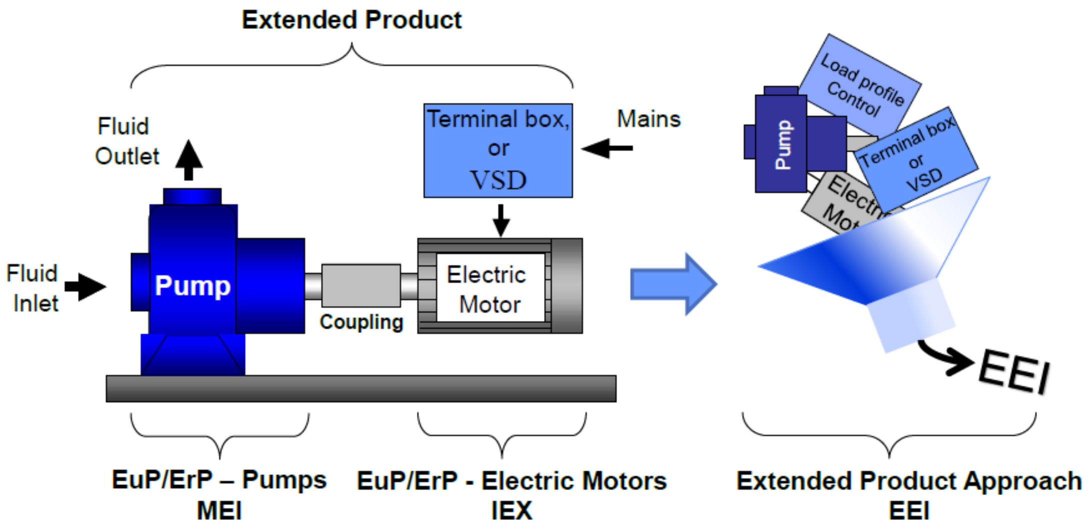


Figure 1-22 Definition of Extended Product Approach – (Source Europump)

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

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

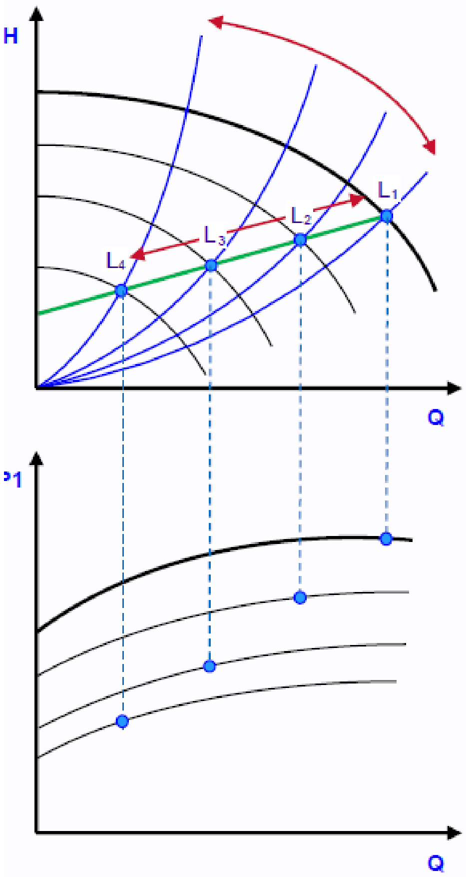
Extended Product Approach System Types

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

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

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

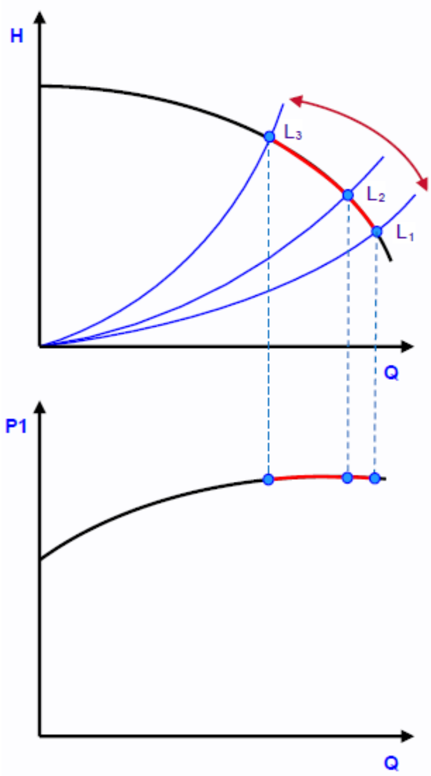
In order to apply the EPA to a particular pump application a load profile first needs to be derived. A load profile describes the proportion of time a pump typically spends pumping a particular flow rate. In variable flow systems this change is flow rate can achieve through the use of variable speed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



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

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

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



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

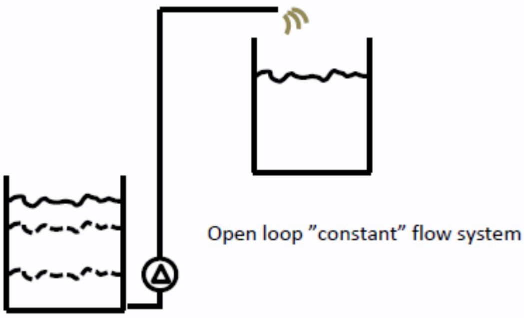


Figure 1-24 Load profile for a typical constant flow system

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

1.6 Conclusions

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

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

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

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

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

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

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

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

The Extended Product Approach considers the energy consumption of the entire pump + motor + controls system, based on assumed duty profiles. In this way it is similar to the existing regulations governing Circulators. Within this study, it will be necessary to reflect the performance of both the individual pump "wet end" (MEI) and the Extended Product (EEI)[20].

