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The Recycling Potential of Submersible Sewage Pumps in the EU

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Abstract: Sewage pumps have been among the main electromechanical equipment of the sewage and wastewater management facilities around Europe for over 30 years. Their operational life ranges between 15 and 20 years. Therefore, a significant proportion of that equipment is currently non-operational, and many of them must be disposed of in the forthcoming years. Although the "Waste electrical and electronic equipment" Directive (2012/19/EU) is the main related legislation, sewage pumps are not directly addressed. EcoDesign Legislation is the main legislation applicable on such cases. This work investigates the possibilities of recycling sewage pumps used in wastewater management facilities after their renovation or upgrade. Evaluation results indicate that there is high potential for material recovery and for significant economic benefit. Therefore, the recovery of materials and safe handling of non-operating industrial and possibly hazardous electrical equipment waste, could contribute to the minimization of their impact on the environment.

Keywords: sewage pump recycling; WEEE Directive; materials recovery; industrial waste reduction

1. Introduction

Sewage or wastewater is defined as a community's spent water. Although it mainly consists of pure water (over 98%), it contains waste of almost every form and description, with the remainder being dirt. About 25% of the pollutants in normal domestic sewage are in suspension and 75% in solution. Sewage contains many complex organic and mineral compounds. The organic portion of sewage is biochemically degradable and, as such, is responsible for the offensive characteristics usually associated with sewage. Furthermore, sewage contains large numbers of microorganisms, most of which are bacteria. Fungi, viruses and protozoa are also found in sewage, but to a lesser extent. Although most of the microorganisms are harmless and can be used to our advantage regarding sewage treatment, viruses and some bacteria are pathogenic and may cause diseases [1–3].

In wastewater management facilities, different types of pumps are in use, depending on the processes to be executed (collection of wastewater, transport of wastewater during different treatment stages, sludge handling, etc.). Their classification can be based on the general nature of the liquid to be handled (wastewater or sludge), or on their mode of operation (centrifugal or positive displacement pumps), including the installation type. This work focuses on submersible sewage centrifugal pumps, which are the most common types of pumps used in wastewater management installations [1,3,4]. There are two basic installation types for these pumps, wet-pit and dry–pit installations [2,3]. Each installation type can be divided into two subtypes as Figure 1 shows [5,6]. Table 1 presents the estimated installed stock waste water pumps. Table 1 presents the available official data used by the EU for evaluating the environmental impact, after the application of ecodesign regulations to wastewater pumps. Also, the reference studies executed by the EU are based on the same data. Thus, these data can be considered as the base reference for use in such calculations [7].

Table 1. Estimated installed waste water pumps [7].

Pump Type		**Estimates of Installed Stock in (Units)**
		Year 2011
Centrifugal submersible pump		
	Radial Sewage pumps 1 to 10 kW	1,120,000
	Radial Sewage pumps >10 to 25 kW	120,000
	Radial Sewage pumps >25 to 160 kW	70,000
	Mixed flow & axial pumps	4900
Centrifugal submersible pump-once a day operation		
Shredding, grinding pumps		280,000
Radial Sewage pumps 1 to 10 kW		910,000
Where volute is part of tank		385,000
Centrifugal, submersible domestic drainage pump <40mm passage		12,250,000
Submersible dewatering pumps		280,000
Centrifugal dry well pump		
	Radial Sewage pumps 1 to 10 kW	150,000
	Radial Sewage pumps >10 to 25 kW	37,500
	Radial Sewage pumps >25 to 160 kW	14,000
	Mixed flow & axial pumps	2000
Slurry Pumps		
	Light Duty	60,000
	Heavy Duty	15,000
Total		**15,698,400**

