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Energy Benchmark for Wastewater Treatment Processes

- a comparison between Sweden and Austria

Malin Jonasson

Dept. of Industrial Electrical Engineering and Automation
Lund University

Department of Industrial Electrical
Engineering and Automation

Faculty of Engineering
Lund University

Department of Environmental
Engineering

Faculty of Civil Engineering
Univerity Innsbruck

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Supervisor: Prof. Bernhard Wett, University Innsbruck
Dr. Ulf Jeppsson, IEA, Lund University.

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Abstract

International benchmarking can be used as an important tool to improve energy efficiency for wastewater treatment plants. In Austria, continued benchmarking has resulted in decreased electrical energy costs by 30 %. A similar study has recently been carried out in Sweden as well. Due to increased energy consumption combined with rising energy prices the Swedish Water & Wastewater Association initiated an energy saving program. The objective of the project was to survey the energy usage and from that determine where energy usage can be decreased. International studies show that Sweden is using more energy than many other countries in wastewater treatment processes.

This thesis is a benchmark study between WWTPs in Sweden and Austria with focus on energy consumption. Input data from previous studies carried out in both countries has been evaluated and compared. The potential of energy self-sufficiency in wastewater treatment plants is also discussed.

The results from the energy benchmark study shows that Swedish WWTPs uses approximately 45 % more electricity compared to Austrian WWTPs. Hence, potential for energy savings in Swedish WWTPs is high.

Keywords: Benchmark, wastewater treatment plant, biogas, electrical and thermal energy.

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Malin Jonasson

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1 Introduction

1.1 Background

Due to a growing water demand and increased energy consumption the European Union demands energy saving programs for wastewater treatment plants (WWTPs). The International Water Association (IWA) has put together a task group on benchmarking of control strategies for WWTPs. Since the 1990´s benchmarking processes have been used between countries and organisations in the wastewater treatment sector.

A natural monopoly in the public water supply system contributes to limited competition. Along with a growing population, the water supply sector has to ensure sustainability of existing and new services. High quality is always first priority of the effluent water. Global warming and need for reduced CO_2 emissions places pressure on wastewater treatment plants to improve and develop more energy efficient technologies, and still remain high water quality.

To improve energy efficiency and the quality of service an international benchmarking system can be an important tool. By comparing different processes and by learning from the best, improvements can be achieved and energy efficiency increased. Continued benchmarking studies between WWTPs have resulted in decreased energy consumption (Wett *et al.,* 2007).

In Austria, a benchmarking program started up on the basis of the efficiency and quality study of water supply in Bavaria, called EffWB. The Austrian Association for Water and Waste (OWAV) covers approximately 40 % of the wastewater treatment sector in Austria with their annual benchmarking study over energy consumption in the wastewater facilities. The Swedish Water & Wastewater Association, SWWA, has performed a similar study recently in Sweden. International studies show that Sweden is using more energy than many other countries in wastewater treatment processes. Hence, potential for energy savings in WWTPs is high.

1.2 Objectives

The main objective of this thesis is to compare the energy consumption in wastewater treatment plants in Austria and Sweden. From statistical data and previous benchmarking studies costs and energy usage for every treatment process can be determined.

By doing a benchmarking study, conclusions can be drawn as to where improvements can be implemented for more energy efficient processes.

Comparing two countries, valuable knowledge and experiences can be exchanged for a positive development in the WWT sector. In this thesis information and practices from two different countries is put together for a cross-boarder exchange. The results of the thesis are of importance for further international cooperation and for the development of more energy efficient WWT processes in Europe.

When discussing energy consumption in a WWTP it is also interesting to see how the biogas is being used. The anaerobic process in a WWTP has the advantage as an energy producer. The biogas produced, in most cases, can contain enough energy to heat up the whole plant. Therefore, another objective of the thesis is to compare the biogas production and its usage for both countries.

The results of this thesis will lead to a better understanding of energy consumption in wastewater treatment plants and more energy efficient wastewater treatment systems. Moreover, it will recommend solutions on how to improve the energy efficiency.

1.3 Delimitation

A comparison between the Swedish and the Austrian benchmark study meant a configuration of the input data and given variables. In the Swedish study all records where in Watt units, meanwhile the OWAV had valued all their energy costs in Euro. Therefore, to avoid problems that can occur by comparing costs between different countries, e.g. differences in tax-legislation, tariffs, etc., Watt-hour (Wh) will be the unit presented in this work. In addition, data in the two studies were not based on the same processes. In Austria, the study was focused on the differences in costs between every individual process in the plant, whereas the Swedish Water study did a more overall comparison of the energy usages in the treatment plants.

In Austria, secrecy is valued high in governmental reports. Their benchmarking study was anonymous, whereas in Sweden, it is public information. Confidentiality is a problem for the work of the thesis. It is also a problem for the whole European Union, which is working towards an open market with a strong international cooperation. Official secrecy in one country can lead to an outsider position in international development.

In the study made by the Swedish Water and Wastewater Association data from two separate studies were used. By extrapolating data provided from each study based on total water consumption in Sweden, both studies indicate similar results. The extrapolation, along with a probability of incorrect input data, was estimated to give a margin of error of approximately 10 %.

Only data from one group in the Austrian benchmarking study is used in this thesis. The study group taken into consideration is the one with the largest wastewater treatment facilities in Austria (>100 000 pe). To be able to make a comparison between the two countries, data from the Swedish study was also reduced; showing results from only the largest wastewater treatment plants.

1.4 Target group

This report is written with the purpose of being read and used by people working at WWTP and also for members of water associations and authorities in both Austria and Sweden who are working with benchmarking. Moreover, the thesis can be comprehended by engineering students and researchers or by people with an interest in energy and environmental issues.

1.5 Methodology

The author of the thesis is a civil engineer master's student at the Faculty of Engineering, Lund University, Sweden. Supervisor for this thesis is associated professor Ulf Jeppsson, head of the Industrial Electrical Engineering and Automation (IEA) department in Lund. At the IEA department research projects regarding energy efficiency in wastewater treatment processes are progressing and many international projects have been carried out. IEA has a great international co-operation, e.g. with universities in Austria. The thesis was written at the Leopold-Franzens University in Innsbruck, Austria, under supervision of Prof. Bernhard Wett. Among many prominent research projects, Prof. Bernhard Wett has done a case study on the energy efficiency of the Achental-Innertal-Zillertal WWTP.

Data for the thesis was collected from interviews at the WWTP in Zillertal. Statistical data were provided by personnel at ARA Strass WWTP by help from Prof. Bernhard Wett. Mr. Hans Bäckman at Swedish Water provided the Swedish data. To understand and to be able to draw correct conclusions regarding the data contents Mr. Mats Lundkvist at Sweco VIAK, Sweden, was a big asset.

1.6 Outline

The introduction chapter is followed by a discussion of constraints and different processes in wastewater treatment plants in Sweden and Austria. Furthermore, in Chapter 2, wastewater characteristics and temperature, and also requirements on effluent water quality and applied technologies will be described. To create understanding for the topic of the thesis the energy consumption in the wastewater treatment process will also be discussed in Chapter 2.

In Chapter 3, benchmarking processes will be described and their importance for the improvement and development in the wastewater sector discussed.

Furthermore, there will be a discussion of the benchmarking studies done in Sweden and in Austria, as well as in other countries around the world. The results from the two main studies will be presented in Chapter 4, with focus on energy consumption in WWTPs.

By using a general flow scheme of the energy balance in a WWTP the differences between the studies will be presented in Chapter 5. Moreover, potential energy saving approaches will be discussed, with given examples of different technologies.

A case study of the WWTP Strass in Austria will be presented in Chapter 6. A review of the efforts related to energy efficiency carried out at this plant during the last ten years will be presented. The case study will present the motives and the results of the energy saving measures; what it has led to and what is planned for the future. Furthermore, there will be a comparison between the conclusions drawn from the benchmarking studies done in Sweden and in Austria.

The results and conclusions of the thesis will be summarized in Chapter 7.

2 Legislation and technologies in WWT

Depending on pollution grade of the wastewater, population equivalent[1], size of the plant, etc. the technologies in wastewater treatment differ between plants and geographical locations. In this chapter, the most common wastewater treatment processes, in Sweden and Austria, will be introduced. Furthermore, there will be a description of the wastewater treatment legislation in Sweden and Austria, respectively. Consequently, there will be an introduction regarding the energy consumption for different treatment processes and a review of energy and wastewater treatment plants interaction in the society.

For a better understanding of the design and functionality of a wastewater treatment plant, this chapter begins with a description of the constituents in wastewater, on the basis of Sweden and Austria.

2.1 Wastewater characteristics and temperature

Wastewater consists of physical, chemical and biological constituents. Physical constituents are suspended solids. Other physical constituents are colour, temperature, conductivity and density. Suspended solids are partly removed at the inlet of a plant and if they reach a natural water environment, sludge deposits and anaerobic conditions can occur (Metcalf & Eddy, 2004).

2.1.1 Temperature

The temperature of the wastewater plays an important role in the treatment process, because it has an effect on gases, chemical reactions and biological activity. Bacteria in wastewater have a growth rate proportional to increased temperature. The temperature of wastewater varies due to geographical location, but another important variation factor is the condition of the system. An old and worn out system with high in-leakage has lower temperature than a well-functioning system. The Swedish wastewater temperature varies from 7-8 °C in February and March to 17-20 °C in August and September (SWWA, 2005). The influent wastewater temperatures are similar in Austria, where the variation is between 8-18 °C over the year, according to the provincial government of Tirol (Kläranlagenkaster, 2004). Hot water from households and industries makes the influent wastewater temperature relatively high,

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[1] One population equivalent, pe, is the reference- and mean value for the water usage and pollution in the wastewater caused by one person in one day, and is found by measuring the organic matter.

normally higher than the air temperature. Optimum temperature, for biological activity is between 25 to 30 °C (Metcalf & Eddy, 2004).

2.1.2 Organic and inorganic matter

Chemical constituents are divided in organic and inorganic matter. Organic compounds originate from carbon, hydrogen and oxygen, and sometimes nitrogen. Organic compounds take forms of protein, carbohydrate and fat. It is of great importance to remove the organic matter from the effluent water. If organic matter reaches the environment, natural oxygen resources can be depleted and septic conditions can develop (Metcalf & Eddy, 2004).

Inorganic chemicals include nutrients, non-metallic constituents, metals and gases. If nutrients, such as nitrogen and phosphorus, are released in water they stimulate growth of aquatic plant life. For example, in Sweden over-fertilisation and excessive algae growth caused by nutrients in the aquatic environment is a major problem, especially in the North Baltic Sea.

Biological characteristics in wastewater are organisms that can cause epidemics for humans, when not treated. Micro-organisms are bacteria, algae, fungi, protozoa and viruses. In higher temperatures bacterial growth is better stimulated and is therefore a larger problem in warmer countries (Metcalf & Eddy, 2004).

2.1.3 BOD and COD measurements

The characteristics of the wastewater change depending on season, temperature and flow volume. To be able to optimize the treatment process it is essential to take frequent samples to find representative average values for the wastewater characteristics. To determine the organic content in the wastewater, the biochemical oxygen demand, BOD, or the chemical oxygen demand, COD, is normally measured.

In a BOD test the dissolved oxygen concentration in the wastewater is determined and the sample is stored during a five or seven day period of time. BOD_5 is most common in Austria and around the world but in Sweden the BOD_7 test is used. The relation between them can be determined as $BOD_5=60/70*BOD_7$ (Kjellén and Andersson, 2002). The oxygen in the sample is degraded by microorganisms. The difference in the oxygen concentration at the beginning and the end of the test period gives the BOD_5 or BOD_7 value. The BOD test measures the biochemical degradation of organic matter (Gujer, 2002).

The COD test oxidizes both biologically degradable and non-biologically degradable organic material by adding an oxidizing agent, normally potassium dichromate ($K_2Cr_2O_7$). The COD test determines the energy released due to oxidation of the carbonaceous compounds. The COD test requires only 2 hours and is a more precise estimation of the organic content than the BOD test (Novotny, 2006).

2.1.4 Typical wastewater characteristics

The energy balance in a wastewater treatment plant is depending on the characteristics of the influent wastewater and removal requirements. More restricted emission requirements of the effluent wastewater leads to higher energy consumption in the treatment process (Ulf Jeppsson, 2007). The characteristics of the influent wastewater for a typical plant in Austria and Sweden are given in Table 2.1 below. The influent wastewater volume is calculated and determined in litre per population equivalent. To give a good representation for both countries the population equivalent is based on COD tests with a specific load of 110 g per day and person. A more profound discussion about organic load will be given in Section 4.1.

Table 2.1 Characteristics of influent wastewater to WWTPs in Austria and Sweden.

Parameter	**Austria**[2]		**Sweden**[3]		**Ratio A/S**	
Influent flow rate	210 l/pe, day		242 l/pe, day		0.87	
Unit	**mg/l**	**kg/pe, day**	**mg/l**	**kg/pe, day**	**mg/l**	**kg/pe, day**
BOD_5	291	0.0611	176[4]	0.0426	1.66	0.70
COD	547	0.115	473	0.114	1.16	1.00
Total nitrogen, N	44	0.0092	40	0.0097	1.10	1.05
Phosphorus, P	7.5	0.0016	6.4	0.0015	1.18	0.98
Ammonia, NH_4-N	26	0.0056	24	0.0058	1.08	1.06

For input data and calculations for Table 2.1, see Appendix I. As can be seen in Table 2.1, the Swedish influent wastewater is more diluted than the Austrian. This means that in Sweden more water is used per person and day and the hydraulic load to a wastewater treatment plant is larger per inhabitant. When the influent wastewater is more polluted it is often easier to make the treatment process more efficient, due to higher concentrations of the organic load. The reason for higher influent volumes in Sweden might be differences in precipitation or that Austria uses more separated pipe systems than Sweden. In separated pipe systems rainwater is lead out to the aquatic environment without treatment.

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[2] Values are based on weekly measurements; data from the provincial government in Tirol, 2004.

[3] Mean values measured on basis of Environmental reports from larger WWTPs in Sweden, 2005.

[4] In Sweden the degradation is calculated during a 7-day period. $BOD_5=60/70*BOD_7$ (Kjellén and Andersson, 2002)

For a comparison between the two countries, it is also of interest to see the ratios between the key parameters in the influent wastewater. A more detailed discussion about the influent wastewater characteristics will be given in Chapter 4.3 where the ratios are more analysed in relation to energy consumption.

2.2 Wastewater legislation

Primarily, wastewater treatment processes are operated to remove water pollutions. Along with concerns about the impact from greenhouse gases, the wastewater treatment sector has to meet higher requirements on air emissions from the treatment process. This has lead to new technologies in wastewater treatment with another focus on energy efficiency (Wett *et al.*, 2007).

Effluent wastewater legislations affect the organization and operation of a WWTP and what is prioritised. In Europe, the effluent wastewater quality is legislated by the EU Urban Wastewater Directive (91/271/EEC). The Directive was made to protect the environment from pollutions from industries and sectors with high organic load (Benedetti, 2006).

In Sweden, every wastewater treatment organisation has to write an annual environmental report according to the Environmental Code (1998:808). In this report, technical data, operations and restrictions are described.

According to the European Union, Sweden has a more sensitive aquatic environment and need to lower its threshold values for nitrogen emissions. Although Sweden has implemented nitrogen removal in WWTPs along the North Baltic Sea, the Swedish government has been penalised by the European Union in December 2006. Sweden has to improve their measures for the algae prevention even more (SWWA, 2007).

In Sweden and Austria, the water supply and wastewater treatment is owned and operated by the local government or municipality. The wastewater management is independent and the costs are covered by consumers' fees, determined by the municipality, and in some cases also taxes. In Sweden, during the last ten years this traditional way of organising the water supply sector has changed by the introduction of co-operations between communities and private companies. This does not affect the effluent water quality, which is legislated in the Environmental Code from 1998.

In Austria, the wastewater treatment is only operated by public owned facilities. Sometimes industries treat their waste in a separate process before the wastewater ends up in a public WWTP.

Sweden is divided into counties and it is up to every administrative board in every county to set the emission levels for each plant located in the specific county. Values vary depending on how sensitive the location of the WWTP is and how many pe are connected. Therefore, the emission legislation values vary from plant to plant. Typical emission legislation values are given in Table 2.2. Normally, the higher the pe the stricter the directives are (SWWA, 2005). In Table 2.2, values from only larger plants have been taken into consideration.

Table 2.2 Emission legislation values in mg per litre water for WWTPs in Sweden and Austria compared to Europe.

Parameter	**Austria**[5]	**Sweden**[6]	**Europe**[7]
BOD_5	15 mg/l	10 mg/l	25 mg/l
COD	75 mg/l	70 mg/l	125 mg/l
Total nitrogen, N	≥70%, T>12 °C	10 mg/l / ≥70%	10-15 mg/l, (70-80%)
Phosphorus, P	1-2 mg/l	0.3-0.5 mg/l	1-2 mg/l
NH_4-N	5 mg/l, T>8 °C	10-15 mg/l	15 mg/l

From Table 2.2 it can be seen that when the temperatures are increasing over 8 °C the ammonium nitrogen removal in Austria is more restricted. Nitrogen emissions accumulate in the environment and therefore, the emission discharge is set to an average limit of 70 % in Austria.

The values in Table 2.2 vary from plant to plant. This variation leads to differences in the wastewater treatment process and as a result, also different energy consumption depending on to which the wastewater needs to be treated. This knowledge is important to consider when comparing different plants and their energy consumption. This will be further discussed in Chapter 4; Energy benchmark for Sweden and Austria.

2.3 Applied technologies for WWTP

Considering the significant differences in technologies depending on WWTP size, the focus of this thesis in on the larger plants (>100000 pe). In this section, technologies typical for Swedish and Austrian wastewater treatment will be described.

2.3.1 Physical treatment

In wastewater treatment, physical, biological and chemical techniques are used. Influent wastewater to a WWTP comes normally by self fall through a screen where suspended solids are partly removed. Next step in the physical treatment

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[5] Values from: *AEV für kommunales Abwasser,* May 1996.

[6] Emission legislations given in Environmental reports from larger WWTPs in Sweden.

[7] Benedetti, p 25, 2006.

is the primary sedimentation, including a sand trap and a grease trap. See Figure 2.1 for a plant layout. The slow motion of the wastewater makes large particles sink to the tank floor, while grease float up on the water surface. This separation method makes it possible to further remove unwanted material. Oxygen might be added to make grease removal easier.

