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Evaluation of the potential for Swedish wastewater treatment technology solutions in Portugal

Utvärdering av potentialen för svenska vattenreningstekniklösningar i Portugal

Åsa Flydén

ABSTRACT

Evaluation of the potential for Swedish wastewater treatment technology solutions in Portugal

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The situation for the Portuguese wastewater treatment is unsatisfying. Since Portugal entered the European Union in 1986, large improvement on the infrastructure has been made, but roughly 50% of the wastewater is still insufficiently treated. Investments of € 6 188 million on improved treatment are therefore planned until 2013.

This study has investigated the environmental effects of wastewater treatment in Portugal with the aim to assess Portugal's wastewater treatment in order to suggest improvements and advice on how Swedish technology can be used to solve the identified problems.

The main problems arising from the poor wastewater treatment are eutrophication, pathogens and high levels of heavy metals in rivers and estuaries. Hence, the areas of municipal, private and saline wastewater, sludge management, manufacturing industry wastewater, and pulp and paper industry wastewater were further studied.

Swedish technology was found to provide the best remedies within municipal and private wastewater treatment, where products like biorotors and small scale treatment plants are much needed. Moreover, advanced automatic-control and online-measuring systems would help decrease effluent pollution for large wastewater treatment plants. For industries, these systems could also improve water, energy and chemical recycling and hence improve not only environmental but also economical sustainability.

Within sludge management and biogas production, Swedish technology does not only provide environmentally sustainable but also in many aspects unique solutions and the Portuguese interest for this technology is large. Special techniques, such as ultrasound, ammonia removal and cryogenic upgrading, increase biogas production, and fields of application, significantly. Combined with treatment of sludge-rests for fertilizer production it represents a sustainable sludge management solution with both environmental and financial benefits.

Key words: Wastewater treatment, environmental problems, Portugal, Swedish technology solutions, sludge management, anaerobic digestion, biogas production

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REFERAT

Utvärdering av potentialen för svenska vattenreningstekniklösningar i Portugal

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Portugal ha idag bristfällig avloppsvattenrening och trots att landet efter inträdet i EU har gjort stora förbättringar i infrastrukturen så är 50% av avloppsvattnet fortfarande otillräckligt renat. Till följd av detta planeras nya investeringar i förbättrad teknik på totalt € 6 188 miljoner fram till år 2013.

Syftet med denna studie har varit att undersöka miljöeffekterna av den undermåliga vattenreningen i Portugal och ge förslag på vilka svenska tekniklösningar som skulle kunna hjälpa till att förbättra situationen.

De största problemen som uppstår till följd av den bristfälliga vattenreningen är övergödning och förhöjda nivåer av patogener och tungmetaller i floder och estuarier. Områdena kommunal vattenrening, enskilda avlopp, salthaltigt avloppsvatten, slamhantering samt verkstadsindustriavlopp och pappersindustriavlopp anses vara bidragande orsaker till dessa problem och valdes därför ut för djupare undersökning.

Potentialen för användning av svensk vattenreningsteknik i Portugal är störst inom kommunal och enskild avloppsrening, där behovet av produkter för småskalig vattenrening är stort. Vidare finns det också en marknad för reglertekniska system och system för onlinemätning och övervakning av utsläppsvärden. Sådana system passar bra för större reningsverk och skulle markant förbättra reningsgraden på utgående vatten. För industrier skulle dessa system dessutom kunna förbättra återvinningen och återanvändningen av vatten, värme, och kemikalier.

Inom slamhantering och biogasproduktion erbjuder svensk teknik inte bara miljömässigt hållbara utan även i många fall unika system och det portugisiska intresset för dessa system är stort. Systemen innefattar tekniker för ökad gasproduktion; ultraljudsbehandling och ammoniakavdrivning, samt uppgradering med kryogen teknik för att möjliggöra användning inom flera olika områden. I kombination med tekniklösningar för framställning av gödningsmedel ur rötrester, ger detta kompletta slambehandlingssystem som inte bara ger stora miljövinster utan som även kan ge finansiella vinster om biogasen säljs.

Nyckelord: Vattenreningsteknik, miljöproblem, Portugal, svenska tekniklösningar, slamhantering, rötning, biogasproduktion

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PREFACE

This degree project is part of the M.Sc. in Aquatic and Environmental Engineering Programme at Uppsala University, and the project covers 30 ECTS. The project was performed on behalf of the Swedish Trade Council in Portugal. The Swedish Trade Council is owned by the State of Sweden and the Confederation of Swedish Enterprise (Svenskt Näringsliv) and its mission is to promote Swedish export and to aid Swedish companies in their establishment on foreign markets. Supervisor for this project was Erik Swerup, consultant at the Swedish Trade Council in Lisbon, Portugal. Subject reviewer was Professor Lars-Christer Lundin at the Department of Earth Sciences, Uppsala University.

I would like to take the opportunity of thanking all people who have helped me to realise this project; colleagues at the Swedish Trade Council who have contributed with information and cheering, and everyone at Portuguese authorities, organisations and companies who have answered questions and supplied information on Portuguese wastewater treatment. A special thank you to my mentor Erik Swerup for sharing insight into the Portuguese market and way of thinking and for teaching me all about ”fees”.

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POPULÄRVETENSKAPLIG SAMMANFATTNING

Utvärdering av potentialen för svenska vattenreningstekniklösningar i Portugal

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Portugal är ett relativt litet land på 92 100 km^2 och har cirka 11 miljoner invånare. Sedan Portugals inträde i Europeiska Unionen 1986 har både landets ekonomi och infrastruktur förbättrats avsevärt och detta gäller även avloppsreningen. I dagsläget är 80 % av befolkningen inkopplade på det kommunala avloppsnätet men bara 50 % av vattnet renas i tillräcklig grad, det vill säga med biologisk rening som tar bort organiskt material i vattnet.

Det organiska material som är kvar när vattnet inte renats ordentligt innehåller höga halter av närsalter och när dessa släpps ut i floder och sjöar leder det till övergödning. Avloppsvatten innehåller dessutom höga halter av tungmetaller på många håll i Portugal. Tungmetallerna kommer oftast från olika verkstadsindustrier som kopplat sitt avlopp till det kommunala avloppsnätet utan att ha förbehandlat avloppsvattnet. Problem uppstår dessutom ofta på grund av att industrier kopplar på sig illegalt på det kommunala avloppsnätet. Vanligen separeras inte heller dagvatten från nederbörd och vanligt avloppsvatten. Detta betyder att det vid perioder med mycket nederbörd kommer in för mycket vatten till reningsverken vilka då översvämmas och tvingas släppa ut vattnet utan tillräcklig rening.

Syftet med den här studien har varit att undersöka dessa miljöeffekter som den undermåliga vattenreningen ger upphov till och ge förslag på vilka svenska tekniklösningar som skulle kunna hjälpa till att motverka problemen. De specifika områden som valdes ut för undersökningen var kommunal vattenrening, enskilda avlopp, salthaltigt avloppsvatten, verkstadsindustriavlopp, pappersindustriavlopp samt slamhantering.

I undersökningen har personer på de ansvariga myndigheterna i Portugal, samt företag, miljöorganisationer och branschorganisationer, intervjuats. Därefter har potentiella åtgärder identifierats och en matchning gjorts med svenska tekniklösningar.

Största problemet med den kommunala vattenreningen i Portugal är övergödningen. I området kring Lissabon har det till exempel satsats mycket på att bygga avloppsledningar längre ut i havet istället för att rena vattnet. Detta har kritiserats av EU och man planerar därför stora åtgärder. Fram till år 2013 skall det byggas 302 nya avloppsreningsverk och 131 befintliga verk ska byggas om. Största behovet av biologisk rening finns i de små och medelstora reningsverken. I dessa fall är det dock väsentligt att tekniken är enkel, lättskött och billig eftersom den annars inte blir konkurrenskraftig. Den låga utbildningsnivån och ont om pengar i de små kommunerna gör att dyra och komplicerade lösningar säljer dåligt oavsett kvalité. För större reningsverk kan däremot mer avancerade system vara av intresse eftersom de ofta har tillgång till större resurser.

Även för enskilda avlopp är övergödning det stora problemet. I Sverige är enskilda avlopp relativt vanliga och svenska företag har utvecklat minireningsverk med mycket god rening. Det finns även lösningar för småskalig vattenrening, till exempel satsvis rening, för samhällen där kommunal rening inte finns tillgänglig. I dagsläget regleras kraven för installering av enskilda avlopp i samband med bygglov, men det finns inga krav på rening för befintliga hus vilket begränsar efterfrågan.

Salthatigt avloppsvatten är ett problem som ökar i takt med att mer bevattning sker med renat avloppsvatten, vilket är en följd av en ökad industrialisering av jordbruket samt sinande vattentillgångar. De alltför höga salthalterna i avloppsvattnet kan leda till att jorden blir mindre bördig och växtligheten minskar. I framtiden kan detta ge ett större intresse för avsaltning med till exempel filtrering, men i dagsläget är marknaden begränsad och eftersom problemet inte finns i Sverige finns heller inte någon specifik teknik att erbjuda.

Verkstadsindustrin är den största källan för tungmetallföroreningar eftersom man ofta kopplar avloppet direkt på det kommunala avloppsledningsnätet. Eftersom detta även sker illegalt, är information om vattenreningen i denna bransch svårtillgänglig och det har därför inte gått att dra några slutsatser om vilka tekniklösningar som skulle kunna förbättra situationen.

Pappersindustrin i Portugal använder sig fortfarande av klorblekning och det finns för närvarande inga planer på att upphöra med detta, trots den miljöpåverkan som dioxiner och andra kända och okända klorföreningar ger upphov till. I svenska pappersbruk används andra typer av blekningsmetoder med framgång och dessa skulle kunna användas även i Portugal. Pappersindustrin skulle dessutom kunna göra stora miljövinster, och även ekonomiska vinster, på att förbättra återvinningen och återanvändandet av vatten, värme och kemikalier. Svenska tekniksystem för reglering, dosering, mätning skulle kunna användas och skulle dessutom kunna förbättra optimeringen av produktionsprocessen.

Slam innehåller näringsämnen som kan användas för gödning av odlings- eller skogsmark, men är till stor del en outnyttjad resurs i Portugal. Det mesta av slammet som produceras vid avloppsvattenrening dumpas istället på avfallsanläggningar eller släpps ut i sjöar, hav eller vattendrag.