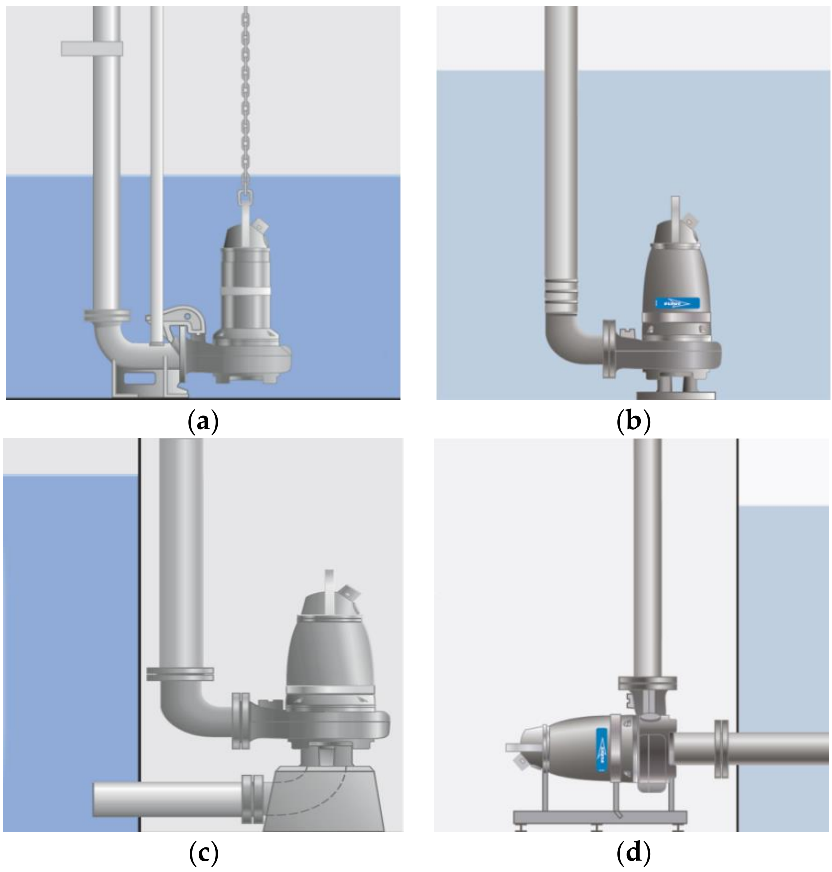

Figure 1. Installation types of sewage dewatering pumps [5]. (**a**) Wet-pit installation; (**b**) Portable installation; (**c**) Vertical dry installation; (**d**) Horizontal dry installation.

In the wet-pit and portable installations (Figure 1a,b), the pumps are submerged in a wet well. The submersible pumps (nonclog, vortex or torque flow and grinder depending on the impeller type) handle wastewater very well and allow for convenient maintenance in wet-pit stations, because of easy pump removal. The wet-pit installation is a semi-permanent submersible installation. In that setting, the pump is installed with twin guide bars on a discharge connection. The portable installation is also a semi-permanent type of installation. This is a transportable version with a pipe or hose connection [2,3,6–11].

Dry-pit installations consist of two separate wells: the wet well and the dry well. Wastewater is stored in the wet well, which is connected to the dry well by horizontal suction piping. At dry-pit stations, centrifugal pumps (nonclog, vortex or torque flow, cutter or grinder depending on the impeller type) are usually used. The main advantage of the dry-pit station is the availability of a dry area for personnel to perform routine and emergency pump and pipe maintenance. This type of installation consists of vertically and horizontally placed pumps as Figure 1c,d shows. The centrifugal wastewater pumps (dry or wet well) can handle sewage or primary sludge with up to 2% (5% the newest types of open impellers) solids, while positive displacement pumps, mainly those of progressive cavity and Archimedes' screw, can handle sludge with more than 2% solids as well as sludge and sewage [2,3,6–11].

Sewage pumps play an important role in wastewater collection and treatment because they have been among the main electromechanical equipment of these facilities around Europe for over 30 years [1–4,6–9,12]. Their operational life is around 15–20 years and thus a significant number of them are non-functional any more [2,7–10,13–16]. The need for replacement of these pumps has increased the number of pumps that must be disposed of in the forthcoming years [17]. The WEEE Directive (2012/19/EU) for "Waste of electrical and electronic equipment" is the main relevant legislation. Nevertheless, sewage pumps seem not to be unambiguously included [18]. The recent EcoDesign and WEEE Directives describe their end of life [7,18,19].

This work investigates the possibilities of recycling sewage pumps based on current EU policies for the installed quantities. It is an effort to present, evaluate, quantify and monetize the valuable materials that can be recovered after the end of life of sewage pumps. This effort could support the development of new approaches, not only in the EU, where the study is conducted, but globally, in order to promote standardized methods for sewage pump recycling, leading to higher materials recovery, increasing economic benefits, and protecting the environment and natural resources. Evaluation results are in line with the suggestions mentioned previously.

