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Wastewater heat recovery in sewer systems from wastewater treatment plant operational point of view

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Abbreviations

ASB	Activated Sludge Basin
BOD5	Biological Oxygen Demand in 5 days
c	Heat Capacity from Water (4.18 J/K*g)
CHP Plant	Combined Heat and Power Plant
COD	Chemical Oxygen Demand
$C_{COD, tot,in}/C_{N,tot,in}$	Total Chemical Oxygen Demand to Total Nitrogen in the Inflow Biology
DN	Denitrification Nitrogen Load
DS	Dry Substance
K	Kelvin
kW	Kilowatt
N	Nitrogen
NH4-N	Ammonia-Nitrogen
NO3-N	Nitrate
NO2-N	Nitrite
Ntotal	Total Nitrogen
oDS	Organic Dry Substance
OP	Oxygen Production
OVC	Oxygen Demand for Oxidation of Carbon Compounds
P	Phosphorous
PE	Population Equivalent
/PE/a	per PE per year
/PE/d	per PE per day
PE_{120}	PE regarding COD related to 120 g /PE/d in raw water
PE_{60}	PE regarding BOD5 related to 60 g /PE/d in raw water
$PE_{Ntotal11}$	PE regarding Ntotal related to 11 g /PE/d in raw water
$PE_{NH4N6,5}$	PE regarding Ammonia-Nitrogen related to 6.5 g /PE/d in raw water
$PE_{Ptotal1,7}$	PE regarding Ptotal related to 1.7 g /PE/d in raw water
PE_{oDS22}	PE regarding organic dry substance related to 22 g /PE/d in raw water
PSB	Primary Sedimentation Basin
PSC	Power Supply Company
PV	Photovoltaic
Ptotal	Total Phosphorous
Q’	Usable Heat Performance in kW (kilowatt), correspond to Contingent
$Q_{buildings}$	Heating Quantity for Buildings
Q_D	Production-, Storage- and Distribution Loss
$Q_{d\ DW}$	Average Discharge of Dry Weather Flow
Q_{dw}	Dry Weather Flow
Q_S	Sludge Heating
$Q_{supply\ air}$	Heating Quantity for Supply Air Device
Q_T	Transmission Loss, Digester Tank Heating
SA_{aer}	Aerobe Sludge Age
SA_{ano}/SA_{tot}	Ratio between Anoxic and Total Sludge Age
SF	Security Factor

ΔT	Usable Temperature Difference in Kelvin (K); assigned in accordance to the AWEL-guideline
V’	Wastewater Volume Stream in l/s; dry weather flow Q_{dw}
WWTP	Wastewater Treatment Plant
η_{tot}	Total Efficiency Factor
μ_{max}	Maximal Growth Rate of the Nitirficant
ρ	Specific Density (of water) in kg/m^3, 998 kg/m^3

Abstract

Wastewater in the sewer system is still an unused energy source in Austria. The first project of *“wastewater heat recovery in front of a wastewater treatment plant (WWTP)”* was not implemented until the year 2012. Building on this technology it is now intended to implement this method in the future since it is a promising new technology. In order to fulfill the EU 2020 targets. Reduction of greenhouse gas emissions and increased energy efficiency and more renewable energy must be achieved. However, if heat is removed which is generated in the sewer system process, negative effects can arise in the context of the actual cleaning performance of the wastewater treatment facility.

In this respect the objective of this master thesis has been to create and develop a method, how it is possible to detect a general suitable WWTP in Austria in the context of wastewater heat recovery in the sewer system. The first part of the thesis focused on technical and legal fundamentals of different German-speaking countries with regard of wastewater heat recovery. The second part dealt with data validation and performance evaluation of a WWTP. The last part of the thesis will evaluate the detection and general suitability of a WWTP with respect to wastewater heat recovery in the sewer system. Since the experience of Austria is quite limited in this area it has been analyzed applicable wastewater recovery efforts in Switzerland during the past thirty years. Afterwards all parts have been combined to develop a theoretical method. This theoretical method has been applied on one national case study. According to the application of the method it has been determined that the developed method is applicable, consistent and valid results have been obtained. Further through the detection of a general suitable WWTP, it has been determined that the case study is not a suitable WWTP.

Keywords: wastewater heat recovery, unused energy source, energy optimization potential, energetic analysis, WWTP Freistadt;

Zusammenfassung

Abwasser im Kanal ist noch immer eine großteils ungenutzte Energiereserve in Österreich. Das erste Projekt, *„Abwasserwärmenutzung vor der Kläranlage“*, ist erst im Jahre 2012 umgesetzt worden. Aufbauend auf dem Projekt versucht man nun diese Methode in Zukunft zu forcieren, um auch die EU 2020 Ziele zu verfolgen und zu erfüllen. Diese stehen im Zusammenhang mit der Reduzierung des Treibhausgases und der Steigerung der Energieeffizienz und erneuerbarer Energie. Jedoch können durch die Entnahme von Wärme aus Abwasser negative Effekte im Reinigungsprozess der Kläranlage entstehen.

In dieser Hinsicht, ist das Ziel dieser Masterarbeit gewesen eine Methode zu erstellen, wie eine *„geeignete“* Abwasserreinigungsanlage (ARA) in Österreich, im Zusammenhang mit der Abwasserwärmenutzung vor der Kläranlage identifiziert werden kann. Der erste Teil der Arbeit beschäftigte sich mit den technischen und rechtlichen Rahmenbedingungen verschiedenster deutschsprachiger Länder in Bezug auf die Abwasserwärmenutzung. Der zweite Teil behandelte die Datenüberprüfung und Leistungsbewertung einer ARA. Und der letzte Teil beschäftigte sich mit der Überprüfung einer generellen Eignung der ARA im Zusammenhang mit der Abwasserwärmenutzung im Kanal. Da Erfahrungswerte in Österreich sehr gering sind, wendete man die Methode der Schweizer an. Diese Methode der *„Abwasserwärmenutzung“* wird seit fast 30 Jahren von den Schweizern verwendet. Danach sind alle Teile kombiniert worden um eine theoretische Methode zu entwickeln und hat diese auf eine nationale Fallstudie übertragen. In Folge der Anwendung der Methode auf die Fallstudie sah man, dass durch die Methode anwendbare, konsistente und gültige Ergebnisse erzielt wurden. Weiters hat die Ermittlung gezeigt, dass die Fallstudie keine geeignete Kläranalage in Bezug auf die Abwasserwärmenutzung im Kanal ist.

1. Introduction

The topic of this thesis was selected due to the dependence of Austria on Fossil fuel energy resources, which lead to energy scarcities. The EU tries to counteract this and has developed 5 targets for the EU in 2020. These targets include (European Commission, 2012):

- Employment (75% of the 20-64 year-olds to be employed)
- R&D / innovation (3% of the EU's GDP (public and private combined) to be invested in R&D/innovation)
- Climate change / energy:
    - greenhouse gas emissions 20% (or even 30%, if the conditions are right) lower than 1990
    - 20% of energy from renewables
    - 20% increase in energy efficiency
- Education (Reducing school drop-out rates below 10%, at least 40% of 30-34–year-olds complete a third level education)
- Poverty / social exclusion (at least 20 million fewer people in or at risk of poverty and social exclusion)

The thesis focuses on the third point of the five targets a climate change and energy. *"Eighty-six percent of the world's energy is produced through the burning of fossil fuels"* (Anon., 2014). Fossil fuels are a non-renewable resource that get more expensive and the method to acquire fossil fuels become more frightening. This type of energy contributes to environmental damages. The burning of fossil fuels produces around 21.3 billion tonnes of carbon dioxide (CO_2) every year (Anon., 2014):

As a consequence the people should look for new sustainable, renewable methods to gain energy. Furthermore they should focus on more than one energy resource, so they are able to stand on several energy options, thus being more flexible when different disasters happen in the future.

That's why wastewater becomes more important. It's a rarely used energy resource, which will always be available wherever people live and has numerous energy advantages. There are some countries that already use these advantages. One of the leading countries is Switzerland. They developed many projects on this topic and have experience in these technological advancements for the past 30 years (Schmid and Müller, 2005). So Austria, which is one of the biggest producers of renewable energy in the EU, began with one project in 2012. Now they want to develop this big energy potential in the future (E-Control, 2009).

The principle is to take heat energy from the wastewater through a heat exchanger and with a heating pump it is brought up to the required temperature level that is needed to heat or cool buildings (Ochsner et al., 2013). In general the more something is cooled down, the more energy is produced. This method of cooling down the wastewater has major consequences for the cleaning process in the wastewater treatment plant. There are three different possibilities how energy from wastewater can be obtained. One is after the WWTP, before the plant and in the building. Focus of this master thesis has been on the wastewater heat recovery in front of the WWTP. The removal of heat from wastewater has negative impacts on the reduction of ammonia and carbon. In order to determine if negative influences are appearing, water authorities need a permit to prove when wastewater heat recovery in the sewer system is implemented. Since

Austria has only few experience values in this case and therefore has developed no guidelines to date, the objective of this master thesis is to evaluate a general suitability of a WWTP regarding to wastewater heat recovery in the sewer system. Further, it is to develop a theoretical method on how it can be detected. Likewise this theoretical method has to be applied on a national case study to see if plausible and consistent results are obtained.

In the end this theoretical method should help the water authorities if a wastewater heat recovery plant is allowed to be installed in the sewer system or not.

2. Objectives

The main goal of the master thesis is to develop a general approach (flowchart) how to evaluate the general suitability of a WWTP for heat recovery in sewer systems.

This approach will address two major aspects: validation of WWTP data (input data) and application of validated data for the evaluation of suitability (output data).

The following tasks were:

(1) The first objective is to shortly describe technical and legal requirements of wastewater treatment and wastewater heat recovery in the sewer system.

(2) The second objective is to illustrate possibilities how to validate WWTP data and to evaluate the general suitability of a wastewater treatment plant with regard to wastewater heat recovery in the sewer system.

(3) The third objective is to summarize relevant validation and evaluation methods in a standardized approach (flowchart).

(4) The fourth objective is to apply the technical approach in a case study to check practical applicability.

3. Fundamentals

3.1 Technical and legal fundamentals in Austria, Switzerland and Germany

The function of a WWTP is to remove doubtful substances of wastewater and transform them into harmless substances.

The temperature in the WWTP is important for the biological degradation processes. It is needed for the reduction of ammonia and carbon. That is why it is so essential to have a certain temperature level. Without a certain temperature in the WWTP the biological cleaning does not work properly. So the EU assigned set parameters to obtain the certain temperature values in the council directive. The different parameters are BOD, COD, total suspended solids; Phosphorus and Nitrogen should be observed as well. The temperature as well as the parameters are an essential part of the master thesis. Further the different countries (Austria, Switzerland and Germany) have their own directives. These legal directives and laws will be discussed in the following points. For the structuring of a modern plant the temperatures must be fixed, where the prescribed performances have to be fulfilled. The temperature as before mentioned is important for the biological process. For each incremental change of 10 degrees Centigrade, there can be an acceleration of 2 – 3 factors (Gujer, 2006). Thus there is more and more separation in the sewer system from the infiltration water and the wastewater is warmer than the groundwater. That's why a trend can be observed when more and more warm water is produced. Wastewater temperature decreases rarely under 12 °C (Gujer, 2006). A *"reserve capacity"* of 20% is then realized. (Gujer, 2006).

3.1.1 Technical fundamentals of a wastewater treatment plant

The primary level is also known as the mechanical pretreatment. The task that the mechanical pretreatment has to do is the cleaning from sand, fat and coarse substances. The goal of the mechanical pretreatment is to prepare the water for the actual cleaning. The coarse substances and the sand from the wastewater should be removed because they can lead to clogging, smelling, adhesions or to problems in the treatment of sludge. There are several mechanical treatments.

The first is the rake. Rakes are produced for different construction forms and they are installed behind one another with different bar distances. The typical bar distances for the coarse rakes are 30 – 60 mm and for the fine rakes are 6 – 30 mm. Today, there is a trend to more and more finer rakes. But on the one hand the amounts of held back rake goods are higher and on the other hand the whole plant is more protected. The rakes are presented on the upper left side in figure 1.

The next part of the treatment is the grit and grease chamber. The aim of the grit chamber is to separate the mineral substances, which have high sedimentation speed and are able to deposit it very quick, from the wastewater. Through that the following pumps are protected from abrasion and sediments in the standing water. The separation from the floating grease and oil prevents that the substances later on accumulate and clog and produce an odor problem.