Slam innehåller också organiska ämnen som kan användas för biogasproduktion genom rötning, en process där bakterier under syrefria förhållanden bryter ner organiskt material och producerar biogas. Slammet leds in i en rötkammare och rötas, biogas bildas och denna biogas kan sedan användas för energiproduktion. Biogasproduktion är en teknik med stora miljövinster eftersom slammet tas till vara, och är dessutom ekonomiskt positivt eftersom det genererar förnyelsebar energi.

Biogasproduktion är fortfarande relativt ovanligt i Portugal, men i Sverige finns en lång rad tekniker för produktion, optimering och rening av biogas. Det finns dessutom svenska tekniker för återvinning av näringsämnena i rötresten som sedan kan återföras till jorden istället för att orsaka övergödning. Sammantaget bör detta område därför ha en god potential för framtida export av svensk miljöteknik till Portugal.

CONTENTS

1 INTRODUCTION

One of Sweden's fastest growing export areas at the moment is environmental technology and the export potential within this area is large but not yet so well investigated. Environmental problems are receiving increased attention all over the world and environmental technology is well worth promoting as it can provide remedies for some of these addressed problems. Environmental technology is, however, a very wide area ranging from renewable energy to air cleaning filters and it is therefore important to locate which technologies are needed in which areas.

The Swedish Government has, in order to encourage the benefits of environmental technology, with the help of the Swedish Trade Council initiated a large market analysis to investigate where the Swedish environmental technology would suit best. This study, as a part of the large market analysis, is investigating the market in Portugal and is focused on environmental technology for wastewater treatment. The aim is to assess the status of Portugal's wastewater treatment and identify possible environmental problems caused by the wastewater. Further, the study intends to suggest improvements and advice on how Swedish technology can be used solve some of the identified problems.

Previous studies of similar type in Chile (Risberg, 2006) and China (Hagberg, 2007) have indicated that in a country where the environmental situation in not well documented personal contacts and interviews is the most efficient way to gain information. As Portugal is a member of the EU some records are kept according to law and the country has reporting duty and is surveyed by the EU regulatory bodies. However, the level of documentation of the county's environmental status is, to a high extent, dependent on the country's own control and inspections. It can therefore vary significantly within the member states. Reports from the OECD (2001) indicate that the auto-control performed by Portugal is lacking in many areas. For these reasons, and taking into account the results from the studies of Chile and China it was decided that the desired information for this study would best obtained through a combination of literary studies of the data available and interviews with key actors within the area. Also the use of a questionnaire, sent out to the key actors to assist the interviews, was adopted with reference to the aid this type of document has demonstrated in the previous Chile and China studies.

2 BACKGROUND

2.1 THE PORTUGUESE WASTEWATER TREATMENT MARKET

Portugal is a relatively small country; 92 100 km^2 with ca 11 million inhabitants. Portugal joined the European Union in 1986 and has since significantly improved both its infrastructure and economy with the assistance from EU structural and cohesion funds. These funds are now also a great contributor to the investments in improved wastewater treatment. During the last 10 years Portugal has made a massive effort in improving the wastewater treatment in the country. However, the level from which the country started was very low and despite the efforts made so far almost 50% of the wastewater is still insufficiently treated, subjected only to mechanical treatment, according to the Instituto da Água, INAG (2007).

The Portuguese market is mainly under the control of the Ministry of Environment and Finance with the municipalities responsible for the management of the water treatment. Management is sometimes done in concession with private firms. There is a trend towards a significant increase in the number of concessions. To attract private investment, the government has a special tax incentive for investments in private environmental protection assets, such as equipment (in effluents, air pollution and solid waste). This incentive is a tax credit equal to 8% of the relevant investment up to 25% of net profit tax to a ceiling of € 53 600 (Canadian Trade Commissioner Service, 2006).

There have been indications of obstacles for private actors in entering the market. The municipalities are sometimes pressured to join multi-municipal ventures and the PEAASAR (the national water and wastewater treatment plan) favours integration between the sewage pipeline networks and wastewater treatment plants, which detriments private firms having difficulties to cover both (Levy, 2008). New companies wanting to enter the market claim that private companies already established in the wastewater treatment market hinder their new projects by raising the tender to the court of justice and making the process last for months and years (Nascimento, 2008).

Business experiences from the Portuguese wastewater treatment market (Lundberg, pers. com. 2008) show that high technological solutions are not so popular in general. The technology should be simple, cheap and well-reputed to attract buyers.

2.1.1 Environmental status

Portugal currently imports 90% of its energy and the GDP energy intensity[1] grows continuously. These facts, together with the materials consumption, also growing faster than the GDP, indicate a non-sustainable situation. This is also emphasized by the fact that greenhouse gas emissions in the year of 2003 stood 37% over 1990's level while the Kyoto target is 27%. Further, the ozone precursor emissions are increasing (Roseta Palma, 2006).

[1] Energy consumption per GDP, usually measured in tonnes of oil equivalent (toe)

The country has been subject to several complaints from the European Commission for inadequate nature conservation planning and management, insufficient wastewater treatment and it is suffering from a staggering growth in the number of forest fires as well as burnt areas. On the other hand Portugal has managed to increase the drinking water supply to cover more than 95% of its population. Waste management is also improving although still dominated by landfills. Some areas of Portugal have vast problems with eutrophication, which aside from poorly treated wastewater mainly originates from soil fertilizers and extensive cattle and pig farming. Nonetheless, EU funds used in Portugal have been properly managed (Roseta Palma, 2006).

The renewable energy production is increasing, but so is energy consumption, which means that despite the increased amount of renewable energy the total share is not increasing. Portugal's energy goals, however, are to increase the share of renewable energy from 39 to 45% and to increase biofuel in the transport sector from 5.6 to 10% (Sá Da Costa, pers. com. 2008).

2.1.2 Administrative structure of the waste water treatment

The administrative structure of the wastewater treatment is illustrated in figure 1 and the responsibilities of the respective entities are described.

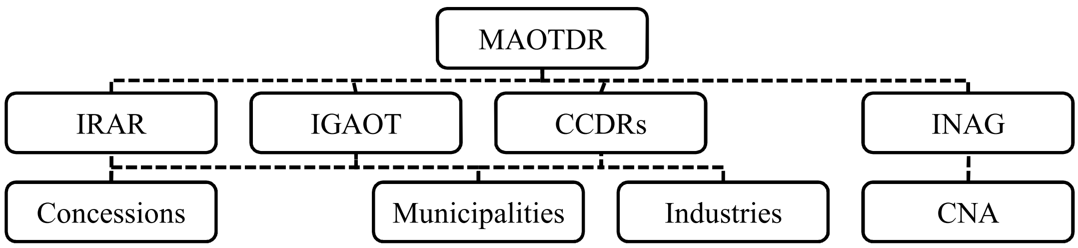

Figure 1. The structure of the Portuguese wastewater treatment administration

MAOTDR- Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional (The Ministry for Environment, Spatial Planning and Regional Development) is the head administrative authority of wastewater treatment. MAOTDR defines general policies and regulates the market but is not responsible for any information exchange between its subordinated bodies.

IRAR- Instituto Regulador do Água e Resíduos (Water and Residue Regulatory Body) surveys the implementation of legislation and the permits and functions of the concessions.

IGAOT - Inspecção-Geral do Ambiente e do Ordenamento to Território (Environmental Inspection Body) has a general inspection duty on all wastewater treatment plants, municipal, concession and industry. It does not inspect on a regular basis but makes random inspections. Any violation of effluent limit values should be reported to the IGAOT.

CCDR - Comissões de Coordenação e Desenvolvimento Regional ~ Alentejo, Algarve, Centro, Lisboa e Vale do Tejo, Norte (The Regional Development and Coordinating Commissions) regulate permits for, and performs inspections on, the industries and municipalities within their territories. CCDR also design programmes for auto-control which should be performed and reported every three months.

INAG- Instituto da Água (National Water Authority) acts as state representative in water resource issues and as advisory to the Ministry of Environment in policy matters. From 2006 INAG is responsible for gathering and centralising all information about the wastewater treatment plants. INAG has started the work on setting up a database for all wastewater treatment information.

CNA - Conselho Nacional da Água (National Water Council) is supportive to the INAG on general water issues.

The Municipalities are responsible for the wastewater treatment within their territories, alone or in conjunction with other municipalities. The municipalities are allowed to delegate the wastewater treatment to a private company, a concession. When running their own wastewater treatment they report to the CCDRs, when concessions are formed they report to the IRAR.

The Concessions are municipal wastewater treatment delegated to a private company, usually on 30 year contracts. They report to and are regulated by the IRAR.

The Industries are responsible for their own wastewater treatment but are allowed to connect to the municipal wastewater treatment. They report to and are regulated by the CCDRs.

Figure 1 illustrates the structure of the wastewater treatment administration in Portugal as well as the fact that the structure is not clearly defined. In general the different units work without much internal communication (Carreira, pers. com. 2008) and none of the units have a full overview of the whole system. The MAOTDR is the head authority and regulates legislation and allocated finances but does not do any central information gathering. This task has now been appointed to the INAG but the decision was not made until 2006 so the work of constructing a national database has begun just recently. Before this appointment there was no overview of the national system and hence it is still difficult to assess the status of the wastewater treatment quantitatively.

2.1.3 Water and wastewater treatment plan – PEASAAR

The Portuguese Ministry for the Environment (MAOTDR) has created PEASAAR (MAOTDR, 2007); an ambitious plan for drinking water and wastewater and all associated environmental issues. The plan covers the period 2007 – 2013 and is a continuation of the work from PEAASAR I. It includes statistical information, objectives and budget. The major objectives of the plan are to increase the percentage of the population connected to a municipal (or other) wastewater treatment to 90% and the population connected to a drinking water supply to 95%. The intention is to complete the construction of adequate wastewater treatment facilities and to expand their coverage as well as to improve and extend the pipeline network for both wastewater and drinking water, with purpose to decrease spillage and losses.

There is also a need to create a sustainable system with socially acceptable tariffs and to have the polluters pay principle (PPP) implemented. The main means to reach these goals are, according to the PEAASAR, to increase financial stability and efficiency by increased privatisation. This can be achieved by having the wastewater treatment run by companies through concessions.

2.1.4 Legislation

Most of the EU Directives regarding water and wastewater have been implemented into Portuguese law. Unfortunately, that does not mean that Portugal always comply with the directives. As of 2005 Portugal has new water legislation, Act 58/2005, which fully implements the EU Water Framework Directive (2000/60/CE) for sustainable water management. As for legislation regulating wastewater treatment, the Decreto-Lei n.º 152/97 from 19 July 2001 (altered by Decreto-Lei n.º 172/2001 from 26 May 2001 and later revised by Decreto-Lei n.º 149/2004 from 22 July 2004) regulates wastewater and how and where it is discharged. This law implements the Urban Wastewater Treatment Directive (UWWTD 91/271/EEC).