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

Annex A

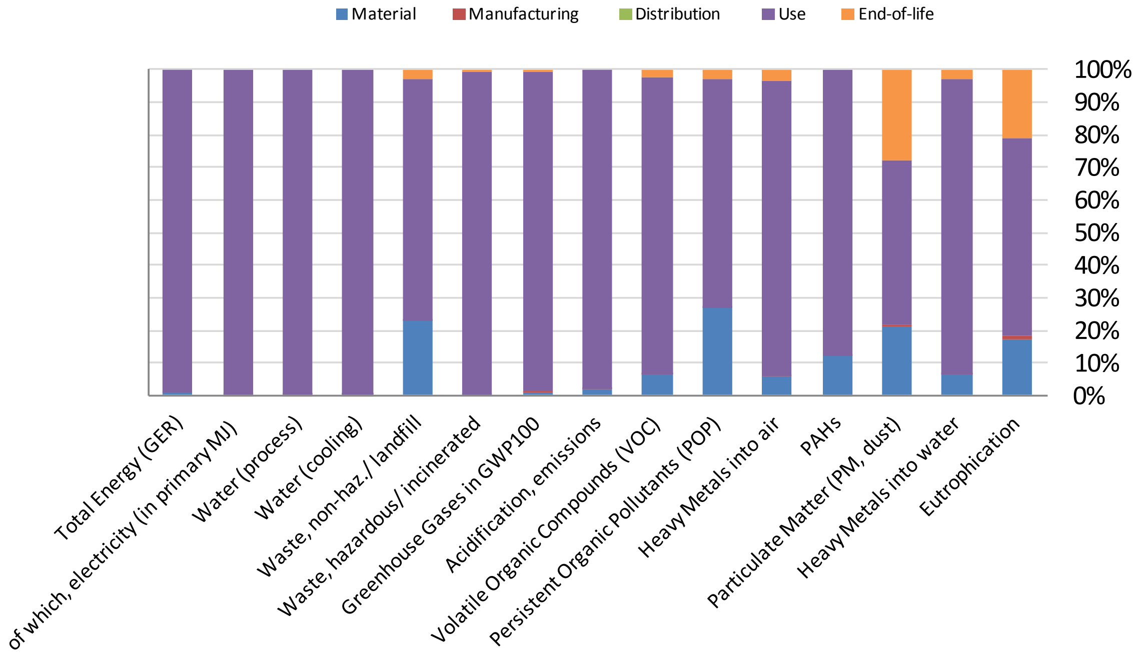


Figure 1-25: Relative significance of each life cycle phase per environmental impact category CS RSP 1 to 10

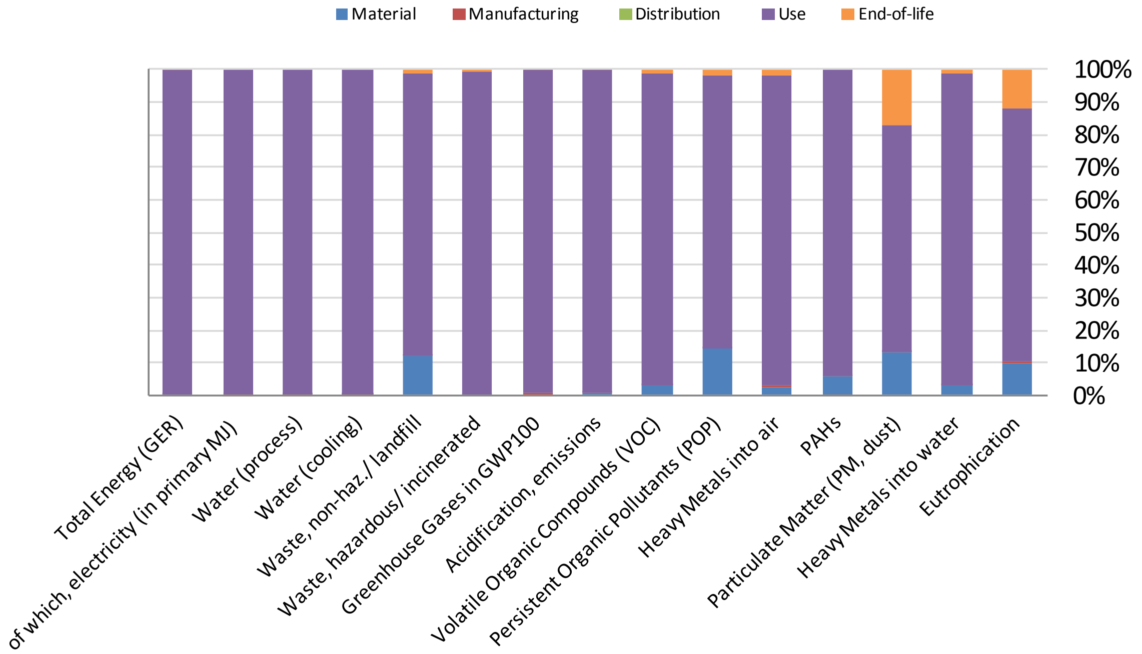


Figure 1-26: Relative significance of each life cycle phase per environmental impact category CS RSP 10 to 25