Pretreatment has to remove the sediment sludge components from the incoming wastewater to protect the next cleaning processes. Very often the surplus sludge from the biological treatment is added to the pretreatment to enable thickening.

In the chemical wastewater treatment, chemicals were used to support the flocculation of the solid matter. It has to be differentiated between flocculation and precipitation. In most cases the two processes are running together. The chemical waste water cleaning is used to remove phosphorus, to relieve the following processes and in some cases as an independent wastewater cleaning if the requirements on the water are not that high (Gujer, 2006).

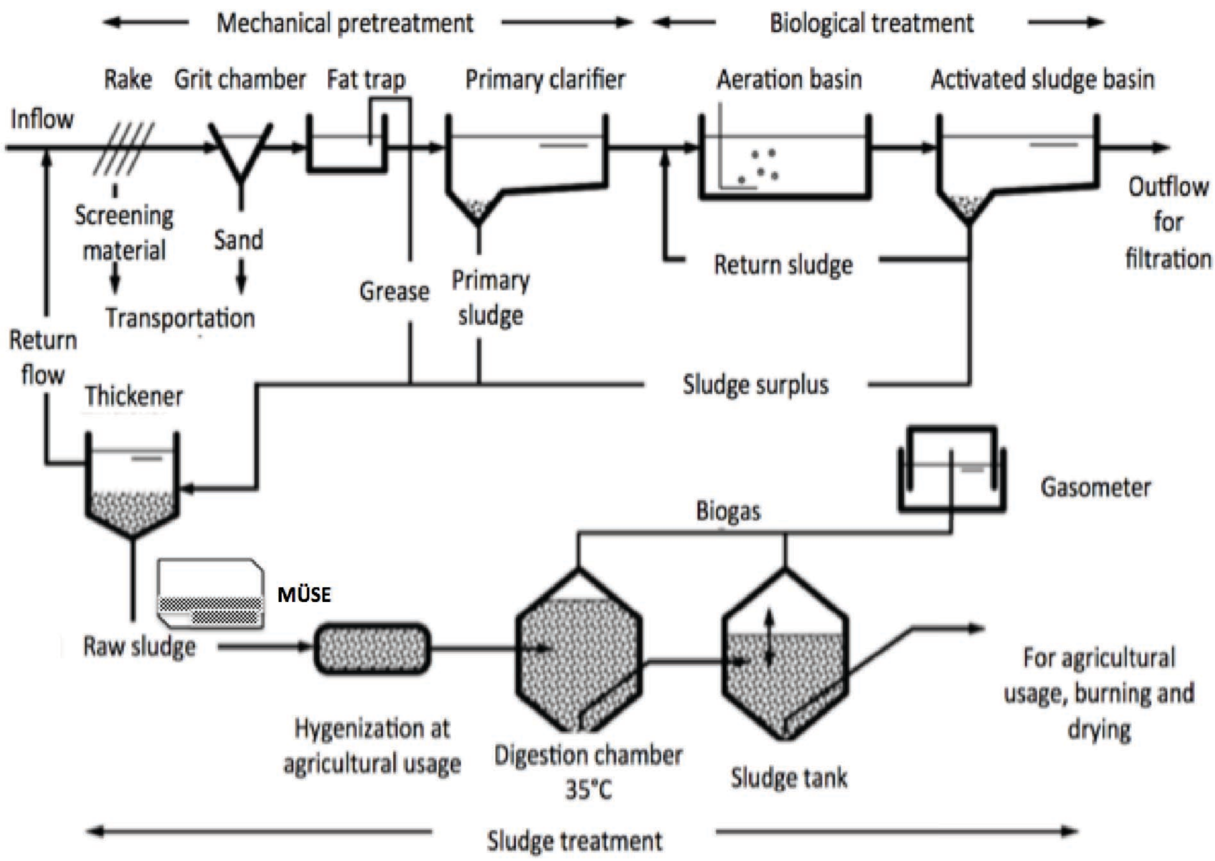

Figure 1: Flow chart of a WWTP (Source: Gujer, 2006, adapted)

The secondary treatment is the biological wastewater treatment. This includes the most efficient part of a modern WWTP. There are two major groups of processes; one is the activated sludge process with microorganisms, which suspend in the wastewater and the trickling filter process, which is not presented in figure 1. There are many different processes in the biological treatment as result many cleaning processes can be solved through this processes. The aim of the cleaning is to separate the effluents that occur in nature, which have undesirable properties from water. In the biological wastewater treatment the growth of the different microorganisms is supported (Gujer, 2006). One important factor, which influences the activity and performance of the bacteria, is temperature. The lower the temperatures the less efficient are the bacteria. So the cleaning performance and the residence time of the water in the activated sludge basin depends on temperature. That is why in summer months the performance of the bacteria is higher than in winter months. They transform doubtful into less doubtful substances. But it will be never possible to remove all doubtful substances from the water. There will be always a residual load. The most important biological processes are: growth, decomposition, hydrolyzes nitrification and denitrification. In the biological wastewater treatment there are two different groups of processes; the process with suspended biomass and the process with fixed biomass (Gujer, 2006).

In the process with suspended biomass, the biomass is held float on the water through turbulences. This process is recreated from nature. It simulates a sea where algae float. The performance of the process is restricted through the mass of the organisms from the biological reactor.

In the process with fixed biomass, the biomass is a thin film fixed on a surface for growing. This is not presented in figure 1. The water runs over this biofilm and it moves relatively to the biomass. This process is recreated from running waters, especially from small streams. In the stream the biggest part of the active microorganisms are located on stones, leaves. In the course of the self-cleaning the water runs over this biomass and changes the pollutants with the biofilm. The performance of the process depends on the supply of the growing surface (Gujer, 2006).

The activated sludge process is the most important biological wastewater treatment in the industrial countries. This process is presented in figure 1 on the right upper side. The efficiency of this process and its cleaning performance is strongly dependent on temperature. There are many different microbiological, chemical and physical processes. These processes are able to degrade organic substances, flocculation and partly degradation of particular substances, oxidation of ammonia to nitrate, reduction of nitrate to nitrogen, chemical phosphorus elimination, biological phosphorous elimination and elimination of specific organic compounds. Further the process of the oxidation of the nitrogen compound is called nitrification. As mentioned previously the growth of the nitrifying bacteria is largely dependent on temperature. This means that the nitrifiers are reached easier in summer than in winter. The growth rate of the nitrifying bacteria takes longer than of other bacteria. For example the degradation rate of bacteria at a temperature of 20°C is more than twice that high at a temperature of 10°C (Gujer, 2006). The diversity of the processes is expressed in differing constructions of reactors and diversity of the environment for microorganisms.

In the secondary clarifier the difference to the pretreatment or primary clarifier is the activated sludge, which must be separated from the cleaned wastewater and then the separated activated sludge has to be returned to a concentrated and activated sludge (Gujer, 2006).

Another important part in the WWTP that is connected to temperature is the sludge treatment. But before it goes into digestion the sludge has to be dewatered to reduce the volume and increase the energy value. This process is done through the machine called MÜSE. The abbreviation comes from mechanical surplus sludge dewatering machine. Further if the sewer sludge is used for agriculture purposes, the thickened raw sludge has to undergo a controlled sanitization. Germs are killed through temperatures of 60-70°C (Gujer, 2006). This necessary heat normally provides the biogas. Additional biogas is produced through digestion. In the digestion chamber the degraded organic substances are decomposed under exclusion of oxygen into biogas. A temperature of around 35°C has to be maintained to accelerate the decomposition process. Through the biogas it is possible to produce electrical energy, which is more beneficial than thermal energy. Likewise in the sludge tank the digested sewage sludge is stored under constant temperature of 25°C, which creates thickening. It can be used directly in farming field applications (Gujer, 2006).

3.1.2 Legal guidelines

3.1.2.1 Legal guidelines in EU

The EU has introduced a council directive 91/217/EEC of 21 May 1991 concerning urban wastewater treatment. “*The objective of the Directive is to protect the environment from the adverse effects of the abovementioned waste water discharges*” (Council Directive, 1991). In article 5, paragraph 4 of the directive there have to be hold a minimum percentage of reduction of the overall load in sensitive areas. At least 75% of the total Nitrogen and also at least 75% of the total Phosphorus have to be reduced (Council Directive, 1991). Furthermore for discharges to sensitive areas, which are subject of eutrophication the total Phosphorus of a concentration of 2 mg/l (10 000 – 100 000 P.E.[1]) and 1 mg/l (more than 100 000 P.E.) has to be reduced of a minimum percentage of at least 80%. The total Nitrogen of a concentration of 15 mg/l (10 000 – 100 000 P.E.) and 10 mg/l (more than 100 000 P.E.) has to be reduced of a minimum percentage of 70-80% (Council Directive, 1991).

3.1.2.2 Legal guidelines in Austria

Austria adheres to the EUs council directive and has adapted it to a certain level. In Austria all areas are defined as sensitive areas. In the 1.AEV (Abwasser Emissions Verordnung) that’s the Austrian directive of the wastewater emission, article 1, paragraph 4, point 2, the design temperature of a plant of 5 000 P.E.60 has to be 10°C. Further it has to be 8°C for the nitrification and 12°C for the denitrification of a plant bigger than 5 000 P.E.60 (1.AEV, 2014). In the emission limit according to the article 1, paragraph 1, there they defined the minimum efficiency level in percentage of the inflow of total nitrogen. There it says that at least 70% of the total Nitrogen has to be reduced in WWTP bigger than 5 000 P.E.60 (1.AEV, 2014).

In point 2.2 of the article the maximum outflow concentration in mg/l, depending on the sizes are (1.AEV, 2014).

1. bigger than 50 P.E.60 but not bigger than 500 P.E.60 of the total nitrogen is 10mg/l and 0 mg/l of the total phosphorus
2. bigger than 500 P.E.60 but not bigger than 5 000 P.E.60 of the total nitrogen is 5 mg/l and 2 mg/l of the total phosphorus
3. bigger than 5 000 P.E.60 but not bigger than 50 000 P.E.60 of the total nitrogen is 5 mg/l and 1mg/l of the total phosphorus
4. bigger than 50 000 P.E.60 of the total nitrogen is 5 mg/l and 1 mg/l of the total phosphorus

[1] P.E. – Population Equivalent, in wastewater treatment is the number of expressing the ratio of the sum of the pollution load during 24 hours by industrial facilities to the individual population load in household sewage produced by one person in the same time (Gujer, 2006).

Continuing the emission limit is valid at a wastewater temperature of 12°C in the outflow of the biological treatment in the WWTP. It is not valid if the measurement of the temperature is discontinuous and does not exceed 12°C, 5 times in a day. But it is also not valid if the arithmetical mean value of the wastewater is not bigger than 12°C in one day. And for the WWTP with the sizes 3 and 4 a temperature regulation with 8°C has to be applied (1.AEV, 2014).

In the directive of the general waste water emission AEEV (Allgemeine Abwasseremissionsverordnung), it is quoted that the temperature of the discharge in a stream of flowing waters has to be maximum 30°C. Furthermore according to the emission limitation paragraph 4, the discharge temperature in a sewer system has to be of maximum 35°C (AEEV, 2014).

3.1.2.3 Legal guidelines in Switzerland

In the introductory law of the water protection law, EG GSchG (Einführungsgesetz zum Gewässerschutz) article 8 states that if somebody wants to change the water quality or the water quantity, he has to have a cantonal permission to do so. This permission is valid for plants where the used wastewater is discharged in the WWTP outflow and plants where the wastewater is discharged in some other water bodies (EG GSchG, 1974).

In the directive of the water protection GSchV (Gewässerschutzverordnung) in article 12, paragraph 3 of the water quality has to be fulfilled even when there are building interventions, water abstraction and discharge of water, which leads to flowing water. These interventions should not have deleterious impacts on the hydrodynamic, morphology and temperature of the body of water. The self-cleaning process and the water quality should not diminish (GSchV, 2014). Furthermore in article 12, paragraph 4, the temperature of flowing water is maximally allowed to be affected through a heat entry or heat withdrawal about 3°C, in waters of region of trout's about 1.5°C. There by water temperature is not allowed to exceed 25°C. These requirements are valid after mixture of water (GSchV, 2014). In the article 6, paragraph 1 there are the general requirements for the discharge of urban wastewater in the body of water. If the ammonia concentration has bad effects on the water quality of flowing water than the water temperature has to have more than 10°C. The discharge water concentration has to be 2 mg/l of nitrogen and the efficiency factor of the treatment has to have 90%. Moreover for the discharge in sensitive water bodies the total phosphorus discharge concentration for 10 000 P.E. at flowing waters has to have 0.8 mg/l and the cleaning effect with regard to raw sewage has to have 80% (GSchV, 2014). For the discharge of industrial wastewater the maximum temperature, which is allowed to be induced in the sewer system, is 60°C. The temperature in the sewer system is only allowed to have 40°C after the mixing (GSchV, 2014).