The actual compliance with the UWWTD is failing both in terms of collection and in terms of treatment, in part due to an increased population pressure in vulnerable coastal areas (Roseta Palma, 2006) but also due to difficulties in fulfilling both the plans on construction of new and remodelling of old treatment plants on time (Carreira, pers. com. 2008). The act is also old and is becoming outdated in the types and intervals of sampling and certification of laboratories. An amendment to the act can be expected within a few years (Carreira, pers. com. 2008).

Licenses, monitoring programmes and penalties are regulated under the Decreto-Lei n.º 226-A/2007, but the authorities do not normally exert penalties in cases where a municipality has insufficient wastewater treatment, but prefers to use other incentives. An example of such a remedy is blocking all other municipal construction licenses until the wastewater is properly treated (Almeida, pers. com. 2008).

The first act on complete sludge management, Decreto-Lei n.º 118/2006, came into action in 2007. The act regulates sludge management licensing and sets effluent limit values. However, according to the responsible authority (Carreira, pers. com. 2008) the act has not been working well, as it is very administratively heavy and difficult to apply.

Most industries in Portugal are connected to the public wastewater treatment network. Those who are not connected instead follow under the Decreto-Lei n.º 152/97, according to how many person equivalents they produce. The industries must also comply with the IPPC Directive, which states that all production facilities of a given size and/or production, new or old, must comply with the four principles of the IPPC; integrated approach, best available techniques, flexibility and public participation, as of 30 October 2007. Effluent limit values are regulated by Decreto-Lei n.º 236/98.

2.1.5 Investments

According to the MAOTRD (2007), the total predicted investment for Portugal to reach the intended sustainability in wastewater and drinking water systems is € 6 188 million. The budget for completion of wastewater constructions in 2007 - 2013 is € 1 958 million, whereof € 480 million is designated for treatment plants and € 1 478 million is designated for improvement and expansion of the sewage pipeline network, including elevating stations and reservoirs. Table 1 shows the number of wastewater treatment plants planned or constructed within the planned budget.

Table 1. Number of wastewater treatment plants constructed/to be constructed and remodelled/to be remodelled (Laginha, pers. com. 2008)

	New	Remodelled
Constructed	280	137
Planned for 2008-2013	302	131
Total	582	268

The AdP (Águas de Portugal Group) is the single largest actor on the market and it is owned to 70% by the state (INAG, 2007). It has a capital of € 300 million, controls 64 companies, and supplies 48% of the total population with water. AdP's investment plans are seen in table 2.

Table 2. AdP investment plans in water infrastructure (Laginha, pers. com. 2008)

Year	2008	2009	2010	2011	2012
Amount (€10^6)	682	659	408	227	88

2.2 PORTUGUESE INDUSTRY

Portugal has large natural resources but have salaries among the lowest in the EU and the level of education is also very low. The climate makes Portugal a productive country, both for forestry and farmland, and heavy industry and agricultural production are dominating. Examples of large industry sectors are moulding, pulp and paper, cork manufacturers, cement, ceramics, petrochemical, vegetable oil and wine production.

2.2.1 Environmental interest

In general the environmental interest of the industry in Portugal has been moderate, but it is now increasing due to greater restrictions and an enlarged environmental awareness of the population putting greater pressure on the industry.

There was a 39% increase from 2005 to 2006 in expenditure on environmental protection measures made by the industry (INE, 2007). There are also voluntary agreements between industry and the Ministry for the Environment that support the adaptation to EU directives (Contratos de Adaptação Ambiental) and funds for investment in technologies that reduces pollution rates (Canadian Trade Commissioner Service, 2006).

According to a report on the environmental strategies of the industries made by Instituto Superior Técnico (Sarmento & Durante, 2004), larger companies have a greater interest in protecting the environment. In the study performed, 30% of the companies that answered the questionnaire admitted to having caused pollution to a recipient at one or more occasions. The occurrence of a pollution event was found to be independent of the size, location and area of production of the company, but the companies already responsible for a pollution event appeared more likely to invest in environmental protection measures. Of the industrial businesses with 100 - 249 employees, more than two thirds effectively take some sort of action or use means for pollution abatement and control (INE, 2006).

2.2.2 Investments

As seen in table 3 the amount of money invested in wastewater treatment technology by the industry was € 29 million in 2006 (INE, 2007).

Table 3. Investments in wastewater treatment per type of industry (INE, 2007)

Industry	**Amount (€ 10^3)**
Pulp and paper	12 079
Food, tobacco and beverage	6 423
Electricity, gas, water	2 645
Chemical industry	1 989
Wood and cork production	493
Total	29 493

2.3 SWEDISH WASTEWATER TREATMENT TECHNOLOGY

Sweden has a long history of wastewater treatment and the combination of an early start in the construction of wastewater treatment infrastructure and a relatively strict environmental legislation has given Swedish companies a good knowledge within the field. Swedish wastewater treatment technology is strongest in the areas where Swedish industry is strong. Examples are forestry, pulp and paper, steel and iron industry, mining, engineering and manufacturing industry and pharmaceutical production (SWENTEC, 2008).

2.4 ANAEROBIC DIGESTION – BACKGROUND THEORY

This chapter aims to describe the processes behind anaerobic digestion and the production of biogas in order to aid understanding of the technologies developed to improve the process.

The production of biogas or methane through anaerobic digestion is a biological process that occurs in nature in many different places; swamps, hot springs, deep ocean trenches, and the intestinal tracts of certain animals. It is also a frequently used method for sludge management where the sludge from for example wastewater treatment plants is digested in digesters in order to minimise the volume, stabilise and extract energy from the sludge. Anaerobic digestion takes place through several steps of bacterial activity and is performed by a wide range of bacteria that all use different substrates. It is therefore of utmost importance that any sludge to be digested contains a wide range of substances.

2.4.1 Digestive process

The digestive process of anaerobic digestion occurs in several steps which are illustrated in figure 2.

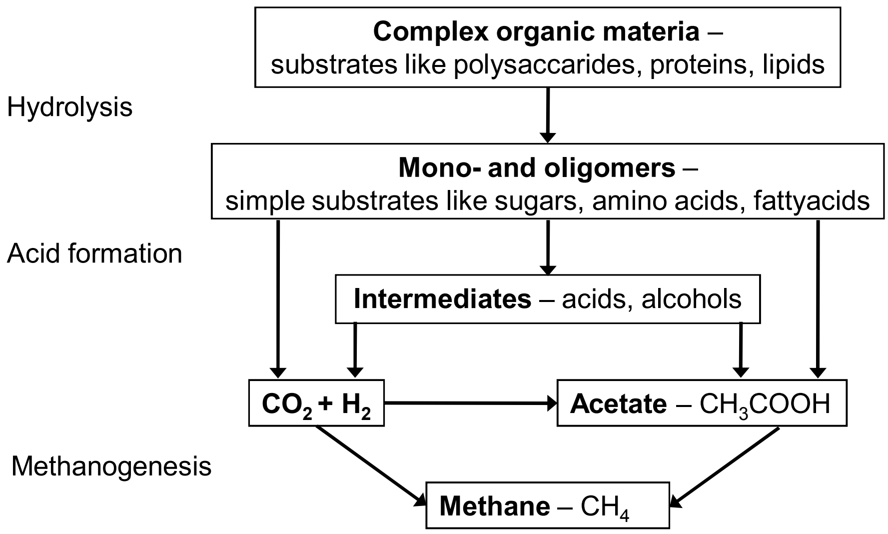

Figure 2. The digestive process of anaerobic digestion

Hydrolysis
Hydrolysis is the process in the anaerobic digestion that breaks down the colloidal or particulate waste in the sludge so that the substance becomes soluble and is more easily digested by the bacteria. Hydrolysis is the splitting (lysis) of a compound with water (hydro) and is an exocellular reaction where enzymes on the cell surface splits the molecule into smaller entities.

For example the hydrolysis of cellulose:

$$(C_6H_{12}O_6)_n + H_2O \xrightarrow{Cellulomonas} nC_6H_{12}O_6$$

Acid formation
After the hydrolysis the compounds have become soluble and are small enough to enter though the bacteria cell wall. Here the compounds become fermented into acids or alcohols with a resulting hydrogen gas and carbon dioxide production. The most important of the acids formed is acetate as it is the principal organic acid used as substrate by the methane forming bacteria.

For example the fermentation of hexose to acetate:

$$C_6H_{12}O_6 \xrightarrow{acetogenic-bacteria} 3CH_3COOH$$

Methanogenesis
Methane is formed from a range of compounds; mostly acetate, hydrogen gas and carbon dioxide but also formate, methanol and methylamine. The methane is formed from these compounds by the methane forming bacteria called methanogens. Some reactions forming methane are seen below:

$$CO_2 + 4H_2 \xrightarrow{Chemolithotrophic-methanogens} CH_4 + 2H_2O$$

$$CH_3COOH \xrightarrow{Methylotrphic-methanogens} CH_4 + CO_2$$

$$2HCOOH \xrightarrow{Chemolithotrophic-methanogens} CH_4 + CO_2$$

$$3CH_3OH + 3H_2 \xrightarrow{Methylotrophic-methanogens} 3CH_4 + 3H_2O$$

$$4(CH_3)_3N + 6H_2O \xrightarrow{Methylotrophic-methanogens} 9CH_4 + 3CO_2 + 4NH_3$$

Biogas from anaerobic digestion of sludge normally consists of mainly three gases; 50 - 80% methane, 20 - 50% carbon dioxide and 0 - 5% hydrogen sulphide (Schnürer, pers. com. 2006). The composition of the gas depends on many factors such as type of sludge, type of substrates, pH, temperature, et cetera.

2.4.2 Toxicity

Gerardi's *The Microbiology of Anaerobic digesters* (2003) states that a variety of inorganic and organic wastes can cause toxicity in anaerobic digesters. Some substrates that aid the digestion at certain amounts can become toxic when abundant. Methanogens can often tolerate higher levels of toxicants if allowed to acclimate over time. How toxic a substance is depends on three criteria:

1. The ability of the bacteria to adapt to a constant concentration of toxic waste
2. The absence or presence of other toxic wastes
3. Changes in operational condition

The most commonly mentioned toxicants for anaerobic digesters are heavy metals, hydrogen sulphide and ammonium. Heavy metals, when in free form, have an inhibitory effect on the enzyme systems of the bacteria causing the gas production to decrease and eventually killing the bacteria.

