Municipal sewage sludge - a problem that must be solved

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Abstract

Sewage sludge production is an international problem with several environmental and public health impacts. Portugal has more than 2,000 wastewater treatment plants (WWTP) and around 1,700 collective septic tanks due to the European Directive 91/271/EEC. The sludge management remains a relevant and challenging issue because data production sludge is scarce, some even is estimated and presented heterogeneously. The present study aims to contribute to characterise the sludge production in Portugal and then propose mitigating measures in production and suitable disposal. Extensive literature reviews were made on data published from WWTP and surveys were sent to the management entities. In Portugal the number of management entities (ME) is around 280, so it was necessary to select the most representative in terms of served population, wastewater treated and sludge production. Twenty WWTP were analysed in detailed from six ME: SIMTEJO, SIMDOURO, SIMLIS, SIMRIA, Águas do Algarve and Águas do Sado, treating in 2012, a total of 155,946,480 m^3 corresponding 2,165,905 pe and sludge production of 136,243 ton. The results show that each ME has same record of the sludge amount, but the general situation is not well known due to the high number of different ME and the sludge route (collection, storage, treatment, transport and final disposal). The mainly sludge disposals are agriculture application and landfill. The annual sludge production in Portugal is around 416,457 ton (DM).

Key words: wastewater, sewage sludge, waste, sludge composition

Introduction

To control and minimize water pollution is necessary to improve wastewater treatment (WWT). In the last years, there has been a significant increase in the municipal WWT, which is a response to EU (Directive 91/271/EEC, Directive 98/15/CE and Regulation (EC) 1882/2003) and national legal requirements (Decree-Law 152/97, Decree-Law 348/98, Decree-Law 149/2004 and Decree-Law 198/2008) in order to protect water as a natural finite resource (APA 2015). The WWT produces different by-products, like screenings, grit and sludge's. With the increasing WWT, the sludge amounts are estimate to increase in next years and will be a major challenger for the European Member States (Kelessidis & Stasinakis 2012) mainly in urban areas.

The sustainable development concept is included in the waste management European legislation, which has the following management hierarchy, prevention, re-use, recycling, incineration (with energy recovery) and landfill.

The sludge production from wastewater treatment plant (WWTP) is a key factor in management this kind of infrastructure, because of the composition and amount produced. In the 28 EU Member States, are estimated a production more than 10 million ton of sewage sludge dry matter. Typically, the sludge composition consists of high organic matter, some nutrients and microorganisms, which can cause serious environmental and public health impacts (Millieu/WRc/RPA 2010). Nevertheless, in WWT there are different kinds of sludge depending of the WWT scheme. In WWT, usually three kinds of sludge are generated, primary sludge from physical and/or chemical treatment, secondary sludge from secondary treatment, mainly biological, and the tertiary sludge often by nutrient removal (Fytili & Zabaniotou 2008).

Therefore the sludge are in liquid or semisolid form depending of operations and processes treatment used, with a solids content varying from 0.25 to 12 percent by weight (Metcalf & Eddy 2013).

Usually primary sludge contains inorganic solids and the coarser fractions of the organic colloids. The secondary sludge consists mainly of biological solids and the amount produced is related with the biological treatment process. The biological process can be by suspended or attached-growth, which produced light flocculent solids and heavier solids, respectively. The sludge quantity is related to the food-to-biomass ratio. Typically, primary sludge is more granular in nature and has a higher solids concentration than secondary sludge (Table 1). The tertiary sludge may contain heavy metals, phosphorous, nitrogen and some viruses. The sludge quality is significantly affected by the pollution load of WW before treatment and by the treatment process. Usually the treatment efficiency affects in a limited way the amount of sludge produced (Fytili & Zabaniotou 2008). However, if correctly managed sludge by biological treatment such as composting and anaerobic digestion represents an important natural resource to promote sustainable development with the possible recover the nutrients.

Table 1

Nowadays, the sludge is considered a waste according with the European List of Waste (Commission Decision 2000/532/EC and Commission Decision 2014/955/EU) and the Portuguese legislation (Ordinance 209/2004), which attributed the following code “19 08 05 - sludges from treatment of urban waste water”.

Over the years, sludge had several disposal ways, ocean dumping, incineration, land spreading and landfilling with some important environment impacts on water, air and soil.

According to the management hierarchy, the sludge disposal technologies include land application with nutrients and organic valorisation, incineration with energy recovery and landfilling. When applying these options several factors should be taken into account like heavy metals, pathogens and organic pollutants contents. According to Fytili, A. & Zabaniotou (2008), in Europe the agriculture options for sludge is increasingly viewed as an insecure handling way; the landfills route is been abolishing due to EU recent legislation and increased costs and incineration offers a significant volume reduction.

Most sewage sludge can be applied in agriculture because has valuable agronomic properties (Cunha-Queda et al. 2015, EC 2014). For correct use in agriculture sewage sludge must be characterized in terms of nutrients to provide the plant's needs. Therefore, the sludge application must be done with the obligation to respect the soil, surface and ground water qualities. Some sludge may have metal and organic compounds, which can be toxic to plants and humans (Alonso et al. 2009, EC 2014).

The use of sludge in agriculture has already legislation in order to protect the soil quality and the agricultural products (Directive 86/278/EEC).

The Directive specifies rules for the sampling and heavy metals analysis in sewage sludge and soil in order to keep limit values for concentrations. Each Member State may adjust the established limits values for the parameters concentrations, even with some stricter limits than those determined in Directive 86/278/EEC, e.g. Austria (Table 2) and Nordic or Baltic countries (EC 2012).

In order to compare the Portuguese legislation with the EU Directive and other countries like, Spain, Austria and USA in Table 2 the sludge limits for metals are presented.

Portugal has adopted the lower limit proposed by EU Directive and included limit values for chromium as well as for pathogens (Decree-Law 276/2009) (Table 2). The Portuguese legislation also allows that the competent authorities may require the analysis of organic pollutants like LAS, NPE, PAH, PCB, PCDD, PCDF to complying with respective limits. Spain has lower limits than the EU Directive for Ni.

Thus, it’s prohibited the use of untreated sludge or sludge with concentration of some metals (Cadmium, Copper, Nickel, Lead, Zinc, Mercury and Chromium) exceeds the limits values. Therefore, sludge and soil must be sampled and analysed. In countries with sludge application in agriculture there is growing concern about the possible environmental impacts.

Table 2

The appropriate option to sludge disposal depend of several factors such as local or national, cultural, historical, geographical, legal, political and economic circumstances; ranging from country to country. Nevertheless, WWT should include sludge treatment and disposal. Nowadays the decision makers most evaluated the different disposal options in terms of environmental impacts, economically feasible and social acceptable level (Kalderis et al. 2010).

In Europe, the municipal sewage sludge disposal were 58.1% treated and used on farmland, 25.5% was incinerated, 9.3% was landfilling and about 7.1% was disposed of in other ways (values from 2010) (Eurostat 2015). Sludge treatment and disposal account for the WWTP total costs and can represent 50% (Spinosa et al. 2011). Therefore, the sludge production is an international environmental problem.

In last years, in Portugal has been found a significant growth in municipal WWT with consequent sludge production. The amount of sludge produced in Portugal in 2000 was about 177,000 tons of dry matter, according to the Commission's report on the implementation of Directive 91/271/EEC (COM 2004).

Since 2002 up to 2012 the population served by WWT increased from 58% to 79% respectively. The urban WW service in Portugal mainland has 283 management entities (ME) or operators, 2,536 WWTP and 1,732 collective septic tanks, values from 2012. The wastewater production is 235 $L.d^{-1}$ per capita and the sludge production achieved 416,457 ton (ERSAR 2015).

According to Eurostat (2014), Portugal sewage sludge productions and disposal from urban WW for 2007 and 2009 were 189,000 and 344,000 ton of dry matter were produced, respectively.

The present study aims to contribute to obtained real values of sludge production in Portugal and then propose mitigating measures in production and suitable disposal.

Methodology:

To achieve the proposal goal in the present study an extensive literature review were made on data published from European Commission, WWTP and ME working in Portugal (financial reports and other legal information). In addition, there was a direct contact with the ME of

WWT to get information of sludge production in last years. This was achieved by sending an application form to be filled by each ME, with several data like, wastewater flow treated, population served, WWT level, sludge types, sludge treatment, sludge amount and composition and final disposal. The selection criteria used in the present study was the most representative entities in terms of highest wastewater treated flow and population served. Therefore, the surveys were sent to twenty ME of WWT from Portugal mainland, including seventeen from ADP Group. Only seven ME (SIMARSUL, SIMLIS, ÁGUAS DO ALGARVE, SIMDOURO, ÁGUAS DO NORTE ALENTEJANO, SIMRIA E ÁGUAS DO SADO) answered the surveys, but the data collected was some gaps related with sludge production, flow treated or served population. Therefore, it was difficult to bring together the sludge production national scenario and was necessary to estimate some values. In the present study, the surveys together with the data collected in the literature review allowed to present detail information from only a few ME representing WW flow of 155,946,480 m^3, 20% of WWT flow produce in Portugal (2012). With the data collected several calculations were carried out such as, the per capita sludge production and the sludge amount by cubic meter of WW treated.