Interventions in the heat balance of the wastewater require a permission of the water pollution control through the canton. If the heat withdrawal or return of the water inlet of the WWTP has a theoretical temperature change of more than 0.1°C. This is the so-called de minimis limit (AWEL, 2010).

3.1.2.4 Legal guidelines in Germany

Germany has been inspired by the Swiss and developed a similar directive for the cooling down of the wastewater in front of a WWTP.

If through the heat removal of the sewer system in the WWTP inflow, the temperature in the winter months December, January and February is not falling below 10°C and the resulting cooling down in the WWTP inflow is below or exactly 0.5 K[2], then a heat removal of the wastewater is able to be done with out any detailed investigations. Moreover if the temperature is not falling down under 10°C but is higher than 0.5 K a detailed investigation has to be completed (DWA-M 114, 2009).

In point 7.3.5 of the pamphlet it is noticed that WWTPs must ensure nitrogen elimination if they have temperatures of 12°C or above in the outlet of the biological reactor. As well as instead of 12°C there could be a temporal restriction between the First of May and the 31st of October (DWA-M 114, 2009). The detailed information of the nitrogen elimination is in the wastewater directive of 1997, AbwV (Abwasserverordnung). In appendix 1 of the AbwV the water legislation permit for the concentration of nitrogen can be permitted up to 25 mg/l, if the reduction of the total nitrogen is at least 70% (AbwV, 2013). Beyond this WWTPs have to make sure that in the winter months the nitrification works even during low temperatures. Different states in Germany request that the ammonia nitrogen limitation should be observed at temperatures between 8°C or higher and 10°C or higher (DWA-M 114, 2009).

Table 1: Summary of the legal guidelines of the different countries (own presentation)

Characteristics	Switzerland	Germany	Austria
Reduction of total bonded Nitrogen	At least 90%	At least 70%	At least 70% (bigger than 5.000 P.E.60)
Maximum outflow concentration of total Ammonia (mg/l)	2 mg/l	Depend on the water authorities	5 mg/l (bigger than 5.000 P.E.60)
Cooling limit without permission	0.1 °C Depend on the canton	0.5 K (If temperature is not falling down 10°C)	None
Design temperature	10°C	10°C	8°C for nitrification and 12°C denitrification

[2] In the DWA-M 114, 2009 the Germans define their temperature limit with 0.5 K. But in this context to compare the temperatures with each other it is meant 0.5 K that are 0.5 °C.

3.2 Technical and legal fundamentals of wastewater heat recovery in front of wastewater treatment plants

3.2.1 Technical fundamentals

3.2.1.1 General information heating pump

The heating pump transforms heat from the surrounding area through application of work from a lower into higher temperature level so it can be used for a heating purpose or for warm water preparation. But the operating power of the heating pump is lower than the power, which is produced from it. The heating pump can also be used as a cold generator to cool down buildings (DWA-M 114, 2009). The wastewater heating pumps achieve temperature levels of 50 °C to 70 °C. There are different heating pump systems, which are presented in figure 2 and figure 3.

1. Variation monovalent: 100 percent heating pump

The concept of heat production from wastewater heating depends primarily on the objective. It should possible to exploit wastewater energy and avoid fossil energy. In this case it is a monovalent system. Further to vary the heat performance, aggregates with two to four compressors are used or several pumps are parallel connected. This procedure ensures the system security as well the space heating and the water heating are able to be regulated individually. But the negative effects are this system has a lower annual performance and it needs higher amounts of wastewater (Müller et al., 2009).

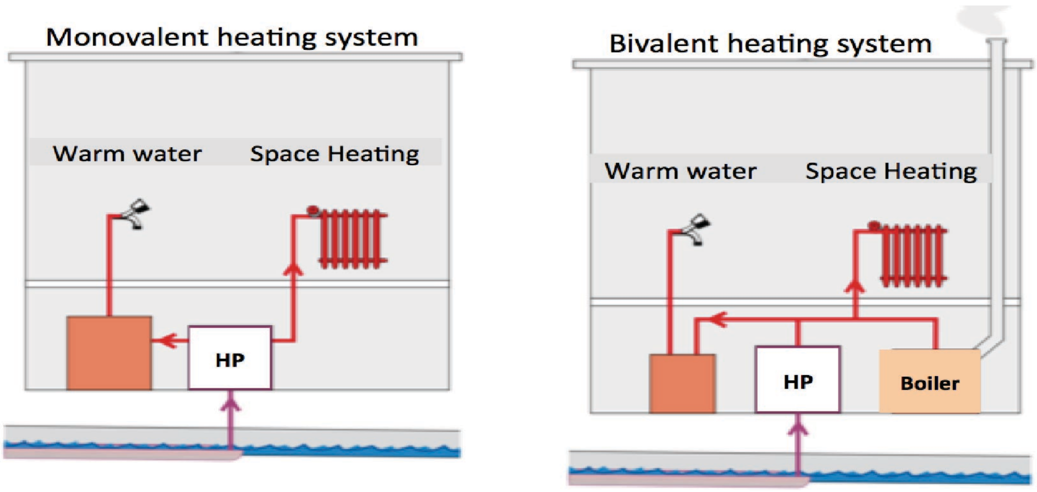

Figure 2: Monovalent and bivalent heating system (Source: Müller et al., 2009, adapted)

2. Variation bivalent: boiler for peak loads

   In most cases of the wastewater heating systems, the heating pump is connected to a boiler for operational security. In this case it is a bivalent heating system. This system guaranties the energy supply in situations when the heat from the sewer system is not available. But in regular operation the boiler is turned on only in peak times. The combination with the boiler allows the heating pump to be designed on the base load operation to keep the heating pump operation in a simple way. The result is a lower operating cycle of the heating pump and a better annual performance. In comparison with variation 1 the investment for a bivalent system is lower. But the proportion of the wastewater heat is lower from the total energy supplied (Müller et al., 2009).

3. Variation multivalent: combination of efficiency techniques

   The best energy efficiency is the combination of the wastewater heat pump with a combined heat and power plant (CHP plant). Through the entire process this variation needs the smallest amount of primary energy. Development of a multivalent wastewater heating facility allows the additional benefit of an emergency back-up power supply. If other heating sources are available, like waste heat from technical processes, it can be used also. Multivalent systems are feasible when large amount of heat are required for example a district heating for an entire quarter (Müller et al., 2009).

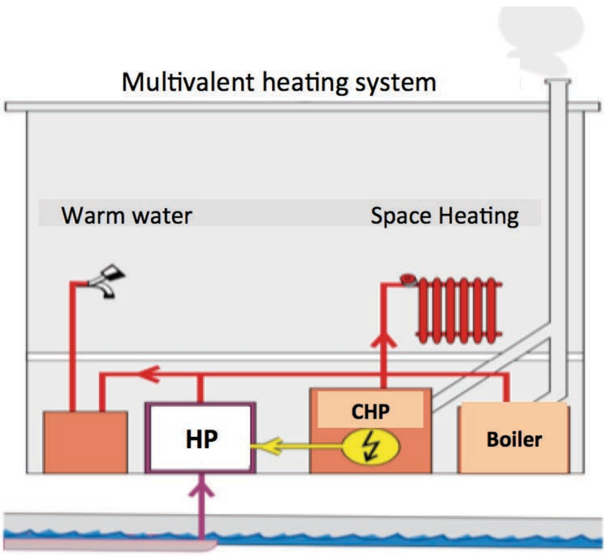

Figure 3: Multivalent heating system (Source: Müller et al., 2009, adapted)

3.2.1.2 General information of a heat exchanger

A heat exchanger fulfills two functions: it takes energy from the wastewater and it separates the clean heating system from the sewage water. The heat exchanger can be installed either in the sole of the sewer channel or in the WWTP. This is presented in figure 4. In the first case the raw water is used and in the second case the energy of the cleaned wastewater is gained. The heat exchangers can be installed in sewer systems, which are already built or in systems, which are renovated or entirely rebuilt (Schmid and Müller, 2005).

3.2.1.3 Locations of heat recovery

Depending on the location of the heat exchanger there are three different possibilities for the heat recovery from wastewater (see figure 4):

- Recovery in the building (of untreated water)
- Recovery in the sewer system (of untreated water)
- Recovery in the WWTP (of treated water)

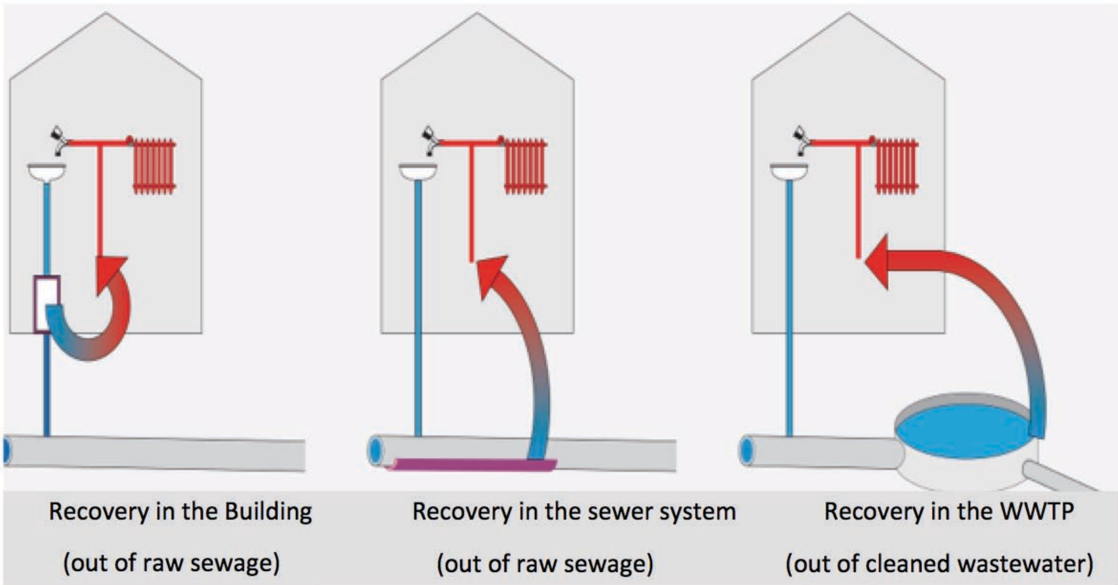

Figure 4: Location of the usage for heat recovery (Source: Schmid and Müller, 2005, adapted)

Recovery in the building occurs before induction into the public sewer system. This usage is only applicable with bigger heating consumers like schools, hospitals, retirement homes and bigger hotels. It can be done individually. The wastewater temperature is normally clearly over 20 °C (Ryser Ingenieure AG, 2013).

Recovery in the sewer system before the WWTP has to be permitted from the WWTP operator as well from the responsible environment expert. Since there can be an impairment of the WWTP (Ryser Ingenieure AG, 2013).

Recovery in the WWTP at discharge has the highest usable wastewater potential. This option, if it is possible should always be exploited (Ryser Ingenieure AG, 2013).

Further table 2 has listed the different advantages and disadvantages of the locations.

Table 2: Advantages and disadvantages of different locations for heat recovery (Source: DWA-M 114, 2009)

Location	Advantage	Disadvantage
in the building	relative high wastewater temperatures very short distance of heat transport operator = heat consumer network independent operation no impact through rain water	little discharge with daily fluctuations disturbing contents of wastewater decentralized facilities with high operating expenses
in the drainage system	bigger wastewater amounts short to middle distance of heat transport monitoring and operating reliable	dependence on the network operator installations need monitoring influence on wastewater cleaning
in or after the WWTP	no influence on wastewater cleaning big/relative constant wastewater amount and so biggest heat offer clean wastewater cooling down of the wastewater in favor of the water body	if there are no users near by , there is a longer distance of heat transport dependence from the WWTP operator

3.2.1.4 Possible ordering of heat recovery plants

The heat recovery plants can be installed in sewers of the main or bypass flow. The different advantages are listed in the following points (DWA-M 114, 2009):

Main flow:

- no additional space,
- no outflow structure (with removal of coarse matter) is necessary,
- no feed pump is necessary,
- no waste disposal of residues.