Normally the bacteria use sulphur as a nutrient just as some heavy metals in low amounts are beneficiary for the production. However, dissolved hydrogen sulphide is direct toxic to the anaerobic digester as it is inhibitory to the metabolic activity of anaerobic bacteria.

In the case of ammonical-nitrogen the situation is equally bilateral as the ammonium-ion (NH_4^+) is a nutrient and free ammonia (NH_3) is toxic. The relationship between ammonia and ammonium-ions is pH-dependent according to the reaction:

$$NH_4^+ \leftrightarrow NH_3 + H^+$$

The amount of ammonia decreases as pH goes down. As the reaction is endothermic the amount of ammonia also increases as temperature increases. Free ammonia is inhibitory to the methanogens, but the adaptation rate to ammonia is high so that a slow increase in the amount of ammonia is not harmful for the digestion. To a certain extent the ammonia toxicity is self-regulating because if pH goes up the amount of ammonia increases as does the inhibiting effect on the methanogens. As the methanogens are inhibited and decrease their digestion the volatile acids will start to accumulate and pH will drop again, decreasing the amount of free ammonia.

2.4.3 Energy yield

In the digester different substrates have different levels of putrescibility and hence also different gas yield. Examples for some substrates are shown in table 4. However, when substrates of different kinds are mixed in co-digestion the gas yield is often greater than the sum of the individual substrates. This effect is called positive co-digestion and is due to the fact that a variety of substrates provides a variety of nutrients for the microorganisms, which increase their metabolic efficiency (BioSystem, 2004).

Table 4. Gas yield and energy yield for different type of substrates (Sjöholm pers. com. 2008)

Substrate	**Gas yield** (Nm^3 CH_4/tonne total solids[2])	**Energy yield** (kWh/tonne total solids)
Cattle manure	170	1 700
Greens	420	4 100
Protein	510	5 000
Fat	960	9 400
Sludge (domestic)	167	1 600
Aviary manure[3]	290	2 800

2.4.4 Gas purification

For biogas to be used as car fuel, injected on the gas grids or used in a gas combustion engine for electricity production, it needs to be purified or upgraded so that the methane is gathered in a more concentrated form. There are several techniques for gas upgrading such as Pressure Swing Adsorption (PSA) and water scrubbing, both using absorption of carbon dioxide in water at high pressure; also chemical absorption where the carbon dioxide is reacted with a chemical can be used (Persson, 2003).

[2] Nm^3 = "Normal cubic meter" - measured at 0°C and a pressure of 1 atmosphere (Energimyndigheten, 2008)
[3] This figure is based on the assumption from BioSystem (2004) that the gas yield of aviary manure is about 1.7 times that of cattle manure

2.4.5 Thermophilic and mesophilic anaerobic digestion

Thermophilic anaerobic digestion occurs in a temperature interval of about 50 - 60˚C and mesophilic anaerobic digestion between about 30 to 35˚C. The interval of 40 - 50˚C is inhibitory for methane forming bacteria. Anaerobic digestion can also occur at other temperatures, both lower and higher. In general mesophilic anaerobic digestion is the method most commonly used in municipal sludge treatment. In Sweden, however, the number of thermophilic anaerobic digesters is increasing according to Energimyndigheten (2008) and within co-digestion 50% uses the thermophilic approach. The main differences between mesophilic and thermophilic anaerobic digestion are presented in Table 5.

Table 5. Advantages of mesophilic and thermophilic anaerobic digestion (Gerardi, 2003)

Mesophilic anaerobic digestion	Thermophilic anaerobic digestion
Less need for sludge dewatering	Less reactor volume needed
Less sensitivity to toxicants	Higher loading rates possible
Less need for heating	Less need for stirring due to lower viscosity
Easier temperature control	Destruction of pathogens
Lower operational costs	Higher gas production

Most literature sources, for example Gerardi (2003), states that increased temperature in the digester leads to increased digestion but also an increased instability in the anaerobic digestion process as fewer kinds of methanogens work in the higher temperature ranges. However, according to a study by Starberg et al. (2005) the Swedish reference facilities that have changed to thermophilic conditions reported a more stable process with less formation of foam.

3 METHOD

This project was carried out according to the flowchart shown in figure 3. Initially organisations and authorities that could provide information about the situation of the wastewater treatment and its consequential environmental problems in Portugal were mapped. The organisations and authorities were then interviewed to find out within which areas the treatment was inadequate and which environmental problems this caused.

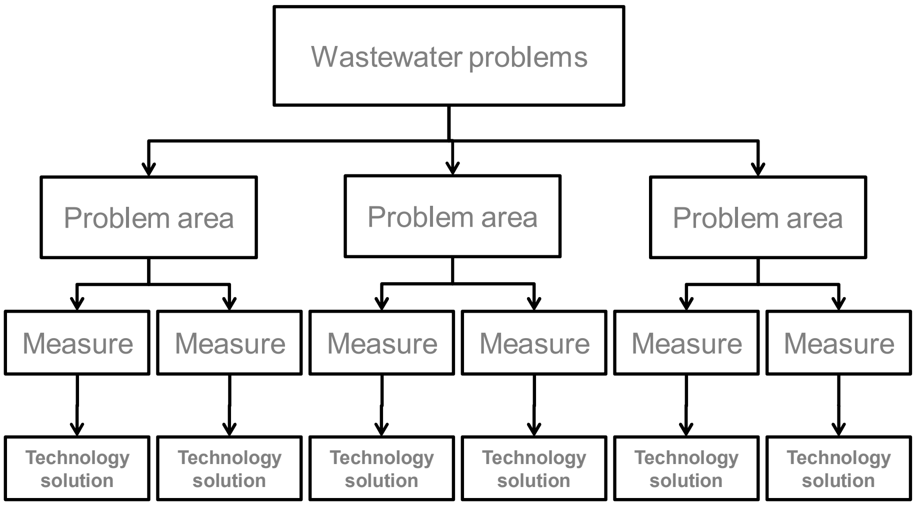

Figure 3. Conceptual flowchart of the used method

Once the general assessment was made, the wastewater activities that appeared to be causing the largest pollution problems were identified and targeted for further study. The choice was also to a certain extent based on the strong areas of Swedish technology and the amount of accessible information on the area. The problem areas chosen were municipal wastewater, private wastewater, saline wastewater, sludge management, manufacturing industry wastewater and the pulp and paper industry wastewater.

A deeper analysis of the areas of interest was then performed and regulatory bodies, branch associations and individual companies were interviewed to obtain more specific information. To aid in the gathering of information and to assist the interviews a first contact was made by sending out an email with a questionnaire (see Annex 1). Roughly 30 questionnaires were sent out. Those which contained useful information where then interviewed further. Attempts were made to first remind, via email, and then phone the actors that did not answer the questionnaire. In a few cases this lead to interviews but in most cases the actors remained unwilling to be contacted.

Literature studies and interviews with experts gave possible solutions for remedial measures that could be applied to the wastewater problems. The different remedial measures were analysed with the Portuguese situation in mind and aspects that were taken into account were environment, climate, technological complexity, legislation and market interest.

Possible Swedish technology solutions that matched the remedial measures were then identified and an analysis of their suitability for the Portuguese market was performed.

To illustrate how Swedish technology could help improve the environmental situation, a planned sludge management project in Portugal was selected. The project was selected as an example as it was, at the time of the study, in the process of choosing which techniques to use and also because the project was well planned and could supply the relevant data required to perform an analysis. The project was studied and specific technology solutions suitable for the project where selected and analysed as to how they might improve the efficiency and environmental situation compared to traditional methods.

4 MATERIAL

The material for this study has been gathered from various reports, interviews and answers to an email questionnaire sent out. Of the roughly 30 questionnaires that where sent out 10 where answered. Some of these where followed up with interviews and some further interviews where held when opportunity arrived. The material in presented in the different areas of activity selected for this study.

4.1 MUNICIPAL WASTEWATER

The municipal wastewater treatment in Portugal is performed by 1 035 wastewater treatment plants run by 319 different entities - municipalities, multi-municipalities, municipally owned companies and concessions with private companies. Data from the Instituto da Água INAG (2007) show that the multi-municipal structures dominate, with 31 multi-municipal systems providing wastewater treatment for 215 municipalities. These municipalities have approximately 6.9 million inhabitants.

The vast variety of ways in which the country's wastewater treatment is run makes it difficult for any institution to get a full overview. It also makes the system difficult to homogenise. One example is the tariff system for wastewater treatment, which is very complex. In some parts of the country there is no tariff but a municipal tax independent of amount of wastewater produced. There is a need for an effective tariff structure, equal for all regions, to reduce the complexity of the present system. The income from tariffs on wastewater treatment is very low and cost recovery of the wastewater treatment is only 54%. To reach a sustainable system cost recovery must increase. For Portugal on average the tariff is € 0.42/m^3 treated wastewater according to the Canadian Trade Commissioner Service (2006).

4.1.1 Problem area

In Portugal 93% of the population has access to publicly supplied drinking water, and 80% is connected to municipal wastewater treatment. However, the wastewater treatment services are below the target levels for the UWWT Directive. A significant part of the treatment is classified as insufficient (see Table 6) as the minimum secondary treatment needed to reach EU requirements is lacking.

Table 6. Wastewater per type of treatment in percent (INAG, 2007)

Type of treatment	%
Preliminary	14
Primary	7
Secondary	40
Tertiary	14
Not treated	6
Not specified	19

That the treatment is insufficient is further illustrated by a study performed by the IGAOT (2006), inspecting all the major wastewater treatment plants along the coast line, which is classified as a sensitive area. The study showed that only 7% of the plants specifically removed phosphorous from the water and only 16% had any type of biogas production.

According to the LPN - Liga para Protecção da Natureza, Portugal's largest environmental NGO (Vitorino, pers.com. 2008), the greatest environmental problem arising from the insufficient municipal wastewater is eutrophication. When the wastewater is poorly treated, or not treated at all in some cases, it contains elevated levels of organic matter. When this water is released into the ocean or the estuaries, vast eutrophication problems arise.

This is especially the case in the Lisbon area, where most of the wastewater only receives primary treatment. Large investments have been made in an off-shore effluent system, but this has proven to be one of the major reasons for the current pollution problem as dumping sewage at sea is only a way of hiding the problem; not dealing with it. The eutrophication is also worsened in many areas, like Guadiana River in the southeast of Portugal, due to badly treated effluents coming from upstream in Spain.