Results and discussion

Urban WW management service in Portugal

The Urban WW management service in Portugal includes drainage, elevation, transport, treatment and rejection of WWT in nature (Figure 1). The solid phase treatment is different from WWTP to WWTP due to the composition, the type and amount of sludge and the final disposal route (ERSAR, 2015). The structure of management service encompasses retail service carry out by municipal systems and a bulk service accomplish by state system. The retail service was 1,596 WWTP and 1,679 collective septic tanks. The bulk service consist of 950 WWTP and 53 collective septic tanks.

Figure 1

In the last years, there was a significant increase in the wastewater service (Figure 2) as a consequence of more investment and infrastructures construction. Nowadays, the population served by WWT is around 80%. Therefore, it was expected an increase in the amount of annual sludge production.

Figure2

Portugal have a significant number of WWTP with different dimensions and configurations for example the design flow from SIMTEJO WWTP ranges from 80 to 140,000 m^3d^{-1} and SIMDOURO WWTP vary from 13 to 66,700 m^3d^{-1}.

As presented in the methodology it was only possible collected detail from few ME. First overall data were collected from a leading group operating in the environmental sector in Portugal. This group called ADP (Águas de Portugal) aims to provide services to more than 80% of Portuguese population served by wastewater treatment. Since 2009 to 2013, the annual flow treated by ADP increased from 392,800,000 to 505,500,000 m^3, nevertheless the population decreased slightly (Figure 3) (ADP 2009a to 2013a, 2009b to 2013b).

Figure 3

In the ADP group, there was a significant growth in the WWTP number, more than 50%, which resulted in an increase of almost 7% on sludge production (Table 3). In 2013, the ADP group had nearly 1,000 WWTP. 721 WWTP treated and managed the sludge and the remaining WWTP sent the sludge for the solid phase of the firsts or the sludge was occasional removed. In the ADP group the sludge production is diffuse, SIMTEJO (28 WWTP) representing 32% of the total sludge and Águas de Zêzere e Côa (191 WWTP) contributing with less than 2% of sludge production (Martins 2015).

In 2013, the ADP group presented a sludge production of 317,699 ton, corresponding to 0.63 kg.m^{-3}. In the last years, the sludge final disposal was mainly agriculture valorisation (Table 3) (ADP 2009a to 2013a, 2009b to 2013b). In 2012, the agriculture valorisation occurred by direct application (45%) or by indirect application with composting (51%) and around 4% was sent to landfill (Martins 2015).

Table 3

Due to the high number of WW ME in Portugal and the lack standardized individual data, in the present study was necessary to select some representative ME, from the north, center and south of Portugal. In addition, for each ME was essential to choose the WWTP with highest flow and sludge production.

Therefore, detailed information was collected from five main WW ME from ADP Group: SIMTEJO, SIMDOURO, SIMRIA, SIMLIS, Águas do Algarve and one outside Águas do Sado (Figure 4). Table 4 shows some data from the selected ME.

Figure 4

Table 4

In order to compare the sludge production with the liquid phase treatments applied in the WWTP detailed information was collected from SIMTEJO, SIMDOURO, SIMRIA, SIMLIS, Águas do Algarve and Águas do Sado.

The main features of the eight selected WWPT from SIMTEJO and the five WWPT from SIMDOURO are presented in Tables 5 and 6, respectively.

Table 5

Table 6

From SIMRIA the two largest WWTP were chosen. The Norte WWTP has a capacity of 48,705 $m^3.d^{-1}$ (272,000 pe), a secondary treatment by activated sludge (medium load) and a solid treatment by anaerobic sludge and belt filters (Ramos 2011). The Sul WWTP has a capacity of 39,278 $m^3.d^{-1}$ (159,700 pe) (SIMRIA, 2015) and activated sludge (medium load) as liquid treatment.

From SIMLIS the three largest WWTP were chosen. The Norte WWTP (233,800 pe) with a capacity of 38,000 $m^3.d^{-1}$, representing about 68.3% of SIMLIS total capacity (ADP, 2015). The WWTP Olhalvas with a capacity of 6,566 $m^3.d^{-1}$ (52,000 pe). These two WWTP have liquid phase treatment with activated sludge (medium load) and a solid phase that treats mixed sludge, with thickening, anaerobic digestion and dehydration with centrifuges (ADP, 2015). The Fátima WWTP has a capacity of 5,193 $m^3.d^{-1}$ (33,100 pe) (Ramos 2011). In this WWTP the liquid phase was by activated sludge (extend aeration) and the solid phase comprise thickening and dehydration with centrifuges.

From Águas do Algarve, the Vale de Faro WWTP was chosen with a capacity of about 12,500 $m^3.d^{-1}$ (130,000 inhabit). The liquid phase process comprises a secondary treatment with activated sludge by extended aeration. The solid phase consists in thickening by mechanical gravity and dehydration by centrifuges (Águas do Algarve 2009a).

From Águas do Sado, the Setúbal WWTP was chosen with a capacity of 253,000 pe (56% from industrial component). Liquid phase consists of activated sludge by medium load, the solid phase comprises primary sludge thickening and flotation of secondary sludge, anaerobic digestion, dehydration with centrifuges and lime addition (Águas do Sado 2015 & Specifically surveys).

For the twenty WWTP analysed it was possible to verify a prevalent wastewater secondary treatment by activated sludge. Most of the WWTP sludge is treated by anaerobic digestion and then dehydrated. The treatment capacity varies significantly from WWTP to

WWTP with a range of 2,085 to 140,000 $m^3.d^{-1}$ for SIMTEJO and from 1,750 to 66,700 $m^3.d^{-1}$ for SIMDOURO.

Sludge type and composition

As mention above the sludge characteristic and amount depend on the wastewater composition, the nature and efficiencies of the treatment operations and process units. In Europe, a great percentage of WWTP are equipped with secondary or even tertiary treatment processes as a result of Urban Water Directive implementation. The same occurred in Portugal, so the sludge produced by WWTP is mainly of primary and secondary type. As previously, mentioned sewage sludge contains nutrients and organic matter, but can also enclose some heavy metals, pathogens and others contaminants.

Joint Research Centre of the European Commission attempted to assess the quality of the produced sludge in few urban WWTP from 15 countries (including Portugal) (EC, 2012). In this report, 22 minor and trace elements and 92 organic compounds including ingredients of personal care products and pharmaceuticals, with respect to potential agricultural use. Some examples are: Inorganic pollutants (Ag, Al, As, Ba, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Ni, P, Pb, Sb, Ti, V, Zn); PAH (Benzo(a)pyrene, Fluoranthene, Pyrene) and Emerging pollutants (Caffeine, Carbamazepine, Chlorotetracycline, Ciprofloxacin, Clarithromycin, Enrofloxacin, Erythromycin, Gemfibrozil, Ibuprofen, Lincomycin, Naproxen, Ofloxacin, Oxytetracyclin, Roxithromycin, Sarafloxacin, Sulfadiazine, Sulfadimethoxine, Sulfamethazine, Sulfamethoxazole, Sulfathiazole, Tetracycline, Trimethoprim).

Table 7 presents a sludge composition from some Portuguese WWTP collected from the surveys filled out by WW ME and the study carried out by Bancessi (2009 & 2011).

Table 7

The sludge composition from the eight WWTP (Table 7) varies from WWTP to WWTP, probably due to the WW characteristics and WWTP treatment. Heavy metals and organic compounds values presented are below the Portuguese legislation, with one exception for one WWTP in which the LAS parameter is slightly higher. However, the sludge produced by three WWTP were contaminated with Salmonella and E. Coli microorganisms.

Sludge production

According to Samolada & Zabaniotou (2014) in 2010, the annual sludge production for EU27 was estimated around 11,564,000 ton (DM). The countries with lower sludge production were Cyprus, Malta, Luxemburg, with a production of about 10,000 ton and the countries that produced more sludge were Spain, France, Italy, UK and Germany, which produced more than 1.2 million ton each. Results obtained by Kelessidis & Stasinakis (2012) also present a substantial difference in annual specific sludge production between European countries, ranging from 0.1 kg per capita (p.e.) by Malta to 30.8 kg per capita (p.e.) by Austria.

In Portugal (2009) more than 344,000 ton.year^{-1} of dry matter (DM) (Figure 5) sewage sludge was generated, which represented an annual value of 34 kg per capita (Eurostat 2014).