Figure 2.1 illustrates a typical plant layout for an Austrian WWTP with a population equivalent around 100 000.

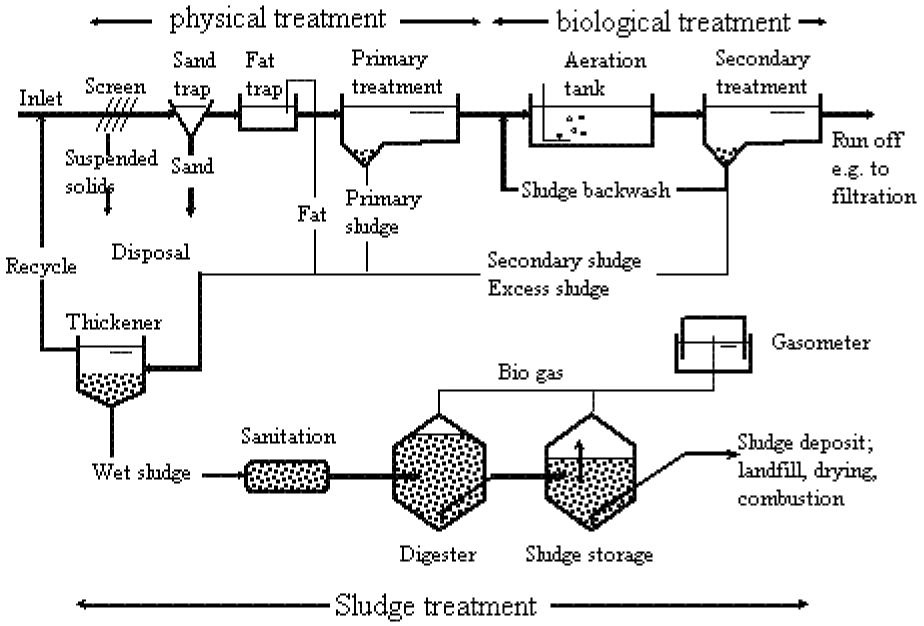

Figure 2.1 A plant layout for a typical WWTP (pe>100000) in Austria (Gujer, 2002).

2.3.2 Biological treatment

In the biological treatment process, bacteria break down organic matter to carbon dioxide and water. Nitrogen is separated from the wastewater through a nitrification-denitrification process. This treatment occurs under both aerobic and anaerobic conditions.

The biological treatment process, occurring under aerobic conditions, is mostly known as activated sludge treatment. In aeration tanks, oxygen is added to feed the microorganisms and to mix the activated sludge. This can be done by pure oxygen, compressed air or mechanical oxygen addition. The aeration tanks are followed by secondary sedimentation tanks in which the particles are separated by flocculation and gravity sedimentation. Some of the flocculated sludge is recycled back into the wastewater treatment process, and into the aeration tank to obtain the level of microorganisms for the aeration process. The excess sludge is separated from the process and lead to the sludge treatment (Metcalf & Eddy, 2004).

Due to high nitrogen removal requirements, the activated sludge treatment is the most common wastewater treatment process, both in Sweden and in Austria.

2.3.3 Nitrogen removal

Nitrification occurs when the nitrogen, in the form of ammonia, is oxidised into nitrate (see Formula 2.1) (Gujer, 2002).

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \qquad (2.1)$$

Denitrification is the second step in the nitrogen removal process. By anaerobic denitrifaction, nitrate is reduced to nitrite, to nitric oxide, to nitrous oxide, and to nitrogen gas. Nitrogen gas, N_2, dissolves then into the atmosphere (Gujer, 2002).

$$5\ CH_2O + 4\ NO_3^- + 4\ H^+ \rightarrow 2\ N_2 + 5\ CO_2 + 7\ H_2O \qquad (2.2)$$

2.3.4 Phosphorus removal

Removal of phosphorus from wastewater can be done either in the biological process or in a chemical treatment process. In the chemical treatment process, metal ions are added as iron (Fe), aluminium (Al) or calcium, in the form of lime, [$Ca(OH)_2$]. The metal ions precipitates the dissolved phosphate and the particles in the water attach to one another in a process called flocculation. The chemicals can be added in the primary or in the secondary treatment (Metcalf & Eddy, 2004). Common flocculation additives in Sweden are aluminium sulphate, aluminium chloride or iron chloride (Kemira, 1991). In Austria, iron chloride is the most common additive, followed by poly-aluminium chloride (Lindtner *et al.*, 2007).

Biological phosphorus removal occurs through anaerobic and aerobic processes. Heterotrophic bacteria, called polyphosphate-accumulating organisms (PAO) are enriched in the wastewater. The organisms accumulate polyphosphate in their cells while consuming phosphorus for growth. Hence, phosphorus is stored in the bacterial biomass. At the end of the process the biomass is separated and phosphorus is removed (Gujer, 2002).

2.3.5 Sludge treatment

Sludge is produced during the whole treatment process. Some of the sludge produced circulates back to the activated sludge basins and the rest goes to a sludge treatment process. Sludge treatment is an important part of the wastewater treatment, partly because the sludge can be used as an energy producer. Sludge can be dewatered, dried or incinerated. The anaerobic digestion process is an old method for sludge stabilization. The anaerobic process is not that energy consuming and has the advantage as an energy producer. The biogas produced, in most cases, can contain enough energy to heat up the whole plant. Anaerobic digestion can be operated in mesophilic or termophilic processes. Mesophilic digestion occurs at temperatures around 35 °C, and termophilic is occurring at temperatures above 50 °C. The average time the solids remain in the digestion process is called the Sludge Retention Time, SRT. The SRT is a design parameter for the anaerobic digestion process and can be calculated by dividing the mass of the sludge in the digester by the mass of the sludge removed during one day. In mesophilic conditions the sludge has normally a retention time of 20 days (Gujer, 2002).

In Sweden, approximately 240000 tonnes of sludge is produced each year, of which 6000 tonnes is phosphorus. Phosphorus is used as an agricultural fertiliser and, therefore, sludge can be used for soil improvement. Whether to use treated sludge for agricultural purposes or not, is an ever lasting issue for politics, because of potentially high values of heavy metals in the sludge (SWWA, 2005).

According to regulations in Austria, only 1 % of the total sludge production is used as a fertilizer. In Austria 77 % of the sludge produced from WWTPs is delivered to composting companies and used mainly for landfill and landscaping e.g. beside streets and construction sites and also for reclamation areas for examples ski slopes and tracks. The remaining percentages are incinerated or used for landfill and landscaping (Kläranlagenkataster, 2004).

2.4 Energy consumption in WWT processes

The choice of treatment process plays a major role on the energy use. Larger plants with more advanced technology generally need more energy than smaller plants (pe<50000). Conversely, larger plants have the ability to use energy more efficiently in view of population equivalent. In wastewater treatment plants it is the pumps, blowers, mechanical aerators, and solids-handling systems that consumes most electrical energy. The following section will describe the different wastewater treatment processes and their energy consumption.

2.4.1 Energy consumption in different treatment processes

The biological treatment process is the largest energy user for every WWTP and stands normally for 50-80 % of the total electrical energy consumption. This is due to the fact that the reduction of organic matter is oxygen demanding and aeration systems require high amounts of energy. Nitrogen treatment processes consume more energy than simple COD removing processes mostly because of the oxidation process and circulation system needed (Kjellén and Andersson, 2002).

Preliminary sedimentation also plays a big role for the energy balance because it affects the amount of sludge to the biological treatment process and, consequently, the need for aeration (Kjellén and Andersson, 2002).

The sludge treatment is the process where the energy use differs for different processes the most. The electrical energy is used for transporting sludge by pumps, sludge mixing systems, dewatering and thickening. Aerobic sludge treatment uses twice the amount of energy compared to anaerobic sludge treatment. The reason for this is the high electrical energy demand for the oxidation process. It should also be mentioned that an aerobic treatment process does not produce any useful energy of its own, as the anaerobic sludge treatment does (Kjellén and Andersson, 2002).

Electrical engines at a wastewater treatment plant dominantly consume electrical energy. Other electrical energy consumers at a plant are compressors, water pumps, valves and heaters (Kjellén and Andersson, 2002). The geographical location of a WWTP has an effect on the electrical energy demand for the inlet pumping station. The inlet elevation between plants can differ by more than 50 meters, which indicates a significant difference in energy demand.

2.4.2 External energy sources

Most WWTPs can use their own produced biogas to heat up the facility. The electrical usage needed for the processes is on the other hand in need of an external energy source. Indirect, this electrical energy can have its source in the WWTPs gas production. Produced biogas is to a great extent delivered to electrical power plants where it is transformed into electricity. To be able to extract electrical energy from the biogas at the WWTP, a gas-powered engine must be installed.

Energy sources can be divided into fossil and renewable energy sources. The fossil energy sources exist in large amounts, but they are limited because of slow regeneration. Fossil energy sources are, for example, natural gas, crude oil and coal. Coal is the world's largest fossil energy source, but it is also the energy source that releases the most carbon dioxide. CO_2 is a green house gas that is directly contributing to global warming. The climate change is an international problem and it is of high priority to find alternative electrical power resources (STEM, 2007-03-02).

The most important gas as an energy source is natural gas. Natural gas mostly consists of methane and it is naturally a part of the crust of the earth. Biogas (primarily methane) from wastewater treatment is produced from the excess sludge production in the treatment process and from the influent organic material.

Nuclear power plants use uranium, which is a non renewable energy source. In Sweden almost 50 % of the electricity is produced by nuclear power. This can be compared to 17 % for the rest of the world (Vattenfall, 2007).

Renewable energy sources are regenerating all the time by energy from the sun. These energy sources are also called green energy sources because their limited influence on the environment. Examples of renewable energy sources are sun, wind, water and wave energy (STEM, 2007-03-02).

Hydroelectric power plants are the largest energy producers in both Sweden (Vattenfall, 2007) and Austria (Austrian Energy Agency, 2007).

50 % of all Swedish households are heated by using energy from district heating. The energy used for district heating is mostly waste heat from industries that otherwise would had been lost. There are also some power plants only producing district heat. In Austria, the district heating system only provides 12.5 % of the households (Froning, 2003). According to the Austrian natural gas and district heat association, the district heating system is the energy source that is increasing most rapidly in the energy sector. District heat as an energy source is both economically and environmentally friendly. Along with harder restrictions on green house gas emissions, the district heating systems represents a good alternative source growing stronger around Europe.

2.4.3 Energy contributors

The potential energy production in a wastewater treatment plant is large. The main energy contributor in a WWTP is the biogas produced in the digester. The energy in the methane gas can be extracted and transformed into both thermal and electrical energy. This energy extraction can be enough to provide the whole plant with heat and electricity. If the influent load of organic matter is high, it is also easier to extract more energy, compared to a low loaded plant. Hence, wastewater treatment plants with a high load have higher energy efficiency than plants with a lower load (Kjellén and Andersson, 2002).

The heating energy from the wastewater itself is an important renewable energy source. The produced heat from treatment processes is higher than the needs of heating energy in the plant. By using heat exchanger and heating pumps, heat energy from the wastewater can be used for heating up neighbouring residences or added to the district heating system. Moreover, a lowered temperature in the effluent water will lead to better water quality in the aquatic environment (Kjellén and Andersson, 2002).

In some cases energy contributions from wind, solar and hydroelectric energy may also be used. WWTPs with natural differences in elevation can use hydroelectric power. As a consequence of traditional location at low elevations for WWTPs, the direct use of wind energy is a difficult task. To extract solar energy, large horizontal surfaces are needed. WWTPs are covering large areas and therefore the potential in solar energy contribution from WWTPs is relatively high. However, the operating cost for solar energy is today not yet economically beneficial (Kjellén and Andersson, 2002).

3 Benchmarking for WWTPs

The purpose of this chapter is to define different benchmarking processes and to describe the needs and usage of benchmarking in wastewater treatment plants. Furthermore, different benchmarking studies, performed in Europe and around the world, will be presented. Results from the Swedish energy saving program will be discussed. Likewise, the benchmarking and best practices in the Austrian water supply sector will be presented.

The major part of this chapter is the comparison between the Austrian and the Swedish study, presented as Energy benchmark for Sweden and Austria.

3.1 Benchmarking processes

To increase the efficiency of an organisation, benchmarking is an important tool. Benchmarking is about learning from other organisations and their best practices. There are two different benchmarking processes; the metric and the process benchmarking.

Metric benchmarking is a quantitative comparative study that can be used between comparable companies. The focus in a metric benchmarking study lies within the development of quality, environmental efforts and costs over a period of time in a facility.

In process benchmarking, the focus lies within the specific processes in a facility, instead of the whole business. By comparing different processes and by learning from the best, improvements can be achieved and energy efficiency increased. With the goal of continued improvements and decreased energy consumption a benchmarking study encourages competition between WWTPs.

3.1.1 Performance indicator systems

In a benchmarking study, the information and data collected is to be valued and compared. To be able to measure the quality of the data and to understand the value of the information given, a performance indicator (PI) system is used. IWA published their first manual for Performance indicators in 2000. This manual was developed to be used for any wastewater utility.

In IWAs manual *Performance indicators for water supply services* (Alegre *et al.,* 2006), describes different key elements for a benchmarking study. Variables are used to define performance indicators while explanatory factors explain them.

Another element used is context information, which is useful when comparing different systems.

A performance indicator should be easy to understand with a clear definition to present an objective measurement of the system. The variables are there to describe the PI and have to go along with the performance indicators. In this thesis, WWTPs from two different countries are to be compared; therefore, the availability, accuracy, dates and geographical area of the variables are not to be changed. For an optimal performance indicator system it is then important to obtain the variables from a primary official survey source. The performance indicators, variables and the context information should all be univocal, reasonably achievable and be as few as possible (Alegre *et al.*, 2006).

3.1.2 IWA benchmarking of control strategies for WWTPs

In the mid 1990's the IWA Specialist Group on Instrumentation, Control and Automation (ICA) together with the EU COST Action 682 developed a simulation benchmark, used for WWTP control strategies. Today the work is led by the IWA Task Group for benchmarking of control strategies. The IWA Task Group has developed a benchmark simulation model (BSM), used for development of control strategies related to organic and nitrogen removal. The simulation model is objective and has the purpose to be run for a general WWTP [8].

3.1.3 The 6-cities group

As early as in the 1970's the three biggest cities in Sweden; Stockholm, Gothenburg and Malmo, started a co-operation together with the three neighbour capital cities in the Nordic countries; Copenhagen, Oslo and Helsinki. The project is called "the 6-Cities Group" and its purpose is to share information regarding their water and wastewater works. Initially, the project was about design and construction of new systems. This view of management changed gradually into a focus on operation and maintenance of existing systems. To be able to make a public controlled business more competitive by increased performance, a benchmarking program was started in Scandinavia in 1995.

In the 6-Cities Group the performance indicators are focusing on continuous improvements of water and wastewater facilities (Stahre *et al.*, 2005).

3.1.4 The Bavarian project

Together with the water sector and municipalities the Bavarian water conservation authority and the Bavarian gas and water conservation association started a benchmarking study (EffWB) on the basis of the IWA performance

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[8] www.benchmark.org (2007-04-25)

indicator system. The goal of the EffWB project was to improve the efficiency and to analyse the quality of the water services in Bavaria. The participants had the opportunity to compare their position to other water undertakings to approach more energy efficient operations in the company. The first study was carried out in 2003 (Theuretzbacher *et al.*, 2005).

3.1.5 Other benchmarking studies around the world

Underdeveloped regions and poor countries around the world have reduced resources to develop high-quality water and sanitation services. A minority of the population in larger cities in South Asia, with populations over 10 million, has access to a 24-hour water supply system. To improve the development of water supply systems, performance benchmarking in these areas of the world can be very useful. The Water and Sanitation Program-South Asia (WSP-SA) is the leading actor in the development of performance measurement and benchmarking studies in Asia. The WSP-SA is associated with the World Bank and is also supported by many countries around the world (Sharma, 2006).

3.1.6 Energy manuals for WWTPs

Instead of a benchmarking study for performance improvements, the Swiss Ministry for Environment, Forest and Landscape (BUWAL, 1994) published an energy manual for WWTPs. Additionally, in Germany a manual for energy optimization (MURL) in WWTPs was published in the late 1990's. The German project was coordinated by the ministry for the environment (MUNLV) in Nordrhein-Westfalen, and covers almost 50 % of all WWTPs in Germany.

Both manuals describe electrical and thermal energy consumption at WWTPs and are presenting approaches for how to make wastewater treatment processes more energy efficient (Wett *et al.*, 2007). A more profound discussion about energy efficiency measures and technologies will be given in Chapter 4.

3.2 The Swedish energy saving program

Due to increased energy consumption combined with rising energy prices the Swedish Water & Wastewater Association, SWWA, decided to initiate an energy saving program. The project started in 2004, supported by the Swedish Association of Suppliers of Effluent and Water Treatment Equipment (VARIM), Swedish Energy Agency (STEM) and Sweco VIAK. According to consultants at Sweco VIAK, the electricity usage from the water and wastewater sector in Sweden is about 1.5 TWh/year, which is about 1 % of the total electricity used in Sweden (Kjellén and Andersson, 2002). The energy consumption from the WWTPs is considerably higher than from the rest of the utilities in the water supply sector and represents almost half of the total electrical consumption (Lundkvist *et al.* 2007). Moreover, from a feasibility study, measures were found for more energy efficient operation and possibilities to decrease the electrical energy consumption.

The objectives of the Swedish energy saving program, called "*SWWA's contribution to make Sweden more energy effective*", is to survey the energy usage and from that determine where energy usage can be decreased. The goal of the project is to find benchmarks to be able to decrease the use of high-quality energy (primarily electrical energy) (Lundkvist *et al.*, 2007).

3.2.1 Data collection

As a first step, all members of SWWA were asked to fill out a questionnaire about energy usage in water facilities, pipe networks and wastewater treatment processes. In this thesis, only the wastewater treatment plants will be discussed. For details of the questionnaire for the wastewater treatment facilities, see Appendix II.