In addition, the water in some rivers contains pathogens because of lack of separation of domestic effluents from stormwater. Normally, combined pipeline systems are used, leading domestic wastewater and stormwater in the same pipelines. During heavy rain the wastewater treatment plants are sometimes flooded, letting untreated wastewater directly into the recipient. In some cases the problem with pathogens is also caused by illegal connections of domestic effluents to the stormwater drainage system. Examples of this are the streams of the west, Rivers Ribeira do Jamos and Ribeira das Vinhas, as well as the outlets of Lisbon.

4.1.2 Remedial measures

Reduction of nutrients and organic matter in the wastewater can be done using different techniques, but they are all based on the same bacterial decomposition process. The technological solution to the basic problem, the inexistence of treatment, is simply to build tanks with active sludge, trickling filters, and chemical or biological flocculation of phosphorous.

4.1.3 Swedish technology solutions

Swedish companies have technology solutions for almost all kinds of municipal wastewater treatment – from pumps to sophisticated online measuring systems. Most of the technology, however, well known and the Swedish technology solutions are rarely unique (SWENTEC, 2008).

4.2 SALINE WASTEWATER

4.2.1 Problem area

A further environmental problem with domestic wastewater, according to the LPN (Vitorino, pers.com 2008), is that even the water treated in wastewater treatment plants that function well, contains elevated levels of salts. This water is after treatment released into reservoirs and used for irrigation, aggravating the risk for salinisation. Salinisation is the process that leads to an excessive increase of water-soluble salts in the soil solution (Várallyay & Tóth, 2008). In dry areas this can cause creation of desert land, degradation of the soil and contamination of the groundwater. This is a problem in the Roxo reservoir in Alentejo and will be a problem in Alqueva and in Guadiana, as well as in innumerable small reservoirs, especially when the irrigation is made upstream the reservoir.

Irrigation with treated wastewater is of great importance for Portugal as both subterranean and surface water resources are declining. Further, Portugal is, according to the OECD (2001), one of the few countries in Europe where water usage is increasing on a yearly basis as industrial agriculture is expanding.

4.2.2 Remedial measures

If treated wastewater is to be used for irrigation the salt content must be decreased or the soil will be deteriorated and loose its fertility. The electrical conductivity of the outgoing wastewater in Portugal often exceeds 1.5 dSm^{-1} (Vitorino, pers.com. 2008). As a comparison, saltwater has a conductivity of 50 dSm^{-1} and potable water 0.005 - 0.5 dSm^{-1}. According to information from Texas Agricultural Extension Service (2008) water with an electrical conductivity above 0.03 dSm^{-1} is unsuitable for irrigation of crops. Hence for the water to be suitable for irrigation and not cause the soil to be degraded by salinisation it needs to be desalinated.

4.2.3 Swedish technology solutions

The most common way to desalinate water is to use filtration. There are different kinds of filters of different pore size and generally the larger the pore size the higher the capacity. Reversed osmosis filters are the finest filters but they are also expensive and have a low capacity in relation to their size. For desalination of wastewater it might be possible to use filters of larger pore size to get a more economically efficient solution. Capacities up to 100 m^3 per hour are possible to obtain but for some treatment plants this may not be enough. (Ottefjäll, pers. com. 2008).

4.3 PRIVATE WASTEWATER

4.3.1 Problem area

The level of wastewater treatment for people on the countryside is still highly uneven. In Portugal, as well as in Sweden, lack of treatment of wastewater on the countryside (private wastewater treatment) is a non-prioritised environmental problem causing an unknown but probably significant eutrophication. Most frequently a simple stone caisson is used and the water is then infiltrated without further treatment. The construction of adequate wastewater treatment is a requirement to get a permit for constructing a new house but there are not yet any laws regulating wastewater treatment from single households already built (Almeida, pers. com. 2008).

In some areas where municipal wastewater treatment already exists, there is still a lack of sewage pipeline networks connecting the population to the treatment plants. According to the Environmental Inspection Agency (IGAOT, 2005), an average of 34% of the existing treatment plants are over-dimensioned due to the failure of the responsible municipalities to complete the sewage pipeline network. Hence the population for whom the wastewater treatment plants were built to serve remains unconnected.

4.3.2 Remedial measures

Legislation regulating private wastewater treatment in general is needed, as well as an expansion of the sewage network to also incorporate minor villages. For the areas where this for some reason cannot be achieved, there are technical solutions for single households or villages. Examples would be installation of some kind of compact treatment plants, septic tank or proper infiltration with sludge separation and biological degeneration.

4.3.3 Swedish technology solutions

Sweden has a good selection of compact treatment plants to offer, as private wastewater treatment has long been regulated and this has created a national market. There are several brands of compact treatment plants with efficient, environmentally adapted treatment and low energy consumption. Swedish companies also offer systems for small scale wastewater treatment with for example sequencing batch reactors where batch treatment is used instead of continuous flow. The advantages of batch treatment are that undisturbed settling is allowed and the ideal microorganism composition is readily obtained making the system easily managed with a minimum of supervision.

4.4 SLUDGE MANAGEMENT

4.4.1 Problem area

Even when the wastewater treatment of the municipalities is working well, problems occur. One such environmental concern is that there is often no final destination for the sludge produced. The major part of it ends up on landfills or is dumped into a recipient. The cultivated soils, especially south of Tagus and in the inner part of the country have a very low content of organic matter. The amount of phosphorus is also low, or very low, and it has been attempted to use sludge as complementary organic matter and as phosphorus fertilizer. However, even though the results have been good it has not been used frequently. The price of the transports makes this system economically unsustainable (Vitorino, pers.com. 2008). There is also the issue of the potentially high levels of heavy metals in the sludge to take into consideration.

Alternative sludge management such as producing biogas is still an underdeveloped area in Portugal. The number of wastewater treatment plants with biogas generation from sludge is very low. Only 16% of the largest wastewater treatment plants along the coast have biogas production in any organized form (IGAOT, 2005). The biogas production facilities that exist generally have a low efficiency. For example one of the newly built wastewater treatment plants has an anaerobic digester with an expected reduction of volatile acids (level of putrescibility) of 40% once it is fully operational (Fonseca, per. com. 2008). As a comparison the wastewater treatment plants in Sweden usually have a reduction of 50% and theses are not always optimized. (Doverhög pers. com. 2008)

4.4.2 Remedial measures

There are a few different techniques for sludge management, for example anaerobic digestion, pelleting and sludge incineration. Incineration is, however, seldom used in Sweden and will therefore not be discussed further in this study.

The production of biogas from anaerobic digestion of wastewater sludge, animal manure and other organic wastes is beneficial for many reasons. From an energy point of view it is a renewable energy from non desired waste-products with no net contribution to the greenhouse gases as long as it is burnt properly. Apart from generating biogas, anaerobic digestion also decreases the sludge volume and stabilizes the sludge enabling it to be more easily used for fertilization. The stabilisation according to BioSystem (2004) in turn results in an 85 - 100% reduction in foul odours and destruction of weed seeds as well as being insect repelling. Further, the digestion process alters organically bound nitrogen into ammonium, which is more easily available to plants and hence speeds up the fertilizing effect when the residue is used for soil fertilization. The high level of acclimatization of the bacteria in the digester also to substances such as ethanol and other solutes makes anaerobic digestion suitable for destruction of hazardous waste.

Pelleting is a way to turn the sludge into a more easily managed product. Pelleting dries the sludge, decreases its volume and makes it better suitable for transport. Pelleting, however, does not make the sludge more hygienic or in any other way change its bacterial composition so usually the sludge must, before the pelleting, go through some kind of heating process.

4.4.3 Swedish technology solutions

The Swedish knowledge in sludge management is extensive and there are various Swedish companies that provide environmentally sustainable technology solutions for sludge management.

Ultrasonic treatment of sludge for biogas production
Ultrasonic treatment of sludge is used as a means to increase the biogas yield from the organic substrate. In the sludge some of the organic substrate is incorporated in cell structures and can therefore not be broken into smaller, soluble entities by the bacteria performing the hydrolysis. By pre-treatment using for example ultrasound, some of this organic matter can be released and made available for the digestive process which facilitates the hydrolysis and thereby shortens the hydraulic retention time. What happens is that the ultrasound causes short-lived cavitations to occur in the medium and when these cavitations implode the shear-forces cause the cells to disintegrate (Doverhög & Balmér, 2008). According to Scandinavian Biogas Fuels AB (2008) the ultrasonic treatment also enhances dewatering and prevents filamentous sludge bulking and foam formation.

Ultrasound has been used for pre-treatment of sludge in for example the wastewater treatment plant in Oskarshamn. The operation of the ultrasonic system has, according to Doverhög & Balmér (2008) been unstable but during some of the shorter operating periods a significant increase in the level of putrescibility was obtained, from 38-45% without the ultrasonic system to 55-59% with the ultrasonic system. The system is, however, sensitive to long fibres such as hair (Johansson, pers. com. 2008).

Ammonium reduction
Ammonium is a substance which is toxic to the digester bacteria and inhibits anaerobic digestion (see chapter on Toxicity) . The amount of free ammonia in the digester sludge is dependent on pH and temperature but the main factor determining the level of ammonium is the total nitrogen content in the sludge. For sludge which is high in nitrogen content such as from pig-farming and aviaries the ammonium toxicity can cause a severe reduction in gas production and prolong the retention time significantly and consequently has a negative effect on the economy of the production.

BioSystem AB (2004) has developed a technique for ammonium reduction of ammonium rich sludge where temperature is increased and pH on incoming substrates is increased by addition of slaked lime. Consequently ammonium in the sludge is turned into free ammonia (gaseous). The ammonia, as it is in a gaseous form, rises, is collected and led though a by-pass-pipeline directly to the sludge-rest storage. The ammonia is then dissolved in the sludge-rest and as the temperature and pH there is lower the ammonium is once again turned into ammonia. The technique both enables the digestive process to work better and the excess nitrogen to be returned to the sludge-rest to be used for fertilization. The ammonium reduction process is suitable for digestion of nitrogen rich sludge such as manure from pig-farming and aviaries and with this process it is possible to double the biogas production and run a stable thermophilic process with a retention time of only 3 days.