According with ERSAR (2015) in 2012 sludge production achieved a value of 416,457 ton, corresponding to value of about 40.2 kg per capita, considering the 2011 INE population data.

Figure 5

In order to have actual sludge production data and as mentioned in the methodology the present study focuses on various WWTP from several ME in order to characterize and analyse the sludge production and calculate sludge amount by cubic meter of WW and by per capita in Portugal.

The sludge production, treated flows and sludge production by cubic meter of treated WW data for the eight WWTP from SIMTEJO are presented in Figures 6 to 8.

Figure 6, 7 and 8

The Alcântara WWT is the greatest sludge producer accounting for 48.2% of the total followed by Frielas with 13.6% (Figure 6). The smallest sludge producer is the Bucelas WWTP. From 2011 to 2012 the flow and precipitation decreased 5.3% and 20% respectively. Nevertheless, the sludge production increased 6.2%, mainly due to greater functional stability of the WWTP Alcântara. From 2012 to 2013 the SIMTEJO flow increased 10% (Figure 7) because the flow rate increase in all WWT probably by the precipitation growth. In 2013 the Alcântara WWTP contributed with 50.7% for the sludge production.

In Table 8 shows the per capita range values for the eight WWTP.

Table 8

However, WWTP that present a higher production of sludge is Mafra (Figure 8) (Table 8), this WWPT received sludge from others WWTP. Comparison of the four main WWTP, two with secondary treatment by activated sludge, one with a biofilter and one with activated sludge plus a biofilter (Frielas) shows no significant difference in per capita values. However, the Frielas WWTP has the lowest average value and Chelas WWTP has the highest value.

One of the biggest northern ME from Portugal is the SIMDOURO, the sludge in SIMDOURO dropped substantially since 2011 to 2013 from around 18,700 ton to 11,500 ton (Martins 2015).

The sludge production and treated flows data for SIMDOURO WWTP, Gaia Litoral, Febros, Areinho, Lever, and Crestuma are presented in Figures 9 to 12.

Figure 9, 10 and 12

The analysis of Figure 9 shows that the WWTP with the highest sludge production were Febros and Gaia Litoral WWTP account for 76% of total production of SIMDOURO. The sludge produced in compact WWTP are forwarded to other WWTP where it makes the sludge dewatering. The Febros WWTP produces more sludge than Gaia WWTP despite the lower WW flow treated. The great difference between Gaia WWTP and Febros WWTP sludge production can be explained by solid phase treatment process that includes anaerobic digestion.

Despite the slightly increase of WW flow (Figure 10), it turns out that the sludge production in recent years decreased (Figure 9), possibly due to the increase of the solid phase treatment efficiency.

In SIMDOURO WWTP it was found that the per capita production and the sludge amount produced by WW treated varies from WWTP to WWTP as happened in WWTP of SIMTEJO.

Compare the three WWTP (Febros, Crestuma and Lever) with identical liquid and solid treatment processes was observed a highest sludge production per cubic meter of WW treated by Febros and Crestuma, which can be explained be WW loads before treatment. The highest sludge per capita production was also obtained in Febros WWTP. In last years there was an environmental positive evolution in the WWTP analysed with a decrease of sludge production per capita.

For the ME, SIMRIA, SIMLIS, Águas do Algarve and Águas do Sado the data collected was scarcer and does not allowed to present detailed conclusion for the ME. Thus, the results obtained for SIMRIA are presented in Figures 13 to 15, SIMLIS in Figures 16 and 17, Águas do Algarve in Figures 18 to 20 and Águas do Sado in Figures 21 and 22.

Figure 13 to 22

Within the same ME the WWTP where the solid phase treatment with anaerobic digestion exhibit usually produce less sludge production, because the biological organic removal.

The results show that the annual per capita sludge production varies greatly from WWTP to WWTP (5.5 to 766 kg per capita), the value depends largely on incoming wastewater characteristics and depend on liquid and solid treatment technology. Therefore, it was very difficult to estimate the amount of sludge produced. Identical findings were presented by Kelessidis & Stasinakis (2012), when compared the annual per capita (pe) from different countries, which range between 0.1 kg (Malta) to 30.8 kg (Austria) per capita.

Sludge treatment and disposal options

In Europe the sludge produced are treated before disposal in order to remove organic pollutants and microorganisms. Usually the sludge generated in WWT has the first treatments inside the WWTP, especially in large WWTP. The solid phase treatment has several steps like thickening (gravity and flotation), stabilization (anaerobic or aerobic digestion, lime addition) dewatering (belt press or centrifuge), storage, transport (road or pipeline) and final destination.

Nowadays several sludge treatment technologies are available in Europe, although differences can observed between several European countries. According to Kelessidis & Stasinakis (2012) the most prevalent stabilization methods are anaerobic and aerobic digestion, applying in 24 and 20 countries, respectively. The main sludge dewatering methods is mechanical and thermal drying frequently is applied in Germany, Italy, France and UK.

The main final disposal methods are agriculture reuse, incineration and landfilling. Nowadays the use of sludge in agriculture requires treatment and the concentration monitoring of metals and organic compounds in order to protect human health and the environment and comply with the metal limits and organic pollutants (ex. PAH). The Sludge Directive is under revision probably to establish of lower limits (Fytili & Zabaniotou, 2008). The incineration of sludge in Europe has increased because the calorific value is almost equal to that of brown coal; therefore incineration offers the possibility of recovering that energy content; there are a large reduction of sludge volume and destruction of toxic organic compounds.

This method has de advantage to generate about 30% of ash, so it is necessary another disposal method for the ash like landfill and to produce some dangerous emissions. However, it’s expected the incineration growth as the new technologies are implemented to minimize the disadvantages of this method. In last year’s other methods have been introduced, the thermal processes: pyrolysis, gasification, wet oxidation, but the sludge high moisture contents complicates the energy balance. Another possibility is the sludge utilization in a cement industry as a fuel or for mortar production (Fytili & Zabaniotou, 2008).

The evolution of final disposal methods in Europe is shown in Figure 23.

Figure 23

The agricultural method has decreased while composting and incineration has increased due to the raising prohibition of landfill disposal (Braguglia et al. 2012) and because as referred above the incineration has a significant volume reduction and in recent years the gaseous phase has less environmental impacts.

In order to quantify environmental impacts of WW and sewage sludge treatment and disposal processes several life cycle assessment of sewage sludge were made (Yoshida et al. 2013).

Figure 24 shows the sludge disposal methods in European countries. From Figure 24 it can be observed that Portugal is the country with the highest percentage for reached sludge disposal by agriculture valorisation, around 90%. This value includes the direct and indirect (by composting) agriculture valorisation.

Figure 24

According to Kalderis et al. (2010) the cost estimation of the sludge treatment technologies is difficult due to the diversity of the parameters involved and frequently one technology has different cost for each country.

In a recent study five technology configurations to recover energy of sludge were analysed (Mills et al. 2014) and it was found that the most sustainable solution economically and environmentally was the option used to create a solid fuel to displace coal, by combination of thermal hydrolysis process and anaerobic digestion with combined heat and power.

In Portugal several studies were made about the sludge characterisation (Santos 2007) biological treatment (Flor et al. 2004, Bancessi et al. 2011) thermal treatment (Barbosa 2008) and final disposal as fuel (Pereira 2015).

The sludge potential utilization as fuel was recent evaluated from the 19 Portuguese WWTP with an annual production 200,000 ton (DM). It was possible verified that to that to replace 5% of fossil fuels in cement industry were needed 172,800 ton of sludge with 80% of water or 49,371 ton with 30% of water (Pereira 2015).

In 2013, the ADP group had a total sludge disposal costs of 7,776,202 €, which were divided by composting (55%), agriculture valorisation (38%) and landfilling (7%). With the WWTP optimization is possible to reduced significantly the sludge costs (Martins 2015).

Conclusion:

In the present study has found that the sewage sludge amounts values exist in different bibliographic sources. The various units used and the different high number of WWTP and ME difficult a comprehensive overview at national level. In some ME the values are discrepant and even estimated. One possible explanation for the discrepant values are the moisture contents variation during the sludge route (collection, storage, treatment, transport and final disposal).

The results achieved revealed that sludge production varies greatly with the WW used and the ME. In 2012, sludge production achieved a value of 416,457 ton, corresponding to value of about 40.2 kg per capita. The sludge final disposal methods were mainly agriculture valorisation (about 90%) and landfilling.

The high output of sewage sludge, which is increasing during recent years, and the limitations of the existing means of disposing sewage sludge, highlights the need to find alternative routes to manage this waste.