The collection of data was made over SWWAs online statistical system, called VASS. The study was carried out during 2006 and a status report was presented in January 2007. Sweden has approximately 2000 wastewater treatment plants located all over the country. However, the participation from the wastewater treatment plants was only 42 municipalities representing 256 wastewater facilities. Furthermore, treatment plants from the same municipality with less than 2000 pe, were grouped together, which means that the study only reported data from 132 wastewater treatment plants (Lundkvist *et al.*, 2007).

A previous study made in VASS during 2005 also involved questions about energy usage in WWTPs. In this former study the number of participants was higher, approximately 86 %. Based on similarities in the two studies, the statistical data were extrapolated based on the total number of connected water consumers in Sweden. By using extrapolation, the SWWA's project team estimated the margin of error to be roughly 10 %. Furthermore, participants in the study were mostly larger WWTPs, which give vague information of smaller plants (Lundkvist *et al.*, 2007).

The quality of the input-data varies from plant to plant in the Swedish study. Because it is the first study of its kind to be made, the wastewater treatment plants do not have access to all data required for the report. During the questionnaire time many misunderstandings occurred. Furthermore, many numbers may have been reported wrongly in the report, which has lead to misleading results (Lundkvist *et al.*, 2007).

3.2.2 Results

In this subsection, the results of the Swedish water and wastewater study from March 2007 will be presented. Input data from every participant is an official document and was provided from personnel at the Swedish Water and Wastewater Association.

Energy consumption and production

Total electrical and heat energy consumption from wastewater treatment plants in Sweden is estimated with extrapolation from the 2005-year's study. Total amount of bought electricity and other external energy sources is 930 GWh for one year. In addition to this, more energy is used in forms of chemicals and internally produced energy. Due to the fact that it is hard to estimate energy consumption from chemical usage, there is no data available for this energy (Lundkvist *et al.*, 2007).

The heat energy is mostly coming from waste heat. Waste heat includes all heat energy that can potentially be extracted from the wastewater treatment processes. Waste heat is difficult to determine, and therefore, data from the more comprehensive study in 2005 was collected. This heat energy goes today directly to the district heating system of the energy companies, which do the energy extraction. One of the problems today is the lack of space in the district heating pipe system. The aim is to increase this amount of waste energy production from the wastewater treatment plants, but the limited capacity of the district heating system means that all energy cannot be taken care of. If all energy from the wastewater and biogas could be used for energy production the potential heat energy yield from Swedish WWTPs is approximately 2 TWh per year, according to the study from 2005 (Lundkvist *et al.*, 2007).

According to the study, only 9 % of the used electrical energy was produced by the WWTP. In all cases, the electrical energy production is based on biogas. See Figure 3.1 for source of electricity used in Swedish WWTPs.

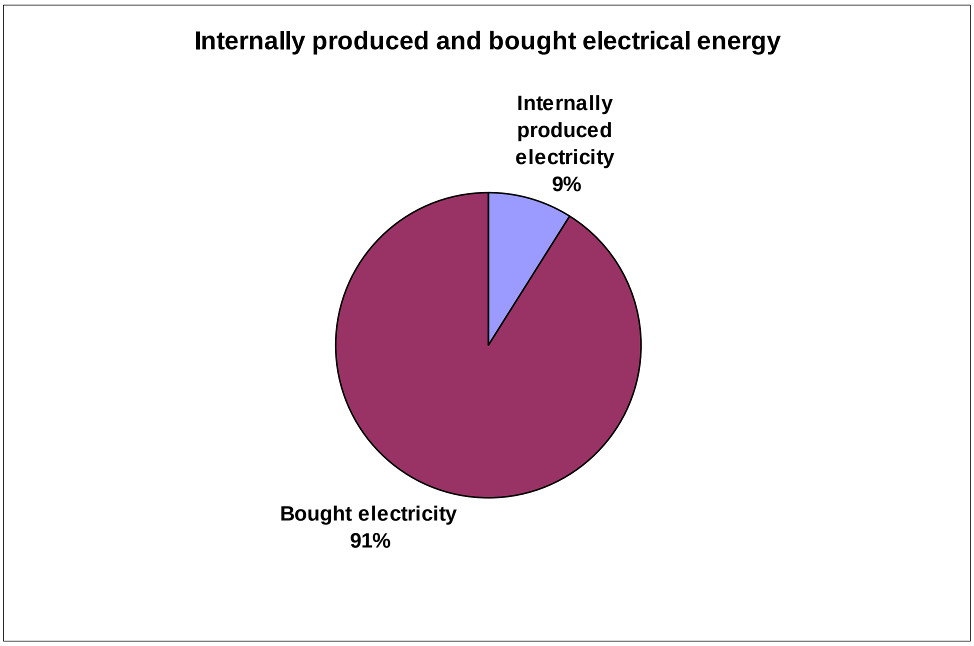

Figure 3.1 Percentage of consumed electrical energy taken from internally produced or from an external producer (Lundkvist *et al.*, 2007).

For a better understanding of the electrical usage in the treatment processes, the electrical usage needed for aeration processes compared to other processes is presented. According to the wide range of participants in the study, answers in the report differ between different plants. Of the total electrical consumption, 24 % is used for aerobic treatment, as a given mean value for all participants in the energy study (Lundkvist *et al.,* 2007). This percentage is an approximation of the Swedish WWTPs consumption. It is important to take into consideration that input data differs a lot from plant to plant. As mentioned earlier, the biological treatment process normally stands for 50-80 % of the total electrical energy consumption: when including pumps, blowers, activated sludge process etc.

To be able to find the accuracy of the result of the energy consumption for the aerobic treatment, the value of 24 % is compared to a large and functional WWTP in Sweden, Henriksdal WWTP, located in Stockholm region and with a population equivalent of more than 500000. The electrical consumption for the aeration process in Henriksdal WWTP is 27 % of all electrical consumption by the processes. The results are similar to the mean value, which makes both the mean value and Henriksdal's result a good representative for the total study and Swedish WWTPs (Lundkvist *et al.,* 2007).

The measured mean value of total electrical consumption is estimated to be approximately 2500 – 3000 kWh/ton removed BOD. In Sweden, the electrical consumption is mostly based on removed BOD. This method will have margins of error because different plants have different treatment requirements. Furthermore, other parameters affect the BOD treatment, which can give a misleading result, e.g. nitrogen treatment and influent wastewater quality.

From the results, it is shown that there are great differences in the energy extraction from biogas, especially between smaller plants. One of the reasons for this can be that larger plants are doing digestion treatment for smaller plants without resources to operate this process themselves. Furthermore, the access of organic matter may be very low and the digestion volumes may not be dimensioned for the right amount of pe.

To measure the benefits of energy effectiveness, the amount of used electrical energy and produced biogas energy is compared. Great differences between plants indicate potentials for the water sector as an energy producer. Communities with food product industries have a larger organic load in the influent wastewater and therefore a higher biogas energy extraction potential. The usage of thermophilic processes also indicates increased biogas energy production.

According to Mats Lundkvist, the most important results are the biogas production related to the electrical consumption. This relation represents 50 % of all wastewater treatment plants with biogas production in Sweden; therefore, it is a good representative value for Sweden. In Figure 3.2, the biogas production compared to the electrical energy consumption and the organic load is illustrated. The Y-axis presents the exchange ratio between the gas production in kWh/pe and the annual electrical energy consumption in kWh/pe. The theoretical energy value of the biogas production is calculated by using a relation between the methane content during ideal conditions at 0 °C and the energy content of the methane gas, which is 50014 MJ/kg, CH_4 (Jeppsson *et al.*, 2005). This gives a theoretical energy content of the methane gas of 9.84 Kwh/kg, CH_4. See Appendix III for calculations of energy content of methane gas.

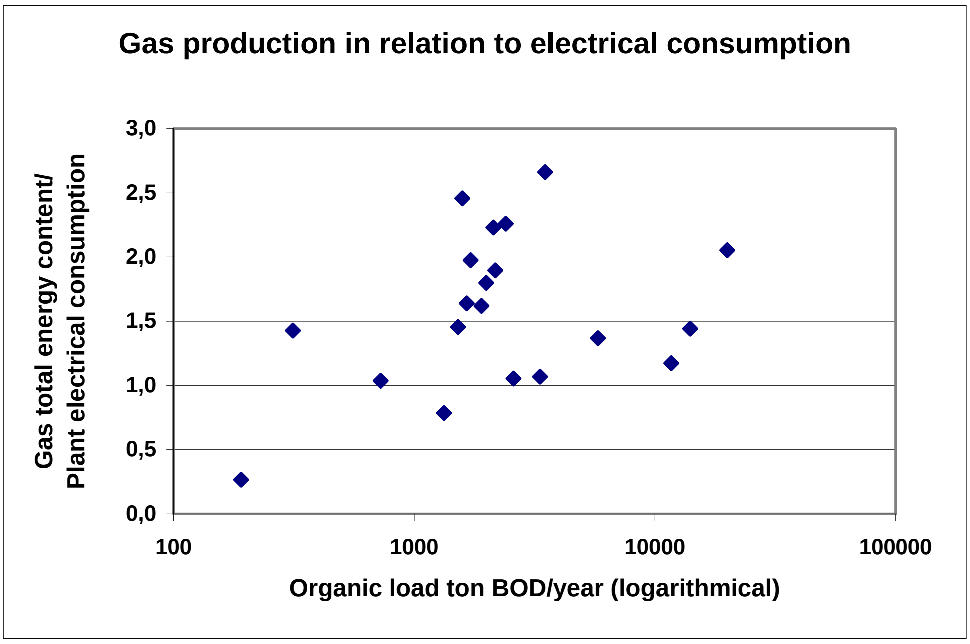

Figure 3.2 Biogas production compared to electrical energy consumption and the organic load in BOD_7 in Swedish WWTPs (VASS, 2007).

Sludge and gas

Digestion is only possible for larger WWTPs and according to the report (SWWA, 2007) a mean value for the participants for the digested sludge is 80 % of the total available sludge. This leads to the conclusion, that 20 % of the sludge is not used for energy extraction. According to the study, three WWTPs uses thermophilic[9] digestion, while 23 plants are using mesophilic[10] digestion. The gross energy production from biogas is approximately 600 GWh/year. Approximately 30 % is converted into electricity (Lundkvist *et al.*, 2007).

How to optimize the usage of the biogas is one of the most important questions related to the energy efficiency of WWTPs. How the biogas usage is divided can be seen in Figure 3.3. The largest biogas usage is for heating the WWTP and for district heating system. Some of the produced biogas is also delivered as vehicle fuel or for electrical energy production. In some cases the biogas is used for both, which indicates a transition from electrical generation to vehicle fuel. Furthermore, some treatment plants are delivering biogas for local gas networks. Sometimes biogas is overproduced, i.e. the facility does not have the ability to convert the biogas into energy. Due to the fact that methane is highly explosive and also a greenhouse gas, the gas has to be combusted in a torch to prevent pollution and explosion (Lundkvist *et al.*, 2007).

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[9] Thermophile is an organism best operated in temperatures around 55 °C (Wett).

[10] Mesophile is an organism that grows best in temperatures around 35 °C (Wett).

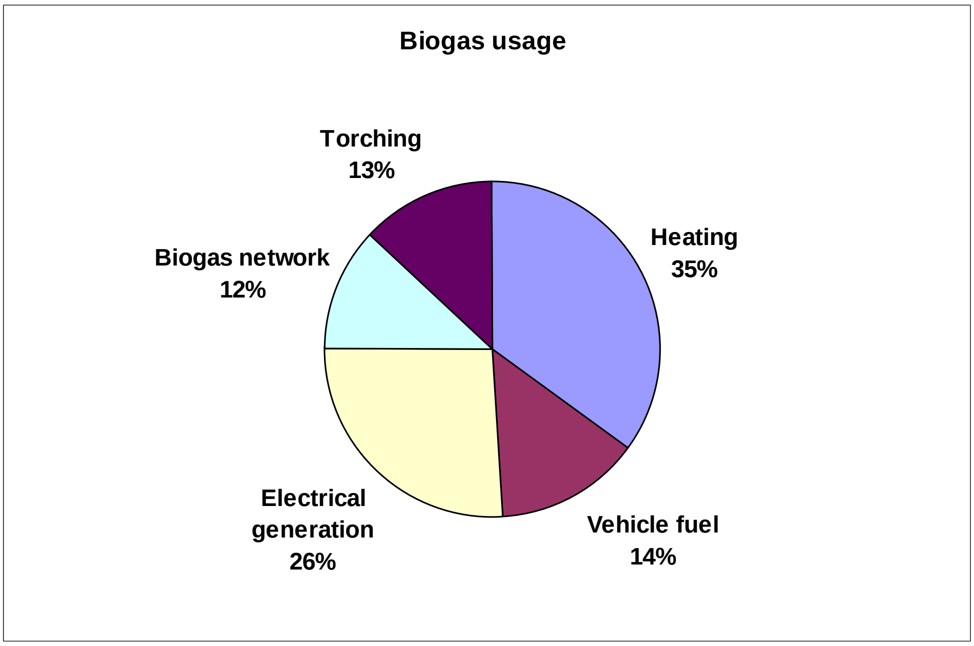

Figure 3.3 Produced biogas usage in Swedish WWTP (VASS, 2007).

The produced gas from the digesters consists of approximately 65 % methane gas and the rest is carbon dioxide and other gases such as nitrogen, oxygen and hydrogen sulphide. To be able to use the gas as vehicle fuel the gas has to be purified to more than 97 % of methane. This process itself is energy consuming. Some WWTPs have to buy electrical energy from an external producer just to be able to produce the vehicle fuel (Environmental report, Borås, 2006). Therefore, the most effective exchange of the energy from biogas is, according to WWTP operators in Sweden, to deliver it to external users. However, as the vehicle fuel prices are rising high it leads to a more economically profitable energy exchange to sell the biogas as vehicle fuel than to convert it into electricity (Mats Lundqvist, May 3rd, 2007).

Chemicals

The energy content in the chemical used for wastewater treatment is mostly based on high-quality energy. In Swedish wastewater treatment, the most energy consuming chemical treatment is the use of external carbon for denitrification. However, other facilities, e.g. breweries, have carbon as a by-product that WWTPs is given for free or for a small amount of money.

Some WWTPs are using lime for sludge treatment. However, from the study made, the input data is not detailed enough to give a correct value for the chemicals impact on the energy consumption. It is necessary to make a deeper analysis about the chemical impacts to be able to make any conclusions about the energy consumption from chemicals in wastewater treatment (Lundkvist *et al.*, 2007).

3.3 Benchmarking and best practices in Austrian WWTPs

The Austrian Association for Water and Waste, OWAV, is the project coordinator for the benchmarking program in Austria, called *Benchmarking and Best Practices in the Austrian Water Supply Sector*. The program started on the basis of the efficiency and quality study of the water supply in Bavaria, called EffWB, in 1999. The benchmarking study is voluntary and anonymous and covers today approximately 40 % of the country's total number of WWTPs.

The procedure of the OWAV-Benchmarking project starts off with the collection of operational characteristics from all WWTPs through an online database, open for the first six months of the year. When all data are collected the project team evaluates the information. Plants with similarities in size, volume of treated wastewater and population equivalent, will be compared and sorted into the same evaluation group. After approximately three months, the participants will have the outcome of the study available via the online database. The goal with the benchmarking study is to encourage the WWTPs to carry out improvements, and to achieve better results for next year's report. Therefore, the most valuable stage in the benchmarking project is the exchange of experiences between the participants. This takes place after the evaluation, when the participants meet in smaller workshops to exchange their ideas and experiences from the benchmark (Lindtner *et al.*, 2007).

3.3.1 Structure of evaluation report

In the Austrian study, fixed-, variable- and capital costs are presented. The study covers costs of sludge treatment, labour, material, services from a third part, energy and other operational costs. The study does not cover the biogas production.

Participants in the Austrian benchmarking study are given individual evaluations of the performance for their WWTP. Before evaluation the plants are divided into four different groups, according to population equivalent. The energy costs are presented in Euro per population equivalent calculated on a basis of 110 g of chemical oxygen demand (Euro/pe$_{110}$). The individual costs are given in percentage, designed for relative comparison and anonymous results. The presentation is given in form of box charts, presenting minimum, maximum and median values, and in addition, the 25-percentile and the 75-percentile. The charts also present the benchmarks; hence, it is easy for every WWTP to establish which process improvements are potential most beneficial (Lindtner *et al.*, 2007).

3.3.2 Processes

In the Austrian benchmarking study, every process in the wastewater treatment plant is analysed. The study focuses on the four main processes with two additional help processes. Every process is then further divided into more specific processes for a better understanding and an objective comparison between different undertakings. Short descriptions of the processes are as follow.

Process 1: Inlet pump station and mechanical preliminary treatment
The first process consists of the inlet pump station and the mechanical preliminary treatment. The inlet pump station is separately compared in the benchmark, and is dependent on the elevation change of the water.

Process 2: Mechanical and biological treatment
The mechanical and biological treatment processes includes primary sedimentation, activated sludge tanks and secondary sedimentation. It also covers machines, electrical devices and installations for phosphorus precipitation. Furthermore, process 2 includes Combined Heat and Power units (CHPs) and gas engines for the compressor system.

Process 3: Sludge treatment and stabiliser
At the request of WWTP operators the surplus sludge treatment and the digestion processes are separated to be able to see the specific costs.

Process 4: Continued sludge treatment
Because of the high percentage of the total costs in the sludge treatment, process 4 represents sludge drainage and sludge recycling. The sludge drainage includes thickeners and dewatering systems and the sludge recycling also covers waste disposal.

Help Processes
The additional help processes include energy costs for the remaining facility e.g. laboratory areas, workshops, changing rooms and also materials and administration.

On the contrary to the Swedish report the biogas production is not evaluated in the Austrian benchmarking study.

3.3.3 Results

The data presented in this thesis is taken from the public report 2007, with collected data from financial year 2005, provided by Dr. Stefan Lindtner, Engineering office k2W, Vienna, Austria.

In the Austrian benchmark study, the different wastewater treatment processes have been compared with regard to variable costs. The major cost for plants with pe between 10000 and 50000 is costs for laboratories, administration and infrastructure. On the other hand, for larger plants (pe >100000) the most expensive process is the sludge treatment. This is due to the fact that larger plants normally treat sludge from smaller plants that do not have the ability to treat excess sludge.

The variation between the variable costs for the different cost types is given in Figure 3.4. As can be seen in the figure, the labour costs are the most expensive individual cost for operating a WWTP. Expenses for sludge treatment is placed as number two, followed by material costs. Energy costs are placed fourth in the ranking of variable costs in a wastewater treatment plant.