2. Wastewater Management and Sewage Pumps

In most cases, sewage/wastewater management systems are divided into two basic and different (in terms of operation) parts: collection systems and treatment systems. Both require pumps and pumping stations. Collection systems consist of a network of sewers that collect and convey sewage from individual residences, commercial establishments, and industrial plants to one or more points of disposal. Pumping stations are often needed at various points in the system to pump from one drainage area to another or to the treatment plant. The judicious location of pumping stations enhances the economy of the overall design by eliminating the need for extremely deep sewers. Often gravitational collecting systems exist where the landscape of the area permits it, and further reduce the operational costs [1–5,8–11].

A treatment plant uses a series of treatment stages to clean up the water so that it may be safely released to the environment (e.g., lake, river or stream, sea, land, etc.) or reused (e.g., agricultural and landscape irrigation, industrial procedures, non-potable urban uses, etc.). Treatment usually consists of two major steps: primary and secondary, along with a process for disposing of solids (sludge) that are removed during the two previous steps. Primary treatment can be further divided into "preliminary treatment" where by screening, grit and coarse sand removal are executed to separate solids, and "primary treatment" in which settling tanks for finer solids and skimming of fat, oil and grease separation are used. Primary treatment removes a significant portion of the suspended solids and organic matter from the wastewater and is typically accomplished by chemicals for disinfection processes. During secondary treatment, wastewater still contains solid materials either floating on the surface or dissolved in the water, or both. Under normal conditions, these substances would be food for organisms such as fungi, algae, and bacteria that live in a stream or lake. Secondary treatment is basically a biological process. Basic techniques such as trickling filters and activated sludge are used, mainly targeting the aerobic biodegradation of dissolved and colloidal organic matter. Air is supplied to stimulate the growth of bacteria and other organisms to consume most of the waste materials. In this way, the biodegradable organic matter (in solution or suspension), suspended solids and nutrients (nitrogen, phosphorus, or both) are removed from the wastewater. Excess solids, which may include biofilms of the bacteria performing the treatment itself, are then removed in secondary settling tanks, together with most other remaining suspended solids. The nitrogen and phosphorus removal from the organic matter can be enhanced by tertiary treatment if required. Then, the final step in the secondary treatment is a disinfection process (typically chlorination, UV or another similar method) to kill any remaining harmful bacteria and microorganisms. Then, the clean water produced from secondary treatment is released to the environment or reused internally in the wastewater plant for irrigation or other purposes. Today, there are listed approximately 50,000 urban wastewater treatment plants in EU, with around 90% of them providing at least second stage of treatment including the aforementioned disinfection process, according to European Environmental Agency [1–3,17,20,21].

Sewage pumps play an important role in all these processes as they are used both in collection and treatment. They are characterized as one of the most critical assets of wastewater systems, and their failure analysis and prognosis are critical to the correct operation of the facilities and the required high availability of the equipment. Submersible wastewater pumps are vertical, direct-coupled, extra heavy duty units, which operate under water and have a solid-handling, non-clog capability. While single pumps are often installed, most applications require two pumps (called a "duplex") in order to ensure continued operation if one pump fails, or to minimize the deterioration of one pump with the use of the second pump, and to provide extra capacity for extraordinary loads. This is a typical approach for sewage asset management to increase both the availability of the facility and number of equipment. Typical sewage pumps can be seen in Figure 2, while Figure 3 shows the typical installation of a pump in a sewage pit [2–11,17,22–25].

(**a**) (**b**)

Figure 2. Sewage pumps (**a**) and a typical section (**b**) [10,23].

Figure 3. Submersible sewage pump's installation through rail guiding system [23].

The most common sewage pump is the submersible type. It consists of the motor-pump unit along with automatic electrical controls. Controls can be simple or complex, depending on the application. The latter may consist of an entire factory-packaged station enclosed in a steel or fiberglass tank, ready for installation and pipe-electrical hook-up. Submersible sewage pumps are being increasingly used in applications where self-priming, dry-pit, straight centrifugal, vertical extended-shaft, and pneumatic ejector pumps were once the dominant types [2,3,6–11,22,23].

Like any pumps, submersibles pumps can also be adapted to the capacity requirements of the particular installation. Typically, dynamic heads range from 5 to 100 m. Flow rates range from 2 to 600 m^3/h and larger pumps produce 600 m^3/h or more. The pump-motor unit can be adapted to installation needs. Many large pumps can be used in conjunction with a variable speed drive (VSD) to further fit the performance to the application [2,3,6–11].