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Table 1. Typical composition of primary and secondary sludge (adapted from Metcalf & Eddy 2003)

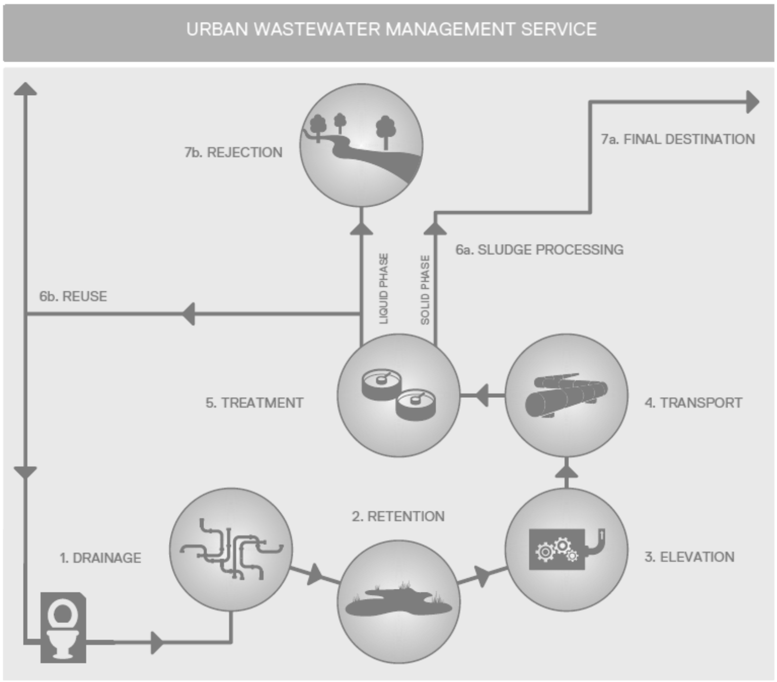
Parameters	**Untreated Primary sludge**		**Digested primary sludge**		**Activated sludge**
	Range	**Typical**	**Range**	**Typical**	**Range**
Total Solids (%)	2.0-7.0	4.0	6.0-12.0	10.0	0.83-1.16
Volatile Solids (%)	60-80	65	30-60	40.0	59-88
Oils and grease (% de TS)	6.0-30.0	-	5.0-20.0	18	-
Protein (% de TS)	23-30	25	15-20	18	32-41
Nitrogen (N, % de TS)	1.5-4.0	2.5	1.6-6.0	3.0	2.4-5.0
Phosphorus (P_2O_5, % de TS)	0.8-2.8	1.6	1.5-4.0	2.5	2.8-11.0
Potassium (K_2O, % de TS)	0-1	0.4	0-3.0	1.0	0.5-0.7
Cellulose (% de TS)	8.0-15.0	10.0	8.0-15.0	10.0	-
Silica (SiO_2, % de TS)	15.0-20.0	-	10.0-20.0	-	-
pH	5.0-8.0	6.0	6.5-7.5	7.0	6.5-8.0
Alkalinity (mg.L^{-1} as $CaCO_3$)	500-1,500	600	2,500-3,500	3,000	6.5-8.0
Organic acid (mg.L^{-1} HAc)	200-2,000	500	100-600	200	1,100-1,700

Table 2. Limits for metals in Portugal, Spain, Austria, USA and the EU Directive

Parameter mg/kg (dry matter)	Directive 86/278/EEC	Portugal Decree-Law 276/2009	Spain EC (2012)	Austria EC (2012)	USA EC (2012)
Cd (mg kg^{-1})	20 - 40	20	20 -40	10	85
Cu (mg kg^{-1})	1,000 – 17,500	1,000	1,000 – 1,750	500	4,300
Ni (mg kg^{-1})	300 – 400	300	100	100	-
Pb (mg kg^{-1})	750 – 1,200	750	1,200	500	-
Zn (mg kg^{-1})	2,500 – 4,000	2,500	0.4*	0.2*	0.75*
Hg (mg kg^{-1})	16 – 25	16	25	10	-
Cr (mg kg^{-1})	1)	1,000	1,000 – 1,750	500	-
As	-	-	-	20	75
Co	-	-	-	-	100
Sb	-	-	-	-	100

(1) - It is not possible at this stage to fix limit values for chromium. The Council will fix these limit values later on the basis of proposals to be submitted by the Commission within one year following notification of this Directive.

* %.



URBAN WASTEWATER MANAGEMENT SERVICE
1. Collection of wastewater
2. Retention of wastewater
3. Elevation of wastewater to enable it to overcome terrain barriers
4. Wastewater transport to the treatment facility
5. Correction of physical, chemical and microbiological characteristics of water in order to make it appropriate for the receiving environment

Solid phase
6a. Treatment of sludge generated during wastewater treatment
7a. Routing of sludge to an adequate final destination (agriculture, landfill, etc.)

Liquid phase
6b. Use of treated wastewater in a manner compatible with its quality (urban or non-urban uses)
7b. Discharge of treated wastewater into the receiving environment

Figure 1. Urban WW management service in Portugal (ERSAR 2015)

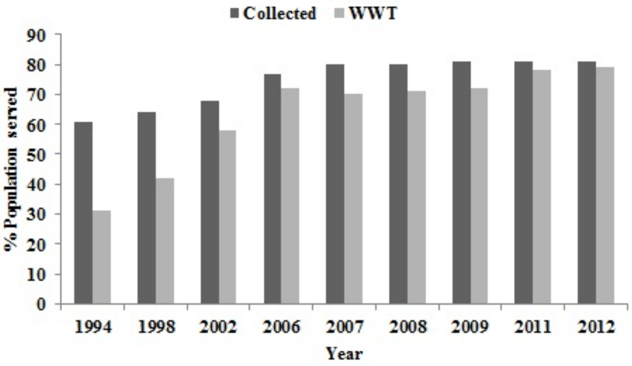


Figure 2. Population served by sewer system and by WWT, in Portugal (ERSAR, 2015)

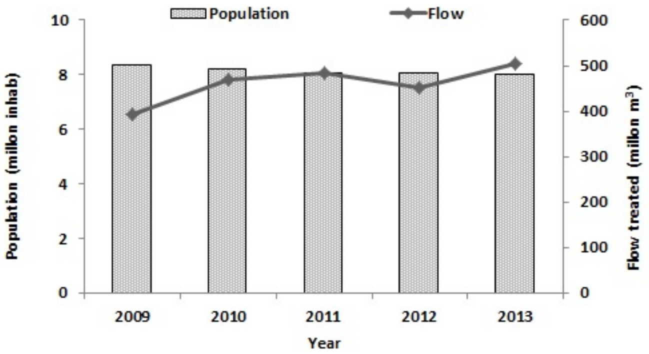


Figure 3. WWT flow and served population from ADP group (ADP, 2009, 2010, 2011, 2012, 2013)

Table 3. Sludge production and final disposal in ADP Group (ADP, 2009, 2010, 2011, 2012, 2013)

Year	**WWTP**	**Sludge production (ton)**	**Final disposal Agriculture Valorisation (%)**
2009	626	na	na
2010	744	na	91
2011	899	297,807	98
2012	953	328,692	96
2013	967	317,699	97

na- not available

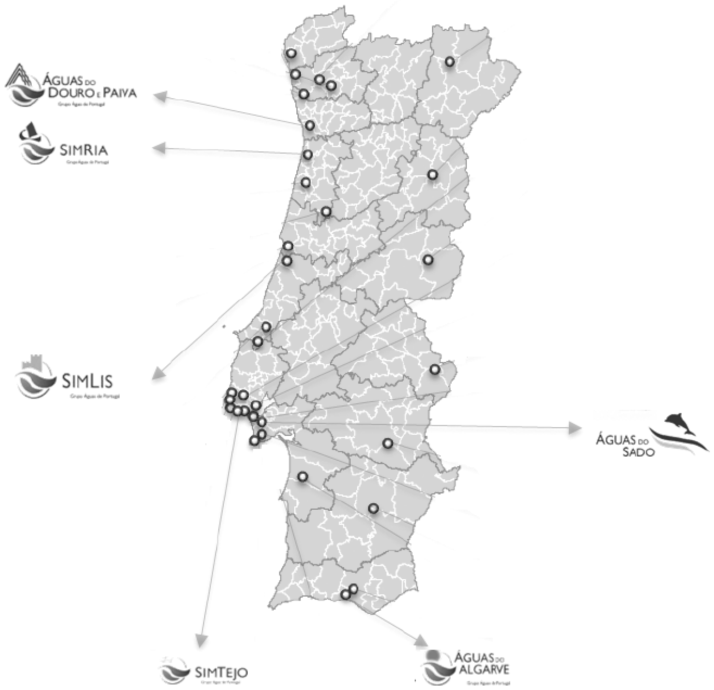


Figure 4. Portuguese ME selected in the present study (adapted from ADP 2011)