Sludge management with nutrient recycling
After anaerobic digestion of sludge there is still a large amount of residue. One technique that is still under development is a recycling process for the nutrients, nitrogen and phosphorus in the digester residue. Swedish Biogas International (Undén, pers. com. 2008) has a pilot facility for treatment of the residue where the aim is recycling of 84% of the nitrogen and 94% of the phosphorus. The nutrients are extracted from the residue either as incorporated in a dry soil which can be used directly as a fertilizer, or in a pure crystalline form.

The water which is extracted from the residue in the treatment process can be considered pure enough to be released into a recipient, but most of it will be reused in the biogas process. The soil residue product will be excellent for fertilization and with a dry residue content of 60% it is also economically and environmentally feasible for transport. The technology is mostly mechanical, will be mobile, and can be used on a small scale.

Sludge management – pelleting
Another sludge management process used at wastewater treatment plants in Sweden that is suitable both for digester-residue and other types of organic sludge is pelleting. Pelleting is a way of decreasing the volume of the sludge to make it easier to handle and transport. The pellets are made by first dewatering and then pressing the sludge though holes. UMEVA (2008) states that their pellets normally have a dry residue content of over 90%, whereof about 55% is organic matter. The high organic content and the fact that the nitrogen is organically bound make it very suitable for fertilization. The organically bound nitrogen makes is less sensitive to leaching and denitrification and gives a slow release of nitrogen that lasts for several years. One tonne of totals solids in the incoming sludge generates about 1.1 tonnes of pellets which is enough to fertilize about 0.25 ha of forestland.

Liquid biogas
Taking the sludge management one step further there are more environmental and efficiency gains to be made. By purifying the biogas produced from the anaerobic digestion, called gas upgrading, it can be used on the national gas grid or as a car fuel. There are several techniques to purify the gas from water, carbon dioxide and hydrogen sulphide. One of the newest and more interesting techniques is the use of a cryogenic (very low temperature) process where the different compounds are separated by a multi-step temperature decrease. There are three main advantages of this technique. Firstly, the process cleans the gas from siloxanes, a type of silicon oxide that damages the gas engines by abrasion. Secondly it removes the carbon dioxide from the biogas in a way that makes it possible to use the removed carbon dioxide directly as carbon dioxide ice or cooling medium in air conditioning. Thirdly the cleaned bio-methane leaves the process as liquid biogas. The advantages of liquid biogas are that it is more easily managed and transported and that its similarity to ordinary petrol makes it more consumer-friendly.

4.4.4 A Portuguese development project for sludge management

EDV Energia – Energy Agency of Entre o Douro e Vouga is an NGO with the goal of improving the environmental sustainability of the Entre o Douro e Vouga-region situated in the northwest of Portugal. The agency consists of the municipalities in the region as well as local companies, industries and organizations. One of the projects of EDV Energia is the planning of a co-digestion biogas production facility for a variety of waste and sludge from the region. According to the director of EDV Energia, Pedro Santos (pers. com. 2008) the final location of the facility is still under investigation. Therefore, there still remains an uncertainty in the specific amounts and types of substrate (presented in Table 7) which will be available for the facility. For this study however, it will still be a fair example of the benefits of a biogas production facility.

Table 7. Type of sludge, amount, and total solids content available for digestion in the EDV Energia co-digestion facility.

Type	Amount (tonne/year)	% total solids	Total solids (tonne/year)
Manure – cattle	77 100	22	17 000
Manure – aviary	3 200	60	1 900
Domestic sludge	1 200	5	60
Dairy production sludge	2 400	20	480

Using the gas energy yields in table 4, denoted Y, and the amount of total solids in table 7 denoted TS an amount of initial energy production in kWh, denoted E can be calculated for each substrate type. $Y \times TS = E$ gives the initial energy production. The different substrates are then summarized to obtain the energy production for the whole sludge composition. For the calculation it is assumed that the sludge from dairy production is made up of 50% protein and 50% fat.

However, there are a few more factors that must be taken into consideration when calculating the potential production of the facility. One is that some of the energy from the gas produced must be used for the internal heating of the system, in Swedish facilities the internal heating, denoted I, of the process normally consumes about 20% of the gas produced (Energimyndigheten, 2008). Hence I is assumed to equal $E \times 0.2$ and is subtracted from the initial energy production E. Another factor is that the combustion engines normally used for turning the biogas into electricity usually have efficiency, denoted Eff, of about 30-35% (Energimyndigheten, 2008). The initial energy production is, after the subtraction of the internal heating, multiplied with the efficiency $Eff = 0.35$. This gives the total energy produced, $E_{Tot.}$. Hence,

$$E_{Tot.} = (E - I) \times Eff = (E - 0.2E) \times 0.35 = (Y \times TS) \times 0.28$$

4.5 MANUFACTURING INDUSTRY WASTEWATER

4.5.1 Problem area

The main environmental concern with industrial wastewater treatment is the emission of heavy metals with wastewater and sludge. A major part of the small and medium size industries as well as some large industries are connected directly to the public sewage network without proper pre-treatment.

Lack of separation of industrial effluents, domestic effluents and stormwater arriving to the wastewater treatment plants often prevents the treatment from reaching the desired level, especially during periods of heavy rain. In general the worst water polluting industries are mechanical and electronic industries as well as some paper mills. The area most affected by industrial effluents is the area around Oeiras, Sintra and Cascais where effluents polluted by heavy metals are diffused through an off-shore discharge 3 km off the coast. Also the area of Setubal has difficulties with heavy metals from the automotive industry and manufacturing industry among others, with elevated levels of Chromium, Nickel and Zink in the sludge. Large investments have been made to realize off-shore discharge but as a method for wastewater management it is directly harmful as most of the wastewater discharged lacks proper treatment (Vitorino, pers. com. 2008).

The treatment in wastewater treatment plants without separation of industrial effluents is a problem since the industrial wastewater contains heavy metals which are toxic to the microorganisms in the active sludge of the treatment plant. Industrial wastewater has aggravated the problem with heavy metals, especially Cupper and Zink. These metals are already a problem because of excess and long term use of "calda bordaleza", a traditional fungicide with copper sulphate and lime, which has worsened by the introduction of copper sulphate into the fodder given to pigs. These factors are also creating a grave problem for the soils; more than 1 000 ton Cupper have been applied per ha and it is concentrated in the top layers of the soil (Vitorino, pers. com. 2008).

4.5.2 Remedial measures

The first and most obvious remedial measure would be to find a way to prevent illegal connections of untreated industrial wastewater to the domestic sewage and/or stormwater pipeline network. This might prove to be a difficult task since governmental regulatory bodies often are underfinanced and undermanned (Carreira, pers. com. 2008).

For the legally connected industrial wastewater the situation is more complex. According to Munter (1999) a combined municipal and industrial wastewater treatment is often most desirable but for a satisfactory operation of the common wastewater treatment process the industrial wastewater should be:

- as homogeneous in composition and uniform in flow rate as possible;
- free of excessive acidity or alkalinity and not high in chemicals that precipitate on neutralization or oxidation;
- practically free of antiseptic compounds and toxic trace metals;
- low in potential sources of high BOD, such as carbohydrates, sugar, starch, and cellulose; and
- low in oil and grease content.

For the industries to attain these water criteria pre-treatment is needed in most cases. Efficient treatment and potential for recycling is also greatest while the compounds are in high concentration and hence not after the wastewater has been diluted and mixed with other types of wastewater. For the Portuguese industries to reach a high level on treatment efficiency there should be a shift from end-of-pipe treatment to integrated process solutions enabling recycling of process chemicals as well as high-quality water purification.

4.5.3 Swedish technology solution

Wastewater treatment for industries and process-integrated recycling solutions are a wide product range where each specific type of industry requires specific techniques and solutions. It is an area that is difficult to generalize or present explicit technology solutions for. In general though, the Swedish technology is, as mentioned previously, strong.

4.6 PULP AND PAPER INDUSTRY WASTEWATER

4.6.1 Problem area

The pulp and paper industry generally have a long history of polluting rivers and coastlines. The main problems have been high amounts of organic matter in the effluent (expressed as biological oxygen demand – BOD, and chemical oxygen demand - COD) and a variety of chlorinated compounds (expressed as absorbable organic halogen compounds - AOX) (Danielsson & Ingman, 1999).

In Portugal there has been a massive improvement of the treatment of effluents from the pulp and paper industry in the last ten years, but some things remains to be done. The industry association claims that there have been no violations of effluent limit values from any of the pulp and paper mills, but the environmental protection organizations in Portugal still consider the industry to be among the worst polluters (Vitorino, pers. com. 2008).

There are, for example, according to the Portuguese pulp and paper industry association (Canaveira, pers. com. 2008) no plans at the moment to stop or reduce the use of chlorine bleaching. In the process of chlorine bleaching, a small amount of dioxin as well as different kinds of organic chlorides are formed; some for which the toxic effects are well known and documented and others of which the toxic effects are unknown (Thorén, 2001).

According to CELPA (2007), all the pulp and paper plants treat their own effluents and on average 70.3% of the effluents receive secondary treatment while 29.7% receive only primary. None receive tertiary treatment. One plant has its effluent connected to the same off-shore-outlet pipeline as the municipal wastewater treatment plant, but the water is treated separately. The off-shore discharge, as previously discussed, is not a beneficiary infrastructure solution for the environment. In some of the mills water is currently reused within other processes, but the concept of "zero discharge" (the equivalence of 100% water recycling) is considered unobtainable and is not even considered (Canaveira, pers. com. 2008).

Regarding environmental performance, the pulp and paper plants all abide with the IPPC Directive and have applied Best Available Techniques (BAT). Some production parameters such as COD and BOD are continuously monitored while others like metal content is sampled with specific intervals (Canaveria, pers. com. 2008).

4.6.2 Remedial measures

The main area in need of improvement within the pulp and paper industry is the use of chlorine bleaching (ClO_2). There are several alternatives to chlorine bleaching, such as ozone bleaching, modified cooking, and hydrogen peroxide bleaching.

Another area in need of improvement is the amount of water used in the production process. To achieve a higher level of recycling of chemicals, heat and energy and in order to minimize effluents and the level of pollution within these effluents, as much water as possible should be reused within the production process.

4.6.3 Swedish technology solutions

Because of the size of the Swedish pulp and paper industry, several companies have evolved in Sweden that are leading on pulp and paper mill technology for wastewater treatment and process optimization.

Some Swedish mills have achieved 96% water recycling (Danielsson & Ingman, 1999). One way to achieve that is through improved monitoring and online measuring systems, for which some Swedish firms supply state-of-the-art equipment. There may also be resource efficiency gains to be made within water use and recycling.