3. WEEE Directive and Sewage Pumps Recycling in the EU

During the 1970s, the European Economic Community (EEC), and later the EU, began to take action for the management of particular categories of waste. The 2012/19/EU Directive focuses on Waste Electrical and Electronic Equipment, which falls into the categories of voltage supply range up to 1000 V AC and 1500 V DC. The purpose of this Directive is firstly to prevent waste of electrical and electronic equipment (WEEE), secondly to reuse, recycle and recover such waste in order to reduce waste disposal, and thirdly to improve the environmental performance of all operators involved in the life cycle of this equipment [17–19].

According to manufacturers' datasheets, the effective or satisfactory operational life time of sewage pumps in wastewater management facilities is estimated to be 15 years. When their operation is no longer satisfactory, they are replaced [5,6,8–11,14,22,23]. In this work, centrifugal submersible waste water pumps are primarily categorized by their power. The categorization can be conducted according to the following ranges:

- ➢ Up to 10 kW
- ➢ Between 10 kW and 25 kW
- ➢ 25 kW to 160 kW

Each category has been divided into subcategories according to the basic pump manufacture materials. These subcategories include pumps primarily manufactured by cast iron or aluminium.

Tables 2 and 3 present the typical composition of commonly used centrifugal sewage pumps, primarily manufactured of cast iron and aluminium, respectively. At the end of their life, these pumps can be recycled and a certain number of their parts can be reused. In this paper, their quantities were calculated based on data available from manufacturers' websites and relevant literature [3,6,8–11,19,24]. Especially for pumps in the range of 25 kW to 160 kW, there are no data for aluminium centrifugal submersible sewage pumps. For this reason, this type of pump has not been included in this work. The WEEE Directive (2012/19/EU) for "Waste of electrical and electronic equipment" is the main relevant legislation, even though it concerns electrical and electronic equipment and does not explicitly include pumps or sewage pumps (Category 6: Electrical and electronic tools, Equipment for spraying, spreading, dispersing or other treatment of liquid or gaseous substances by other means) [17,18,24].

Table 2. Declaration of contents, with the quantity of each material specified as a proportion of the total pump weight in kg per functional unit for typical submersible sewage pumps up to 160 kW primarily constructed of cast iron [3,7–11,17,23,25].

P < 10 kW			**10 kW < P < 25 kW**			**25 kW < P < 160 kW**		
Material	kg/kW	S_D [2] (kg/kW)	Material	Kg/kW	S_D [2] (kg/kW)	Material	Kg/kW	S_D [2] (kg/kW)
Cast Iron	60.40	47.51	Cast Iron	16.75	1.41	Casted Iron	15.90	1.27
Steel	10.47	6.98	Steel	4.38	0.44	Steel	4.90	0.19
Aluminium	1.88	1.15	Aluminium	0.79	0.38	Aluminium	0.93	0.37
Copper	3.34	2.51	Copper	0.99	0.31	Copper	0.96	0.22
Stainless steel	2.28	2.66	Stainless steel	0.83	0.19	Stainless Steel	1.15	0.10
Chloroprene rubber	3.02	3.69	Chloroprene rubber	0.48	0.15	Chloroprene Rubber	0.31	0.02
Oil	0.95	0.74	Other	0.70	0.07	Oil	0.44	0.01
Brass	0.17	0.17				Bronze	0.02	0.01
Other	1.49	0.89				Nitrile rubber	0.00	0.00
						WCCR [1]	0.03	0.00
						Other	0.23	0.06
Total	84.00		Total	24.92		Total	24.87	

[1] : WCCR abbreviation of Wolfram Carbide Corrosion-Resistant; [2] : S_D = Standard Deviation.

Table 3. Declaration of contents, with the quantity of each material specified as a proportion of the total pump weight in kg per functional unit for typical submersible sewage pumps up to 25 kW primarily constructed of aluminium or iron [3,6,8–11,23,25].