Table 4. Data from the selected ME

	Municipalities	**Geographic area (km^2)**	**Population served (inhab)**	**Capacity (million m^3)**	**WWTP**
SIMTEJO[1]	Amadora, Lisboa, Loures, Mafra, Odivelas, Vila Franca de Xira	1,000	1,300,000	123.0	29
SIMDOURO[1]	Arouca, Baião, Castelo de Paiva, Cinfães, Paredes, Vila Nova Gaia Penafiel	1,300	519,000	18,8	15
SIMRIA[1]	Águeda, Albergaria-a-Velha, Aveiro, Cantanhede, Espinho, Estarreja, Ílhavo, Mira, Murtosa, Oliveira do Bairro, Ovar, Santa Maria da Feira e Vagos	1,474	470,000	29.8	8
SIMLIS[1]	Águeda, Albergaria-a-Velha, Aveiro, Cantanhede, Espinho, Estarreja, Ílhavo, Mira, Murtosa, Oliveira do Bairro, Ovar, Santa Maria da Feira e Vagos	1,208	190,000	13.0	9
Águas do Algarve[1]	Albufeira, Alcoutim, Aljezur, Castro Marim, Faro, Lagoa, Lagos, Loulé, Monchique, Olhão, Portimão, São Brás de Alportel, Silves, Tavira, Vila do Bispo e Vila Real de Santo António.	5,412	500,000	53.0	63
Águas do Sado[2]	Setúbal	na	265,800*	na	7

1 – ADP 2015; 2 – Águas do Sado 2015; * population equivalent; na – not available

Table 5. WWTP capacity, sludge type, treatment and final disposal from SIMTEJO selected WWTP

	WWTP							
	Alcântara	**Beirolas**	**Chelas**	**S. João da Talha**	**Frielas**	**Bucelas**	**Vila Franca Xira**	**Mafra**
Project Population (pe)	756,000	213,500	211,000	135,000	700,000	na	73,221	na
Population (2013) (pe)	592,501	161,493	143,524	141,297	201,182	2,704	16,583	8,143
Project flow (m^3.d^{-1})*	140,000	54,500	52,500	15,999	70,000	1,575	15,936	2,085
Flow (m^3) (2013)**	53,708,041	16,971,070	14,177,553	20,634,155	4,210,590	4,388,220	426,020	3,049,151
WWT	Bio-Biostyr	AS + NR	AS + NR	AS	AS + Bio	AS (EA)	AS	AS (EA) +NR
Sludge Type	P + S	P+S	P + S	P + S	P + S	S	P + S	S
Sludge Treatment	Th+LA+Cen	AD+Cen	Th+AD + Cen+Che	AD+Cen	Th (P) and DAF (S) AD+Cen	BF	Th (P) and Thm (S) AD + Cen	BF
Final disposal	AV	AV	AV	AV	AV	AV	AV	AV

AD – Anaerobic Digestion; AS – Activated Sludge; AV – Agriculture Valorisation; BF - Belt filter, Bio-Biofilters, Cen - Centrifuge; Che - Chemical stabilization; EA - Extend Aeration; Lan – Landfilling; LA - Lime Addition; NR – Nutrients Removal; P – Primary Sludge; S – Secondary Sludge; Th – Thickening; Thm - Mechanical Thickening

na – not available; * SIMTEJO (2015), ** SIMTEJO 2013(Financial Reports);

Table 6. WWTP capacity, sludge type, treatment and final disposal from SIMDOURO selected WWTP

	WWTP – SIMDOURO				
	Febros	**Gaia Litoral**	**Areinho**	**Crestuma**	**Lever**
Project Population (pe)*	80,000	300,000	31,000	4,512	25,000
Population (pe) (2012)***	54,924	183,082	20,510	1,728	2,636
Project flow (m^3/d)	14,000	66,700	9,000	1,750	7,000
Flow (m^3) (2012)*	2,512,774	10,386,625	871,866	87,427	450,263
WWT *	AS (EA)	AS (EA or CA)	TF	AS (EA)	AS (EA)
Sludge Type*	S	P + S	P + S	S	S
Sludge Treatment*	Th+Cen	Th (P) and DAF (S) AD + Cen	Th + BF	Th + Cen	Th + Cen
Final disposal*	Comp	Comp	Comp	Comp	Comp

AD – Anaerobic Digestion; AFD - Adequate Final Disposal; AS – Activated Sludge; BF - Belt filter, CA - Conventional Aeration; Cen - Centrifuge; Com – Composting; DAF - Dissolved Air Flotation; EA - Extend Aeration; P – Primary Sludge; S – Secondary Sludge; TF - Tricking filters Th – Thickening;

* http://www.simdouro.pt/home.php

** Financial Reports 2013, http://www.aguasdegaia.eu/paper

Specifically surveys

Table 7. Sludge characteristics from Portuguese WWTP (2012)

	WWPT 1* a)	WWPT 2 a)	WWPT 3 a)	WWPT 4 a)	WWPT 5 a)	WWPT 6 ** a)	WWPT 7 ** a)	WWPT 8**b)	Portuguese legislation Decrete-Law 279/2006
Agronomic									
Dry Matter (%)	26.4	22	14	33	18	38.4	27.1	26.7	-
Organic Matter (% dry matter)	62	56	47	na	55.9	14.3	33.4	na	-
pH	8.2	7.2	6.4	11.1	12.4	12.3	12.2	8.42	-
N -Total (mg.kg^{-1})	29,068	6,360	6,984	15,000	56,000	22,000	31,000	1,260	-
N-Nitric $^{-}$(mg.kg^{-1})	10,257	2271	2,494	<255	22	<100	<100	380.7	-
N- Ammoniacal (mg.kg^{-1})	7,886	1,325	1,455	960	12,610	525	1,600	2.3	-
P - Total (mg.kg^{-1})	17,500	12,000	18,000	18,000	25,000	5,900	7,800	11,250	-
K (mg.kg^{-1})	2,100	2,130	4,480	<5,500	5,160	2,100	2,000	4,250	-
Mg (mg.kg^{-1})	2,885	2,840	3,950	5,850	7,800	2,200	2,700	5,600	-
Ca (mg.kg^{-1})	48,550	27,940	14,770	<5,500	137,100	160,000	150,000	69,300	-
Microbiological									
Salmonella	Pos. /50 g	Pos. /50 g	Pos. /50 g	absent in 50g	0	absent in 50g	absent in 50g	na	absent in 50g
E. Coli (CFU.g^{-1})	240,000	29,000	250,000	26.5	<10	<10	<120	na	<1,000 UFCg^{-1}
Heavy metals									
Cd (mg.kg^{-1})	1.9	1.1	0.97	<5.5		3.9	5.1	2-9	20
Cu (mg.kg^{-1})	365	251	268	290	173	53	88	143.4	1,000
Ni (mg.kg^{-1})	155	18	29	<12	17	13.2	25	85.7	300
Pb (mg.kg^{-1})	64.5	43	43	52	30	18.2	22.5	44.6	750
Zn (mg.kg^{-1})	1,370	901	769	1,500	454	700	400	590.4	2,500
Hg (mg.kg^{-1})	0.79	0.45	0.5	<2.9	0.53	0.5	0.6	na	16
Cr (mg.kg^{-1})	336	36	81	<29	24	20.5	17.9	176.8	1,000
Organic									
LAS (Total) (mg.kg^{-1})	5,850	52	3,600	na	na	5.73	5.7	na	5,000
NPE(Total) (mg.kg^{-1})	7.5	9.4	9.1	na	na	0.83	0.8	na	450
PCB (Total) (mg.kg^{-1})	< 0.2	< 0.2	<0.2	na	na	0.27	0.24	na	0.8
PAH (Total) (mg.kg^{-1})	2.1	1.6	1	na	na	0.61	0.65	na	6
PCDD/PCDF (ng.kg^{-1})	2.4	0.63	1.23	na	na	4.7	3.8	na	100

* - average of two values; ** - average of four values; na - not available; Pos. – positive; a) specific surveys b) Bancessi 2009 & 2011.