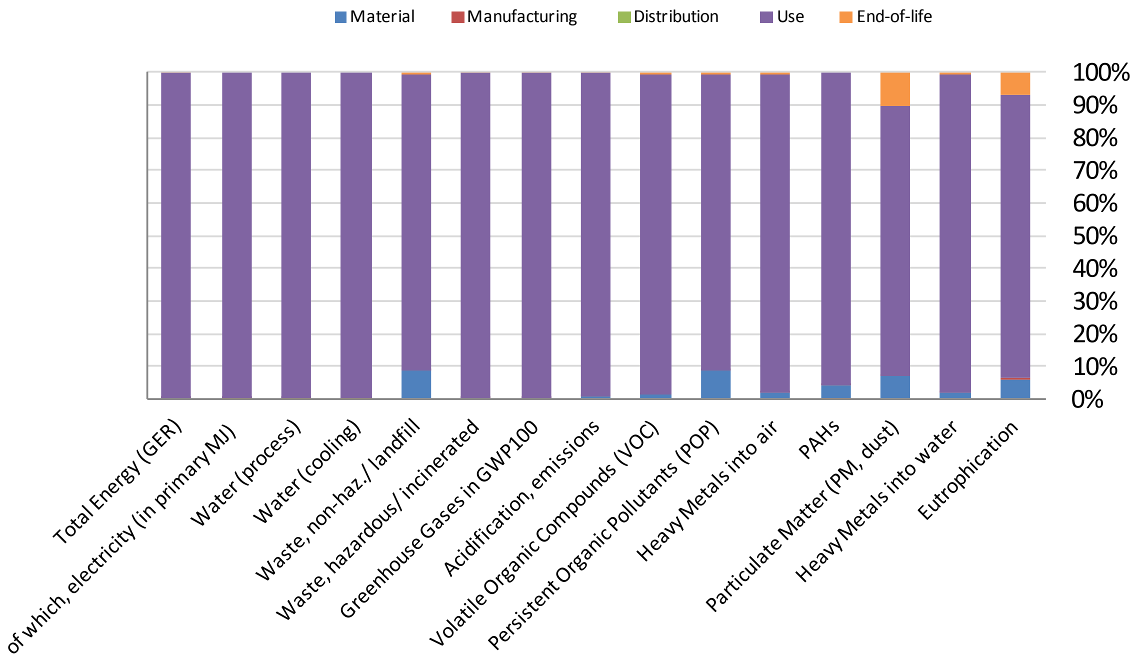


Figure 1-27: Relative significance of each life cycle phase per environmental impact category CS RSP 25 to 1000

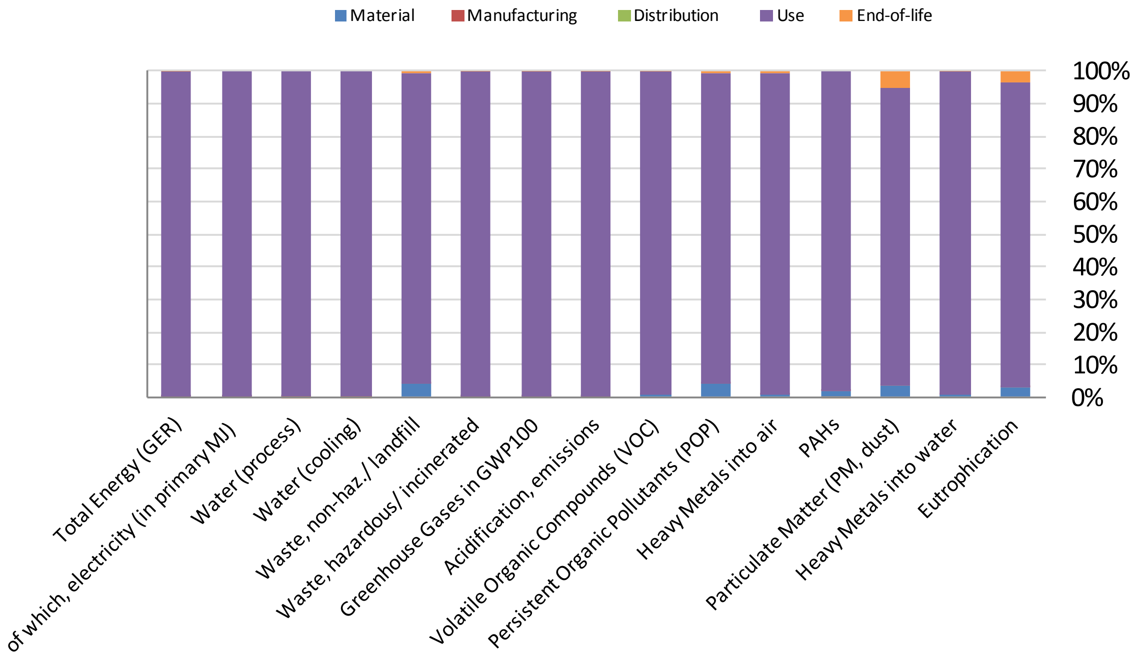


Figure 1-28: Relative significance of each life cycle phase per environmental impact category CS MFAP