P < 10 kW			**10 kW < P < 25 kW**		
Material	kg/kW	S_D [2] (kg/kW)	Material	Kg/kW	S_D [2] (kg/kW)
Aluminium	10.76	4.91	Aluminium	3.57	0.08
Sheet steel	6.17	2.73	Sheet steel	2.68	0.40
Stainless steel	3.11	1.68	Stainless steel	1.18	0.07
Chloroprene rubber	2.58	1.84	Copper	1.13	0.17
Copper	2.28	1.32	White Cast Iron	0.91	0.01
White Cast Iron	2.21	0.65	Chloroprene rubber	0.89	0.24
Nitrile rubber	1.04	0.75	Nitrile rubber	0.28	0.01
Oil	0.86	0.70	Oil	0.14	0.05
Engineering Steel	0.48	0.58	Engineering Steel	0.13	0.02
WCCR [1]	0.09	0.07	Harts	0.04	0.01
Brass	0.03	0.03	Brass	0.02	0.00
other	0.74	0.40	WCCR [1]	0.02	0.00
			other	1.09	1.06
Total	30.35		Total	12.07	

[1] : WCCR abbreviation of Wolfram Carbide Corrosion-Resistant; [2] : S_D = Standard Deviation.

Although pumps consist of metals including copper, aluminium and steel, in Europe only small-scale actions for their recycling have been implemented, all of them included in general programs following the implementation of the WEEE Directive in the EU Member States [17,18,24]. The operation of facilities in which this type of equipment is installed, such as wastewater or sewage tanks, etc., results in a heavily polluted environment [1,3,26,27]. Moreover, severe health hazard conditions exist and the collection, as well as the end-of-life treatment, are similar to the ones used for hazardous industrial waste [26,27].

Another important consideration is that the life expectancy of sewage pumps (around 15 years, even if their maintenance, repair procedures and operation during these years follow the manufacturer directives, precautions and limitations) could be extended, with the ultimate result that a relatively small number of pumps will reach their end of life [3,5–17,23]. Many of these facilities have been in operation for more than 15 years in Greece and around the EU, resulting in an increased number of sewage pumps becoming non–functional. The previous statement in conjunction with the need for renovation of a significant number of wastewater treatment plants leads to the conclusion that a significant number of pumps will be replaced. The number of these pumps is expected to increase further in the following years [3,6–11,17,22].

The storage and transport procedures of sewage pumps before installation is typical and involves wooden enclosures protecting the pumps during transportation, depending on the quantities, trucks, trains and container ships that are usually used. For the end-of-life treatment, the typical procedure for transportation and storage depends on the operator of the waste water treatment or the maintenance company executing the replacement. Typically, when the pump is removed from the operation site, it is washed using typical water from the installation in order to remove any sludge or dirt before storing it or transporting it away from the infrastructure. Afterwards, the pump is stored temporarily somewhere inside the infrastructure or moved to a scrap facility, either by the maintenance company, or by the owner. In the most critical cases, the pumps are installed inside a separated container that can hold any substance not removed during washing (if this actually happened). Apart from cleaning with water, no other action is taken in many cases, except in the case of Scandinavian and Northern EU countries [1,6,8–11,17,18,24,25].

The recycling procedures vary according to the country in which they are applied. In all cases, the basic materials that are recovered from the pump are aluminium, chromium, copper, cast iron, steel, brass, nickel, zinc and plastics. This presupposes that the materials are handed in a suitable recycling plant. During the recovery process in Scandinavian and Northern EU countries (e.g., Germany, Belgium, Netherlands), the pump is first sent for initial clearance, in which small electronic parts are removed, and then for fragmentation, in which it is broken up. Typical equipment and methods that are used afterwards include magnets, air currents, water baths and manual sorting for separating the various materials. According to the existing literature and Life Cycle Analysis (LCA) published for the case of the Flygt company in Sweden and Northern EU countries, 90% (by weight) of pump materials are assumed to be recycled, while only 10% (by weight) go to landfill during the end-of-life treatment [3,6,8–11,18,19,24,25].

If the pumps are not treated in a suitable facility, only the metals are usually recovered and with very low rates considering the official processes. In these cases the same procedure is used, but the materials recovery usually does not include magnets, air currents, water baths, etc., but only manual sorting. Thus, the expected recovered materials cannot be as high as 90%, while not all safety issues are addressed in the process. Here it must be noted that all products that were manufactured and distributed in the EU internal market from 2003 and onwards comply with the European directive RoHS (Directive 2002/95/EC). The previous note means that the products do not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) at levels exceeding the maximum concentration values [3,6,8–11,15,18,19,24].