Alternatives to chlorine bleaching, such as ozone bleaching, modified cooking, and hydrogen peroxide bleaching, are all processes successfully used in Swedish pulp and paper mills (Danielsson & Ingman 1999).

5 RESULTS

5.1 MUNICIPAL WASTEWATER

Many municipal wastewater treatment systems are being built in Portugal at the moment and Swedish technology could be used to improve the performance of these plants. However, since the level of education in Portugal is very low compared to Sweden and labour is cheap, more personnel-intense low technology solutions are of greater interest than high technological solutions. For simpler products prices are very low and competition is strong and hence it is not a good market situation for the Swedish companies. For the larger wastewater treatment plants, though, more advanced technology may be of interest. Many are struggling to reach the effluent limit values set by the UWWTD with traditional techniques, and are in need of more efficient monitoring and control systems.

The kind of Swedish technology that would suit the Portuguese market are biorotors or other types of trickling filters, chemical dosage equipments, measuring equipment, and systems for automatic control and monitoring. These are products which Swedish companies are good at and which can still be sold at reasonable prices.

Biorotors are very suitable for the Portuguese climate; the high annual temperature gives good growth yield for the bacterial film on the rotors. Further, biorotors contain few components, are easily managed and work well on a small scale. Hence, biorotors are excellent for many of the small size treatment plants (2000 – 15 000 p.e.) that according to Decreto-Lei n.º 152/97 should be operating by the end of 2005 but are still non-existing or being planned. The insensitivity to high load also makes biorotors suitable for the many small towns along the coastline, which are overwhelmed by tourists in the summertime.

Automatic control systems for chemical-dosage and flux regulation as well as online monitoring systems are technologies that can help improve the nutrient reduction of the larger treatment plants to reach below EU effluent limit values. With these technologies it is possible to adapt the treatment to changes in the incoming wastewater almost instantaneously. This is especially important in Portugal as changes in both amount of inflowing water and its contents occur frequently and rapidly. The changes are due to the fact that there is no separation of stormwater and domestic wastewater, often causing flooding of the treatment plants, as well as the connection, legal and illegal, of industrial sewers releasing batches of wastewater with different contents.

5.2 SALINE WASTEWATER

With the increasing salinisation and deterioration of the soil there is a potential demand for desalination of wastewater for irrigation purposes. There are, however, no effluent limit values for salt on outgoing water and hence no legislation enforcing desalination. This further diminishes any incentive for installing desalination techniques as it, in comparison to other municipal wastewater treatment products, is not only non-profitable, at least in a short-term perspective, but also has no legislation enforcing it. The need for desalination of wastewater from an environmental perspective not to mention a future agro-production point of view is, nonetheless, obvious. In the long run an interest will have to develop as there are few other ways around the problem.

As the kind of small pore filters that are used for filtering of salt is used for other type of particles as well, especially within the industry, there is Swedish technology of high quality. However, because Sweden has quite vast resources of fresh water there have been no real incentives to create and develop products for desalination, but there are companies offering filters with different sizes and capacities.

5.3 PRIVATE WASTEWATER

In general people in the rural areas of Portugal are poor, which does not benefit the market for small scale wastewater treatment. However, EU restrictions on water use and wastewater treatment is continuously increased and Portugal will be required to abide with the regulations soon enough. In the long run there will most likely be an increase in demand for these types of products.

There is also a potential demand for private wastewater treatment on a “village scale” – from a few households to 1000 p.e. where municipal wastewater treatment is not sustainable but where a joint solution is better and more economically favourable than each household having its own. For this the sequencing batch reactors system would be ideal as the system is easily managed with a minimum of supervision. The simple construction also makes it economically favourable.

5.4 SLUDGE MANAGEMENT

There are three main reasons why biogas production would be an excellent match between Swedish technology and Portuguese need.

1. There is a great need in Portugal for environmentally sustainable sludge management; at the present sludge is mostly used for landfills or into the recipient causing eutrophication and disabling nutrient recycling.

2. There is a growing demand for renewable energy and biogas is a way of supplying it.

3. Sweden has a long history of biogas production and the Swedish companies have technology solutions that both increase biogas yield and live up to high environmental standards.

In contrast to the low production results the Portuguese interest in biogas production is very large. The interest is due to both a general public worry about climate change boosting interest in renewable energy and EU Directives demanding improved wastewater treatment, including sludge management. Portugal’s energy goal to increase the share of renewable energy, as well as the rocketing oil price, is also a contributing factor. Many Portuguese companies are interested in biogas production and in getting into the renewable energy market. There are also university programs aimed towards developing the biogas market in Portugal.

Ultrasonic treatment of sludge before anaerobic digestion is typically the kind of leading-edge technology that is missing in Portuguese sludge management. There are anaerobic digesters in operation but the processes are not in any way optimised. The technology can be used to increase gas yield and hence the economy of the production process. The ultrasound technology does have one drawback that could possibly decrease its popularity and that is the fact that it includes high-technological equipment that may be difficult to manage and which also makes it somewhat unstable.

Sludge ammonia reduction is another much needed process optimisation method and it is one that will most likely be easy to implement and therefore more successful. The reason is its simplicity. Heating, liming and by-passing of ammonia-fumes are easy concepts that do not require advanced technological devices to work. Although the theory behind the method is fairly complex the actual performance of it is simple.

The nutrient recycling technology with its residual water treatment and fertilizer production is also beneficial for the environment and likely to be a preferred solution. The apparatus work on all scales and is a simple, user-friendly device, which will be possible to rent. If the product become reality it would be ideal for the Portuguese market where simplicity and availability is of importance.

Making pellets from sludge or sludge-rests is also a fairly simple technique which could be easily adapted and used at Portuguese wastewater treatment plants. The pellets made are easy to transport and could be used as fertilizer in the areas where it is really needed and not only in the close proximity to the wastewater treatment plant. The technology makes it possible to return the nutrients to their origin and at the same time reduce the environmental stress the sludge is currently casing when dumped on landfill or into lakes, rivers or the ocean. The slow nutrient release from the pellets also makes it extra favourable in Portugal. The country often suffers from heavy rain and hence a high degree of leaching. The slow release of nutrients compared to artificial fertilizers makes it less prone to cause leaching of nutrients and hence lessen the eutrophication burden that fertilizers normally exert.

Making liquid biogas or, as part of the process, cleaning biogas for fuel usage or gas-grid injection, is an advanced technique and requires large investments. There are large gains to be made from implementing the technology, both economical and environmental and this is the reason the technique is popular, and constantly expanding, in for example Sweden. However, using biogas, in its liquid or solid form, for fuel purposes requires extensive investments in new infrastructure. Such an investment might very well be possible in the future but it also requires access to fairly large amounts of biogas for the system to become sustainable. At the time being the gas production in Portugal is not large enough to sustain such a system though the potential exists. In the mean time, while the production hopefully increases, the gas should be injected to the gas grid. The gas grid is an existing infrastructure, ready to be used and the gas only requires up-grading. The biogas can then be used as a substitute for some of the imported natural gas with a significantly higher effect than what can be obtained when it is combusted in a gas engine and used for electricity production.

Thermophilic anaerobic digestion is a technology that is more and more used in Sweden. The reasons for its current popularity are its high gas yield and short retention time, allowing smaller reactor volumes. The largest benefit of thermophilic anaerobic digestion compared to traditional mesophilic anaerobic digestion is the high digestion temperature. The high temperature in the process qualifies as adequate hygienisation and there is no need for pre-heating the sludge in order to kill potential pathogens. However, the thermophilic anaerobic digestion process is more sensitive and hence more technically challenging than mesophilic anaerobic digestion.

The production of the anaerobic digesters would definitely benefit from the increase in gas yield that would be gained if the mesophilic digestion was replaced with thermophilic digestion. Unfortunately, the more sophisticated technology which is needed for this may pose a problem for the rather low level of education among the personnel in Portuguese plants. Moreover, since there is no legislation requiring that the sludge is hygienised before it is spread on fields as fertiliser, there is no need for the higher temperature of the thermophilic process.

One factor in favour for the thermophilic process in Portugal is the climate. The average temperature during some summer days exceeds 40°C which means that the digesters will have to be insulated when mesophilic anaerobic digestion is used, or the process would be inhibited due to the digestion temperatures being too high. With thermophilic anaerobic digestion, the temperature would not be a problem but rather an advantage. This would also be sustainable for the future, as the average outdoor temperatures are not expected to fall, but increase due to climate change.

5.4.1 A Portuguese development project for sludge management

The potential energy production for the proposed biogas production facility of the Entre o Douro e Vouga Project has been calculated and is shown in table 8.

Table 8. Potential energy production calculated from sludge total solids amounts and energy yield per amount of total solids

Type of substrate	Energy produced (kWh)
Manure - cattle	8 100 000
Manure - aviary	1 500 000
Domestic sludge	27 000
Dairy production sludge	970 000
Total	11 000 000

The total production potential for this facility with a standard production process would be 11 GWh. This is close to the production of an average co-digestion facility in Sweden which produces about 12 GWh and would indicate that the facility is a relatively good one. However, both the calculation and the data used contain several uncertainties.

To start with the percentage of totals solids in the data supplied by EDV Energia appear to be high which perhaps gives gas production values that are on the high side. For example cattle manure which is normally considered to have a total solids content of 6 - 8% (BioSystem 2004) is said to have a total solids content of 22% and aviary manure 60% while normally 30% would be expected.

On the other hand the gas yields for each substrate was used although typically the *co-digestion effect* increases the yield above the sum of the yield of the individual substrates different substrates are co-digested. Neglecting the co-digestion effect indicates a lower production than what would be found in reality. Further the assumption was made, since the composition of the dairy production sludge was unknown, that the sludge total solids consisted of 50% protein and 50% fats. If this was an assumption that is indicating a too low or too high production value is impossible to tell without knowing the actual composition of the sludge. Finally it was assumed that the energy used for internal heating is the same in Portugal as in Sweden. As Portugal has yearly average temperature that is significantly higher than Sweden it can be assumed that less energy is needed for internal energy and that the total energy production hence should be larger. How much larger is however, difficult to tell. Information on one of the few existing larger biogas facilities in Portugal (Fonseca, pers. Com. 2008), says that Espinho, a facility near the potential location of the facility of EDV Energia, runs a mesophilic process where no internal heating what so ever is required for on average two months per year when the outdoor temperature in high.