Bypass flow:

- independent of the sewerage operations,
- accessible compact system and dry installation possible,
- ease of dismantling,
- heat exchanger is not dependent on the geometry of the sewer system.

3.2.1.5 District and local heating

The difference between district and local heating is considered in the length of the supply network, from where the heat transmission begins. But it does not exist in any limitless value where the terms are differentiated from each other. However, it is important to differentiate between *"cold"* and *"warm"* district heating (Streit, 2011).

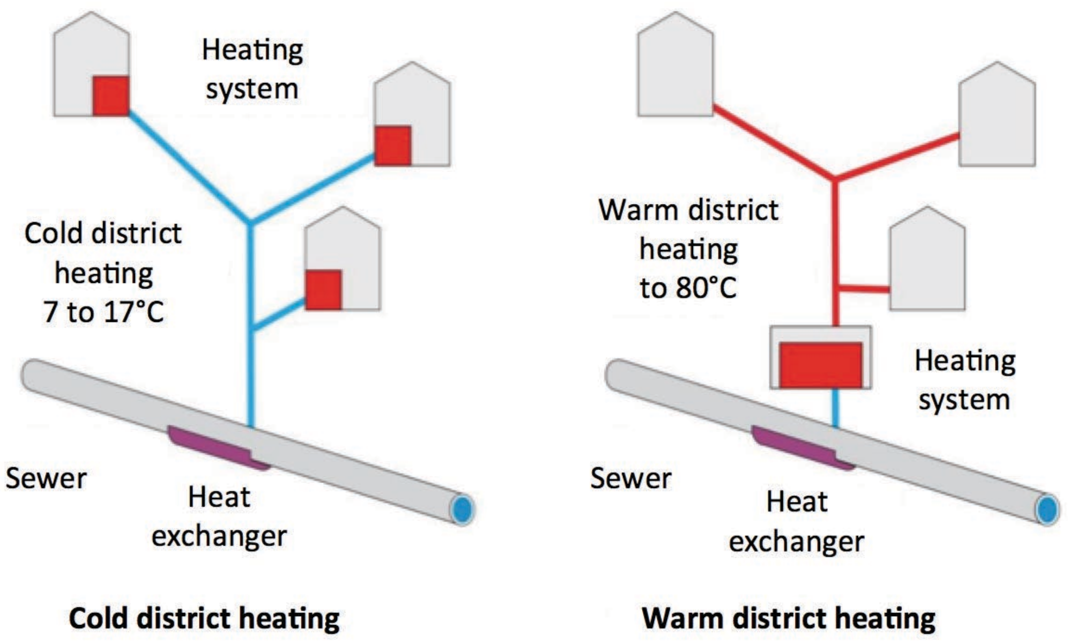

Figure 5: Difference between cold and warm district heating (Source: Müller and Schmid, 2005, adapted)

Cold district heating:

The term cold district heating is used when the decentralized energy is produced in several units. It is presented on the left side of figure 5. The integrated network is located up stream from the energy production and the energy transport is staggered accordingly at a lower level of temperatures of between 7°C and 17°C (Streit, 2011). The loss of the heat in the integrated network is minimalized. This is why this system is efficacious for longer distances between heat source and energy consumer (Streit, 2011).

Warm district heating:

For the warm district heating, the heat is produced at a separate location (e.g. WWTP) and is conducted at a higher temperature level (65°C to 80°C) to the users. This district heating is presented on the right side of figure 5. In order to prevent heat losses, the pipes of the integrated network have to be insulated. Additional insulation dictates that investment costs become higher. So for warm district heating the distances between the source and the consumers must be short (Streit, 2011).

3.2.1.6 Design requirements on buildings

Wastewater heat recovery plants are cost effective in new building construction. For new buildings it is easier to manage and more efficient to integrate a heat pump in the heating system. A higher heat output is given when the wastewater heat pumps are installed by buildings or groups of buildings with a high heating demand of 150 kilowatts (kW) (Schmid and Müller, 2005). This demand corresponds to approximately 50 buildings. For existing buildings is the performance of the installed heat production plant is an indicator. 200 kW is the lower limit of efficiency for a installed unit in a retro-fitted building. The nearer the building is located to the sewer system the cheaper is the gain of the heat. In metropolitan areas distances between 100 m to 300 m are possible (Schmid and Müller, 2005). Objects, which are not overbuilt there are possibilities for distance over 1 km (Schmid and Müller, 2005).

The higher the building density the more economical is the local heating with the wastewater energy (Schmid and Müller, 2005).

Thus the lower the temperature of the energy consumption the higher is the efficiency of the heating pump. New buildings with low temperature heating systems provide a logical basis for the use of energy production of wastewater heat. But for industrial processes where temperatures over 70 °C are needed, wastewater heating is less appropriate (Schmid and Müller, 2005).

3.2.1.7 Design requirements for sewer system

There are not only requirements for heat consumption but also additional requirements on the source of the heat. For the installation of wastewater recovery systems several factors are critically important. The water amount is very important to make the wastewater system economically viable. Generally in Austria, the water demand in one year is around 2.5 km^3 (BMLFUW, 2014). This amount corresponds approximately to three percent of the total available amount per year. The average consumption per person and day (without the industries and services) lies at around 135 liters that go into the wastewater system (BMLFUW, 2014). There must be minimal water amounts available. The wastewater flow should have a minimal of 10 l/s and there should be a night minimum of 5.000 inhabitants (AWEL-Standard, 2012). Further on for the economical use of wastewater energy in buildings there should be at least 8.000 to 10.000 liters per day of wastewater, which corresponds to 30 household units. The average value of the domestic wastewater is 23 °C (AWEL-Standard, 2012). A high temperature of the wastewater permits bigger cooling potential and through that a larger energy consumption. Favorable conditions are acquired at temperatures in excess of 10 °C even in winter (Schmid and Müller, 2005).

For the installation of a heat exchanger in a pipe a performance diameter of at least 80 cm is required (Schmid and Müller, 2005). However, there are no requirements on the design of the sewer system. The installation of a heat exchanger is easier if there is a straight sewer section of at least 20 m, at bigger facilities, a 100 m length is required (Schmid and Müller, 2005). Additionally good access to the sewer is ideal. It reduces the investment- and maintenance costs. The age of the sewer system is also an interesting point because if it is already very old and has to be renewed, then an installation of the heat exchanger in this case, is much less efficient and cost-effective (Schmid and Müller, 2005).

3.2.2 Legal guidelines

3.2.2.1 Legal guidelines in EU

The EU concluded a 2007 directive to increase energy efficiency. The objective is to save 20 % of the Union´s primary energy consumption until 2020 (Council directive, 2012). In paragraph 35 of the EU directive states that high efficiency cogeneration and district heating and cooling have significant potential in the Union. A deeper assessment should be completed so more information is available for possible investors. Further if there are new installations of electricity or reconstructions are done, a high efficiency cogeneration plant for the recovery of the waste heat should be installed if cost benefit analysis is positive. In article 2, paragraph 41, it is mentioned that an efficient district heating and cooling is only one, which includes at least 50 % renewable energy, 50 % waste heat, 75 % cogenerated heat or 50 % of a combination of such energy and heat (Council directive, 2012). Similarly in chapter 3, article 14, point 4, it is stated if the cost benefit analysis is positive and the potential of the usage of a cogeneration or efficient district heat is present than the member states should develop cogeneration and the use of heating and cooling from waste heat and renewable energy sources (Council directive, 2012).

3.2.2.2 Legal guidelines in Austria

Austria has since 1.1.2015 also an energy efficiency law. It is called EEffG (Bundes-Energieeffizienzgesetz). The aim of the government is to reduce energy consumption and contribute to the EU energy efficiency directive. The federal government commits to do energy conservation for their own heated or cooled buildings in respect of the extent of 48.2 GWh till December 31. 2020. Article 16, point 9 specifies that in buildings, which are built or restored, new high efficiency alternative systems should be implemented. Further on in part 7, article 1, point 2 it is explained that if a building is supplied through a district-heating network there must be consumption counter installed. The appendix defines, which measures count for the reduction of energy. In point 1. housing sector, b, to reduce the end-user energy consumed, high efficient heating pumps are valid as a measure for cooling or heating. Details in point d specify that wastewater recovery is part of the defined measures. Additionally renewable district heating is also a measure, which is defined in this point (EEffG, 2014). Part 1 of point 2 in the industry sector, i, requires that heating pumps belong to all integrations of renewable energies for energy supply system (EEffG, 2014).

3.2.2.3 Legal guidelines in Switzerland

The Swiss government already has developed their own energy law. It is called EnG (Energiegesetz). Goals of this law are defined in chapter on. The yearly average production of electricity from renewable energies should be increased by at least 5400 GWh till 2030. Article 3, point b states that renewable energies and the waste heat should be increasingly used. The network operators are committed to take the electricity that is produced from the renewable energies and to refund them (EnG, 2014). Chapter 4 explains the funding of new energy technologies. Article 13 describes only the measures of the support of energy and waste heat usage. It describes the saving and rational energy usage and the usage of renewable energies. It supports the usage of waste heat that emerges at power stations (EnG, 2014).

Beside the energy law the Swiss have their own energy directive called EnV (Energieverordnung). The directive is based on the law and gives precise information of the different topics. Article 15 describes the energy and waste heat usage. As it is written above, there are measures that are supported. But only if it is in a framework of a funding program, it correspond to the energy politics and the state of the art, the energy related environmental pollution is reduced, the function of the water body is not disturbed or changed and without support it is not economical (EnV, 2014).

3.2.2.4 Legal guidelines in Germany

Germany has a law for renewable energy called EEWärmeG (Erneuerbare – Energien – Wärmegesetz). In this law it is precisely explained how the use of renewable energies should be considered. In part 2, paragraph 3 mentions the obligation to use renewable energies. Buildings that are new construction must compensate heating or cooling needs through the proportional use of renewable energies. This is valid as well for public buildings (EEWärmeG, 2014). Furthermore in paragraph 5, point 4, if geothermal power and environmental heat is used, the heat and cooling need must be compensated by at least 50 % from the proportion of renewable energies from the plant. Swiss law requires some financial funding’s for the use of renewable energies. Point 3 describes finding that only occurs when heating pumps for the use of geothermal power, environmental heat or waste heat have a special significant sign. Typical signs are: the *“Euroblume”*, the *“Blue Angel”* or the *“European Quality Label for Heat Pumps”* (EEWärmeG, 2014). There are also requirements for the use of renewable energies. The waste heat recovery level of a plant must be at least 70 % and the figure of merit at least 10 %. The usage of district heating or district cooling is only valid if it consists of a proportional amount of renewable energy. It has to be at least 50 % from plants for the use of waste heat, at least 50 % of cogeneration or at least 50 % of a combination of the prior two possibilities (EEWärmeG, 2014).

3.3 Data validation and performance evaluation at WWTPs

The indispensable requirement for the heat removal of raw water and heat input in raw water is a WWTP with enough capacity with regard to the cleaning performance. Especially this is valid for the nitrification and for an on-site preflooder that has enough thermic capacity. This means a large ratio of discharge to water inflow amount. That’s why feasibility assessments a plant utilizing wastewater energy must determine the environmental next to the WWTP (AWEL, 2010).

Removal of wastewater heat leads to a less effective biological cleaning process. The nitrification performance and the nitrogen elimination are strictly dependent on the wastewater temperatures. As a matter of principle the efficiency factor of the nitrogen elimination is reduced through the cooling of the wastewater because of the reduction of the growth rates of the microorganisms (Buri et al., 2004). Moreover for the ensuring of the cleaning process of the plant and especially the nitrification, the activated sludge concentration in the activated sludge basin or its aerobe volume must be increased. But the nitrogen elimination will be reduced of the aerobe volume, if the volume of the basin is not increased. Thus, expansion costs of the increase in basin volume must be recovered from the heat consumers. (Buri et al., 2004).

Since the day and seasonal fluctuations of wastewater temperatures in the WWTP discharge are normally much higher than the temperature changes from the wastewater energy, these create significant difficulties in the heat balance of raw water. Normally the reduced cleaning performance can be compensated by a technical increase in the energy component in the WWTP itself (AWEL, 2010). This validates the usage of cleaned wastewater for cooling purposes. For the wastewater heat recovery the permitted wastewater temperature difference for cooling purposes is normally higher than for heating purposes (AWEL, 2010).

The biological cleaning process in the WWTP is more effective at higher temperatures. If heat is removed or added from the untreated wastewater different seasonal effects can be seen in the WWTP. The effects are listed in table 3 (AWEL, 2010).