4. Sewage Pump Recycling Potential and Benefits

Sewage pumps play an important role in wastewater management procedure, and in many facilities they are the main electromechanical equipment. Since the early 1950s, they have been in use around Europe, since the middle of the same decade in the USA, and for around 40 years in Greece [1,3,7,17,20,25]. After the end of their operational life (around 15–20 years based on datasheets, existing literature and experience), these pumps should be disposed of as industrial hazardous waste and must not be sent to landfill (including controlled landfills). The pumps, as presented in Tables 2 and 3, contain materials such as machine oil, zinc, Wolfram Carbide Corrosion-Resistant (WCCR), etc., which are considered to be hazardous [6,8–11,24,27]. Therefore, the end-of life-treatment should be applied in appropriate facilities with significant care. Also, considering that these pumps are in use for sewage and wastewater, they are exposed to a significant number of pathogenic microorganisms and bacteria, facts that support the previous assumptions [1–3,17,22,25,27].

The high metal content of pumps leads to them being sold for scrap at the end of their operational life. However, wastewater pumps may need cleaning to remove pathogens prior to being moved to the scrap yard. The Bill of Materials (BOMs) for the pumps reveals that the proportion of non-metallic components by weight is typically less than 1% for larger pumps. Pumps are heavy items and have both a positive scrap value and unavoidable disposal cost. Therefore, it is to a company's advantage to send old pumps for scrap. In practice, it is normal for pumps to be sent for scrap. It is assumed that all of the metallic and none of the non-metallic components are recycled. The percentage (by weight) of the product destined to landfill is estimated to be 8%. The lifetime of a wastewater pump will rarely be dictated by obsolescence. Usually the pump will be replaced when it fails, due to a broken component or an unacceptable drop in output. It should be noted that 100% separation of copper, iron and aluminium metal parts is not achieved during scrap treatment, leading to fractions of lower recycling quality due to remaining impurities [5,6,12,14,24,25].

Typically, small- to medium-scale wastewater management facilities (collection and treatment), which use sewage pumps, are rated from a few kW (typical 10–40 kW installed per small-scale facility, 2–5 kW per domestic facility) to several kW in medium-scale (typical 80–300 kW for 10,000–20,000 persons) and large-scale facilities (up to MW scale, for facilities over 250,000 persons) [1,6–11,24,25]. Based on the above figures, a significant percentage of the installed sewage pumps is removed and replaced by new equipment during the renovation or upgrade of a wastewater management facility. Thus, several pumps must be disposed of in an environmentally friendly manner. Unfortunately, in many cases a significant number of them finally end up in landfill, with obvious environmental impacts based on the aforementioned analysis. At this point, it must be noted that several hundred thousand facilities are in operation in EU Member States alone. Thus, the number of non-operating sewage pumps should be considered to be notably high [6–11,23,25–28].

Tables 2 and 3 present the declaration of contents, with the quantity of the main recyclable materials specified as a proportion of the total pump weight in kg/kW per functional unit, for typical submersible sewage pumps in the power range up to 160kW. Based on the fact that sewage pumps are metallic electrical equipment and considering the installed power per sewage pump, as shown in Table 2, the recyclable materials per pump are quite high, and could result in high values of resources saved per sewage pump [3,6–11,24,25]. At the same time, the hazardous components should be separated and treated properly [26–28].

The calculations were based on the data used by Trigo A. P., Tinetti B., Falkner H., Jugdoyal K., Pahal S., Mudgal in the official preparatory study for developing and adopting an ecodesign regulation in the EU following the 2009/125/EU Directive, and the respected ecodesign regulations for all energy-related products in the EU domestic market. The years 2005 and 2011 were chosen as reference years for the technologies used and applied in the EU [7,25]. Furthermore, the expected end of life for pumps installed during 2005 is going to be reached in between 2020 to 2025 (based on the operational lifetime of 15 to 20 years), which is just two years away for many of them. So the expected quantities could be an opportunity and a challenge at the same time in terms of global efforts to maximize the recovery of recyclables from electrical and electronic equipment and minimize landfilled quantities. The year 2011 is the reference year for the EU ecodesign preparatory study on wastewater pumps as it covers the most recent available market data [7,25].