Possible improvements
The calculation of the potential energy production is an example of what typically could be produced form a biogas facility. However, if the facility was to be built with some of the special technologies mentioned in paragraph 4.4.3, both the energy production and the environmental gains could be increased substantially.

Since about 10% of the sludge for the facility is aviary manure which is high in nitrogen compounds it can be assumed that the digestion process would be inhibited by free ammonium. If the ammonium removal technique was applied the inhibiting factor of the ammonium would be reduced and the gas production increase. If it is assumed that, as stated, the gas production can be doubled, even for just the substrate that has the high nitrogen compound content, the aviary manure, total gas production would increase by 14%.

Pre-treatment of the sludge with for example ultrasound would also increase the level of putrescibility and hence the gas yield, how much depends on the type of sludge. The ultrasonic technology is sensitive to sludge containing long fibres such as hair, a frequent constituent of domestic sludge. Since domestic sludge is only a small part of the total amount of sludge, in this case, the sensitivity should not pose any problem.

However, the greatest gain to be made is where the greatest losses are in a normal facility and that is in the conversion of biogas to electricity. As the typical efficiency of a gas combustion engine is 30% about 70% of the energy is lost in the conversion process. Using gas purification and upgrading to either car fuel use or for injection on the gas grid increases the efficiency greatly. To use biogas as car fuel requires logistics and an infrastructure that is lacking in Portugal at the moment. However, injecting the biogas produced in the gas grid, which is national in Portugal as gas is used for cocking and heating in almost all Portuguese homes, is simple. As the infrastructure already exists and biogas is generally cleaner than natural gas, it is easily connected to the gas grid and when used for heating the efficiency is almost 100%.

Using for example the technology for nutrient recycling from Swedish Biogas International the environmental benefits could also be large compared to the normal Portuguese standard of dumping sludge in landfills as the process not only recycles the nutrients but also cleans the water extracted for the digester-residue. Equivalently using pellet production would produce fertilizer enough for roughly 5300 ha of forestland.

5.5 MANUFACTURING INDUSTRY WASTEWATER

There are most certainly areas in which Swedish technology solutions can help improve the wastewater treatment in the manufacturing industry, which is one of the worst polluters in Portugal. However, the manufacturing industry is a very large and multifaceted sector, and each type of industry need different types of solutions. To suggest technology for each type of industry wound require an extended study and this was not feasible within the timeframe of this project.

Nonetheless, it can generally be concluded that as heavy metals are considered a common factor and the greatest environmental threat from the manufacturing industry wastewater reducing heavy metal levels should be a priority. For reducing heavy metals content in water there are different separation technologies and as Sweden has a lot of manufacturing industries Swedish companies have several options to offer. The most efficient approach used in many Swedish industries is to re-circulate as much water as possible within the production process.

The demand for wastewater treatment technology from the Portuguese manufacturing industry is not large at the moment. Until stricter legislation is adapted and the level of environmental control of the industry increases there is not likely to be any increase in demand. The Portuguese authorities are putting more effort into control however and as the requirements from the IPPC Directive increase the industry will soon be forced to improve their wastewater treatment creating a demand for better and more environmentally sustainable technology.

5.6 PULP AND PAPER INDUSTRY WASTEWATER

The pulp and paper industry is the industry with the greatest expenditure on wastewater treatment technology. The investments that have been made during the last few years have had one major objective and that is to meet the terms of the IPPC Directive. However, at the moment the main environmental focus of the pulp and paper industry, as well as of the rest of Europe, is climate change and hence air pollution. This is of course resulting in a downward trend for the willingness to invest in wastewater treatment. However, EU effluent limit values are not likely to remain on current level and the Best Available Technique is continuously improving, which increases the pressure on the pulp and paper industry to improve as well. This means that even though there is a decrease in expenditure at the moment, the trend is likely to change and there is most likely future business potential for Swedish technology.

Rather than to try and refine the wastewater treatment of outgoing water the primary focus for the pulp and paper industry in Portugal should be to improve the water recirculation. This is necessary both to decrease the environmental impact of the discharge and to maximize reuse of chemicals and energy efficiency. For this purpose the monitoring and online measuring systems used in the Swedish pulp and paper mills are ideal.

6 DISCUSSION

Portugal is a member of the European Union and should act up to the same Directives as the rest of Europe. EU Directives are also readily implemented, but that does not mean that they are also complied with. The preparations for the necessary changes following the implementation of a new directive do often not start until after the implementation has already been done. Oftentimes the control of the compliance is inexistent and both personnel and economic resources are scarce within many areas of environmental control. This of course affects demand for environmental technology negatively, as there are no incentives for or pressure on the municipalities and industry to invest in more sustainable technology.

A common problem in Portugal that has not only caused difficulties in gathering data for this study, but which is also a major problem in the strive for improved wastewater treatment, is the lack of a control function. The administration meant to supervise wastewater treatment does not have a functioning system in place. There is no administrative body with a complete overview of the system and the national information database and the sub-divisions work separately with incomplete information exchange in between them. This has made it more difficult both to attain an insight into how the wastewater treatment system works and to find out what the environmental status of the country actually is.

The questionnaire sent out received a low number of answers. As the questionnaire did not have any statistical purpose but only served as an aid in the search for information the low number of answers did not pose a direct problem for the study. Most of the information sought was included. However, as some of the questions were more opinion-based a larger number of answers could have provided a broader base for the conclusions drawn and possibly provided some new aspects.

Most facts not obtained from interviews and questionnaires have been gathered from environmental organisation reports and the few governmental inspections and surveys that have been made. It should be noted that these surveys and inspections are not in any way comprehensive, but based on samples. At the moment, the main focus is to improve the municipal wastewater treatment. The reason for this is, as expected, the bad state of the municipal wastewater treatment, but also the vast EU-funding which is available for this type of projects.

Gathering data about the industry was equally if not more challenging. In general it proved to be very difficult to get in contact with and obtain information from the various actors within the industry sector. Most of the gathered data are therefore derived from external sources and general statistics. One example which illustrates these difficulties is the manufacturing industry. It is a severely polluting industry, but since the sector is so diverse and specific information so scarce it was impossible to draw any conclusions on which Swedish technology would be suitable. It could however be an excellent area for further studies, as there is most likely large environmental gain to be made from improved wastewater treatment in this sector. Especially the tanning industry with its high level of heavy metals in the effluents would be interesting to further investigate.

The Entre o Douro e Vouga Project provides an interesting example of an ongoing biogas project in Portugal and how it can be improved by Swedish technology. Unfortunately, the data from the project contains many uncertainties and it is therefore difficult to predict what the final outcome will be. There are uncertainties both in the amounts and the types of substrate and in other process data. Nonetheless, the calculation serves as an example how it could be done if correct and complete data had been obtained. The calculation also shows how something previously discarded as a waste and a burden can, with the right technology, be turned into a profitable business.

7 CONCLUSIONS

There are many Swedish technology solutions that would work well in Portugal and these can help to decrease the environmental pollution caused by improper or inexistent wastewater treatment.

Generally, it can be said that simple straightforward technology is more accepted on the Portuguese market but that the competition is large and prices are generally low. More technologically sophisticated products can be sold at higher prices, but will be subject to a much lower demand.

Examples of products and technologies that would sell well in Portugal are small and medium scale wastewater treatment equipment such as compact treatment plants, biorotors and other trickling filters and sequencing batch reactors. In the more advanced categories, automatic control-, measuring- and online-monitoring systems for large municipal wastewater treatment plants and industries would be suitable for export.

There are also a few areas where Swedish technology solutions could really improve the environmental (and in the long-run also the economical) situation in Portugal, but where the interest simply has not developed yet. One such area is the desalination of wastewater intended for irrigation purposes.

Within sludge management there are Swedish products and techniques that would suit the Portuguese market very well. Especially within biogas production, the Swedish knowledge on process improvements and production increase is unique. Since biogas production is a win-win situation with both environmental and economical gains to be made, it is likely to continue to grow in future years and Swedish export potential with it.

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ANNEX 1 – QUESTIONNAIRE SENT TO PORTUGUESE WATER AUTHORITIES AND ENVIRONMENTAL ORGANISATIONS

Questions on general environmental problems with Wastewater treatment in Portugal:

- Where are the greatest pollution problems? Industry or public waste water treatment?
- What are the greatest pollution problems? To what extent?

  1.1. Nutrients causing eutrophication
  1.2. Metals
  1.3. Other organic pollutants, organic chlorides, pathogens etc.
  1.4. Colorants and suspended matter
  1.5. Other

- Which industries are the greatest polluters to recipient?
- To what extent does the industry treat their own waste water, partly or none at all, how much is connected to public wastewater treatment plants?
- Is there a monitoring program and how does it work? Self-monitoring etc.
- To what extent are the problems hidden? Illegal dumps, manipulation of test results etc.
- What is the nutritional status of the soil? Are fertilizers necessary, is sludge being used as fertilizer?
- Within what areas have investments been made, have those investments contributed to better treatment, and where will the future investments be made?
- Does the shortage of water in some regions affect the wastewater treatment? Are any changes expected in the future?
- Are there any regulations on wastewater treatment from private homes, i.e. on the countryside?

Municipal WWT

1. What legislation regulates WWT on EU and national level?
2. What areas do the laws regulate specifically?
3. To what extent are the discharge limit values allowed from municipal WWT plants maintained? Living up to the 10mgN/l?
4. How is the system regulated? (On national, regional, and municipal level)
5. Are there incentives to improve quality of effluent water?
6. Are there subsidiaries and how are they distributed?
7. Are there any other means to improve discharge water quality?
8. Are there any plans to improve water legislation?
9. What is the situation for stormwater, from precipitation?
10. What is the situation for residual water from landfills (águas lixiviados?)
11. What is the situation for sludge management?

Industrial WWT

1. What legislations regulate WWT for the industry?
2. What areas do the laws regulate specifically?
3. What requirements are there on the industry to treat their effluents?
4. Under Decreto-Lei n.º 152/97, de 19 de Junho, it is stated that industrial wastewater must be pre-treated not to harm recipient, workers or plant, to what extent more specifically? Norms?
5. Is the industry complying with the terms of the legislation? Which industries are not? In what way?
6. Is there a monitoring program and how does it work? Self-monitoring etc.
7. Are there incentives for the industry to improve their WWT? Fines for not reaching norms?
8. Are there any subsidies to encourage improvements of the level of treatment?
9. Are there any plans to increase requirements on level of treatment
10. How is the industry coping with the part of the IPPC- Directive that is active from 30th of October 2007? Are the transformation surveyed?