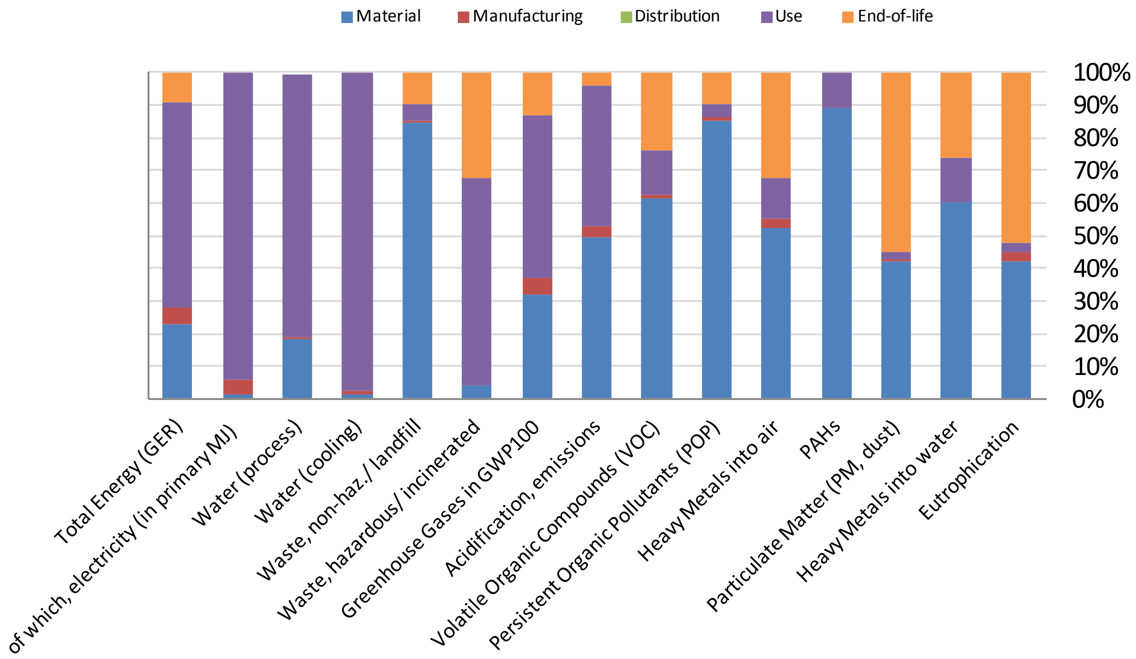


Figure 1-29: Relative significance of each life cycle phase per environmental impact category CS1 SG

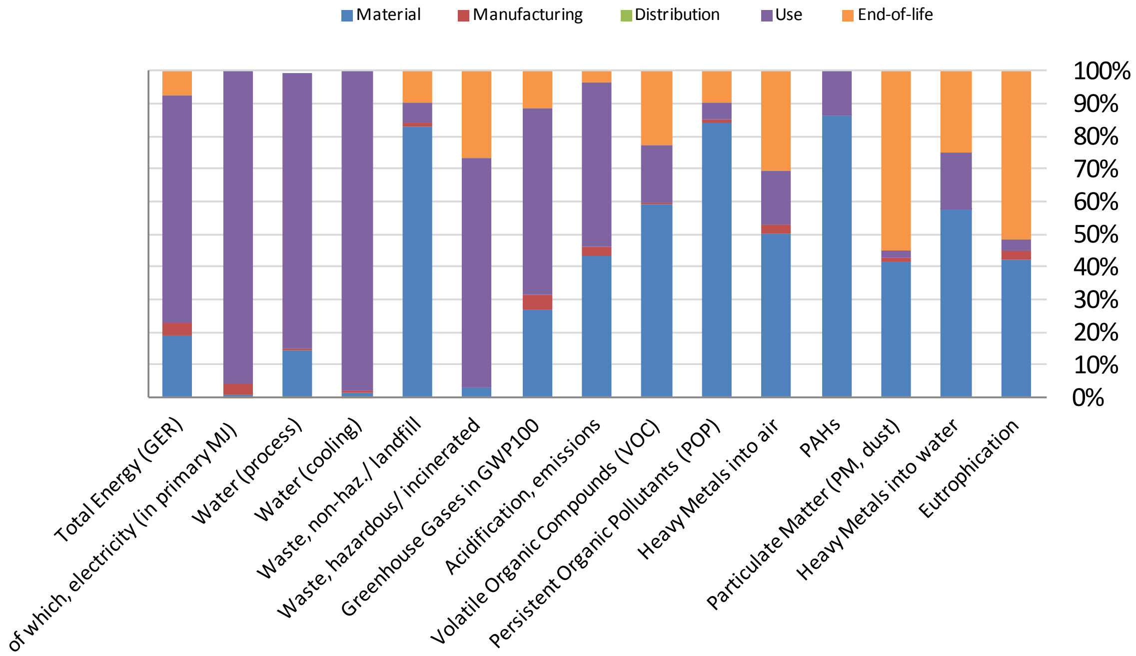


Figure 1-30: Relative significance of each life cycle phase per environmental impact category CS1 RSP 1 to 10

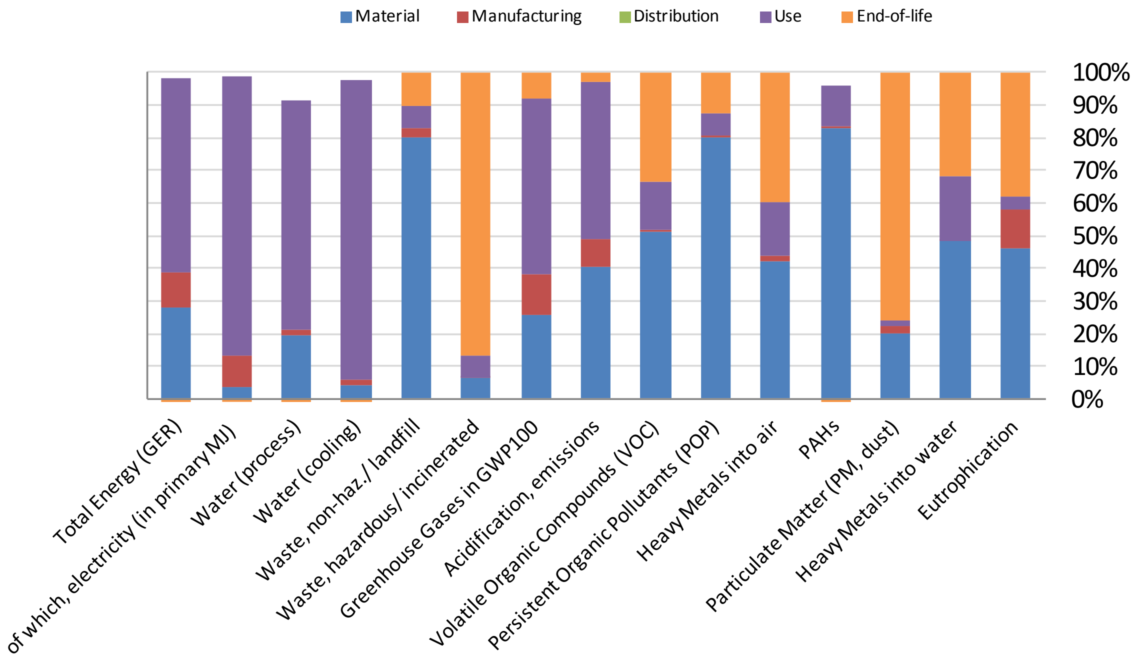


Figure 1-31: Relative significance of each life cycle phase per environmental impact category CS1 V