Table 4 shows the quantities of replaced pumps for the years 2005 and 2011 according to the Europump [7]. Table 5 shows the corresponding recycled materials according to the replaced submersible wastewater pumps for the range up to 10 kW. Table 6 shows the corresponding recycled materials according to the replaced submersible wastewater pumps in the range of 10 kW to 25 kW. Table 7 shows the corresponding recycled materials according to the replaced submersible wastewater pumps in the range of 25 kW to 160 kW. All these numbers are estimations according to the environmental product declarations (EPDs) used for the current work. The quantities for every power range are a product of the replaced pumps, the averages for every category and a typical pump for every category as well. Additionally, it is assumed that the replaced cast iron pumps are 80% of total replacements and the other 20% refers to aluminium pumps. In particular, it is assumed that all the replaced pumps in the range of 25 kW to 160 kW are mainly constructed of cast iron. These assumptions are justified by the high cost of aluminium frame pumps. These recycling estimations are based on the Swedish market, as there is no information on the rest of Europe whatsoever.

Table 4. Numbers of estimated sales and replacements of waste water pumps in Europe for the years 2005 and 2011 [7].

Pump Type		**Estimates of Sales in (Units)**		**Estimates of Replacements in (Units)**	
		2005	**2011**	**2005**	**2011**
Centrifugal submersible pump					
	Radial Sewage pumps 1 to 10 kW	129,206	160,000	90,444	112,000
	Radial Sewage pumps >10 to 25 kW	9690	12,000	6783	8400
	Radial Sewage pumps >25 to 160 kW	4038	5000	2827	3500
	Mixed flow & axial pumps	565	700	396	490
Centrifugal submersible pump-once a day operation					
Shredding. grinding pumps		40,377	50,000	28,264	35,000
Radial Sewage pumps 1 to 10 kW		104,980	130,000	73,486	91,000
Where volute is part of tank		44,415	55,000	31,091	38,500
Centrifugal. submersible domestic drainage pump <40mm passage		1,211,310	1,500,000	847,917	1,050,000
Submersible dewatering pumps		32,302	40,000	22,611	28,000
Centrifugal dry well pump					
	Radial Sewage pumps 1 to 10 kW	16,151	20,000	11,306	14,000
	Radial Sewage pumps >10 to 25 kW	4038	5000	2827	3500
	Radial Sewage pumps >25 to 160 kW	808	1000	566	700
	Mixed flow & axial pumps	81	100	57	70
Slurry Pumps					
	Light Duty	1211	1500	848	1050
	Heavy Duty	242	300	169	210
Total		**1,599,413**	**1,980,600**	**1,119,589**	**1,386,420**

Table 5. Estimated recyclable materials and profit for the submersible waste water pumps up to 10 kW for the years 2005 and 2011 [7,24,25,29].

Up to 10 kw Cast Iron Pumps					Up to 10 kw Aluminium Pumps				
	2005		2011			2005		2011	
Material	**(Kg)**	**($US)**	**(Kg)**	**($US)**	**Material**	**(Kg)**	**($US)**	**(Kg)**	**($US)**
Cast Iron	7,298,304	1,094,746	9,037,773	1,355,666	**Aluminium**	716,333	429,800	887,051	532,230
Steel	1,265,603	202,496	1,567,246	250,759	**Sheet steel**	410,921	41,092	508,853	50,885
Aluminium	226,682	136,009	280,710	168,426	**Stainless steel**	206,825	237,849	256,116	294,534
Copper	403,582	2,098,625	499,771	2,598,809	**Chloroprene rubber**	171,611	-	212,510	-
Stainless steel	275,861	317,241	341,610	392,851	**Copper**	151,641	788,532	187,780	976,457
Chloroprene rubber	365,036	-	452,038	-	**White Cast Iron**	147,314	22,097	182,422	27,363
Oil	114,428	-	141,702	-	**Nitrile rubber**	68,964	-	85,400	-
Brass	21,024	70,433	26,036	87,220	**Oil**	57,448	-	71,139	-
Other	1,796,780	-	222,503	-	**Engineering Steel**	32,152	5787	39,815	7167
					WCCR [1]	5858	-	7254	-
					Brass	1997	6690	2473	8284
					other	49,060	-	60,752	-
Total	10,150,201	3,919,550	12,569,388	4,853,732		2,020,125	1,531,848	2,501,564	1,896,920

[1] : WCCR abbreviation of Wolfram Carbide Corrosion-Resistant.

Table 6. Estimated recyclable materials and profit for the submersible waste water pumps in the range 10 kW up to 25 kW for the years 2005 and 2011 [7,24,25,29].