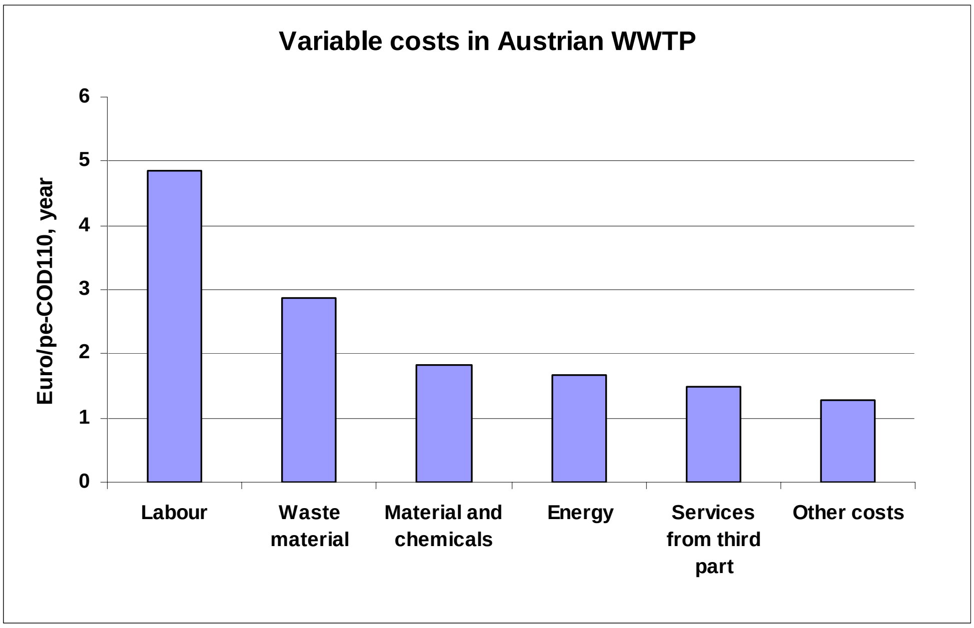

Figure 3.4 The variation of the variable costs for Austrian WWTPs, given in Euro/pe$_{110}$, year (Lindtner *et al.*, 2007).

Figure 3.5 illustrates the distribution of costs over the different processes. The process with the highest cost is process 4; the continued sludge treatment. The sludge recycling and dewatering of sludge are expensive operations to maintain. Biogas is produced in the sludge treatment process. Biogas can be used as energy source for the WWTP and contribute to energy savings. This is not discussed in the Austrian report, where costs are pointed out instead of savings.

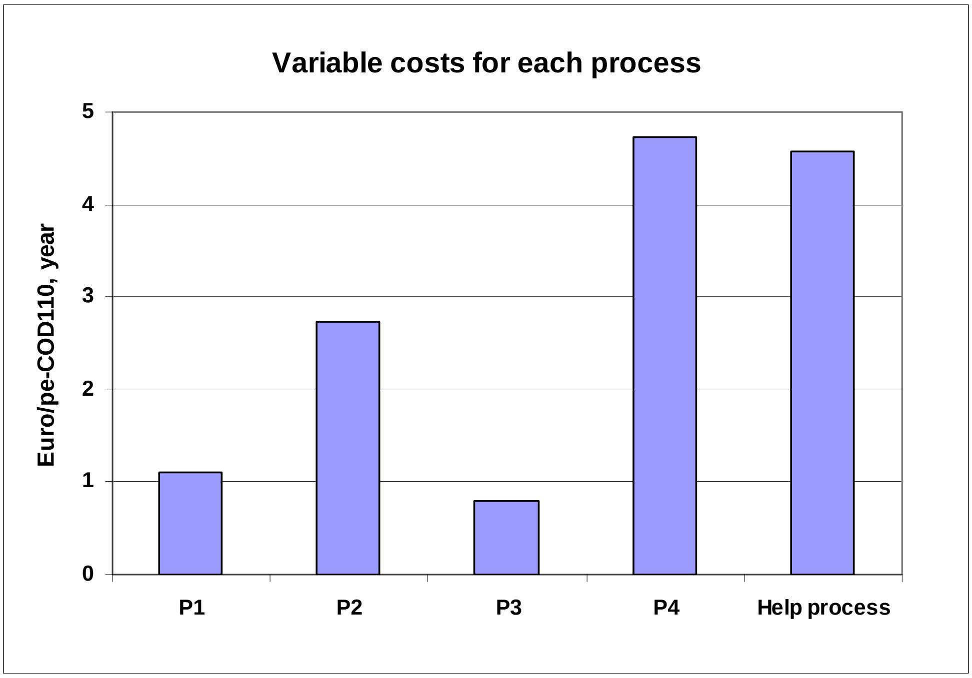

Figure 3.5 Results from the Austrian study for business year 2005 presenting variable costs in Euro/pe and year (Lindtner *et al.*, 2007).

Fixed costs are dependant on time and activity. After a certain time period fixed costs become variable costs. Therefore, it is important to note that the variable costs are depending on the fixed costs and this creates a large variability between different plants. Smaller plants have smaller capacity than larger plants, which increases costs in most aspects. Above all, labour costs and services performed from an external part are higher for smaller plants.

The high costs for the help processes can be explained by high personnel costs. It should also be mentioned that the energy costs for smaller plants are relatively higher than for larger plants. Furthermore, in this study the electricity cost aspect relate to costs of both external energy and to internal energy production (Lindtner *et al.*, 2007).

Energy consumption

Cost for energy consumption is relatively small compared to costs for staff and sludge treatment. The electrical energy consumption is remarkably higher in the biological treatment compared to other wastewater treatment processes. This is due to the fact that the aeration process requires a significant amount of energy. Figure 3.6 illustrates the electrical energy consumption for the different processes, from the Austrian benchmark study. As can be seen in Figure 3.6, process 2; mechanical and biological treatment consumes most energy (Lindtner *et al.*, 2007).

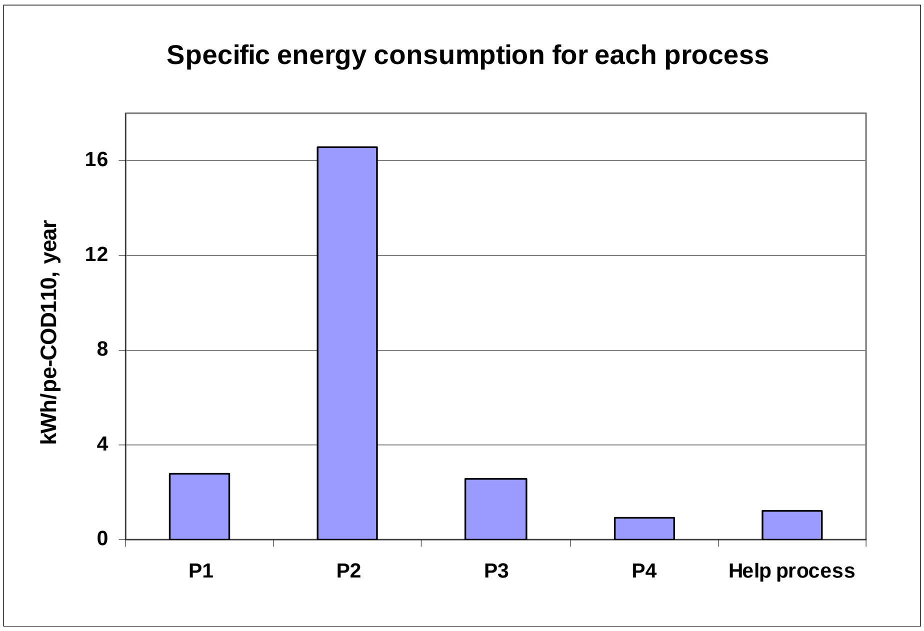

Figure 3.6 Electrical energy consumption for each process in Austrian WWTPs (Lindtner *et al.*, 2007).

To be able to make a comparison between costs and energy usage, those two parameters have been put together in Figure 3.7. Here it is shown how large the energy consumption is in the biological treatment process, compared to the actual costs.

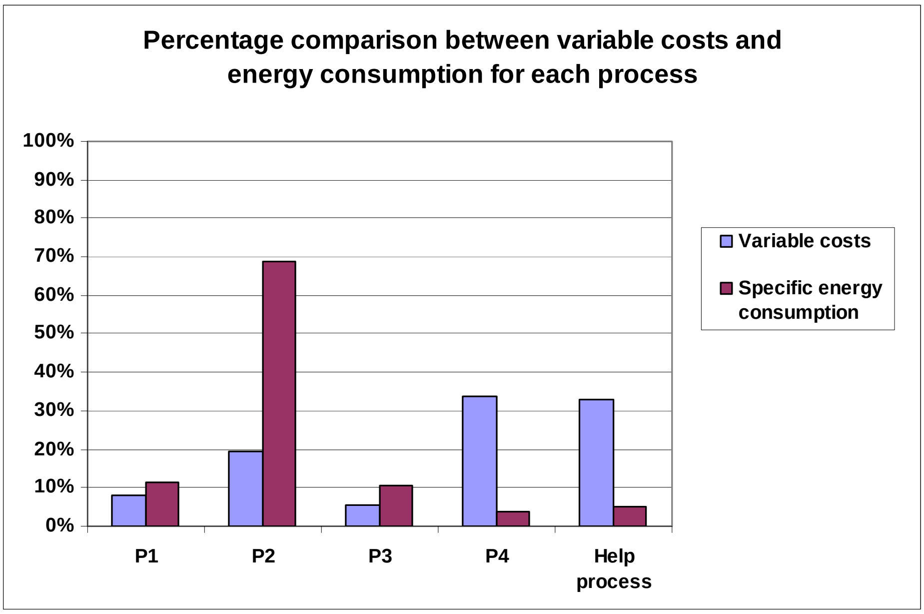

Figure 3.7 Percentage of energy consumption compared to variable costs for each process in Austrian WWTPs (Lindtner *et al.*, 2007).

4 Energy benchmark for Sweden and Austria

Because of the significant variation in data from smaller plants, the focus lies on larger plants and their energy consumption. Therefore, in this benchmark study between Sweden and Austria, results from only the largest plants, participating in both studies, are discussed. Input data are taken from the Swedish energy study, provided by personnel at SWWA, but mostly by direct contact with the plant operators. For the Austrian results, data are taken from the final report based on the five largest plants in the study. Mr. Christian Fimmel, manager at WWTP Strass, Tirol, Austria, provided this final benchmark report, from 2007 with collected data from financial year 2005.

In relation to Austrian secrecy, the individual and detailed data from each question in the report were very difficult to get. The data presented in this chapter is therefore mostly only given as median values for all plants. By help from Prof. Bernhard Wett data from three WWTPs in the Austrian study could be specified. On the contrary, in the Swedish study it was possible to obtain results from every individual WWTP.

4.1 Dimension based on organic load

To be able to do a comparison between Austria and Sweden, the energy consumption had to be presented based on equal dimensions. When doing any comparison between wastewater treatment plants there are many factors to considerate, especially when doing a cross-boarder comparison. As mentioned earlier, the reduction degree of the pollution in the wastewater affects the energy demand of the treatment process. Therefore, comparison in energy consumption between different treatment plants is normally based on population equivalent.

In this thesis, values from Sweden and Austria are compared by using the population equivalent based on the organic load to the WWTP. Due to the fact that all results in the Austrian benchmarking study where based on COD tests, calculated on 110 g per day and person, and only mean values where given, it was more convenient to use this COD load also for the Swedish values. The most common key parameters, used for determining the population equivalent are the BOD- or the COD-load. In Sweden, BOD_7 is used, whereas the population equivalent can be estimated by dividing the BOD_7 load with a specific load of 70 g per day. Below follows a discussion of the relation between designed population equivalent regarding different organic material measurements, based on Swedish data.

Data from the Swedish energy study presents designed population equivalent, influent organic material over the year in ton BOD_7 and raw sludge production in ton TS. To obtain the influent COD load, questionnaires about influent wastewater characteristics were sent out to the WWTPs of interest in Sweden. Results of the questionnaire are presented in Appendix I.

When all data had been collected, the population equivalent was to be determined. The population equivalent based on BOD_7 load was calculated by dividing the influent BOD_7 by 70 g. The relation between the designed pe and the influent calculated pe based on BOD_7-load indicates the reserve capacity (overload), which means that the WWTPs are designed for higher loads than the actual loads. It is normal to have higher capacity for all WWTPs. The ratio between pe_{design} and pe_{BOD} for Swedish WWTPs shows an average value of 1.46, which point out significant reserve capacity.

The population equivalent was also calculated by using the raw sludge production. This was done based on a production of 71 g TS per day (Wett, May 2^{nd}). To be able to examine how well the BOD_7 value is corresponding to the actual total sludge production a comparison between BOD_7 and TS was made. The ratio between the influent pe per BOD_7 and the sludge production has a mean value close to 1. This ratio should be close to one for indication of good stabilisation of the organic matter in the wastewater. If the ratio is too low, it proves that the external sludge volume is high. A high sludge value indicates external sludge intake from other communities or plants in the area. Lower TS indicates large sludge production (Wett, May 2^{nd}). WWTPs with very high sludge production are normally industrial wastewater treatment plants. In this thesis, focus lies on municipal treatment plants.

In Sweden, the BOD_7-test is the most common measurement for organic matter. When collecting data from WWTPs in Sweden, it was shown that COD-tests are not prioritised as a sample method. However, most wastewater plants could provide these data and the population equivalent, based on COD load, could be calculated.

Figure 4.1 illustrates the relation between the energy consumption and the reserve capacity (overload).

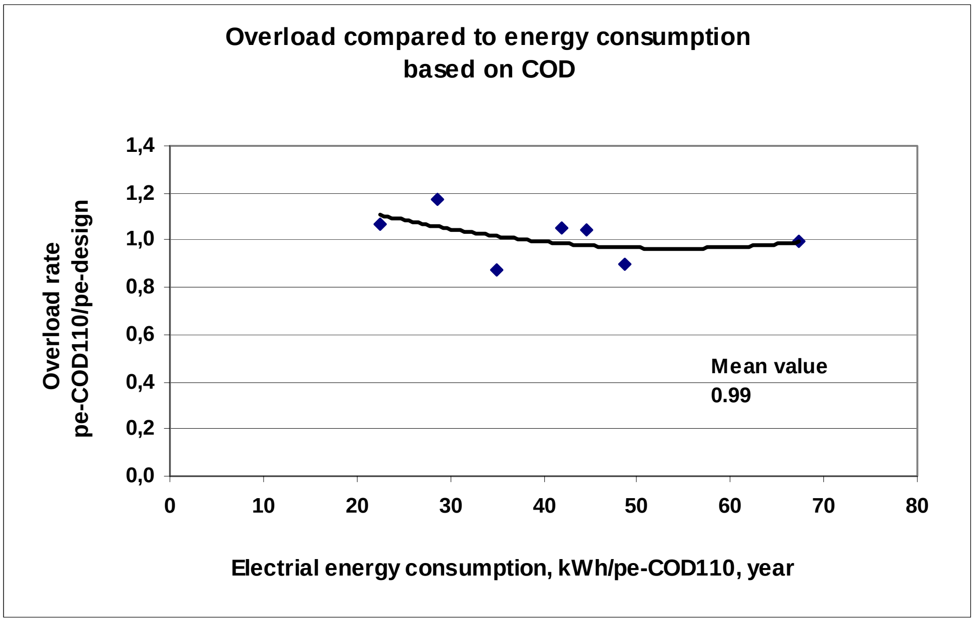

Figure 4.1 The electrical energy consumption in Swedish WWTP compared to the overload rate based on COD load.

Figure 4.1 illustrates the energy consumption and the capacity for different WWTPs in Sweden. The reason to large differences in electrical energy consumption between plants with similar loads is the fact that different processes are being used. Some plants have higher restrictions, depending on how sensitive the residual aquatic environment is, which leads to more complicated and energy consuming treatment processes. In the thesis, specific plants are not discussed and therefore the exact reason for large differences in energy consumption is difficult to estimate.

See Appendix IV for all results related to designed and calculated population equivalent taken from the largest WWTPs participating in the Swedish study. Furthermore, Appendix IV presents influent loads of BOD_7, COD and the total solid production.

4.2 Energy consumption

Figure 4.2 illustrates the electrical energy consumption per population equivalent, calculated on 110 g of chemical oxygen demand (pe_{110}). The Swedish data are compared to the dimension of the plant, to illustrate the efficiency related to plant size. In Austria, only a mean value is provided for the five largest plants and in Figure 4.2 it is the value parallel to the Y-axis.

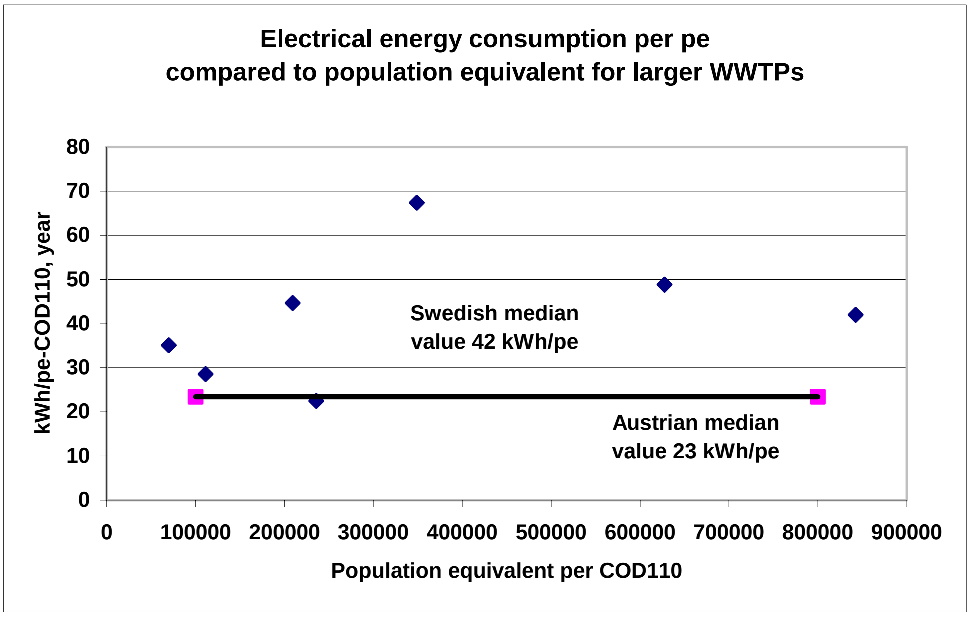

Figure 4.2 The total electrical consumption in kWh/pe, year in Swedish WWTPs. A mean value is represented for Austrian WWTPs (VASS, 2007).