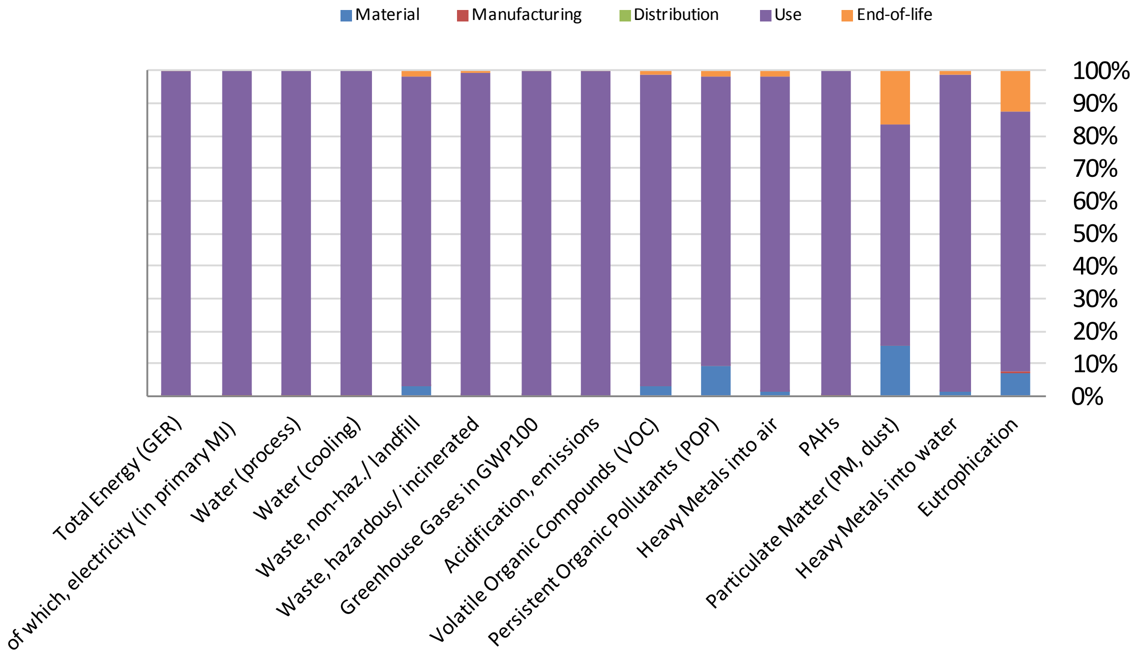


Figure 1-32: Relative significance of each life cycle phase per environmental impact category CDWP RSP 1 to 10

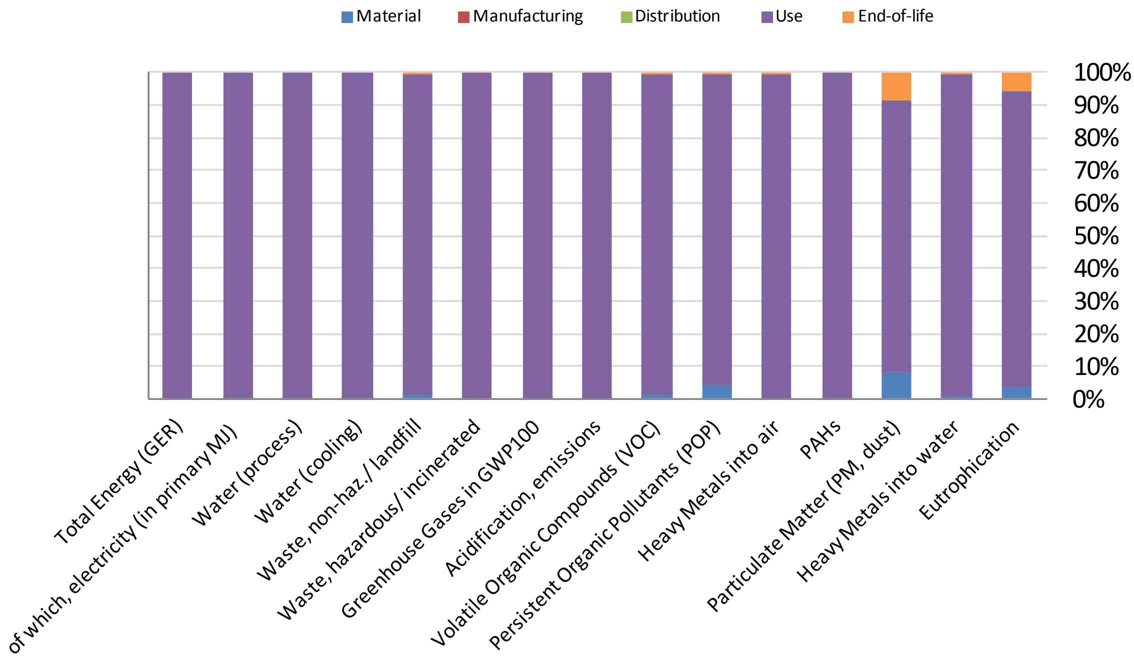


Figure 1-33: Relative significance of each life cycle phase per environmental impact category CDWP RSP 10 to 25