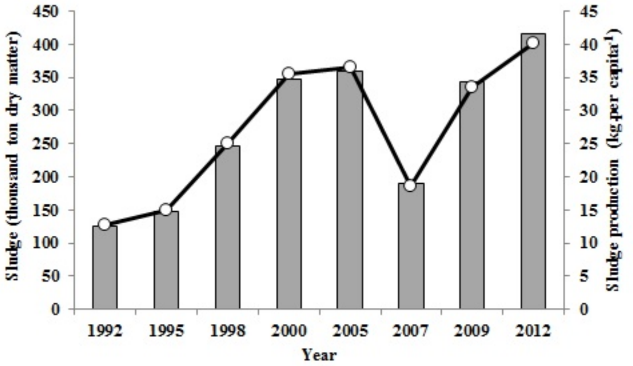


Figure 5. Sludge production in Portugal (Milieu/WRc/RPA, 2010; Eurostat, 2014)

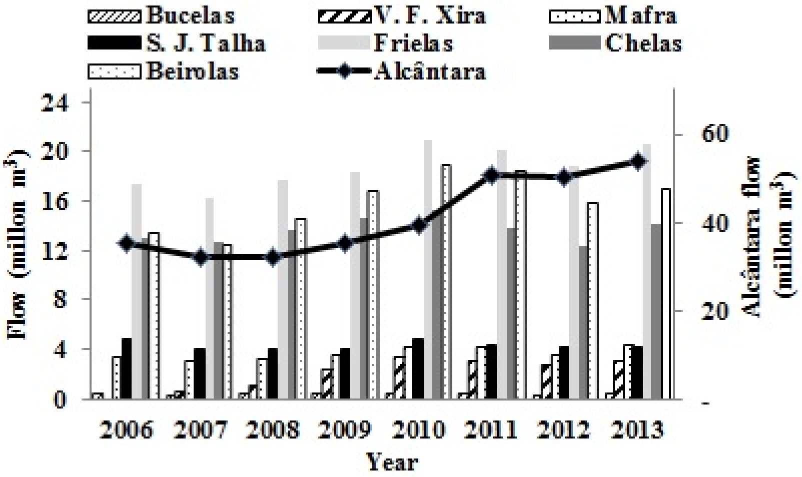


Figure 6. WW flow in WWTP from SIMTEJO

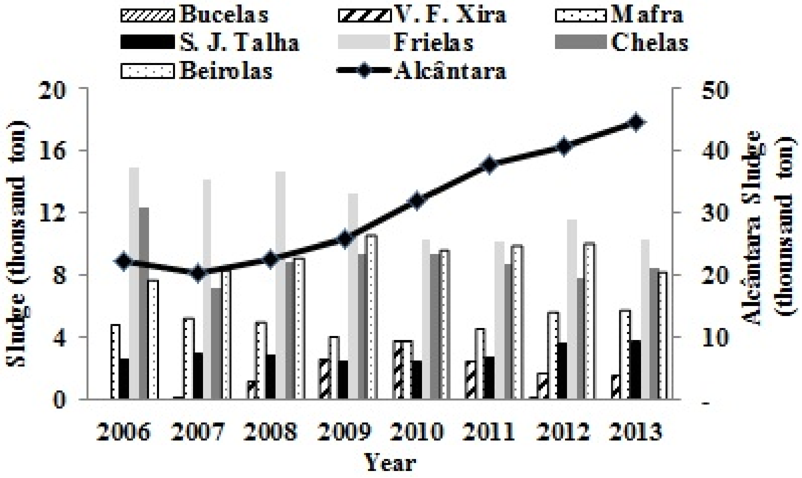


Figure 7. Sludge production in WWTP from SIMTEJO

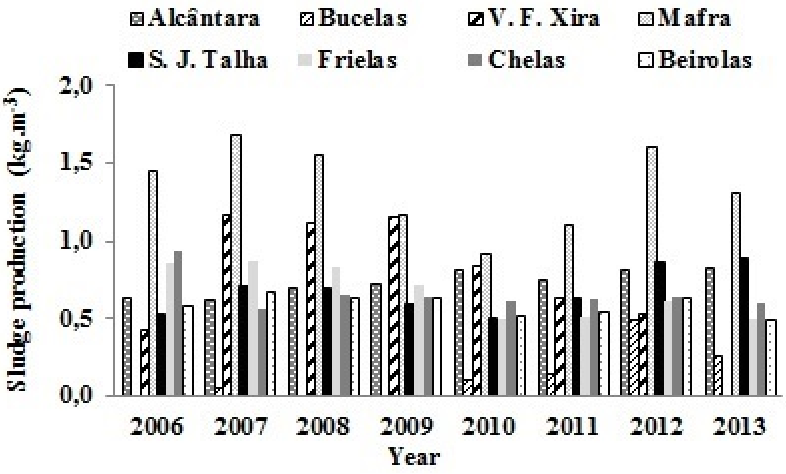


Figure 8. Sludge production by cubic meter of WW treated in WWTP from SIMTEJO

Table 8. Sludge production annual per capita value from some WWTP (SIMTEJO 2009 to 2013)

	Sludge (kg.per capita^{-1}.year^{-1})		
WWTP	Minimum	Maximum	Average
Alcântara	46.4	93.5	73.5
Bucelas	5.5	65.9	30.5
Vila. Franca Xira	25.3	181.6	111.9
Mafra	503.9	766.0	650.2
São João da Talha	14.7	60.7	27.0
Frielas	39.7	64.1	53.5
Chelas	62.0	96.0	77.1
Beirolas	52.8	79.5	67.0