Interesting to note from Figure 4.2, is the result from Sweden's third largest plant, which has an electrical consumption of 67 kWh/pe$_{110}$, which can be compared to the best value of 22 kWh/pe$_{110}$. This high electrical energy consumption is mainly due to high elevation differences at the inlet pump station. The best value in Sweden at 22 kWh/pe$_{110}$, year is just below the Austrian median energy consumption of 23 kWh/pe$_{110}$, year.

In wastewater treatment, the biological treatment process is the major energy consumer, due to the aeration system. Due to geographical location, elevation differences can lead to high electricity consumption for pumping. Therefore, it is valuable to separate the different processes when doing a benchmarking study. Data provided from the Austrian study are more precise, due to the fact that the project has been carried out previous years and the plants have installed meter readers for individual processes. On the other hand, Swedish energy prices have been relatively low until recently and the Swedish municipal WWTPs have not performed energy measurements as a first priority (Charlotta Raudberget, 2007). The total electrical energy consumption in Swedish WWTPs is available, but the separation into how much the different processes are using, are in most cases estimated. However, the electricity needed for the blowers in the aeration process is known in most WWTPs. To find the electrical usage for every other process, backward calculations have been used for some WWTPs in Sweden. When comparing the two countries, the estimated consumption of energy must be taken into consideration as a potential source of error.

For a comparison of the electrical energy consumption between Austria and Sweden the treatment process are divided in physical, biological, sludge and other. The physical process includes inlet pump station and mechanical primary sedimentation.

In Figure 4.3, the specific electrical energy consumption for each process is illustrated, for both Sweden and Austria.

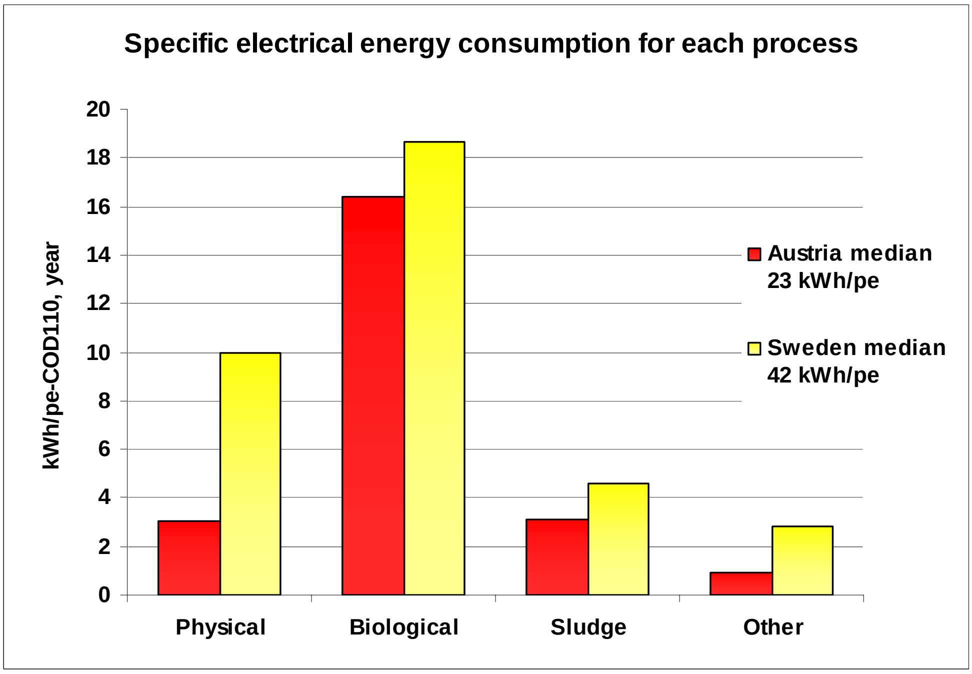

Figure 4.3 The electrical energy consumption in kWh/pe, year for main processes in Austria vs. Sweden (Lundkvist *et al.*, 2007; Lindtner *et al.,* 2007).

As can be seen in Figure 4.3, the energy consumption is higher for every process in Sweden. In fact, Swedish WWTPs uses approximately 45 % more energy than Austrian WWTPs. One explanation to some of the large differences is the lack of specified electrical measurements for each process in Sweden, which means that some values are not in the right column. However, the total electrical energy consumption is correct.

The total energy consumption in Austria is estimated to have a median value of 23 kWh/pe$_{110}$, year. To be able to make a comparison and to have a benchmark for the Austrian electrical consumption a good representative was found in the German energy manual, MURL (1999). Figure 4.4 shows the electricity consumption for German WWTPs.

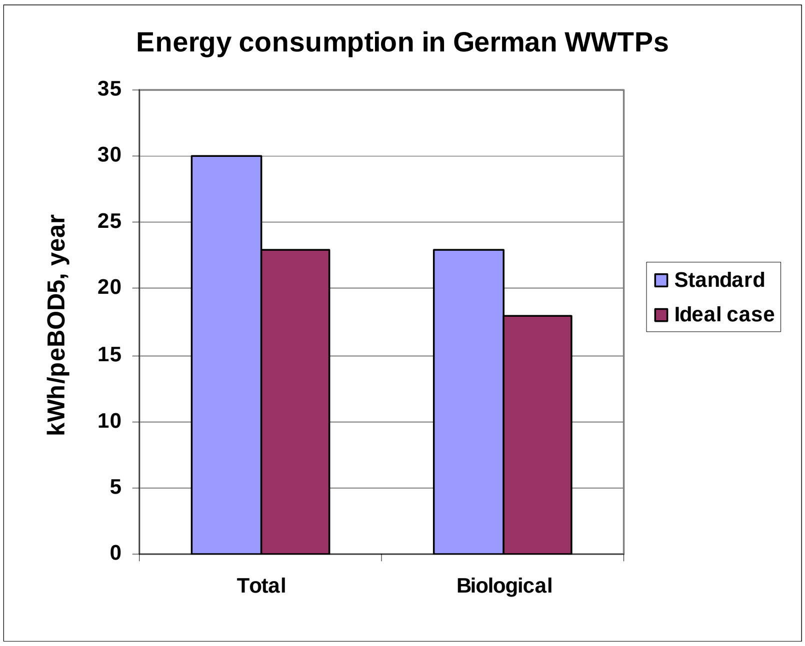

Figure 4.4 Electrical energy consumption in German WWTPs (Thöle, 2006)

The German energy consumption is presented per population equivalent, calculated by using the average BOD_5 load of a year and a specific load of 60 g per day. A typical ratio between BOD_5 and COD is 2 (Wett, 2007), which can also be seen in the results from Austria and Sweden presented in Table 4.1. Therefore, the ratio of 60 g of BOD_5 and 110 g of COD can be approximately set to be equivalent to each other.

The manual presents ideal case values of 23 kWh/pe and a standard value of 30 kWh/pe for the total electricity consumption. Austria presents a mean value representing the German ideal value. For the biological process, the German energy manual recommends a consumption of 18-23 kWh/pe. Austria presents a mean value of 16 kWh/pe for the biological process. This means that both countries indicate similar results.

4.3 Wastewater characteristics related to energy consumption

The physical process with inlet pump-station and primary treatment is over three times more energy consuming in Sweden than in Austria. According to Environmental reports and energy reports from Swedish WWTPs, the influent pumping energy is a large energy consumer. In fact, in some cases pumping represent the majority of the energy consumption at the plant.

Also the nitrogen removal is more energy consuming in Sweden. Explanations for the energy differences can be found in the wastewater characteristics. In

Section 2.1 the wastewater characteristics were given, and here follows a more detailed discussion regarding characteristics of the wastewater and the energy consumption.

Interesting is to identify differences between the ratios in the wastewater characteristics and to see if there are any correlations to the differences in energy consumption. Table 4.1 presents the influent wastewater characteristics for the two countries and ratios between them. From the ratio column it is shown that Austria has higher influent values in all parameters, except for the influent flow rate, which means Sweden has more diluted water. It is known that higher concentrations of influent organic material provides better conditions for energy efficiency in the treatment process (Lundqkvis *et al.*, 2007), which is one explanation to Austrias WWTPs lowher energy consumption.

Table 4.1 Relations between wastewater characteristics in Austrian and Swedish WWTPs.

Parameter	**Austria**[11]		**Sweden**[12]		**Ratio A/S**	
Influent flow rate	210 l/pe, day		242 l/pe, day		0.87	
Unit	**mg/l**	**kg/pe, day**	**mg/l**	**kg/pe, day**	**mg/l**	**kg/pe, day**
BOD$_5$	291	0.0611	176[13]	0.0426	1.66	0.70
COD	547	0.115	473	0.114	1.16	1.00
Total nitrogen, N	44	0.0092	40	0.0097	1.10	1.05
Phosphorus, P	7.5	0.0016	6.4	0.0015	1.18	0.98
Ammonia, NH_4-N	26	0.0056	24	0.0058	1.08	1.06
Ratios						
COD/BOD$_5$	1.88		2.69		0.70	
COD/N	12.4		11.8		1.05	
COD/P	72.9		74.3		0.98	
N/P	5.9		6.3		0.98	

The Swedish BOD$_5$ influent concentration is significantly lower than the Austrian. Reasons for this might be differences in the pipe system, e.g. temperature, precipitation and pipe length. In this case, the countries are similar regarding pipe systems and the most likely difference is due to

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[11] Values are based on weekly measurements; data from the provincial government in Tirol, 2004.

[12] Mean values measured on basis of Environmental reports from larger WWTPs in Sweden, 2005.

[13] In Sweden the degradation is calculated during a 7-day period. $BOD_5=60/70*BOD_7$ (Kjellén and Andersson, 2002)

measuring methods. As mentioned before, Sweden uses BOD_7, which means that the calculation from BOD_7 to BOD_5 ($BOD_5=60/70*BOD_7$) will probably give a small margin of error.

How and when the samples are taken can also be reasons for differences. According to personnel at Swedish WWTPs the samples are mostly taken from unfiltered wastewater. In Austria samples are taken after filtration.

The COD/BOD-ratio indicates differences in energy consumption, due to degradability of available carbon. If the wastewater includes waste from industries the carbon may be more difficult to degrade than if the wastewater originates from households. Because Swedish WWTPs have a high ratio between COD and BOD, waste from industries probably represents a significant fraction of the influent wastewater. Plants participating in the Austrian study are only municipal WWTPs. On the other hand, some plants in Sweden might treat industrial wastewater as well as municipal wastewater.

Differences in energy consumption for nitrogen removal could also be found in the ratio between COD and nitrogen and phosphorus concentrations. However, the ratios with nitrogen and phosphorus are similar for Austria and Sweden and do not explain differences in energy consumption between the countries. Following figures illustrate the relation between electrical energy consumption and influent wastewater volume and influent COD concentrations.

Figure 4.5 illustrates ratio between carbon and nitrogen and the relation to energy consumption in Sweden. As can be seen there is no relation for the participating plants in Sweden. Unfortunately there is only one mean value given from Austria. The Austrian value is 12.4, which is almost identical to the Swedish trend line in Figure 4.5.

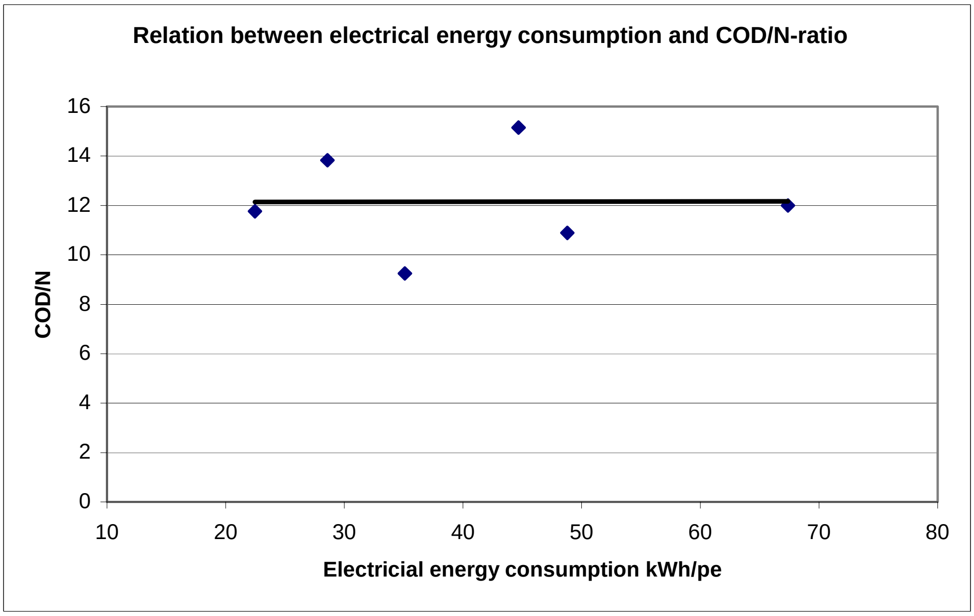


Figure 4.5 Electical energy consumption related to COD/N-ratio in Swedish WWTPs.

Figure 4.6 indicated a correlation to a higher influent wastewater flow rate and increased electrical energy consumption The Austrian mean value of 210 l/pe, day and 23 kWh/pe, is at the lower end of the Swedish trend line.

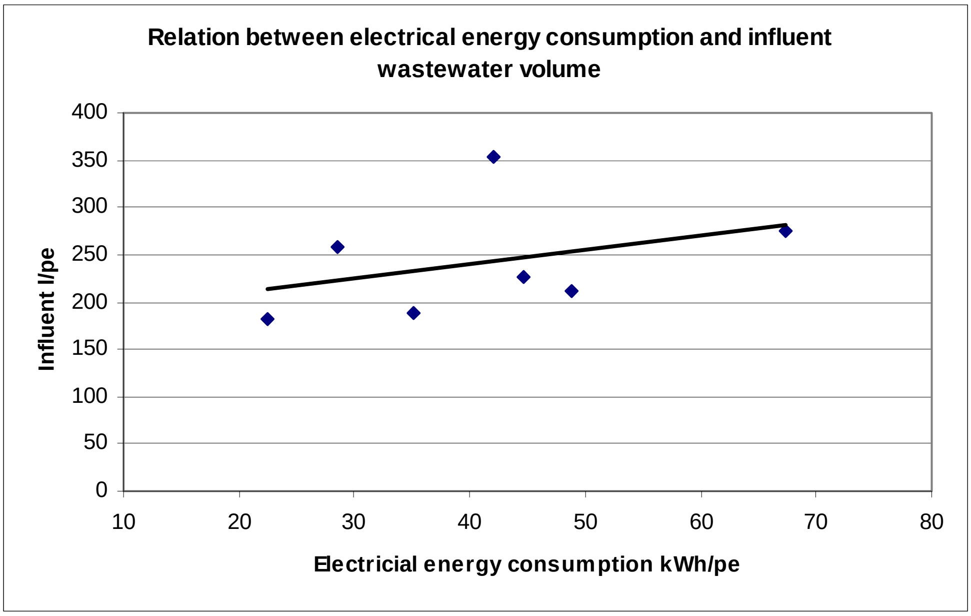


Figure 4.6 Influent volume to Swedish WWTPs compared to electrical energy consumption.

Figure 4.7 illustrates the electrical energy consumption in relation to the influent COD concentration. Figure 4.7 has opposite linear tendency as Figure 4.6: the lower influent COD concentration the higher energy consumption. Also here Austria's mean value is represented at the end of the trend line at 547 mg/l COD for an energy consumption of 23 kWh/pe, day.

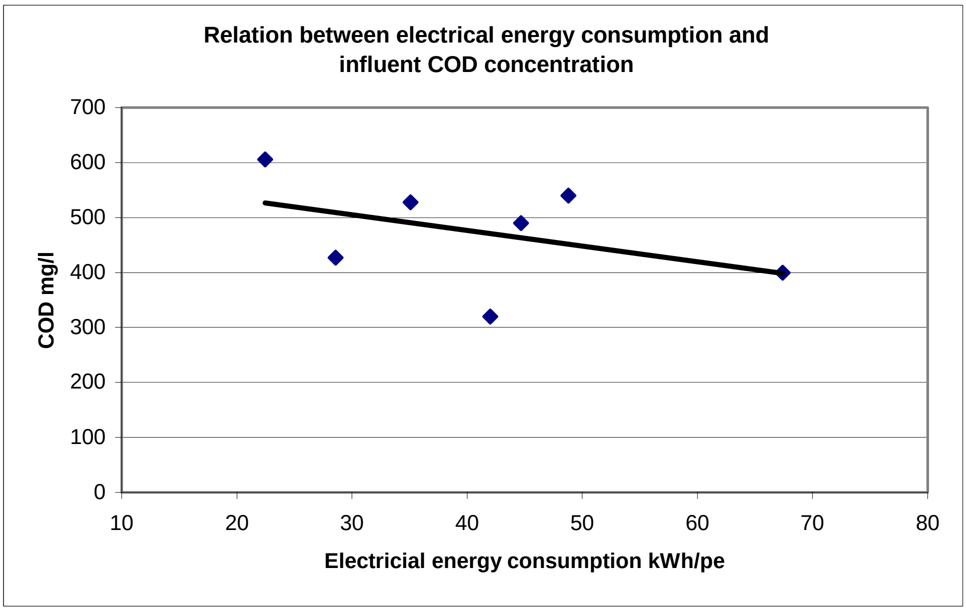


Figure 4.7 Influent COD concentrations to Swedish WWTPs compared to electrical energy consumption.

In addition to the influent wastewater characteristics, the emission legislation effects the energy consumption for wastewater treatment processes. As mentioned in Section 2.2, Sweden has higher emission legislation due to sensitive aquatic environment. Plants with higher legislations have to use more electrical energy to manage the treatment requirements. The quality of the effluent wastewater is always a first priority and therefore, high emission legislation requires more energy consumption.