Table 3: Influence of the heat remove or entry in the sewer system of WWTP and water bodies (Source: AWEL, 2010, adapted)

Heat	Season	Return of the used wastewater	Influence on WWTP cleaning performance*	Influence on water body
Removal	Winter	In the sewer system	Negative**	Desired cooling, higher WWTP discharge concentrations
Removal	Summer	In the sewer system	Negative**	Desired cooling, higher WWTP discharge concentrations
Entry	Winter	In the sewer system	Positive	Undesired warming, lower WWTP discharge concentrations
Entry	Summer	In the sewer system	Positive	Undesired warming, lower WWTP discharge concentrations

*Qualitative Assessment; Influence depend on the scope of the temperature increase or decrease of the wastewater.

**Compensable with an additional aeration basin volume.

Table 3 shows how negative effects are obtained through a heat removal and also in which season. Further the table also explains positive influences through a heat entry in the sewer system.

3.3.1 Rough analysis of data

The rough analysis is done to see how the evaluated WWTP performs. Further if the data that has been measured is comprehensible and plausible. The WWTP operator should provide accurate data sets. The rough analysis is just a simple check and should not consume too much time. It is then possible to compare standardized data sets with similar WWTP`s. Simply speaking the measured data that is provided has to be mathematically logical for further investigations. The main points are as follows:

Data collection:

- A detailed description of the plant with single process steps and specific features.
- The structural main technical characteristics (volumes) and information over the specific aeration (technical equipment), temperatures.
- Efficiency level of the pretreatment.
- The proportion OVC/eta COD of the biology.
- Connected inhabitants (permanently living, tourists) and other dischargers (industry and business depending on type).
- Inlet and outlet data (wastewater amount, concentrations and loads BOD5, COD, Ntotal, NH4-N, NO3-N, P). Probability, location and type of sampling.
- Sludge amount and dry matter and organic dry matter of primarily sludge, surplus activated sludge, stabilized sludge and the disposal of sludge on an annualized basis.
- Supply of energy from external on energy source, energy amount, costs and detailed electricity bill.
- At plants with digestion: sewage gas amount, CO_2 percentage, usage of sewage gas (heating boiler, direct drive, CHP plant, and torch). Data of the used gas engines and CHP plants.
- The specific median methane yield (CH_4 liters/PE/d)
- Internal energy consumption of the system delineated between plant sections when measured by the type of machine, their measurements and other relevant information (e.g. mechanical pre-cleaning, biology, sludge dewatering etc.) (Argis, 2001).

It is then possible through accumulated data to analyze and calculate any measurement errors or deviations.

Analysis and Calculation:

- Compilation of data concerning system inflow, outflow, sludge, sewer gas amount and mitigation of data errors thus resulting in an accurate data assessment.
- Investigation of the P.E. load, assessment of nitrogen proportion regarding the difference of normal wastewater composition.
- Determination and analysis of energy supply.

In more detail:

- At plants with digestion: control of sewage gas, assessment of sewage gas energy and utilization.
- Investigation of the energy used in heating the boiler, gas engine and CHP plant within the respective conversion efficiency.
- Determination of the following parameters in absolute values and on P.E. – bio related values.
    - Energy supply (total, electrical energy, motor fuels and lubricants) with regard to the amount, price and specific consumption must be readily extractable from documents
    - Energy consumption of WWTP: electro-mechanical energy, thermal energy
    - Energy consumption separately detected delineated within each plant section
    - At plants with digestion: sewage gas amount, sewage gas implementation, energy supply level
- Established parameters and estimates of the optimization potential of the standard WWTP and all observable single stages of procedure (Argis, 2001).

After the analysis and calculation of the different data a performance evaluation of the plant is completed.

Overview of expected results:

- Assessment of energy efficiency of the overall plant and if possible with the available data also single process stages.
- The saving potential on energy costs in comparison to an optimal WWTP and a projected improvement of the plant.
- A statement, if a following detailed analysis is useful or not with regard of costs and the expected benefit (Argis, 2001).

Upon receiving a positive preliminary analysis a comprehensive construction and cost analysis is provided to the utility (plant). If the preliminary analysis is inconclusive then a recheck of the submitted and calculated plant variables must be scrutinized for error.

3.3.2 Detailed analysis of data

The detailed analysis builds on the data of the rough analysis and enhances the evaluation. It improved accuracy and significance of the measured data (Argis, 2001).

The detailed analysis augments the initial rough analysis in the following ways:

- Layout of the plant with different procedural devices and relevant monitoring stations.
- An expansion of the analysis period of at least two years to obtain accurate measurement data.
- Acquisition and evaluation of day data. In order that calculation mistakes and interpretation mistakes are detected.

- Evaluation of the energy consumption matrix. For the reconstruction of energy consumption every single technical data of the single consumer is detected and all data variables of the plant are used.

This topic will be defined closer in the next points.

3.3.2.1 Mass flow balance (eDAB)

Detailed mass flow balancing must be maintained to ascertain accurate measured data of a WWTP (Spindler, 2011b). This allows the detection of system errors. Error detection is easily obtained through utilization of the software tool eDAB. The tool is developed for electronic collection, evaluation and balancing of waste water treatment plant data (eDAB, 2014). Through the software the material flows of a WWTP can be itemized in detail. Through the help of the mass balance it is possible to determine possible balance deviations due to measurement errors and analyses (eDAB, 2014). It is possible to gain the following material flows:

- Water amount in total, water amount in detail
- DS in detail
- Phosphorous in total, phosphorous in detail
- Nitrogen in total, nitrogen in detail
- COD in total, COD in detail

Single parameters are chosen because they do not transform into other substances and are able to be measured more in detail (Spindler, 2011b). Figure 6 illustrates an eDAB created wastewater scheme. The next illustration explains a COD plant schematic.

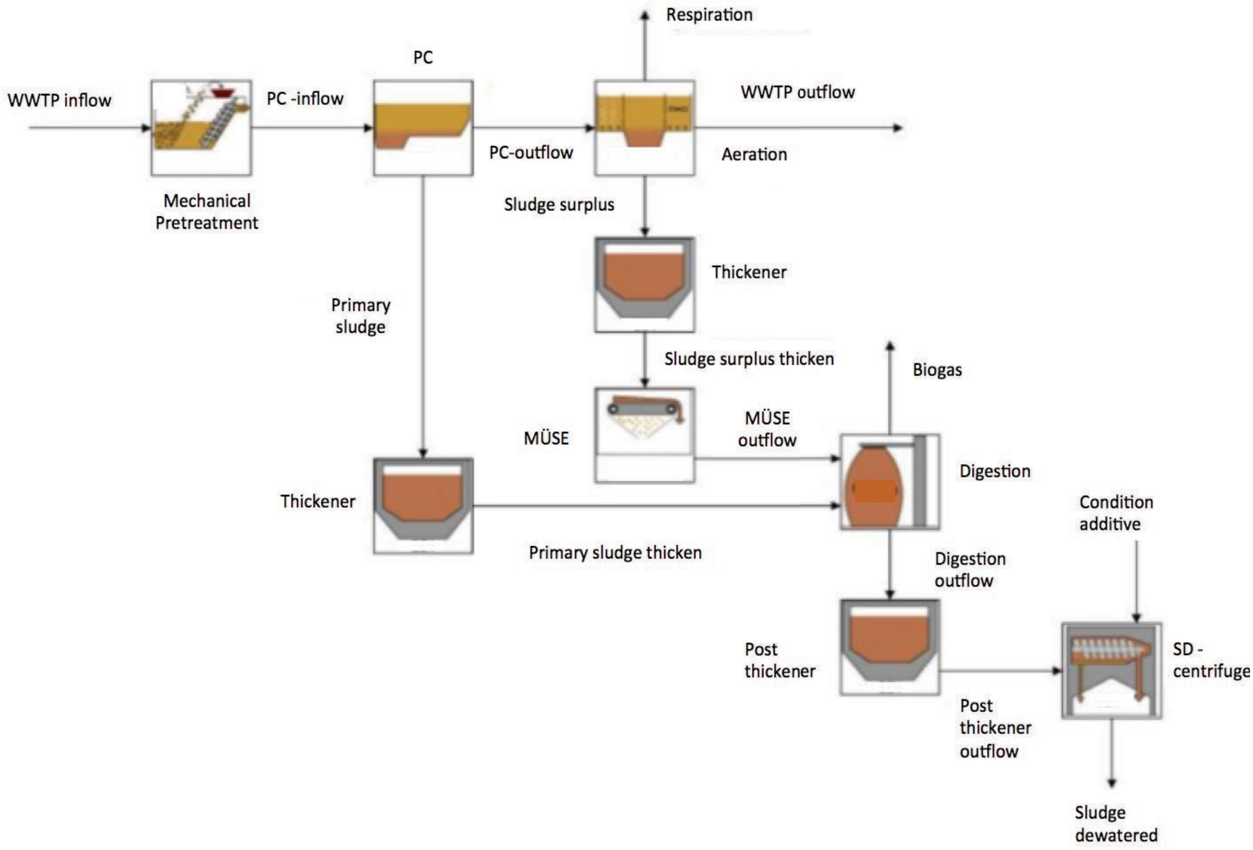

Figure 6: Example of an eDAB created wastewater scheme (Source: eDAB, 2014)

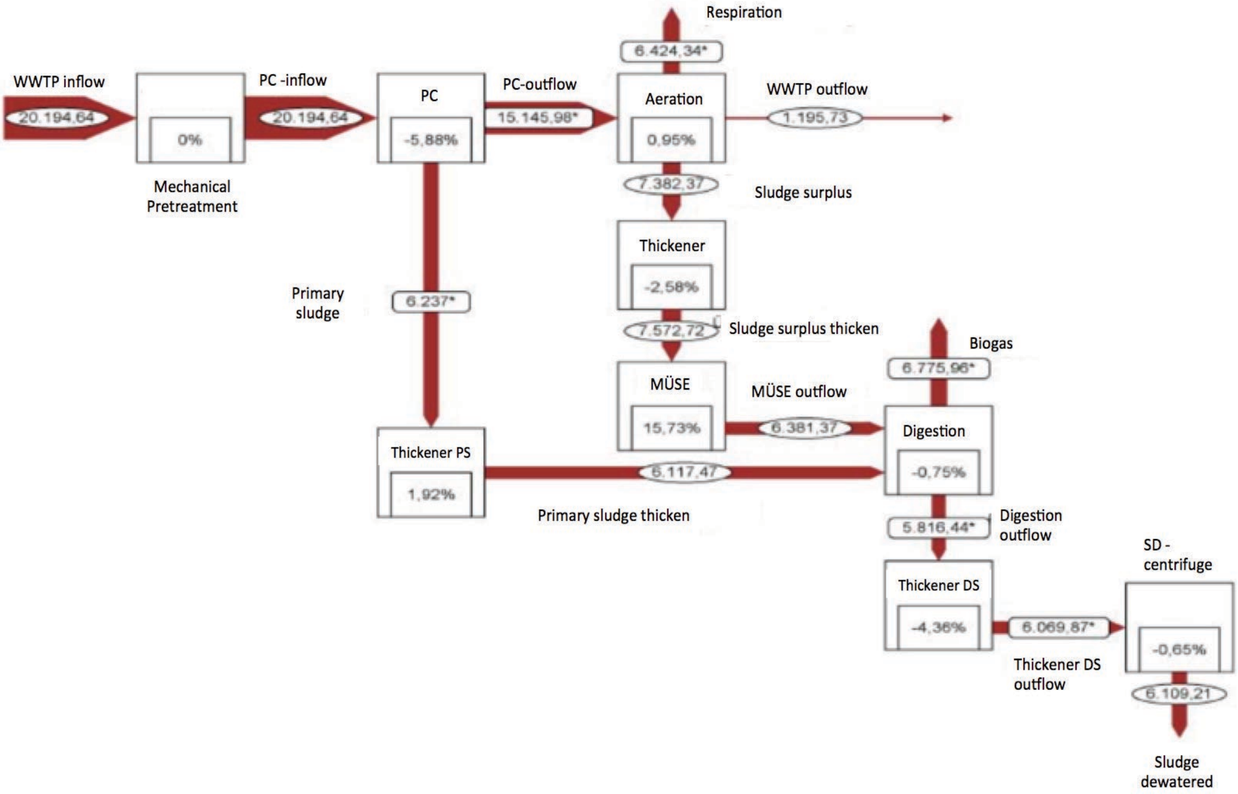

Figure 7: Example of an eDAB created COD scheme in detail (Source: eDAB, 2014)

Balance deviations in the above encapsulate percentage values. This diagram illustrates that if input flows are higher than outflow a positive balance deviation results. Should output exceed the input of the flow then a negative result is obtained. In the end it shows if every measured data is understandable and comprehensible.