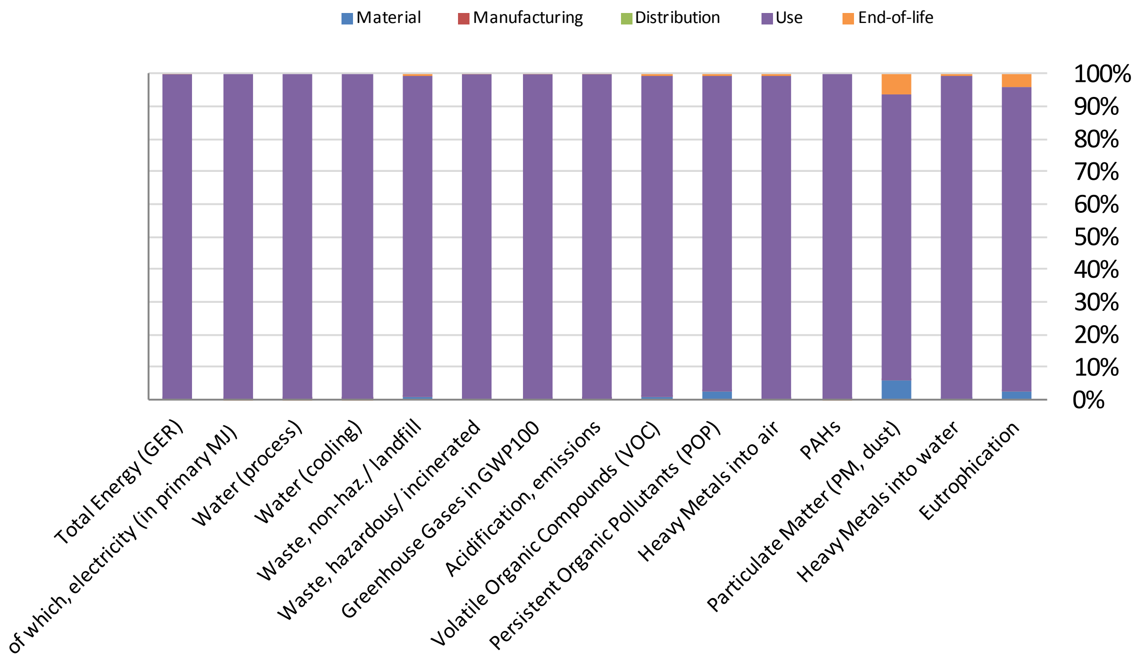


Figure 1-34: Relative significance of each life cycle phase per environmental impact category CDWP RSP 25 to 1000

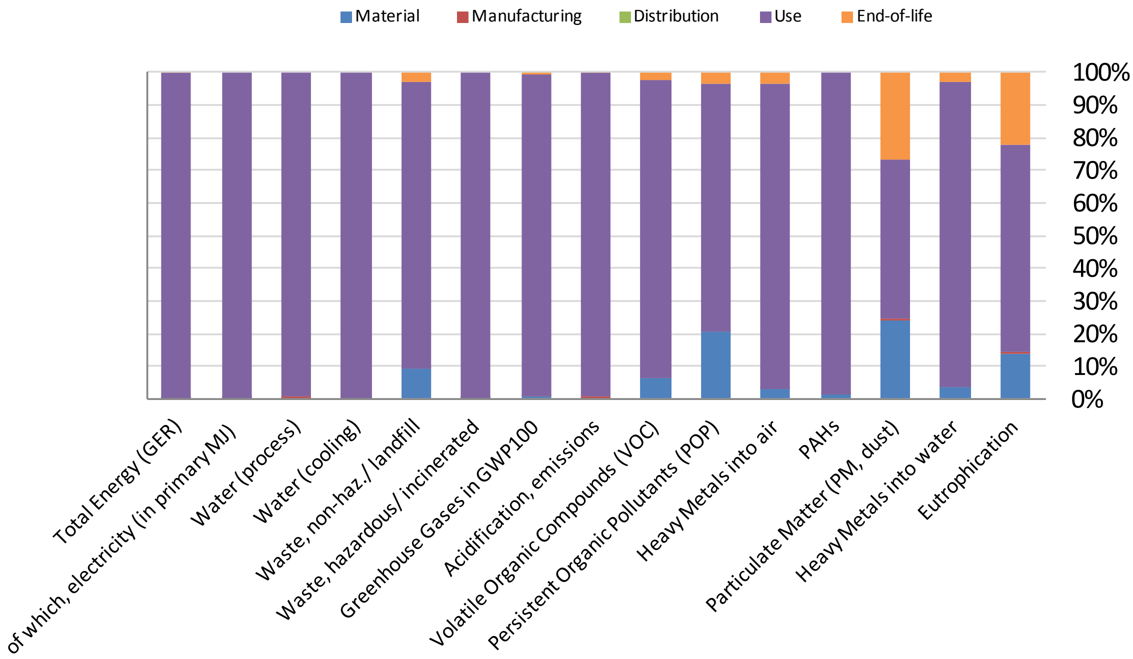


Figure 1-35: Relative significance of each life cycle phase per environmental impact category CDWP MFAP