4.4 Energy production

Results of the biogas production were not evaluated in the Austrian report. Dr. Stefan Lindtner could provide biogas and sludge production, but only given in the 25- and 75 percentile for WWTPs participating in the study (Lindtner, 2007). Questionnaires about the energy production were sent out to Austrian WWTPs. Yet, answers were only received from three plants. Therefore, a comparison between the two countries was eliminated. Following figures represent the energy consumption in relation to the energy production for both Sweden and Austria.

Figure 4.8 illustrates the gas production in relation to sludge retention time, SRT. The gas production is the theoretical energy content that can be extracted from the methane gas. For calculations of the energy content of methane gas, see Appendix III.

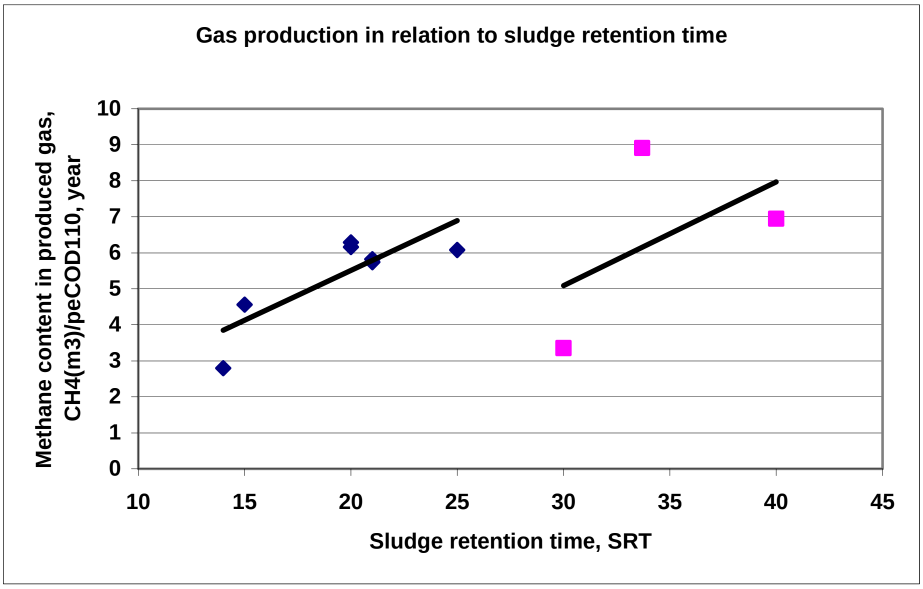


Figure 4.8 Relation between produced methane gas and sludge retention time. Values to the left are representing Swedish values and values to the right are representing Austrian WWTPs

In Figure 4.8, it can be seen that Austria uses larger volumes and therefore longer sludge retention time in the anaerobic digerster. However, the produced methane gas is similar. Figure 4.9 illustrates the energy content in the methane gas compared to the the total electrical consumption.

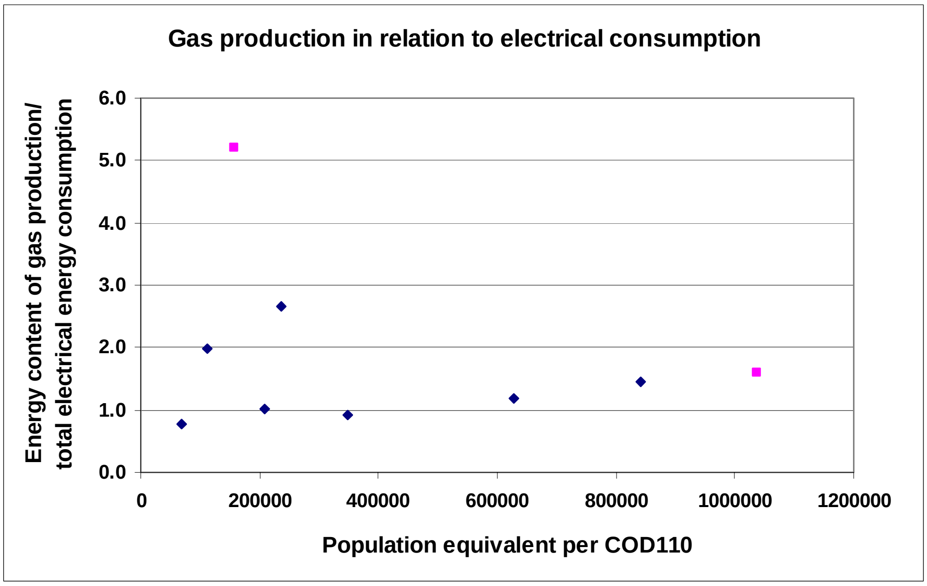


Figure 4.9 Gas production compared to total electrical energy consumption for larger plants in Sweden and Austria. The two pink values represents Austria.

Unfortunately, only two plants are presented from Austria. Figure 4.9 illustrates the theoretical energy self-efficiency of a plant. To be able to transform the energy content into electrical energy a good gas-engine has to be installed. Even though a first-class engine is used only 30 % of the energy content from methane gas can be transformed into electrical energy. Energy self-efficiency will be more discussed in Chapter 5.

4.5 Results

The energy benchmark for Sweden and Austria presents results in electrical energy consumption for WWTPs with a pe>100000. The electrical energy consumption is based on COD tests, calculated on 110 g per day and person. Sweden shows a result of the electrical energy consumption of 42 kWh/pe and Austria's median value is 23 kWh/pe. This is compared to the German energy manual, MURL (1999), with an ideal case value of 23 kWh/pe, which is similar to the Austrian result.

The main reason to differences in electrical energy consumption is that benchmarking studies has been carried out in Austria for many years. Repeated energy benchmarks have decreased energy consumption by the will of improvements. More about improvements from benchmarking in Austria is given in Section 5.2.8.

Wastewater characteristics also play a main role in the energy consumption. Swedish plants have more diluted wastewater, with less external carbon. Higher concentration of influent organic matter provides better conditions for energy efficiency in the wastewater treatment processes. Moreover, higher emission legislation due to sensitive aquatic environment in Sweden results in increased electrical energy consumption to manage treatment requirements.

5 Energy savings in WWTPs

Increasing electrical energy costs, global warming and need for reduced CO_2 emissions put pressure on wastewater treatment plants to improve and develop more energy efficient technologies. This has resulted in new technologies. For example, by removing organic matter using anaerobic digestion renewable energy is produced. In this chapter, there will be a discussion of energy self-sufficiency in wastewater treatment plants. The energy consumption is remarkably higher in the biological process; hence, the improvements of more energy efficient treatment processes in the biological step are of high interest.

5.1 Energy balance of WWTPs

Influent wastewater contains more potential energy than required for electrical energy usage for the plant. If this energy could be captured and used the wastewater treatment processes would be self-sufficient (Wett *et al.*, 2007).

The energy yield from different processes can be divided into thermal energy, E_T, syntheses energy, E_S, and electrical energy, E_E. Syntheses energy is the energy used by the organisms in the aerobic process. Therefore, when the sludge production is high more synthesis energy is generated. Figure 5.1 describes the hydrocarbon degradation from aerobic and anaerobic metabolism, respectively, and how much and in what form energy is transformed. Metabolism is the organic process, occurring in living cells.

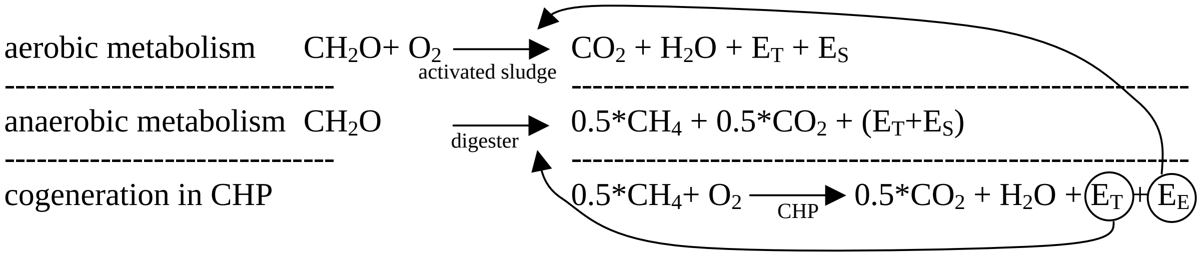


Figure 5.1 The energy yield from different hydrocarbon degradation processes (Wett *et al.*, 2007).

The thermal and syntheses energy generated from the aerobic metabolism cannot be used. In the anaerobic digestion the decomposing occurs during a slow process, which also requires a small amount of energy. Hence, the anaerobic digestion does not generate much energy. However, the methane gas produced from anaerobic treatment contains of a high amount of energy. By using a Combined Heat and Power plant (CHP), the energy in the methane can be transformed into both electrical and thermal energy. This energy can thereafter be recycled back as heating energy for the digester and as electrical energy source for the aeration process. By transferring energy from the aerobic treatment to the digester treatment, the ambition to make the wastewater treatment process self-sufficient could potentially be reached (Wett *et al.*, 2007). A practical example for this is given in the case study of WWTP Strass, in Chapter 6.

The energy flow through the wastewater treatment process is presented in two different energy balances, called thermal and calorific energy balance (see Figure 5.2). From Figure 5.2 it can be seen how the energy changes between the different physical stages of the wastewater; from liquid to sludge and finally to methane gas. To be able to exemplify the energy balance, data from WWTP Strass (see the case study of Strass in Section 6.2) is taken and illustrated in Figure 5.2.

At WWTP Strass the energy in the influent wastewater can be calculated by using the relation between 120 g COD/pe and the calorific energy, found by Shizas and Bagley (2004). The calorific energy balance has an energy input of 1760 kJ/pe estimated from 120 g COD/pe. The thermal energy is estimated by using the relation between litre of biogas and population equivalent. According to simulations done in WWTP Strass, the thermal energy flux of 14100 kJ/pe corresponds to 200 l/pe and with a wastewater temperature at 16.8 °C (Wett *et al.,* 2007).

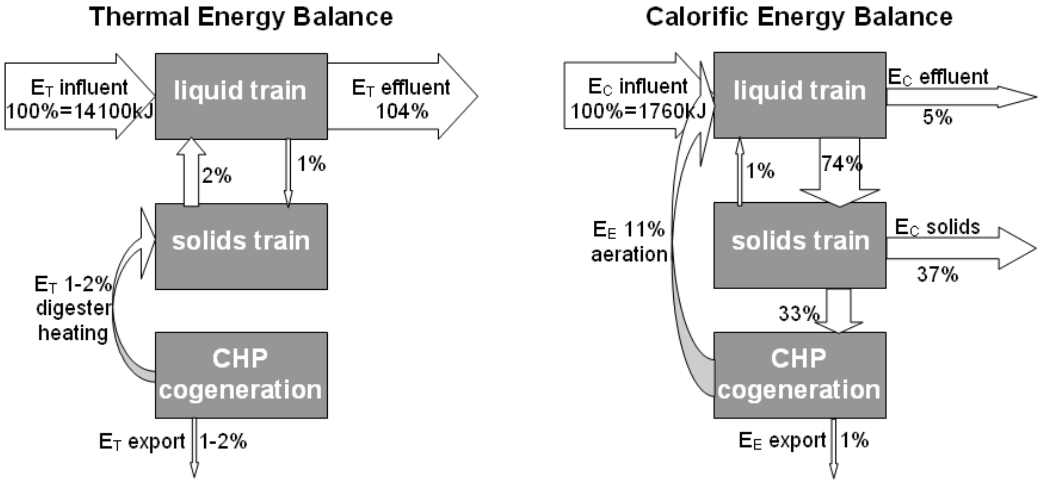


Figure 5.2 Flow scheme of the potential thermal and calorific energy content in wastewater in comparison to the energy fluxes between the liquid train, solids train and the CHP (Wett *et al.*, 2007).

In the liquid train in the thermal energy balance energy is generated. This extra energy is a result of the syntheses energy transformed from calorific energy in the calorific energy balance into thermal energy. This approach can be used on any wastewater treatment plant.

5.2 Potential energy savings in WWTPs

As a result of the comparison between Sweden and Austria conclusions can be made that in Sweden there are high potentials for more energy efficient wastewater technologies. Due to the fact, that the prices of electricity has been relatively low until the 1990's, energy saving has not been a first priority for wastewater treatment plant managers.

According to the energy manual (MURL, 1999) in Germany, the specific electrical usage decreases as the size of the WWTP increases per pe. In the Swedish energy manual for wastewater treatment plants (Kjellén and Andersson, 2002), the specific electrical energy use in Swedish WWTPs is compared to the German study. From this early study, it is shown that Swedish WWTPs use twice as much energy compared to German facilities. Furthermore, in the German study it was found that further energy saving measures of approximately 35 % of the electrical energy consumption is still possible. Consequently, in Sweden it would seem probable to make WWTPs more energy efficient. One of the reasons for the existing difference could be that German WWTPs have lower input load, which leads to less energy consumption and more volume (investment costs). On the other hand, Swedish WWTPs in general have a higher load, which leads to more energy consumption and less volume.

In this section, there will be examples of different technologies and aspects that can lead to higher energy efficiency and also improved energy generation.

5.2.1 Planning and dimension

Wastewater utilities are planned and dimensioned for a future expected demand, normally 20 to 30 years ahead. Engines and other installed machines do not have that long operating time. Therefore, it is of great importance to dimension machinery for the actual demand instead of the future expected demand, to achieve good efficiency (Kjellén and Andersson, 2002).

Another energy consuming parameter is friction losses. Friction losses in pipes have to be compensated by extra energy. By dimensioning pipes for maximum efficiency, energy costs can be decreased. For example, by doubling the pipe dimension for a constant wastewater flow, the friction losses will be reduced by 97 % (Kjellén and Andersson, 2002). However, oversized pipes can cause other problems and increase costs.

5.2.2 Aeration system

From the study made, the most energy effective measures are either to decrease the aeration to the process or to invest in new aeration control systems. The aeration system consumes more energy than any other process, but here is also has the largest potential for energy savings.

To reduce the aerobic treatment of biological sludge in the aeration tank the COD reduction needs to be as high as possible, while the retention time has to be as low as possible (Kjellén and Andersson, 2002). Because of the variability of the influent wastewater, the oxygen added to the aeration process should be controlled and adjusted by on-line measurements (Magnusson, 2006).

Another energy saving potential is to exchange old aeration systems to new and more energy efficient aeration machines. There are many suppliers in the business, and to be able to find the optimum aeration system for the individual plant, a good technical and professional knowledge is required. According to a case study at Käppala WWTP in Sweden, investments in a new high speed motor from ABS Group would decrease the electrical energy needed for the aeration process by about 5 % would be reached (Magnusson, 2006).

Moreover, at one WWTP in Sweden the electrical energy consumption decreased by 10 % by introducing an in-feed filter system for the blowers (SYVAB, 2005).

In another case study from a Swedish WWTP, energy consumption could be decreased by 15 % in the aeration process by using two oxygen sensors in each aeration line instead of one. An introduction of such a control strategy will not only present energy savings, but also deliver a better oxygen distribution. Improved environment for the micro-organisms will lead to higher sludge quality (Andersson and Holmberg, 2006).

There are many different methods for measuring dissolved oxygen concentrations or other associated variables suitable for control purposes, depending on the size of the plant and type of reactor. Chapter 5 will explain how the on-line control system is used in an Austrian WWTP.

By increasing the amount of sludge for gas production the energy consumption will decrease. The energy balance in a WWTP is partially depending on the primary sedimentation. Treatment plants without primary sedimentation use a lot more aerobic stabilisation, which is more energy consuming. To divide the primary sedimentation into smaller units will make the processes more energy efficient. This will also allow for more individual control strategies in the different steps. Consequently, energy can be saved by adjusting processes after load and season (Kjellén and Andersson, 2002).

5.2.3 Pumps

Pumps are large energy consumers in a wastewater treatment plant. The differences in energy efficiency between pumps are also significant. Therefore, it is valuable to compare different pumps regarding efficiency before installation for energy cost savings (Kjellén and Andersson, 2002).

According to a study made in Käppala wastewater treatment plant (Magnusson, 2006), potential energy savings can be achieved by changing the control system of the inlet pump station. By deactivating the inlet pump station when the wastewater inflow is below 0.5 m^3/s the effectiveness of the pump will increase. Moreover, energy savings can be made by changing the location of the pumps and to invest in smaller pumps. Total energy savings has been estimated to 9 % of total electrical energy consumption (Magnusson, 2006).

From interviewing personnel at WWTPs in Sweden concerning choice of pumps regarding age, efficiency and brand, the reason why having a certain brand seems to be because it is the most common one on the market. As mentioned earlier, it is of great importance to have good technical knowledge and to be able to follow the market, for optimal selection of electromechanical equipment.

5.2.4 Mixers

The anaerobic treatment processes requires mixers to keep the sludge suspended. Important is to make the mixers and the basin volume fit together for maximal energy efficiency. Moreover, it is important to dimension and position the mixers for every individual tank, to allow for an energy effective system (Kjellén and Andersson, 2002).

By using online control systems for the mixers the energy consumption could be decreased. For example, by turning off the mixers for a period without affecting the treatment process (intermittent mixing), the electrical energy usage will decrease (Magnusson, 2006).

5.2.5 Sludge

Decreased sludge volume always decreases the energy usage. Dewatered sludge gives a lower sludge volume and it is therefore less energy consuming to pump than hydrated sludge. High sludge content will also lead to energy savings in further treatment steps, like sludge combustion and drying. The most energy saving method for sludge dewatering is static or gravimetric dewatering. By static sedimentation there is almost no energy required and no flocculation chemicals have to be added. The size of the machines used for dewatering makes a big difference in the energy consumption. Larger machines use a smaller amount of specific electrical power than smaller units per kg dewatered sludge (Kjellén and Andersson, 2002).

Case study Käppala (2006) indicates energy saving potentials in increased total solids concentration, TS. According to the study, increased TS concentration by 1 % would decrease the energy consumption by approximately 18 000 Euro per year. A thicker sludge leads to a lower flow, which decreases the electrical energy consumption for the heating pump to maintain equal wastewater temperature in the digester. The temperature of the sludge has significant impact on the energy consumption. By increasing the temperature of the influent sludge, energy can be saved in the digestion chambers. According to the study, by increasing the temperature for influent sludge to the digestion by only 1 °C, energy savings of approximately 24000 Euro per year could be reached (Magnusson, 2006).