10 kW to 25 kW Cast Iron Pumps					10 kW to 25 kW Aluminium Pumps				
	2005		2011			2005		2011	
Material	**(Kg)**	**($US)**	**(Kg)**	**($US)**	**Material**	**(Kg)**	**($US)**	**(Kg)**	**($US)**
Cast Iron	1,137,886	170,683	1,409,251	211,388	**Aluminium**	56,340	33,804	69,751	41,850
Steel	297,549	47,608	368,509	58,961	**Sheet steel**	42,228	4223	52,279	5228
Aluminium	53,871	32,323	66,719	40,031	**Stainless steel**	18,670	21,470	23,114	26,581
Copper	67,322	350,075	83,377	433,561	**Copper**	17,834	92,737	22,079	114,810
Stainless steel	56,249	64,686	69,663	80,113	**White Cast Iron**	14,333	74,534	17,745	92,275
Chloroprene rubber	32,676	-	40,469	-	**Chloroprene rubber**	13,987	2098	17,316	2597
Other	47,553	-	58,894	-	**Nitrile rubber**	4431	-	5486	-
					Oil	2255	-	2792	-
					Engineering Steel	1971	355	2440	439
					Harts	631	-	781	-
					Brass	237	792	293	981
					WCCR [1]	268	-	332	-
Total	1,693,107	665,375	2,096,881	824,054		173,184	230,013	214,406	284,762

[1] : WCCR abbreviation of Wolfram Carbide Corrosion-Resistant.

Table 7. Estimated recyclable materials and profit for the submersible waste water pumps in the range 25 kW up to 160 kW for the years 2005 and 2011 [7,24,25,29].

25 kW to 160 kW Cast Iron Pumps				
	2005		2011	
Material	**(Kg)**	**($US)**	**(Kg)**	**($US)**
Cast Iron	1,423,544	213,532	1,762,436	264,365
Steel	438,255	70,121	542,586	86,814
Aluminium	82,951	49,770	102,698	61,619
Copper	85,681	445,543	106,079	551,609
Stainless Steel	102,961	118,405	127,472	146,593
Chloroprene Rubber	27,799	-	34,417	-
Oil	39,215		48,550	
Bronze	2059	-	2549	-
Nitrile rubber	269	-	333	-
WCCR [1]	2999	-	3713	-
Other	20,816	-	25,771	-
Total	2,226,548	897,370	2,756,605	1,111,000

[1] : WCCR abbreviation of Wolfram Carbide Corrosion-Resistant.

The calculated material recovered values are quite high. The recovered metals are of utmost importance as they present significant purity and can be easily recycled in metal product industries. Copper in the motors of the pump and aluminium are of high purity (e.g., Cu conductors present purity of 99.9%) and have significant interest as pure raw materials in aluminium and copper industries. The cast iron can also be used again to feed to iron smelters and reduce the need for mining new quantities, and the same applies for steel. These materials can be easily returned to production lines as raw recovered materials and reduce the environmental impact of new ones, thus enhancing their environmental "green" characteristics. It contributes to a circular economy when all the valuable materials already extracted from the earth are recycled again and again, significantly reducing the need for further mining. It must also be pointed out that electronic parts accompanying the pumps are removed prior to metals (ferrous and non-ferrous) as they are small in size, and in many cases are not treated properly [7,24,25]. The monetary values of the recovered materials were based on scrap prices from November 2017, which are considered to be close to the average values for the entire year [29]. Even though the monetary equivalent is not especially high, it is not negligible due to the fact that the recovered materials have a significant purity, which can result in additional economic benefits resulting from the lower cost for their reuse and the lower environmental impact [17].

5. Conclusions

In this paper the recycling possibilities for sewage pumps used in wastewater management facilities have been presented. These pumps contain materials such as machine oil, zinc, WCCR, etc., which are considered to be hazardous. These materials must not be disposed of in landfill, but instead should be treated separately, applying the appropriate procedures. Although the WEEE Directive is applicable to such treatment, it does not include them, even though their main composition includes valuable metals. The evaluation presented in this paper indicates the high recycling potential of sewage pumps during the refurbishing or upgrade of wastewater treatment facilities, which may result in significant environmental and economic benefits. Furthermore, these benefits can be even higher if the hazardous materials included in these pumps are treated properly during the materials recovery procedure.

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