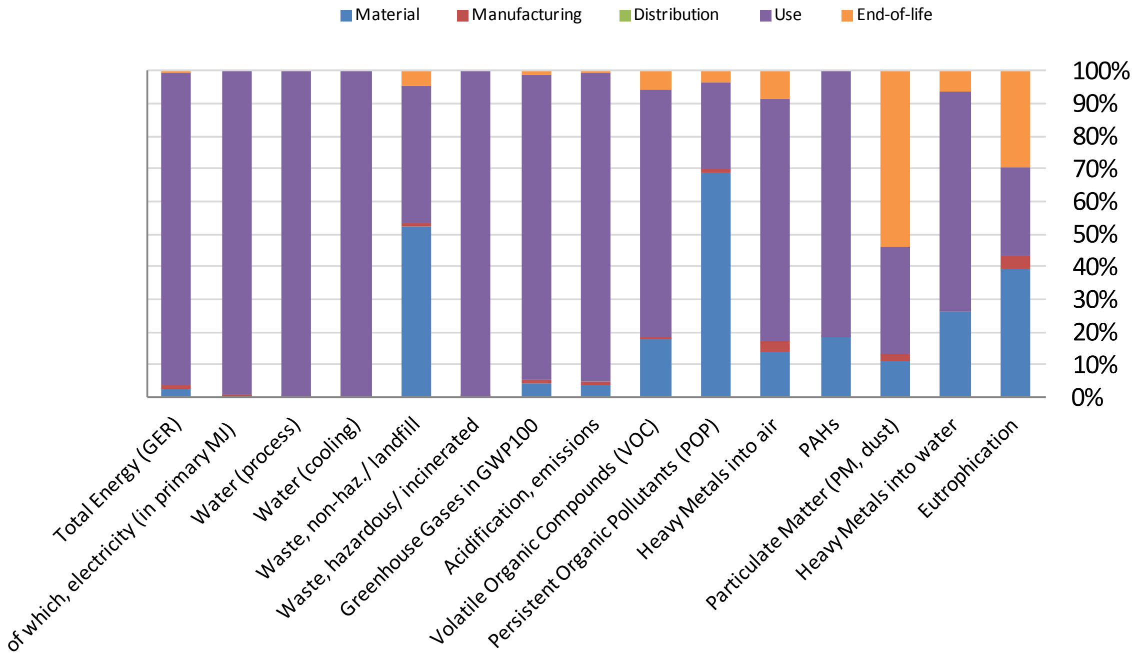


Figure 1-36: Relative significance of each life cycle phase per environmental impact category ASP

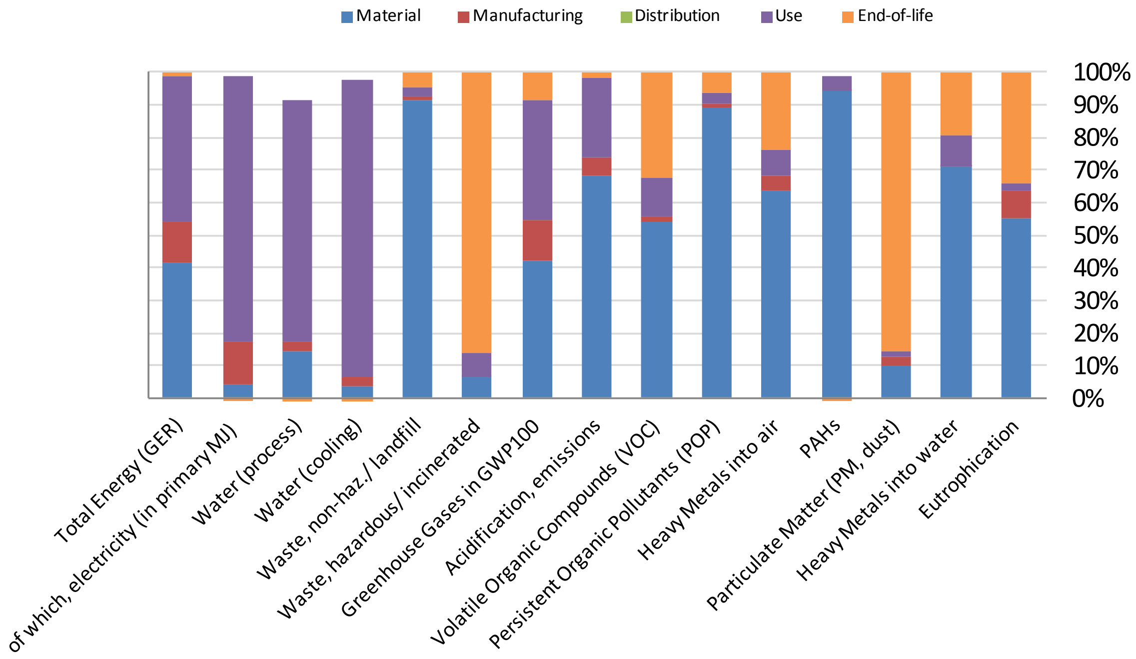


Figure 1-37: Relative significance of each life cycle phase per environmental impact category CSDD

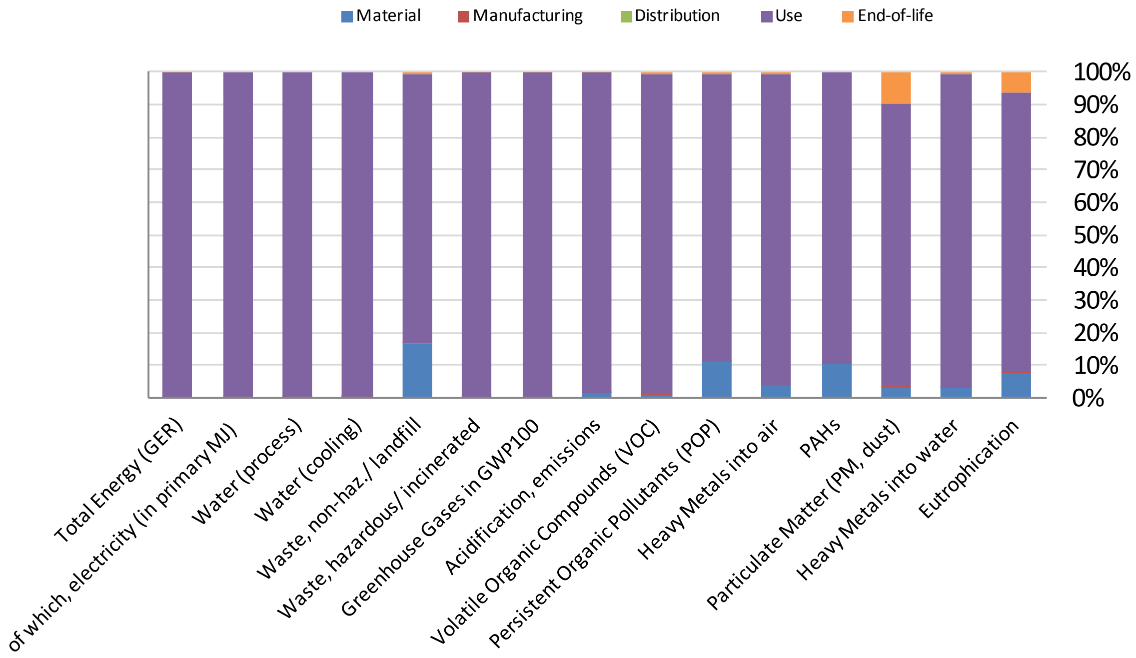


Figure 1-38: Relative significance of each life cycle phase per environmental impact category SDP