5.2.6 Gas

To be able to extract electrical energy from the biogas, a gas-powered engine must be installed. Extracting more energy from waste heat and producing more biogas can generate more electrical energy. Although, a well functioned CHP is used only 30 % of the methane gas can be generated as electricity. 40 % can be transformed into thermal energy and the rest is lost.

The biogas produced should also be used more frequently for heating and as vehicle fuel.

5.2.7 Heating, lighting and ventilation system

There are many small and simple ways to save energy. For example, during nights and weekends light in the facility should be turned off. Fans for ventilation in tunnel systems are relatively energy demanding. These costs are small comparably, but by introducing control strategies for all electrical equipment – small and large – energy savings can be made. From the case study Himmerfjärden, a 20 % energy reduction for a fan would results in a total cost saving of 9700 Euro per year (Andersson and Holmberg, 2006).

5.2.8 Knowledge and experience exchange

According to the task group in the Swedish Water Association, the knowledge and awareness of the staff with regard to energy saving programs is low. To educate and inform the personnel would lead to more energy efficient operation of the wastewater treatment.

As mentioned earlier, improved control strategies in wastewater treatment facilities would lead to better energy efficiency. It is therefore of great importance to take samples with frequent intervals. COD samples should be analysed because it gives a more accurate measurement than BOD. For plants designed to remove phosphorus, it is recommended to analyse COD regularly (Novotny, 2006).

One of the most important energy saving program is to exchange experiences and to follow up with repeated benchmark studies. According to the Austrian study, which takes place every year, an improvement in energy usage is a fact. Figure 4.3 illustrates improvements achieved in Austria from the beginning of the benchmark in 1999 to year 2004.

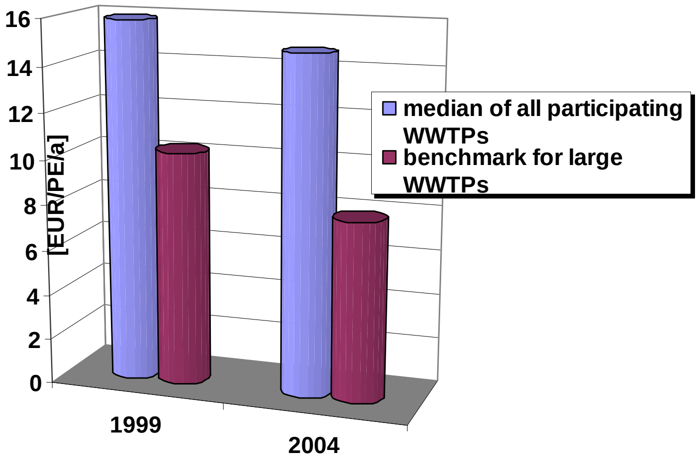


Figure 5.3 Differences in energy costs in Euro/pe and year for WWTPs in Austria from year 1999 to 2004 (Wett *et al.*, 2007).

After the first five years of annual benchmarking in Austria the electrical energy costs has decreased by 30 % (Wett *et al.*, 2007).

5.2.9 Smaller plants

From the Swedish study, smaller plants indicate a very broad variation of results. However, this indicates only that there is potential for more energy efficient wastewater treatment processes within smaller plants. It is of considerable value to have a good management to educate the personnel of how to achieve small – but still effective – improvements. The majority of plants in both Sweden and Austria are smaller plants, pe < 50 000. Therefore, if the energy consumption could be decreased in smaller plants, the total national energy savings would be significant (Lundkvist *et al.*, 2007).

According to estimations done by the Swedish Water and Wastewater Association, the potential energy savings per year for Swedish WWTPs is very high. Smaller plants do not prioritize energy savings, because the need for savings is small. Therefore, it is important to create incentives for energy savings. Furthermore, one of the biggest issues for smaller plants is how to use the sludge. It is important to digest the sludge, and if not possible by every plant, larger plants have to do it for them.

5.2.10 Chemicals

In the wastewater treatment process, different chemicals are used. All chemicals have an energy content as a result of the manufacturing process. This energy is difficult to measure. Some plants might have low energy costs, but on the other hand a high chemical usage, which indirectly also indicates high energy consumption (Ulf Jeppsson, 2007).

The major energy consumer in chemicals is the use of external carbon, used primarily for the denitrification process. The carbon source varies from different plants, but most common in Sweden and Austria is ethanol, methanol and glycol.

If a WWTP uses chemical phosphorus removal, the costs for metal salts for the chemical flocculation process are high (Ulf Jeppsson, 2007).

Other chemicals used are lime and polymers. It is extremely energy consuming to extract lime from limestone. Also, when using lime in the sludge treatment process the energy from the organic matter is not as easily extracted. Energy will be saved, if the usage of lime would be reduced (Lundkvist *et al.*, 2007).

The energy content in chemicals might be as high as the electrical energy in wastewater treatment. In the Austrian benchmark study, the chemical cost is the third largest cost in all WWTPs, larger than the electrical energy cost (see Figure 3.4). From the Swedish energy report this is not presented not discussed but it is mentioned that a more profound study about chemicals and energy consumption needs to be done.

6 Case study – WWTP Strass

In this chapter, a case study of the wastewater treatment plant Strass, Austria, will be discussed. A review of the energy related efforts done over the last ten years will be presented. The case study will describe the motives for the energy related measures, as well as the results and future works. Furthermore, there will be a discussion of how these results correspond to the conclusions given in the benchmarking studies performed in Sweden and in Austria.

6.1 Wastewater treatment plant Strass

The municipal WWTP Strass is located in western Austria. The plant was developed during the late eighties by the association for wastewater purification Achental-Inntal-Zillertal (AIZ). WWTP Strass has a population equivalent load varying from 90 000 to over 200 000, depending on the tourist season.

The treatment processes are divided into two stages of biological removal. The first stage, called the A-stage, removes 55-65 % of the organic load by using intermediate clarification and a separate sludge cycle. The nitrogen in the low loaded B-stage is removed by using pre-denitrification. The aim is to achieve 80 % nitrogen removal efficiency from the B-stage and to reach effluent concentrations of ammonia of 5 mg/l. The sludge retention time in the A-stage is approximately 12 hours, compared to 10 days in the B-stage. (Wett *et al.*, 2007).

Aeration for every activated sludge tank are controlled by an on-line ammonia sensor. It is a feed-back control system, measuring the NH_4 -concentrations at the outlet of the process. A signal controls the dissolved oxygen, DO, set points. The ammonium controls the dissolved oxygen set point in the nitrification and the denitrification tanks, respectively, by following relation:

$$1 \leq NH_4 \leq 2 \Rightarrow DO_{nitrification} = 1.7 \text{ mg/l} \quad \text{and } DO_{denitrification} = 0 \text{ mg/l}$$

$$NH_4 < 1 \Rightarrow DO = 0 \text{ mg/l} \text{ for both nitrification and denitrification}$$

$$NH_4 > 3 \Rightarrow DO = 1.7 \text{ mg/l} \text{ for both nitrification and denitrification}$$

The intermediate clarification is in a sequencing batch reactor (SBR) where the pH-values are changing due to nitrification or denitrification. During the nitrification process, H^+ is produced which leads to decreased pH values. On the contrary, the pH values are increasing during denitrification, due to anaerobic conditions (Wett, 2006). See Appendix V for a plant layout of WWTP Strass.

6.2 Energy saving measures at WWTP Strass

The B-stage is responsible for almost 50 % of the total electricity consumption in Strass WWTP. The energy usage for pumps and for off-gas treatment is relatively high. The pumping energy is high because of a high inlet elevation difference and for the pumping of the off-gas. The central building at the plant includes grit chamber, sand trap and the biological treatment tanks that all give off excess air, off-gas (see Flow scheme number 6-7 in Appendix V). The off-gas is pumped through a compost filter and this system requires a large amount of energy (Wett *et al.,* 2007).

The biological wastewater treatment process has been developed for higher energy efficiency since 1996. The energy self-sufficiency has progressed from 49 % in 1996 to 108 % in 2005. The development of the energy consumption from every process in the wastewater treatment plant is illustrated in Figure 6.1 (Wett *et al.,* 2007).

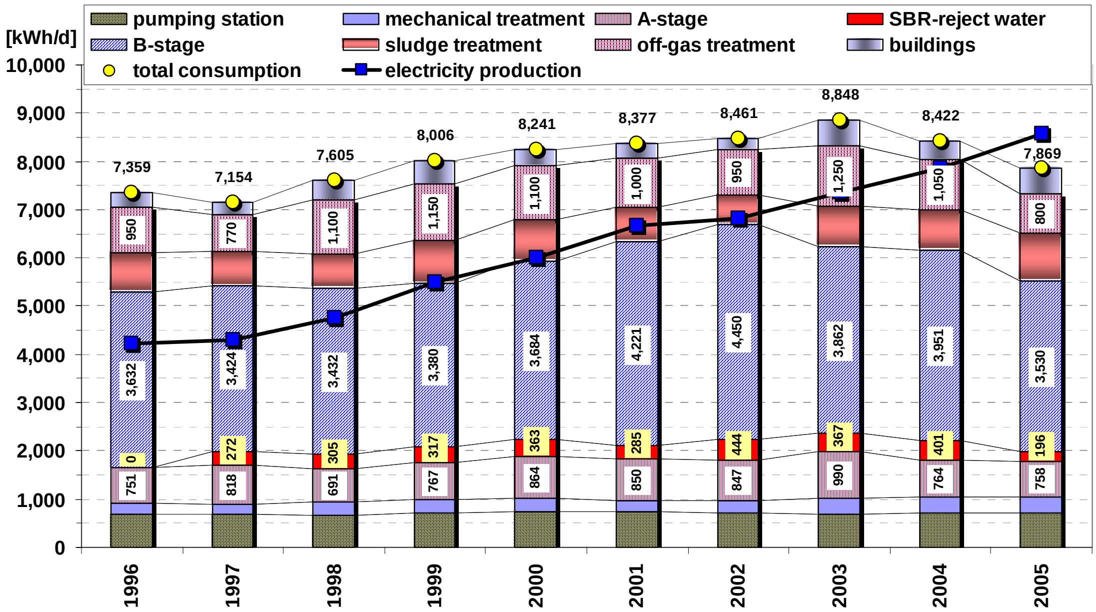


Figure 6.1 The development of the electrical energy consumption and production from every process at WWTP Strass (Wett *et al.*, 2007).

In Figure 6.1, the development of the electricity production is illustrated. One of the energy saving measures done in the plant is the installation of a new combined heat and power unit in 2001. Up till 2001 the consumption and production of energy increased almost in parallel. Figure 6.1 illustrates the increased results after 2001 and also the progress of energy self-sufficient wastewater treatment processes. The new CHP unit converts biogas into electrical energy with a total power yield of 340 kW. WWTP Strass has a biogas production of about 26 l/pe a day, which the CHP unit can convert to electrical energy with an average efficiency of 38 % (Wett *et al.*, 2007). The electricity produced is used for the aerobic treatment.

An energy saving operation was the introduction of the new deammonification process, in 2004. The previous nitrification/denitrification process was an SBR, where sludge from the A-stage was used as carbon source. The deammonification (DEMON®) process has no requirements of excess carbon and higher volumes of sludge increased the methane content from about 59 % to 62 %. Due to the deammonification process, total energy savings of approximately 12 % have been achieved. See Figure 6.2 for the progress in decreased energy consumption after the installation of the deammonification process.

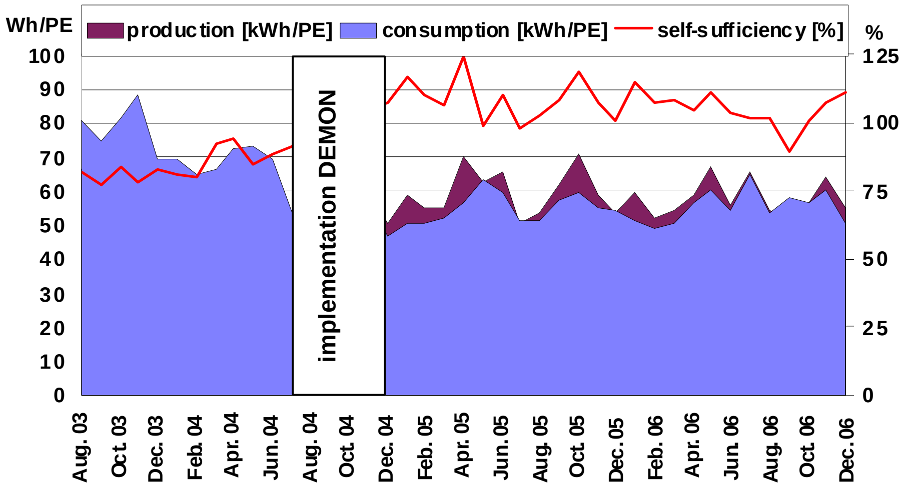


Figure 6.2 Development of energy self-sufficiency at WWTP Strass after implementation of deammonification (Wett *et al.*, 2007).

6.3 Future energy projects

The largest effort to make WWTP Strass more energy efficient is to lower the pumping energy consumption. The sludge recycling system is operated by a high energy consuming spiral pump. By changing this pump with a conventional pump, which is less energy consuming, energy savings will be made.

Efforts to decrease the energy consumption in WWTP Strass correspond to the results given from the benchmark studies in Sweden and in Austria. The energy consumption in the biological step is the largest energy consumer, in

Strass, Austria and in Sweden. Potentials to reduce the energy consumption in this process are high in individual plants as well as in a country as a whole. There is also large interest to improve the treatment process and at the same time decrease the energy consumption, for example by using more sophisticated on-line control.

The energy required for pumps is high and the market offers many new technologies. To change the old pumps with new and more energy efficient pumps could be a good energy saving operation in every plant.

7 Conclusions

7.1 Summary of results

The Austrian Association for Water and Waste has carried out the benchmarking program *"Benchmarking and best practices in the Austrian water supply sector"* for over eight years. Benchmarking studies encouraging WWTPs to improvements and the results from the Austrian benchmarking study indicates decreased electricity costs of about 30 % since the beginning in 1999. The Austrian benchmarking program is presented in Section 3.3.

Due to increased energy consumption combined with rising energy prices, the Swedish Water & Wastewater Association decided to initiate an energy saving program in 2005. The goal of the project is to find benchmarks to be able to decrease the use of primarily electrical energy. The report presented large variations between WWTPs and high potential in energy savings. The results of the Swedish energy program is given in Section 3.2.

The energy benchmark for Sweden and Austria presents results in electrical energy consumption for larger WWTPs (pe>100000). The electrical energy consumption is compared using population equivalent based on influent COD calculated by using a specific load of 110 g per day and person. In the energy benchmark for WWTPs, Sweden uses approximately 45 % more electrical energy than Austria. Sweden shows result of a total electrical energy consumption of 42 kWh/pe and Austria of 23 kWh/pe. This is compared to the German energy manual, MURL (1999), with an ideal case value of 23 kWh/pe, which is similar to the Austrian result. For all results of the comparison between Sweden and Austria, see Chapter 4.

One of the reasons to Austrias lower electrical energy consumption is that benchmarking studies has been carried out in Austria for many years. Benchmarking encourages competition between WWTPs and repeated energy benchmarks have decreased energy consumption by the will of improvements.

Wastewater characteristics also play a main role in the energy consumption. Swedish plants have a higher influent wastewater flow. Austria has less diluted wastewater with higher concentration of influent organic matter, which provides better conditions for energy efficiency in the wastewater treatment processes. In addition to the influent wastewater characteristics, the emission legislation effects the energy consumption for wastewater treatment processes. Sweden has high emission legislation due to sensitive aquatic environment.

WWTPs with higher emission legislations use more electrical energy to manage the treatment requirements and to preserve good quality of the effluent wastewater.

In the anaerobic process, biogas is produced which gives WWTPs the advantage as energy producer. The biogas can be transformed into thermal or electrical energy by using a combined heat and power plant, CHP. The biogas can contain enough energy to heat up the whole plant. Optimization of biogas is important for more energy efficient WWTPs. Moreover, the biogas production has potentials in making any WWTP self-sufficient. In the thesis, a comparison between the total electrical consumption and the biogas production from both countries was not possible due to the fact that the Austrian study did not cover the biogas production. However, the case study of the Austrian WWTP Strass show results in how to make a WWTP self-sufficient. WWTP Strass has a CHP that converts biogas into electrical energy with an efficiency of 38 %. In addition, implementation of deammonification at WWTP Strass has decreased the energy consumption of about 12 %.

Besides installation of a CHP for more energy production, there are many measures that can improve the efficiency of a plant. For instance, it is important to dimension and position the mixers for every individual tank, to allow for an energy effective system. Measures for more energy effective WWT processes are given in Chapter 5.

7.2 Future research

Due to the fact that continued benchmark studies in Austria has resulted in 30 % decreased energy consumption, the potential in energy savings for Swedish WWTPs is high. If the Swedish Association for Water and Waste can keep up with annual energy benchmark for WWTPs, hopefully similar results will be seen in Sweden within five years.

The Austrian benchmarking study is well developed with high participating rates. By increasing the evaluation with biogas production and usage for the produced energy, potentials for more energy efficient WWTPs can be reached.

8 References

8.1 Text books

Gujer W. (2002). *Siedlungswasserwirtschaft,* 2nd ed., ISBN 3-540-43404-6, Springer-Verlag Berlin, Germany (in German).

Metcalf & Eddy (2003). *Wastewater Engineering, treatment and reuse,* 4th ed., ISBN 0-07-049539-4, Tata McGraw-Hill Publishing Company Limited, New Delhi, India.

8.2 Reports

Alegre H., Baptista J.M., Cabrera Jr E., Cubillo F., Duarte P., Hirner W., Merkel W. and Parena R. (2006). *Performance Indicators for Water Supply Services*, 2nd ed., ISBN 1843390515, IWA Publishing, London, UK.

Andersson R. and Holmberg M. (2006). *Energy conservation in wastewater treatment operation – a case study at Himmerfjärden WWTP*, Master thesis, IEA, Lund University, Sweden.

Benedetti L. (2006). *Probabilistic design and upgrade of wastewater treatment plants in the EU Water Framework Directive context.* PhD thesis, Ghent University, Belgium, pp. 304.

Fors J. and Remberger S. (2007). *Eleffektivisering inom Bromma avloppsreningsverk*, EnerGia report 2006-02, Stockholm Water, Sweden (in Swedish).