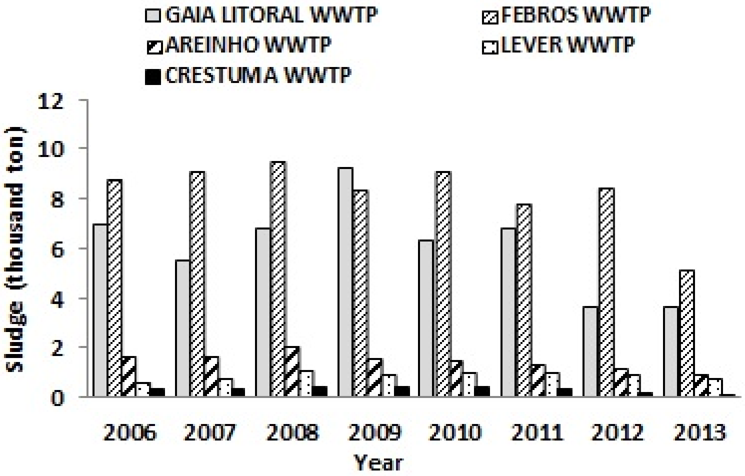


Figure 9. WW flow in WWTP from SIMDOURO

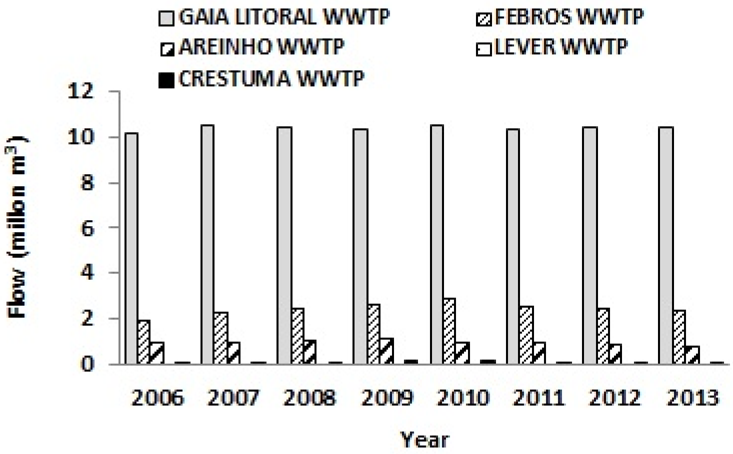


Figure 10. Sludge production in WWTP from SIMDOURO

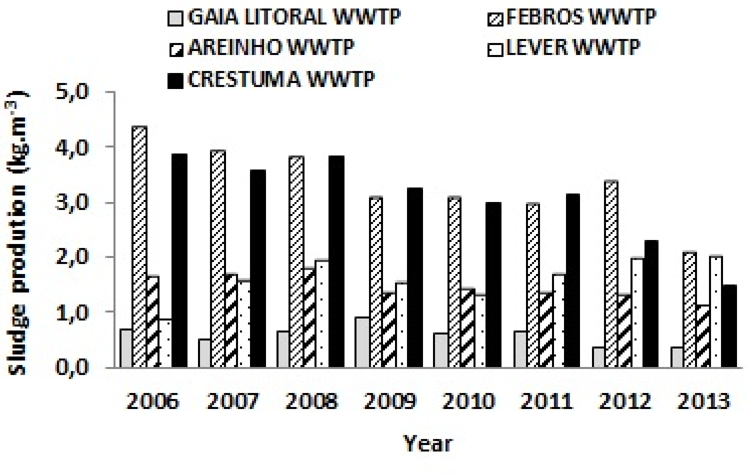


Figure 11. Sludge production by cubic meter of WW treated in WWTP from SIMDOURO

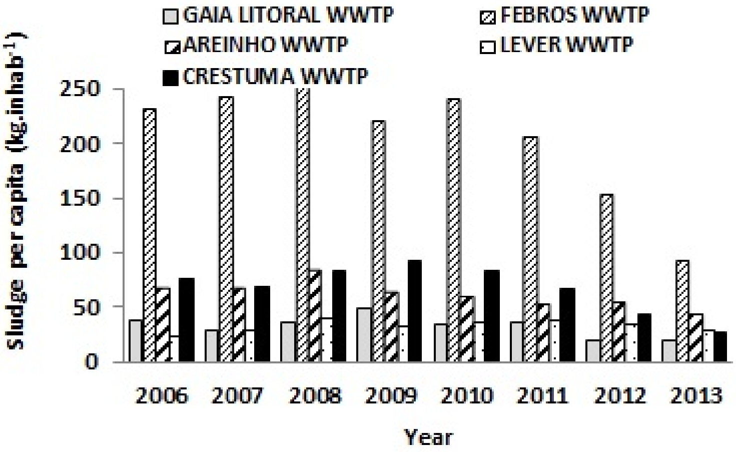


Figure 12. Sludge per capita production in WWTP from SIMDOURO

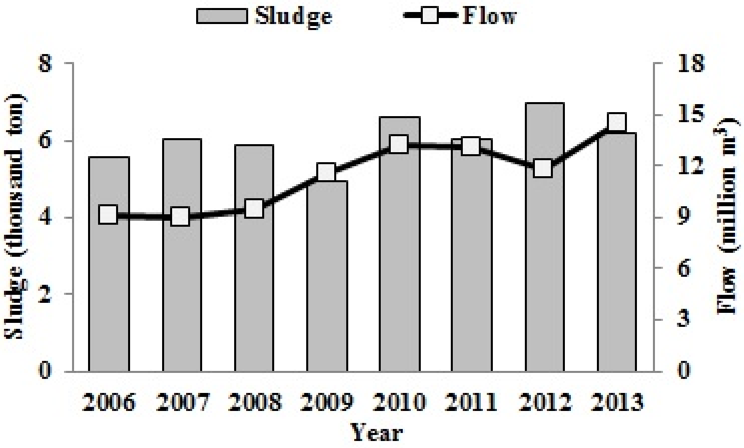


Figure 13. Sludge production and WWT flow in Norte WWTP from SIMRIA

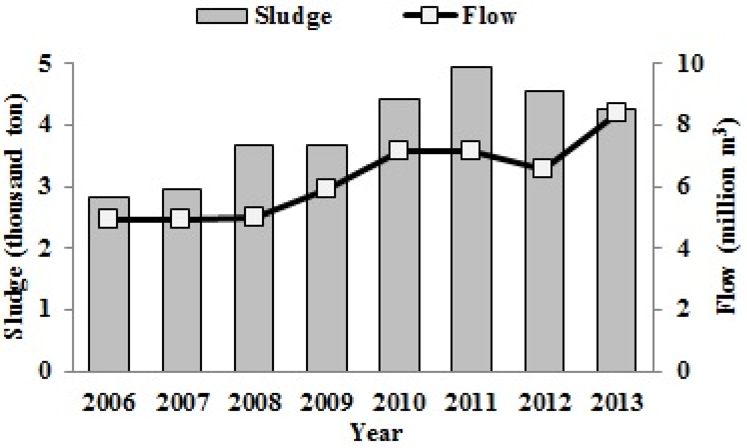


Figure 14. Sludge production and WWT flow in Sul WWTP from SIMRIA

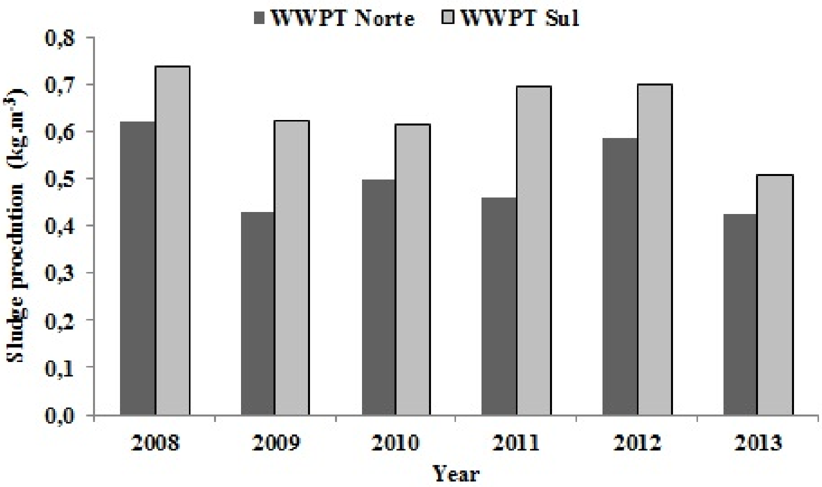


Figure 15. Sludge production in Norte and Sul WWTP from SIMRIA

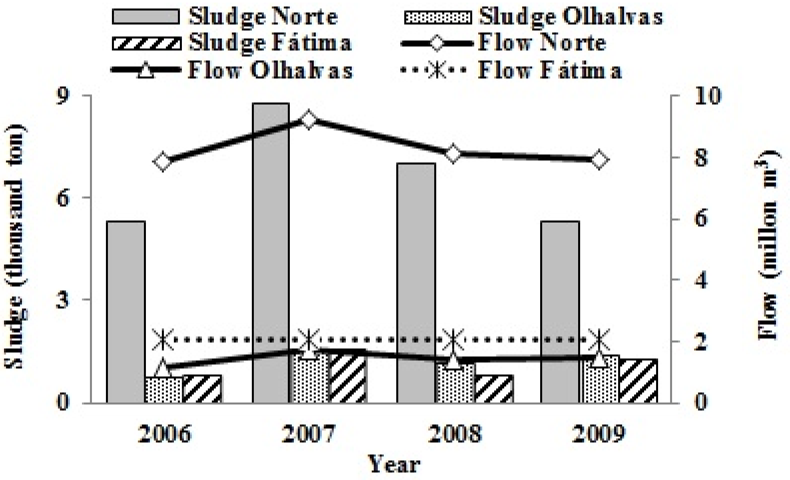


Figure 16. Sludge production and WWT flow in WWTP from SIMLIS

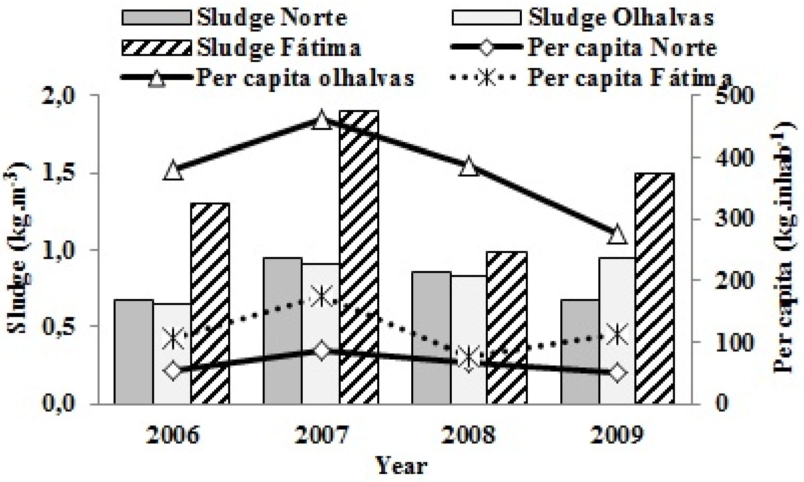


Figure 17. Sludge production and per capita values in WWTP from SIMLIS

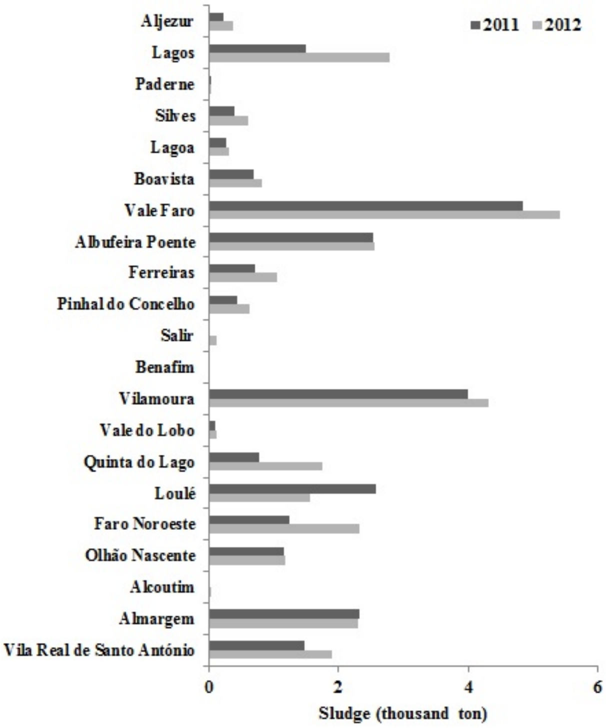


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Figure 18. Sludge production in WWTP from Águas do Algarve