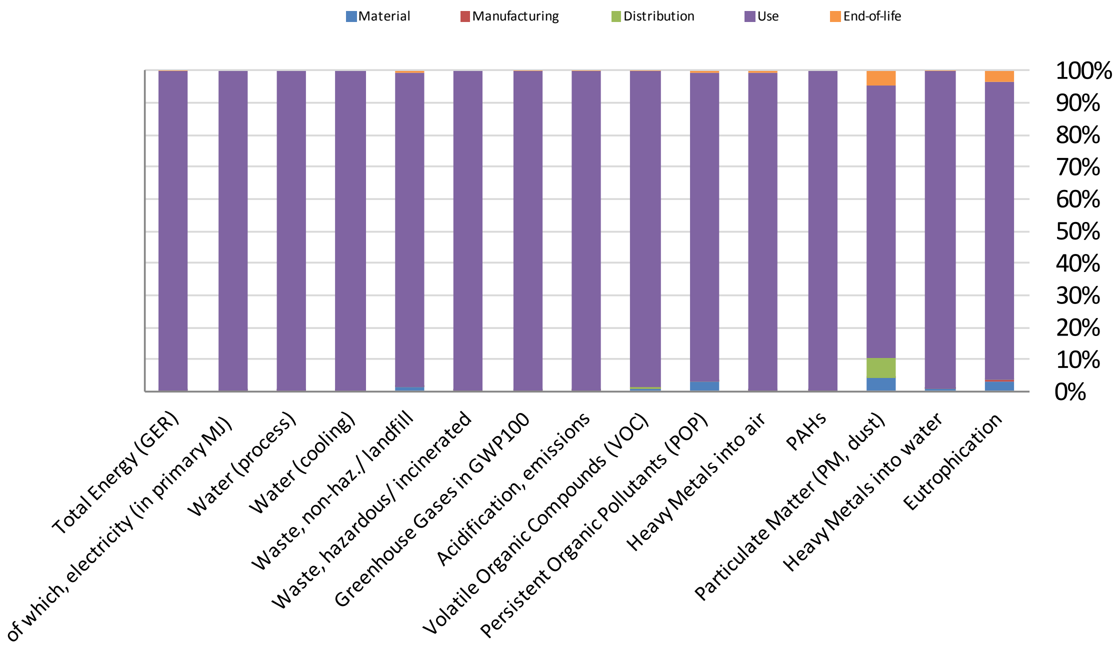


Figure 1-39: Relative significance of each life cycle phase per environmental impact category SP LD

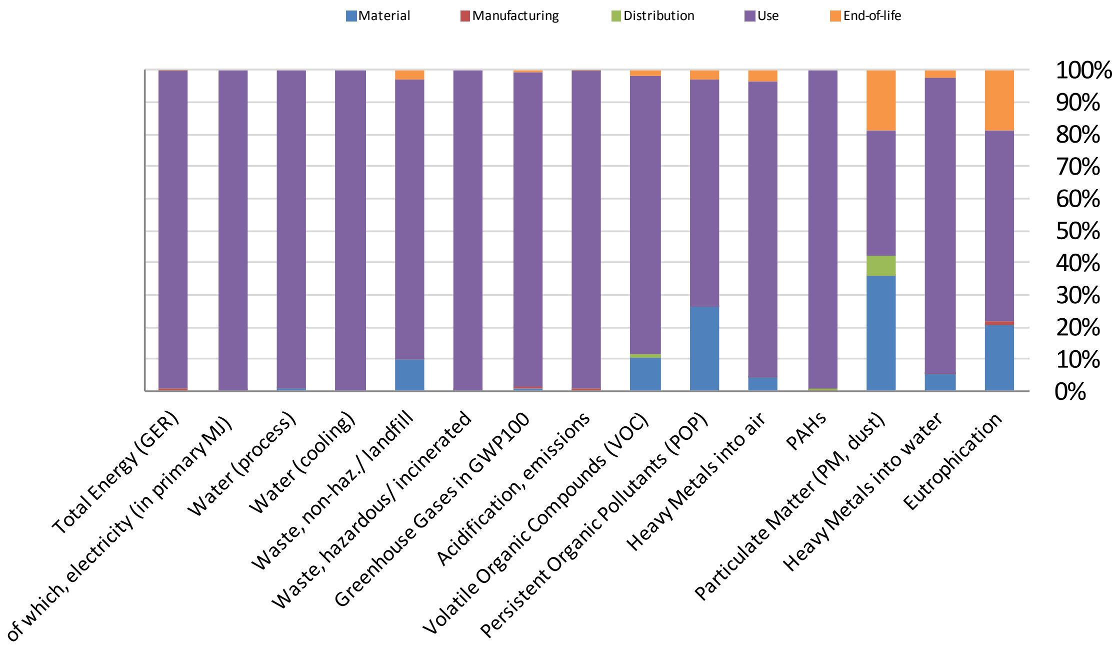


Figure 1-40: Relative significance of each life cycle phase per environmental impact category SP HD

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