Jeppsson U., Baky A., Hellström D., Jönsson H. and Kärrman E. (2005). *The URWARE Wastewater Treatment Plant Models,* Urban Water, Chalmers University of Technology, Gothenburg, Sweden, Report 2005:5.

Kjellén B.J. and Andersson A.C. (2002). *Energihandbok för avloppsreningsverk*, VA-Forsk report nr 2002-2, Swedish Water and Wastewater Association, Sweden (in Swedish).

Lindtner S., Lehner F., Ertl T. and Murnig F. (2007). *Öffentlicherbericht; Benchmarking für Kläranlagen*, *Geschäftsjahr 2005,* Austria (in German).

Lundkvist M., Lingsten A. and Wiberg A. (2007). VA-verkens bidrag till Sveriges energieffekivisering, *Rapport 1: Nulägesbeskrivning*, The Swedish Water and Wastewater Association (SWWA), Sweden (in Swedish).

Magnusson A.S. (2006). *Streamlining of electricity energy at Käppalaverket*, Master thesis, KTH, Sweden (in Swedish).

Sharma A. (2006). *Urban water sector in South Asia; Benchmarking performance*, Water and Sanitation Program-South Asia, the World Bank, New Delhi, India.

Stahre P. (2005). *Performance benchmarking; a powerful management tool for water and wastewater utilities,* Malmö water and wastewater, Malmö, Sweden.

Theuretzbacher-Fritz H., Schielein J., Kiesl H., Kölbl J., Neunteufel R. and Perfler R. (2005). *Trans-National water supply benchmarking: The cross-border co-operation of the Bavarian EffWB project and the Austrian OVGW project*, University of Technology, Graz, Austria.

The Provincial Government of Tirol, Kläranlagenkaster (2004). *Teil 1, Gesamtauswertung*, Tirol, Austria (in German).

The Swedish Water and Wastewater Assosiation (SWWA) (2005). *Facts on water supply and sanitation in Sweden,* Stockholm, Sweden.

Wett B., Buchauer K. and Fimml C. (2007). *Energy self-sufficiency as a feasible concept for wastewater treatment systems,* Institute of Infrastructure and Environmental Engineering, University of Innsbruck, Austria.

Wett B. (2006). *Solved upscaling problems for implementing deammonification of rejection water*, Water Science & Technology, Vol. 53, No. 12, pp 121-128.

8.3 Internet sites

The Swedish Energy Association, STEM, March 2007
http://www.stem.se/

The Swedish District Heating Association, April 2007
http://www.svenskfjarrvarme.se/
Austrian Energy Agency, August 2007
http://www.energyagency.at/projekte/ren-in-a.htm

ABS Group, technical support for wastewater utilities, June 2007
http://www.absgroup.com/

Exchange rates, 2007-06-08
http://www.valutor.se/

WWTP Strass, 2007-06-20
http://www.aiz.at/klaeranlage.htm

8.4 Other references

AEV für kommunales Abwasser, May 1996, Austria.

Froning S. (2003). *DHC/CHP/RES a smile for the environment*, Euroheat & Power, Kiev, Ukraine.

Kemira, (1991). *Inblandning & flockning,* Kemwater, Sweden (in Swedish).

Kläranlagenkataster, (2004). WWTP land register, Statistical data collection, Tirol, Austria (in German).

Novotny G. (2006). *Wastewater Characterization for Evaluation of Biological Phosphorus Removal*, Department of Natural Resources Wisconsin, US.

VASS – Swedish Water Association online database (in Swedish).

2005 Environmental reports from SYVAB, Varberg, Orebro, Kappala, Uppsala and GRYAAB, Sweden.

Thöle D. (2006). *Assessment criteria "Manual Energy Audit" and Recommendation of Umweltbundesamt*, Ruhrverband, Germany.

Directive (91/271/EEC) of 21 May 1991, concerning urban wastewater treatment, Council of the European Communities.

8.5 Oral communication

Mats Ejderby, Director of operation, Bromma WWTP, Stockholm, Sweden.

Leif Eriksson, Skebäck WWTP, Örebro, Sweden.

Ulf Jeppsson, ass. Prof. and head of the department of Industrial Electrical Engineering and Automation (IEA), Lund University, Sweden.

Alexander Keucken, Varberg, Sweden.

Anders Lind, Stockholm Water, Stockholm, Sweden.

Dr. Stefan Lindtner, Engineering office, K2W, Vienna, Austria.

Mats Lundkvist, Sweco VIAK, Halmstad, Sweden.

Sven-Ove Petersson, GRYAAB, Gothenburg, Sweden.

Charlotta Raudberget, WWTP Simsholmen, Jönköping, Sweden.

Johan Stock, Kungsängsverket, Uppsala, Sweden.

Anna Maria Sundin and Torsten Palmgren, Käppala WWTP, Lidingö, Sweden.

Malin Tuvesson, SYVAB, Grödinge, Sweden.

Bernhard Wett, Dept of Environmental Engineering, University Innsbruck, Austria.

9 Nomenclature

BOD	Biochemical oxygen demand; by measuring the biochemical degradation of organic matter the organic content in the wastewater can be determined.
CHP	Combined heat and power plant: power station that both generates electrical and heat energy.
COD	Chemical oxygen demand: test to determine the organic content in the wastewater. A COD-test oxidizes both biologically degradable and non-biologically degradable organic material by adding an oxidizing agent.
DO	Dissolved oxygen; measures the amount of gaseous oxygen (O_2) dissolved in the wastewater.
HRT	Hydraulic retention time: the time the water stays in the system before moving out.
Mesophilic	Process occurring at temperatures around 35 °C
PAO	Polyphosphate-accumulating organisms; enriched in the wastewater for phosphorus removal.
PE	Population equivalent; a reference- and mean value for the water usage and pollution in the wastewater caused by one person in one day, and is found by measuring the organic matter.
SBR	Sequencing batch reactor: wastewater treatment device for BOD and COD reduction.
SRT	Solids retention time; the time the sludge stays in the system before moving out.
Termophilic	Process occurring at temperatures above 50 °C
TS	Total Solids: the amount of dry material in the sludge that remains after a drying process at 105 °C for 1 hour.
WWTP	Wastewater treatment plant

Appendix I
Influent wastewater characteristics

Mean values for influent wastewater characteristics in Tirol, Austria

	Influent	BOD$_5$		COD		Nitrogen, N		Phosphor, P		Ammonium NH$_4$-N	
	m^3/d	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d
Mean value	254 110	**291**	71406	**547**	133384	**44**	14244	**7.5**	33	**26**	6227
Annual value	94274688		26491488		49485378		5284364		12401		2310373

(Kläranlagenkataster Tirol, 2004, Teil 1: Gesamtauswertung Tirol, Wasserwirtschaft)

Influent wastewater flow rate is calculated by using the COD load. The COD mean value is divided by 110 g. Thereafter, the influent wastewater is divided by the COD load to find the influent wastewater in litre per population equivalent.

$$\frac{133384}{0.110} = 1212581 \text{ pe/kg}$$

$$\frac{254110}{1212581} = 210 \text{ l/pe}$$

Mean values for influent wastewater characteristics in Swedish WWTPs

WWTP	Inflow m^3/day	Nitrogen mg/l	Phosphorus mg/l	COD mg/l	BOD$_7$ mg/l	BOD$_5$ mg/l	Ammonium mg/l	SRT days
Jönköping	28686			427	164	140		21
Varberg	13179	38.2	6.9	528	251	215		14
Uppsala	47364	53	7.3	490	190	163		15
Örebro	42795	40	6.7	606	266	228	26	25
SYVAB	95890	34	5.7	400	180	154	23	20
Käppala	133216	45	7	540	250	214	29	21
Gothenburg	297534	29.4	4.6	320	134	115	18.5	20
Average	**94095**	**40**	**6.4**	**473**	**205**	**176**	**24**	**19**

Values given by Environmental reports from Swedish WWTPs, 2005.

Appendix II
Questionnaire for Swedish WWTPs

Energy consumption for Wastewater Treatment Plants; 1 answer per facility, i.e. more than one report per organisation can occur.
One report for plants with >2000 pe, smaller plants will be summarised.

Category	**Code**	**Description**	**Definition**	**Unit**
Energy WWTP	EARV0	Amount WWTP for this questionnaire	Normally 1. When questionnaire is summarized, please report total amount WWTP	amount
Energy WWTP	EARV1	Dimension	State for how many pe the WWTP is dimensioned for	pe
Energy WWTP	EARV2	Treated sewage volume	Volume wastewater treated with mechanical purification during the year	m^3
Energy WWTP	EARV3	Total energy consumption	Total electrical use in WWTP for pumps, purification, heating, lights and so on (also own produced)	kWh
Energy WWTP	EARV4	Other energy consumption	Total energy consumption, except for electricity, in WWTP for heating etc. (e.g. oil, fv, gas) calculated in kWh	kWh
Energy WWTP	EARV5	Energy delivery to external network	Delivered energy amount to external net (electricity, district heating etc.) from WWTP over the year	kWh
Energy WWTP	EARV6	Income organic matter during the year	State volume of income organic matter to WWTP during the year	ton BOD_7
Energy WWTP	EARV7	Electricity consumption in the treatment process e	Electrical consumption in the treatment process exclusive aeration	kWh
Energy WWTP	EARV71	Electricity use in the aeration process	Electricity use in the aeration process	kWh
Energy WWTP	EARV8	Energy for heating	Energy use (electricity, oil, district heating, pellet, gas) for heating of the WWTP converted into kWh	kWh
Energy WWTP	EARV9	Amount heating pumps	Amount installed heating pumps in the WWTP	amount
Energy WWTP	EARV91	Source of heat for heating pumps	Source of energy for heating pumps used during the year. Describe in words e.g. exhaust air, wastewater, sludge.	description
Energy WWTP	EARV92	Electricity consumption heating pumps	Electrical consumption for operation of heating pumps	kWh
Energy WWTP	EARV93	Extracted energy heating pumps	Amount of energy extracted from heating pumps (gross)	kWh
Energy WWTP	EARV10	Amount of heating exchanger	Amount of heating exchanger installed in the WWTP	amount
Energy WWTP	EARV101	Heating source for the heating exchanger	Heating source for the heating exchanger used during the year. Explain procedure e.g. sludge/sludge, exhaust air/draught air.	description
Energy WWTP	EARV11	Carbon source for nitrogen treatment	Explain what carbon source is used for nitrogen treatment	description
Energy WWTP	EARV111	Amount of carbon	Amount of carbon source used for nitrogen treatment during the year	ton
Energy WWTP	EARV12	Sludge production	Amount sludge produced in the WWTP during the year	ton TS

Energy WWTP	EARV121	Anaerobic digestion	Percentage bio gas from sludge production	%
Energy WWTP	EARV122	Sludge combustion	Percentage of sludge production for combustion	%
Energy WWTP	EARV123	Amount compost	Percentage composted sludge production	%
Energy WWTP	EARV124	Amount of sludge with lime	Percentage limed sludge production	%
Energy WWTP	EARV125	Other treatment	Percentage sludge that does not go to anaerobic digestion, combustion, compost or lime	%
Energy WWTP	EARV13	External organic matter that will be treated	External organic matter that will be treated in WWTP during the year	ton TS
Energy WWTP	EARV14	Electricity consumption in sludge treatment	Electricity consumption in sludge treatment	kWh
Energy WWTP	EARV15	Other energy consumption in sludge treatment	Other energy consumption in sludge treatment, e.g. gas, oil, district heating (converted into kWh)	kWh
Energy WWTP	EARV16	Bio gas production	Annual production of bio gas at WWTP (give 0 Nm^3 if there is no gas production)	Nm^3
Energy WWTP	EARV16a	Bio gas production, state plant type	Describe bio gas tank	description
Energy WWTP	EARV16b	Bio gas production, state construction year for the	Construction year for gas production chamber	year
Energy WWTP	EARV16c	Bio gas production, state amount of gas chambers	Amount bio gas chambers in the plant for gas production	amount
Energy WWTP	EARV16d	Bio gas production, total gas chamber volume	Total bio gas chamber volume in the plant for bio gas production	m^3
Energy WWTP	EARV16e	Bio gas production, state process temperature	Temperature in bio gas chamber	Celsius degrees
Energy WWTP	EARV161	Methane percentage in produced bio gas	An average value of the methane percentage in produced bio gas during the year	%
Energy WWTP	EARV162	Bio gas production used for heating	Percentage of produced bio gas used as heating source for the WWTP	%
Energy WWTP	EARV163	Bio gas usage as vehicle fuel	Percentage of produced bio gas used as vehicle fuel	%
Energy WWTP	EARV164	Electricity consumption by gas purification	Electricity consumption by gas purification used as vehicle fuel	kWh
Energy WWTP	EARV165	Electricity consumption in tank station	Electricity consumption by refuelling of bio gas for vehicle	kWh
Energy WWTP	EARV166	Bio gas usage for electricity generation	Percentage produced bio gas used for electricity generation	%
Energy WWTP	EARV167	Produced electricity energy	Own produced electricity at the WWTP during the year	kWh
Energy WWTP	EARV168	Bio gas usage for flare	Percentage of produced bio gas flamed during the year	%
Energy WWTP	EARV169	Bio gas drain to natural gas network	Percentage of produced bio gas that drains to a natural gas network	%
Energy WWTP	EARV17	Other electricity consumption	Electricity consumption exclusive treatment processes; e.g. ventilation, lightning etc.	kWh

Appendix III
Calculations of theoretical energy content of methane gas

At ideal conditions for methane (CH_4) at 0 °C and 1013 Mbar pressure, the gas volume is set to 22.6 L/mol (Berhard Wett, 2007). The mol weight of methane gas is 16 g/mol.

Ideal gas weigh for methane: $\frac{0.016}{22.6} = 0.000708$ kg/l

Theoretical energy content of methane gas is set to 50014 MJ/kg, CH_4 (Jeppsson *et al.,* 2005).

Using the relation of 1 MJ = 0.278 kWh the theoretical energy content can be presented in kWh.

$\Rightarrow 50014 \cdot 0.278 = 13904$ kWh/kg, CH_4

$\Rightarrow 13904 \cdot 0.000708 = 9.84$ kWh/kg, CH_4

Appendix IV
Relation between design pe and calculated pe

- per BOD load and TS load in Swedish WWTPs, 2007

WWTP	**pe design**	**pe BOD$_7$**	**pe(d)/ peBOD$_7$**	**pe COD**	**pe(d)/ pe COD**	**pe TS**	**pe BOD$_7$/ pe TS**	**ton BOD$_7$**	**ton COD**	**ton TS**
Jönköping	95000	67162	1.41	111357	0.85	61316	1.10	1716	4471	1589
Varberg	80000	52004	1.54	69716	1.15	45688	1.14	1329	2799	1184
Uppsala	200000	130333	1.53	209215	0.96	134671	0.97	3330	8400	3490
Örebro	220000	136986	1.61	235766	0.93	135520	1.01	3500	9466	3512
SYVAB	350000	246575	1.42	348692	1.00	208374	1.18	6300	14000	5400
Käppala	700000	457926	1.53	590286	1.19	1474050	0.31	11700	23700	38200
Gothenburg	800000	547593	1.46	842267	0.95	589195	0.93	13991	33817	15269
Average	**349286**	**234083**	**1.50**	**343900**	**1.00**	**378402**	**0.95**	**5981**	**13808**	**9806**
Median	**220000**	**136986**	**1.53**	**235766**	**0.96**	**135520**	**1.01**	**3500**	**9466**	**3512**

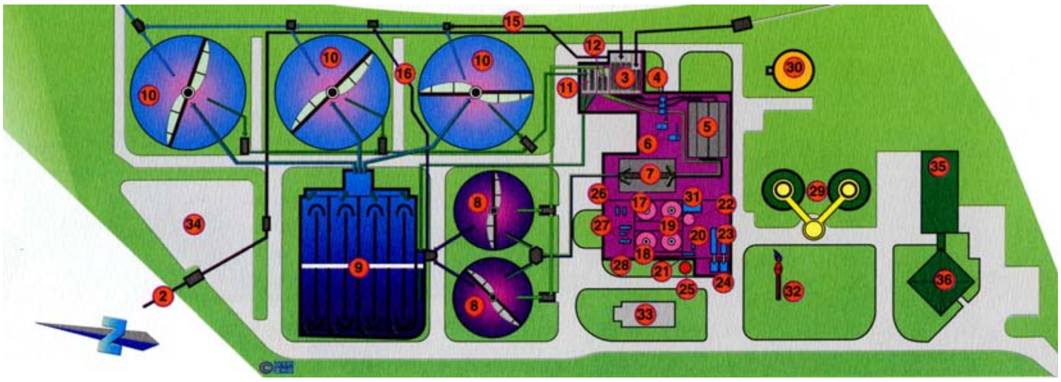
The table presents Swedish's participants in the energy benchmark between Sweden and Austria. Given were Pe_{design}, influent BOD_7 and COD and total sludge production (TS). Pe_{design} is the designed dimension for the plant. To be able to make a comparison with the Austrian study the pe based on influent COD had to be determined. To calculate the pe_{COD} a specific load of 110 g per day was used, see Equation 2 below. Also the pe based on BOD and TS was determined, by using a specific load of 70 g/day and 71 g/day respectively (see equation 1 and 3).

$$pe_{BOD}=\text{ton } BOD_7/70 \text{ g } \frac{1000*1000}{365} \qquad (1)$$

$$pe_{COD}=\text{ton COD}/110 \text{ g } \frac{1000*1000}{365} \qquad (2)$$

$$pe_{TS}=\text{ton TS}/71 \text{ g } \frac{1000*1000}{365} \qquad (3)$$

Appendix V
Flow scheme and view of WWTP Strass



1, 2	main sewers (number 1 is outside the layout, on the top right corner)
3	pump station
4	screen
5	sand/grease trap
6	sand washer
7	high rate biology for carbon removal (now only one tank is as A-stage, the other as an SBR for reject water treatment)
8	intermediate clarifiers
9	low rate biology/ B-stage for nitrogen removal
10	secondary clarifiers
11	sludge recycle pump
17, 18, 19	thickeners
20	mechanical excess sludge thickener
23	filter press
26, 27, 28	cogeneration plant
29	digesters
30	gas storage
32	flare
33	compost filter for off-air treatment
34	biosolids storage
35	shop
36	operator building

Top view of WWTP Strass, Austria

Picture taken in October 1996 (http://www.aiz.at/klaeranlage.htm).