Evaluation of COD is possible when detecting free volumes for co-digestion and through that a higher energy supply to the WWTP. This procedure is mentioned in detail in chapter 3.3.2.2.1 Energy supply (electrical and thermic energy sources).

3.3.2.2 Energetic analysis and optimization potential

Optimization must always be in context with the processes and their influence factors and boundary conditions. That's why energy optimization can occur at WWTP through wastewater technology and power engineering (Argis, 2001).

Wastewater technology:

When reducing energy costs, the main task of the WWTP is the cleaning performance of the wastewater. "*Cleaning*" is the most critically important and should not be reduced simply through a shortsighted plan for cost savings. The return on investment more than "*recovers*" the initial capital outlay of cost for cleaning technologies. The knowledge of wastewater technology and the understanding about the processes is very important for the realization of an energy optimization.

For an evaluation of the energy efficiency a precise knowledge of the effective output quantities of the plant (inflow loads, outflow loads), the cleaning level and the relevant intern source streams (sewage gas amount, usage) are required (Argis, 2001). The inflow loads are not exact every time thus, the calculation varies slightly each time. This is also valid for the amount of the sewage gas and sewage gas usage and their other internal source streams. But it is important to take into account that there are mistakes can be made. An increase of 10 % in the yearly inflow load affects 10 % of the specific energy parameters either negatively (or positively). To isolate or inefficiencies, a detailed audit of the wastewater technical reference values with defined parameters and accounting are necessary. Nevertheless, under optimal conditions of the plant and with precise analysis, many loads and related loads in practice are still have a +/- 10 % variability (Argis, 2001).

Power engineering:

Power engineering is an internal part of the analysis and is used for the determination of the relevant amounts in the energy reference, energy supply and energy consumption. It is intrinsically involved in the analysis of the reference cost and the finding and evaluation of improvement measures. For the establishment of a common and comparable basis, special consumers (e.g. sewage pumping systems, high water pump stations, sewer pump stations) are taken out of the energy amounts and are calculated apart from the WWTP. As part of the rough analysis, the energy determination and evaluation take place only on the data of the energy reference and recycled energy. Contained in the detailed analysis, the energy consumption of every single consumer is assessed and determined. Thereby a more substantially exact statement is gained for the whole plant but also for the itemized list of processes and machines (Argis, 2001).

Through a standardized assignment and representation it is possible to derive and specify energy parameters for the whole plant as well for the important parts of the plant. But it is also possible to derive and conduct valuable and direct comparisons between different process stages and single consumption levels.

Across reference of the energy values of suitable reference values, energy parameters that are relatively independent of size of the plant are gained. And through this, a useful comparison with other plants and a rough assessment is also generated (Argis, 2001).

Energy optimization

Energy optimization for a WWTP can be separated into two sections.

Section one is the current value analysis and comparison within normal parameters. Energy accounting delineates the values accorded electrical and thermic energy. Purchased electricity combined with electricity at the WWTP can be quantified and the net consumed energy saved after (Lindtner, 2008). Thermic energy at the WWTP is sufficient through digestion, thus enabling the thermic energy to be quantified. Only part of individual consumed energy is metered, but if this is possible, then energy consumption can be estimated with the help of connected loads. But is this not the case, than with the help of the connected loads it can be estimated. Supplied water, measured electrical performance, service life and WWTP fixed variables all allow for the presentation of stratified values of electrical consumption per consumer in a verifiable cost matrix. This matrix can be used as a template for all other commercial or local energy consumers. Normally, the thermic consumption of single aggregates of a WWTP is not registered technically. But with the help of the guideline specific key indicators and physical values can be estimated e.g. heat requirements for heated digestion and the infrastructure heating (Lindtner, 2008).

The energy indicators represent the current value analysis of a WWTP from the standpoint of the energetic view. Only the calculation of the indicators permits the comparison with other WWTP and allows the comparison with normal limits, which is specified for every indicator (Lindtner, 2008). Further if there are deviations in the results then energy optimization are achieved (Lindtner, 2008).

3.3.2.2.1 Energy supply (electrical and thermic energy sources)

WWTP energy manifests itself in the form of electrical and thermic energy. The needed energy is primarily bought from electricity companies or gained from oil, liquid gas, natural gas and digestion gas. At some WWTP there are already some alternative energy forms used such as photovoltaic, wind turbines and others. From all measured sources of energy the efficiencies and outputs of these energies are quantifiable. Energy acquired from the combination of heat and power plants (CHP plants), yield a transformed energy utilizing electrical and thermic sourcing. This energy gross yield, minus the electrical energy that is supplied to the electricity company, reveals the electrical energy that is consumed on the WWTP. Electrical energy production of the CHP plant is metered and regulated by the utility regulatory board of Austria and because of this total energy output can be calculated. In table 4 the different energy sources and their efficiency or utilized electrical or thermic energy is illustrated.

Table 4: Energy sources and their produced/utilized electrical or thermic energy (Source: Lindtner, 2008)

Energie sources	Amount	Energy content	usable electrical energy	usable thermical energy
Sewer gas total	***m³/d***	***kWh/d***	***kWh/d***	***kWh/d***
Sewer gas CHP	m³/d	kWh/d	kWh/d	kWh/d
Sewer gas / gas engine	m³/d	kWh/d	kWh/d	kWh/d
Sewer gas heating	m³/d	kWh/d		kWh/d
Sewer gas torch	m³/d	kWh/d		
Natural gas total	***m³/d***	***kWh/d***	***kWh/d***	***kWh/d***
Natural gas CHP	m³/d	kWh/d	kWh/d	kWh/d
Natural gas / gas engine	m³/d	kWh/d	kWh/d	kWh/d
Natural gas heating	m³/d	kWh/d		kWh/d
Liquid gas total	***kg/d***	***kWh/d***	***kWh/d***	***kWh/d***
Liquid gas CHP	kg/d	kWh/d	kWh/d	kWh/d
Liquid gas / gas engine	kg/d	kWh/d	kWh/d	kWh/d
Liquid gas heating	kg/d	kWh/d		kWh/d
Heating oil	l/d	kWh/d		kWh/d
Solar energy PV	kWh/d	kWh/d	kWh/d	kWh/d
Solarthermy	kWh/d	kWh/d	kWh/d	kWh/d
Sum electrical or thermical energy produced on WWTP			***kWh/d***	***kWh/d***
Energy from PSC or district heating bought in addition			kWh/d	kWh/d
Energy provided to PSC or district heating			kWh/d	kWh/d
Energy supply WWTP			**kWh/d**	**kWh/d**

Thermic energy produced at the WWTP, can be from the CHP plant and/or from a heating boiler. If the thermic efficiency factors from a CHP plant and/or a heating boiler are known than it it is easy to calculate the provided thermic energy. But if the efficiency factors are not known, a 10 to 20 percent variance in energy loss must be assumed. Thermic energy can be calculated by subtracting the usable electrical energy and energy transformation losses. Table 4 is a graphic representation of the different energy sources and utilization (Lindtner, 2008).

Energy supply through co-digestion

Through co-digestion it is possible to obtain higher energy amounts through fermentation of sewage sludge combined with further liquid or solid organic wastes in the digestion tank. A net increase of biogas results (Urban and Scheer, 2011).

As mentioned previously it is possible to increase the energy supply through detection of free volumes for co-digestion on a WWTP. Normally the co-digestion is based on digestion time and volumetric loading with organic dry matter. However this process is not critical as long the substances that are added are sewage sludge. But if other substances with different energy contents are added it is sometimes very difficult to determine the admissible quantity of co-substrate. Besides all in the cases of co-substrates with high-energy contents the estimation on the basis of organic dry matter volumetric loading may lead to overcharging of the digester tank. This can be better estimated through the COD, further the energy content of liquid substrates can be determined easily (Urban and Scheer, 2011).

This method has been applied as part of the national project of the WWTP in Freistadt. It is not recommended in the developed standardized approach, it is just an additional benefit. In this connection it has not been presented in detail in this master thesis. It will be shortly presented in the point methods and results.

3.3.2.2.2 Electrical and thermic energy consumers

Energy consumers are divided into thermic and electrical energy users. Since WWTPs with digestion have mostly a surplus of heat and WWTPs without digestion have a low demand on heat, this becomes the most popular attribute for electrical energy consumers. Electrical energy consumption is presented in table 5. Consumer evaluation is the most critical factor when optimizing the energy consumption in a WWTP. The goal is to determine the consumer groups and summarize the electrical energy consumption, which is illustrated in the following table.

Table 5: Electrical energy consumption of a WWTP (Source: Lindtner, 2008)

1) Intake pumping station and mechanical pre- treatment	**kWh/d**
1.1 Outlet pumping station	kWh/d
1.2 Rakes	kWh/d
1.3 Grit chamber and fat trap	kWh/d
2) Mechanical-biological wastewater treatment	**kWh/d**
2.1 Aeration	kWh/d
2.2 Agitator	kWh/d
2.3 RS-pumps	kWh/d
2.4 Others (PSB, ASB,…)	kWh/d
3) Sludge treatment	**kWh/d**
3.1 MÜSE and stat. Thickener	kWh/d
3.2 Digestion (energy digestion/heating)	kWh/d
3.3 Sludge dewatering	kWh/d
4) Infrastructure	**kWh/d**
4.1 Heating (factory building/infrastructure)	kWh/d
4.2 other infrastructure	kWh/d
WWTP total	**kWh/d**

If the electrical energy consumption of the consumer groups are not technically registered then the preparation of a matrix of the electrical energy consumers is recommended. The energy consumption can be calculated by taking the electrical performance and the service time of the respective aggregate. If the electrical performance is not known it can be measured through a current clamp. As a very rough estimation of the expected energy consumption it is possible to take the electrical supply performance of the aggregates and the estimated percentage of the received performance (Lindtner, 2008).

Since there is a surplus of heat on a WWTP, the saving of thermic energy is smaller. If the thermic energy demand is covered through an external bought in addition, the optimization of the heat demand becomes a higher priority. The heat and especially the processed heat is needed for the heating of the sludge digestion and for the digester heating. Additionally, the heat is needed for the infrastructure buildings. The heat demand for infrastructure buildings can be sometimes very high if the plant section is fully covered and these rooms have to be tempered because of the high air change (Lindtner, 2008).

3.3.2.2.3 Calculation of plant performance indicators

Although, for the preparation of an energy concept, the energy indicators stand in the front, the calculation of the indicators of the whole plant is recommended. In the next table 6 there are summarized indicators that structure themselves into calculated inflow loads, population equivalent, ratios and indicators and sludge and sewer gas amount. As measurement standard there has been taken rounded experience and literature values under special consideration of the knowledge from the WWTP benchmarking of 2013(Lindtner, 2008).

Table 6: WWTPs indicators (Source: Lindtner, 2008)

PE_{120}	E		
PE_{60}	E		
$PE_{Ntotal11}$	E		
$PE_{NH4N6,5}$	E		
$PE_{Ptotal1,7}$	E		
PE-digested sludge-oDS22 (PE_{oDS22})	E	**measurement standard**	
N/COD	-	***0.07***	***0.1***
BOD/COD	-	***0.4***	***0.6***
spec-DS-load stabilized sludge	g DS/PE_{120}	***35***	***50***
spec-ODS-load digested sludge	g ODS/PE_{120}	***20***	***30***
spec. Sewer gas amount per PE_{120}	l/PE_{120}	***15***	***22***
spec. Sewer gas amount per PE_{oDS22}	l/PE_{ODS22}	***15***	***22***
DS-sludge dewatering	%	***25***	***35***

Calculation of the population equivalent:

PE_{120} = COD-inflow load [kg/d] / 0.12 [kg/P/d] (Lindtner, 2008) [1]

PE_{60} = BOD_5-inflow load [kg/d] /0.06 [kg/P/d] (Lindtner, 2008) [2]

$PE_{Ntotal11}$ = N_{total}-inflow load [kg/d] / 0.011 [kg/P/d] (Lindtner, 2008) [3]

$PE_{NH4N6,5}$ = N_{total}-inflow load [kg/d] / 0.0065 [kg/P/d] (Lindtner, 2008) [4]

$PE_{Ptotal1,7}$ = P_{total}-inflow load [kg/d] / 0.0017 [kg/P/d] (Lindtner, 2008) [5]

PE_{oTS22} = oTS-digested sludge load [kg/d] / 0.022 [kg/P/d] (Lindtner, 2008) [6]

The calculation of the population equivalent from the mentioned inflow loads gives typical same results of other WWTPs [1, 2, 3, 4, 5, 6]. Considerable deviations of the population equivalent can happen through specific indirect discharger. This means that deviations from the calculated population equivalent must be explainable through indirect discharger (Lindtner, 2008).