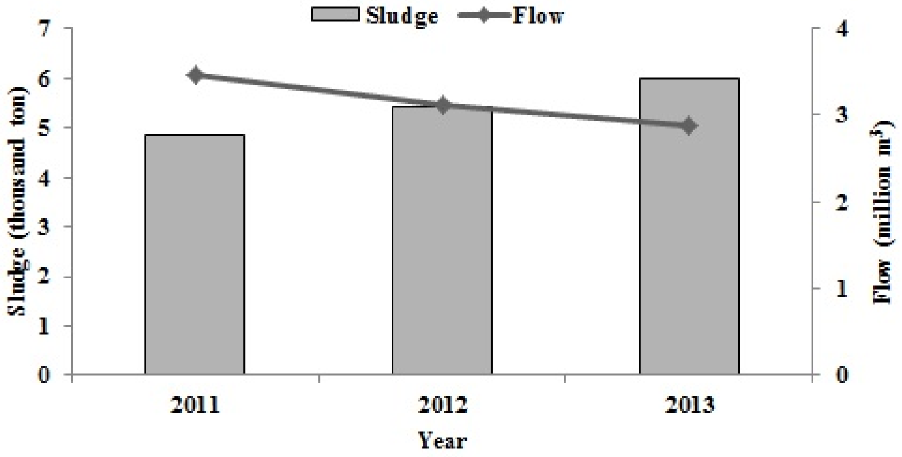


Figure 19. Sludge production and WWT flow in Vale de Faro WWTP from Águas do Algarve

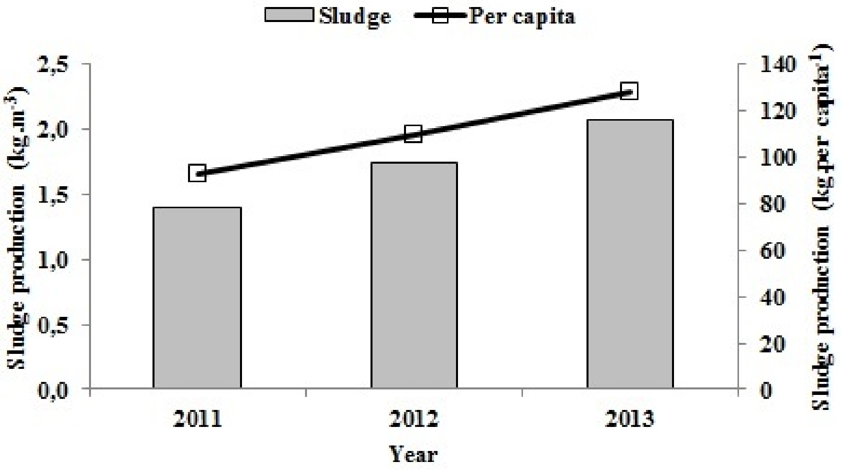


Figure 20. Sludge production and per capita value in Vale de Faro WWTP from Águas do Algarve

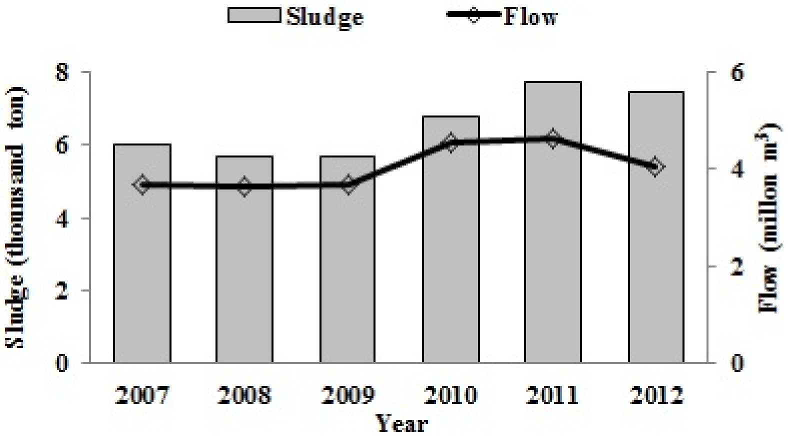


Figure 21. Sludge production and flow in Setubal WWTP from Águas do Sado

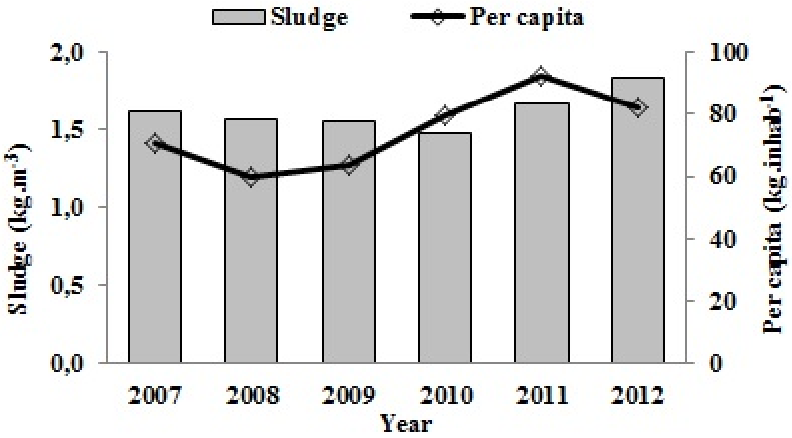


Figure 22. Sludge production and per capita value in Setubal WWTP from Águas do Sado

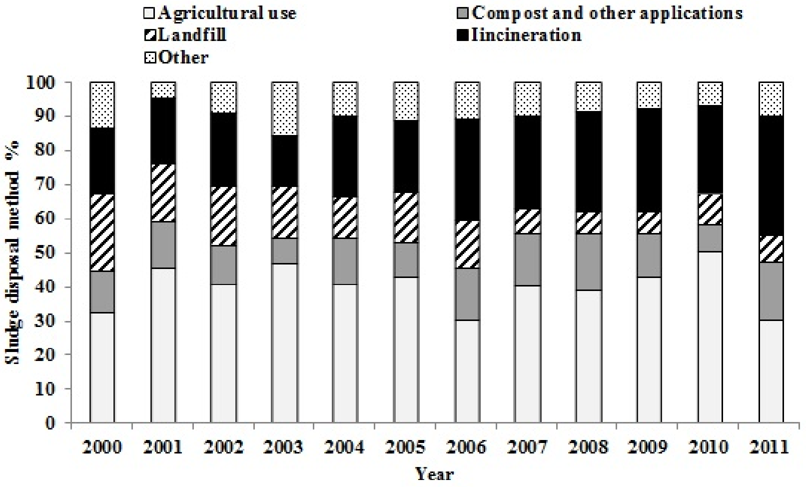
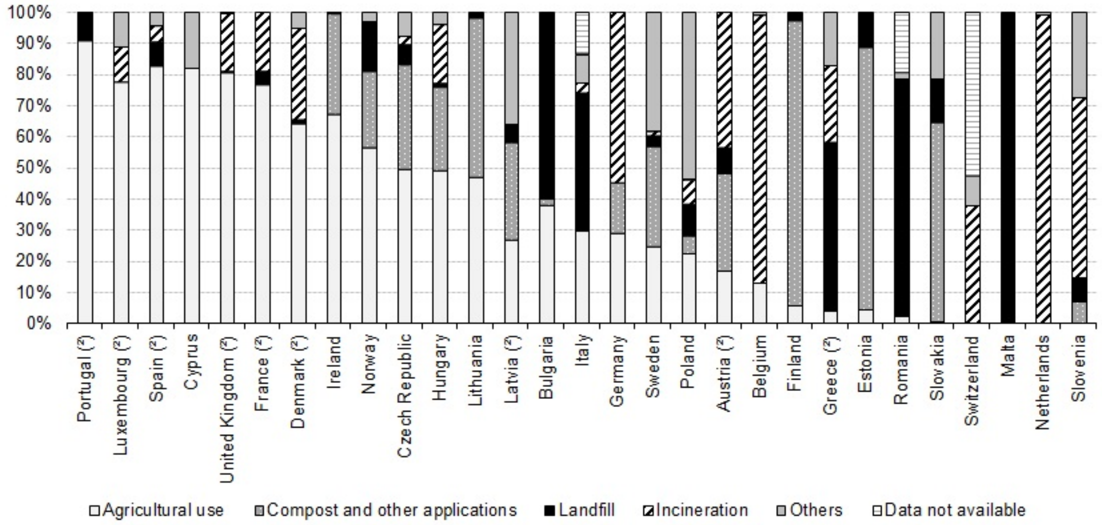


Figure 23. Sludge disposal methods in Europe (Eurostat, 2015)



(1) Belgium, Denmark, Spain, France, Italy, Cyprus, Luxemburg, Netherlands, Austria, Sweden, the United Kingdom, 2010. Latvia, Portugal, Finland, Switzerland, 2009; Croatia, Iceland, Turkey, Bosnia and Herzegovina, no data.

(2) Based on a total excluding the category of other types of treatment.

Figure 24. Sludge disposal methods in European countries (Eurostat 2015)