3.3.2.2.4 Calculation of energy indicators

The calculation of energy indicators and their comparison within the normal limits is essential for the preparation of an energy concept. Through the calculation of specific energy values it is possible to compare different sizes of WWTP. Through different indicators in tables that are presented it is possible to make statements over the provision and consume of electrical energy of a WWTP. For the comparison of every indicator a normal limit is shown. For the limits rounded experience- and literature values under certain circumstances of WWTPs are taken. Moreover for both electrical and thermal indicators, between three different indicator blocks have to be differentiated:

1. indicators of energy supply,
2. indicators of energy consumption and
3. other energy indicators.

Since the aeration energy is very important there is an own energy indicator block. The specific electrical energy consumption is presented in table 8.

Electrical energy indicators

The summarized indicators from table 7 can be calculated through table 4 and through the population equivalent PE_{120}. The gained specific electrical energy from the sewer gas and also the specific electrical energy from photovoltaic, wind wheels, and so on, give information of the percentage of the own power supply. The sum of the produced electrical energy and energy that is bought in addition, minus the energy that is delivered to the electricity company, gives the consumption of the provided electrical energy on the WWTP (Lindtner, 2008).

Table 7: Specific electrical energy provision (Source: Lindtner, 2008)

		measurement standard	
el. energy produced from sewer gas	$kWh/PE_{120}/a$	10	20
other el. energy produced on WWTP	$kWh/PE_{120}/a$	-	-
el. energy bought in addition	$kWh/PE_{120}/a$	10	50
el. energy provided to PSC	$kWh/PE_{120}/a$	0	20
el. energy provided	$kWh/PE_{120}/a$	20	50

The summarized indicators from table 8 can be calculated from table 5 and the population equivalent PE_{120}. The specific energy consumption from the consumer groups' of intake pumping station and mechanical pre-purification consists itself of intake pumping station, rake as well as sand- and grease trap. The specific energy consumption of the intake pumping station is able to be outside the normal limit. If there is no intake pumping station or it must be pumped very high (Lindtner, 2008)

Table 8: Specific electrical energy consumption (Source: Lindtner, 2008)

		measurement standard	
WWTP total	**kWh/PE_{120}/a**	**20**	**50**
1) Intake pumping station and mechanical pre- treatment	kWh/PE_{120}/a	**2.5**	**5.5**
1.1 Outlet pumping station	kWh/PE_{120}/a	1.5	3.5
1.2 Rakes	kWh/PE_{120}/a	0.5	1
1.3 Grit chamber and fat trap	kWh/PE_{120}/a	0.5	1
2) Mechanical-biological wastewater treatment	kWh/PE_{120}/a	**14.5**	**33**
2.1 Aeration	kWh/PE_{120}/a	11.5	22
2.2 Agitator	kWh/PE_{120}/a	1.5	4.5
2.3 RS-pumps	kWh/PE_{120}/a	1	4.5
2.4 Others (PSB, ASB,…)	kWh/PE_{120}/a	0.5	2
3) Sludge treatment	kWh/PE_{120}/a	**2**	**7**
3.1 MÜSE and stat. Thickener	kWh/PE_{120}/a	0.5	1
3.2 Digestion (energy digestion/heating)	kWh/PE_{120}/a	1	2.5
3.3 Sludge dewatering	kWh/PE_{120}/a	0.5	3.5
4) Infrastructure	kWh/PE_{120}/a	**1**	**4.5**
4.1 Heating (factory building/infrastructure)	kWh/PE_{120}/a	0	2.5
4.2 other infrastructure	kWh/PE_{120}/a	1	2

The specific energy consumption of table 8 the mechanical-biological wastewater treatment results from energy consumption of the aeration, stirring and pumping. Another normal limit is indicated for the specific aeration energy. Since the aeration at plants with aerobe stabilization needs more aeration energy than WWTPs with sludge digestion. Plants with digestion and N/COD-ratio of 0.1 need for the aeration of good oxygen production (OP-value of 2.2 kg/kWh) 10 kWh/PE_{120}/a. At unfavorable conditions there are oxygen production ratios (OP-value of 1.5 kg/kWh) and energy consumption for the aeration of 15 kWh/PE_{120}/a. For another N/COD-ratio the specific oxygen demand gets lower (Lindtner, 2008).

At WWTPs with aerobe stabilization and a N/COD-ratio of 0.1, the aeration can be calculated, because of a good oxygen production (OP-value of 2.2 kg/kWh) with 15 kWh/PE_{120}/a. At unfavorable conditions there are oxygen production ratios (OP-values 1.5 kg/kWh) and an increasing energy consume for the aeration of 22 kWh/PE_{120}/a (Lindtner, 2008).

3.4 Evaluation of the general suitability of a WWTP

3.4.1 Evaluation of operating data of a WWTP

The evaluation of a WWTP is important in order to provide measures and detect reserve capacities. Also to detect in this context a general suitable WWTP with regard to wastewater heat recovery in the sewer system. For the detection, the specific data has to be evaluated and compared with each other.

But these methods that have been here presented are only methods for the evaluation of operating data of Swiss WWTPs. Further, these methods only apply to their legal requirements and regulations and not to Austrian ones.

These data should consist the following (Argis, 2001):

- Wastewater temperature:
  - Inlet temperature
  - Outlet temperature
  - Predefined legal requirements

- Performance data with valid notification of the WWTP

- Connection size of the WWTP:
  - Current P.E.
  - Designed P.E.

- Inlet and outlet data this includes:
  - Wastewater amount,
  - Concentrations and loads BOD5, COD, Ntotal, NH4-N, NO3-N, P
  - Predefined legal requirements

- Basin capacity
  - Current basin capacity
  - Designed basin capacity

- Sludge age and sludge amount

Further on through the comparison with the operating data it is simple possible to detect reserve capacities and also maybe a suitable WWTP (Argis, 2001).

Another possibility is how someone can estimate easily the impacts of a heat removal before a WWTP. It is through a Nomo gram. This simple method is developed through the Swiss and adheres to their legal regulations. The basis of daily averages is estimated of the inflow of the biological step. It is possible to evaluate different effects (Buri et al., 2004).

In the first diagram of figure 8 it is shown that if there is a heat removal in the sewer system that lowers down the wastewater temperature, the temperature is only 10 °C and the aerobe sludge age still has 9 days, than the nitrification security according to the diagram 1 is 1.8 [7] (Buri et al., 2004). If the wastewater temperature lowers down to 10 °C and the security factor of 2 should be obtained, than the aerobe sludge age has to be increased to 10 days. This is possible through an enlargement of the activated sludge basin and can be increased through less removal of the sludge. The latter can lead to a overloading of the secondary clarifier during rain events. In denitrified WWTP it is possible that the aerobe sludge age is increased through the expense of anoxic shown in diagram two (Buri et al., 2004).

Likewise in the third diagram of figure 8 there is an increase of the nitrogen volume at the expense of the denitrification volume. For this case there are the same nitrification security and the same ammonia discharge values but reduced denitrification efficiency, which means lower total nitrogen elimination (Buri et al., 2004).

Calculation of the nitrification security factor (SF):

$SF = \mu_{max} * SA_{aer}$ (Buri et al., 2004) [7]

μ_{max} $[d^{-1}] = 0.2 * e^{(0.11 * T_{[°C]} - 10))}$ (Buri et al., 2004)

μ_{max} = maximal growth rate of the Nitirficant

SF = nitrogen security factor

SA_{aer} = aerobe sludge age

SA_{ano}/SA_{tot} = ratio between anoxic and total sludge age

η_{tot} = total efficiency factor

$C_{COD, tot,in}/C_{N,tot,in}$ = total chemical oxygen demand to total nitrogen in the inflow biology

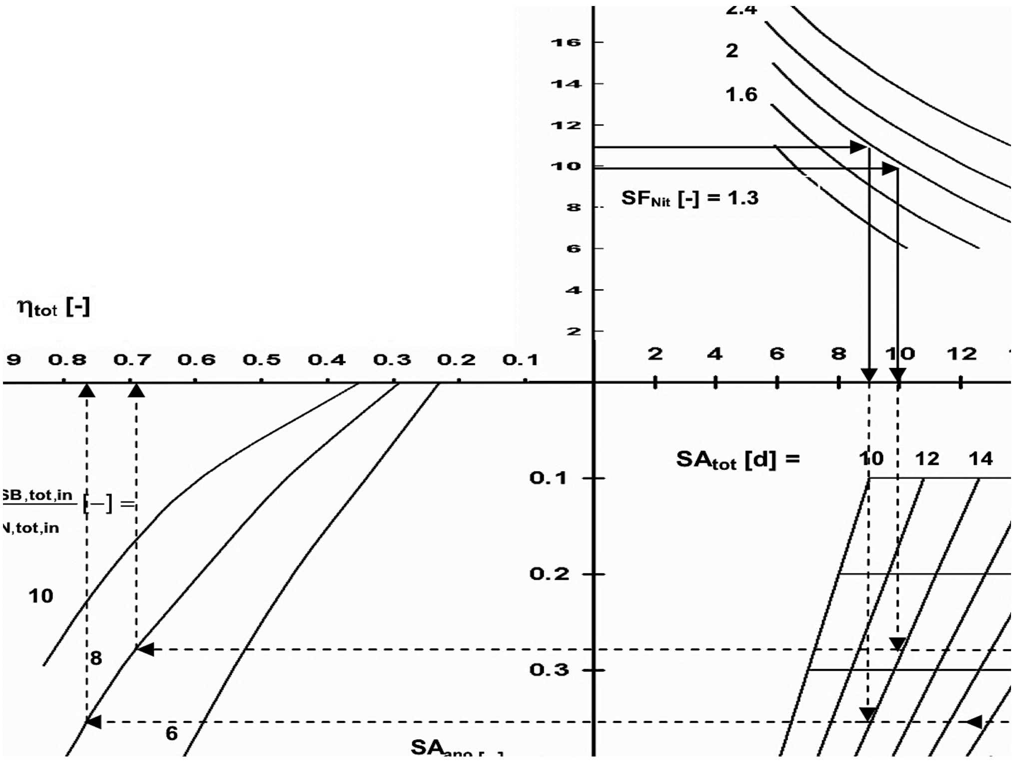

Figure 8: Nomo gram for the estimation of the temperature changes of wastewater in an inflow of a WWTP (Source: EAWAG, 2004)

If the calculation of the wastewater temperature in the inflow of the WWTP is higher than the limitation Temperature ≥ 10 °C and cooling is ≤ 0.5 K then a deeper investigation has to be made. Additional to the Nomo gram there has been another simple diagram developed through model calculation. It is correlated between nitrification security and the ammonia concentration in the WWTP discharge for a 50 % and 85 % day loads. This correlation has been presented in figure 9.

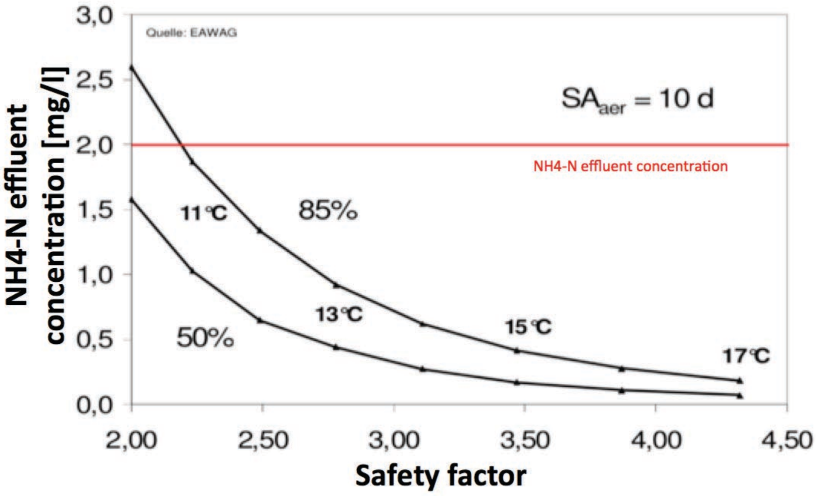

Figure 9: NH4 - concentration in the discharge of the secondary clarifier depending on the nitrification security factor (SF) (50%-85% loads) (Source: EAWAG, 2004, adapted)

In figure 9 it can be seen that through the aerobe sludge age (SA_{aer}) in winter and the lowest discharge temperature in the WWTP, the nitrification security factor (SF) can be calculated. The influence of a temperature reduction of ammonia discharge concentration can only be estimate through the figure 9. At an aerobe sludge age of 10 days (normal value) and a temperature of 10 °C (in Swiss normal design temperature) a nitrification security factor of 2.0 is resulting [7], which means a double security against the wash out of the microorganisms. Nevertheless there is a slightly higher ammonia discharge value than 2.0 mg/l in the diagram. But in the water directive of the Swiss (GschV) there is allowed a maximum of 10-20% of the days in one year (depending on the WWTP) be exceeded (EAWAG, 2004). It can be assumed that the 85 % day load and a lower temperatures of 10 °C are very rarely falling together and an exceeding of the limits are therefore only happening in less than 5 % of the days in one year (EWAG, 2004). Based on a cumulating frequency curve from the ammonia discharge values it is possible with the help of figure 8 to estimate the cumulating frequency curve, which is been expected after a temperature reduction. It already becomes clear that the impacts of a temperature reduction in a WWTP inflow become more harmless, the bigger the design reserve capacities of a WWTP are (Buri et al., 2004).

3.4.2 Contingent calculation according to the guideline of AWEL

The contingent calculation allows a determination of cooling of the wastewater in °C. It is supported through the analysis of the ammonia concentration (90%-value) and the comparison with the valid discharge conditions. Further on it is possible to calculate the wastewater heating potential or wastewater contingents in front or after the WWTP (Ryser Ingenieure AG, 2013).

This method as before mentioned is only required for the calculation of WWTPs in Switzerland because it has been coordinated to their requirements.

For the ammonia values it is possible to take the so-called 90-%value of the cumulative frequency and/or the mean value of the ammonia concentration of the reference period. Another very important parameter for the calculation of the wastewater heat potential or for the determination of the contingents of the WWTP is the wastewater amount. The wastewater amounts are statistically evaluated. For the calculation [8] of the usable contingents, the 20% or 50% cumulative frequency value is determined through the daily discharge amounts. The following formula is derived through the average dry weather discharge (Ryser Ingenieure AG, 2013):

$$Q_{d\,DW} = (Q20\% + Q50\%)/2 \quad \text{(Ryser Ingenieure AG, 2013)} \qquad [8]$$

Wastewater temperature is another important factor. The temperatures must be evaluated to derive the percentage of the days with the average daily temperatures under 10 °C. The reference temperature corresponds to temperatures that are fallen below 5% of the days. This value corresponds to around 2.5 weeks per year. Table 10 shows an example of such a calculation. On the left side of the table there are the temperature levels in percentages per days. In the columns there are listed the day appearances in percentage in the context of the overall measured values. Further the reference temperature is taken if the value is lower the 5%. In this example the temperature is taken before it is yellow marked (Ryser Ingenieure AG, 2013).

Table 9: Results from evaluation of wastewater temperatures of Swiss villages (Source: Ryser Ingenieure AG, 2013)

	Real	Rontal	Sempach-N.	Lützelau
< 6 °C / % days	0 / 0.00%	15 /1.03%	0 / 0.00%	0 / 0.00%
< 7 °C / % days	1 / 0.06%	19 / 1.30%	2 / 0.57%	0 / 0.00%
< 8 °C / % days	3 / 0.19%	23 / 1.58%	15 / 4.27%	0 / 0.00%
< 9 °C / % days	4 / 0.25%	30 / 2.06%	52 / 14.81%	0 / 0.00%
< 10 °C / % days	10 / 0.62%	55 / 3.78%	88 / 25.07%	6 / 1.67%
< 11 °C / % days	34 / 2.11%	158 / 10.85%	120 / 34.19%	42 / 11.67%
< 12 °C / % days	98 / 6.08%	351 / 24.11%	135 / 38.46%	98 / 27.22%
Numbers of measurement	1612	1456	351	360
Reference temperature	11.5 °C	10 °C	8 °C	10 °C

	T. Entlebuch	Moosmatten	Blindei	Oberseetal
< 5 °C / % days	13 / 4.85%			
< 6 °C / % days	36 / 13.43%	0 / 0.00%	0 / 0.00%	0 / 0.00%
< 7 °C / % days	65 / 24.25%	0 / 0.00%	0 / 0.00%	1 / 0.27%
< 8 °C / % days	88 / 32.84%	0 / 0.00%	6 / 1.64%	2 / 0.53%
< 9 °C / % days	100 / 37.31%	5 / 1.50%	40 / 10.93%	9 / 2.41%
< 10 °C / % days	113 / 42.16%	21 / 6.31%	87 / 23.77%	40 / 10.70%
< 11 °C / % days	130 / 48.51%	58 / 17.42%	113 / 30.87%	85 / 22.73%
< 12 °C / % days	150 / 55.97%	88 / 26.43%	138 / 37.70%	117 / 31.28%
Numbers of measurement	268	333	366	374
Reference temperature	5 °C	10 °C	8.5 °C	9.5 °C

Determination of possible cooling in front Swiss WWTPs:

For the calculation of possible cooling of the wastewater [9], where the discharge conditions on the Swiss WWTPs are still valid, it can be used the following formula:

$\Delta T = (\ln (NH_4\text{-}N_{,new} / NH4\text{-}N_{,measured}))/0.33$ (Ryser Ingenieure AG, 2013) [9]

Thereby for the $NH_4\text{-}N_{,new}$ term, the valid discharge limit value of 2.00 mg/l is used.

The calculation of the WWTP looks like this:

ΔT = (ln (2.00 mg/l (NH4-N,new)/1.11 mg/l (90%-value NH4-N,measured))/0.33

For example:

ΔT = (ln (2.00/1.11))/0.33 = 0.589/0.33 =1.78 °C or Kelvin

The value 0.33 is a predefined value from the Swiss and gives the microbial degradation of the microorganisms.

In this case a cooling potential is obtained for this WWTP of around 1.8 °C or Kelvin.

Calculation of the contingents:

The usable wastewater heat contingent [10] (correspond to the possible heat removal of the wastewater) can be calculated with the following formula (Ryser Ingenieure AG, 2013):

Q’ = V’ * ρ * c * ΔT (Ryser Ingenieure AG, 2013) [10]

Q’ = usable heat performance in kW (kilowatt), correspond to contingent

V’ = wastewater volume stream in l/s; dry weather flow Q_{dw}

ρ = specific density (of water) in kg/m^3, 998 kg/m^3

c = heat capacity from water (4.18 J/K*g)

ΔT = usable temperature difference in Kelvin (K); assigned in accordance to the AWEL-guideline

Like before mentioned it is possible to calculate the impacts of the wastewater energy recovery on the ammonia concentration. Important for the determination of the wastewater heat recovery contingents are following criteria:

- Reserve capacities of the surveyed WWTP
- Development of the load on the plant, through population growth, removal and connection of adjacent WWTP and added or removed heavy pollutants
- Existing wastewater heat recovery plants

But the AWEL guideline gives only a guiding principle to install a wastewater heat recovery plant or not. For the implementation of such a plant many processes and conversations have to be taken into account (Ryser Ingenieure AG, 2013).

Finally for the determination of contingents for Austrian WWTPs the AWEL guideline of the Swiss has been taken exactly like presented above since there are not more legal differences between the two countries except the calculation of possible cooling potential. In this case the adapted formula has been taken.

3.4.3 Modeling statically or hydro dynamically

*"The activated sludge process is the most generally applied biological wastewater treatment method"(*Gernaey et al., 2004). There have been many different activated sludge process introduced during the last decays. Further on there are essential differences between an activated sludge model and a WWTP model. The term of the WWTP model indicates several model types. It indicates the activated sludge model, hydraulic model, oxygen transfer model and sedimentation tank model. The hydraulic model describes different characteristics like tank volumes, hydraulic tank behavior and the liquid flow rates and internal recycle flow rate. There are several factors in respect to activated sludge modeling and model applications. Likewise there is a stepwise approach that is needed to develop from the model point of view to the point where a WWTP model is available for simulations. This process is listed in the next steps (Gernaey et al., 2004):

- Definition of the WWTP model purpose or the objectives of the model application
- Model selection: selection of the models needed to describe the different WWTP
- Hydraulics
- Wastewater and biomass characterizations
- Data reconciliation to a steady state model
- Calibration of the activated sludge model parameters
- Model unfalsification
- Scenario evaluations

But these models also have their limitations. There are a lot of assumptions and influences for these models. These influences are the following:

- Temperature: Kinetic models parameters are temperature dependent.
- pH: In activated sludge models, it is assumed that the pH is constant and near neutrality.

- Toxic components: Nitrification is especially sensitive to inhibition by toxic components.
- Wastewater composition
- Cell growth limitations due to low nutrient concentrations are not considered.
- Biomass decay in activated sludge models is modeled according to the death-regeneration concept.

The objective of model application influences the activated sludge model selection. A model will be implemented in the following cases:

- In a service case
- In an advice case

There are two ways a WWTP can be analyzed and designed. One is statically and the other is hydro dynamically.

Normally the more simple and easy way of simulating is by static modeling and designing of a wastewater treatment system (e.g. ATV-DVWK A 131, 2000). There are rough and ready rules for the calculation. The calculations are used to describe conditions that can be compared to real situations. In this case it is possible to detect the impacts that would occur on the WWTP with regard of wastewater heat recovery in the sewer system. Further it is possible to calculate different scenarios that could happen in reality. However the problem is that these models are not able to manage with time variation. Models with the use of time variation can be only designed dynamically (EAWAG aquatic research, 2014). Likewise in this case it is possible to demonstrate the impacts that could happen in a certain course of time and can be calculated up to the smallest detail. Additionally to simply analyze if the evaluated WWTP is a general suitable WWTP with respect to wastewater heat recovery. There are many different models on the market. For example there is Hydro Sim, Samba, and some more.

Since dynamic models are really complex and also time consuming especially for data calibration and validation it has not been taken into account for this master thesis.

4. Material and methods

4.1 Illustration of the theoretical standardized approach

For the development of the standardized approach, it has been focused on the following procedure:

At the project`s inception, an analysis of different projects of Germany and Switzerland was undertaken in the context of wastewater heat recovery in the sewer system. The focus lied on their legal requirements and on how the public authorities implemented their programs. According to this a comparison has been done between authorities in foreign countries and in Austria to evaluate the differences.

Further different possibilities have been considered to detect a general suitable WWTP with respect to wastewater heat recovery in the sewer system. Since the Swiss have the longest experience values their method *"the contingent calculation"* has been taken. However they have different legal requirements, so the part *"determination of possible cooling"*, where the legal difference has appeared, has been adapted to the Austrian requirements. This part has been presented in point 4.2.2.2.

But before a general suitable WWTP can be evaluated consistent and plausible data has to be obtained. So a data validation and performance evaluation has to be done in the context of wastewater heat recovery in the sewer system. This validation consists of two processes. One is the rough analysis and the other is the detailed one. Through these two analyses it is possible to obtain plausible data. Likewise through the detailed analysis including the energetic analysis it is possible to detect in some cases an optimization potential.

Building on this, the developed theoretical approach has to be applicable on one national case study called Freistadt. This should be done to evaluate if the standardized approach is implementable and not only theoretical. Further to detect possible obstacles in the application and to adapt them to certain limit.

4.2 Practical application of data validation and performance evaluation for the case study Freistadt

4.2.1 Data validation

4.2.1.1 Rough analysis of data of WWTP Freistadt

In the practical application the data of the WWTP is taken and is applied on the theoretical standardized approach. The case study Freistadt has been chosen because it is one of three WWTP, which are evaluated according to the national project called *"Energie aus Abwasser"*. The structure of the WWTP is presented in figure 10 and the master data is shown in table 10.

Table 10: WWTP in Freistadt master data (own presentation)

Plant name	Reinhaltungsverband Freistadt u. Umg
Address WWTP	An der Feldaist 15, 4240 Freistadt
Province	Upper-Austria
Expansion size	30.000 P.E.
Year of the last expansion stage	2009
System parts	Activation, digestion

In the beginning every possible data and indicators should be receive. The data sets that have been provided are from the operating year of 2013. Afterwards excel files are created to collect every obtained data. Thereby a sortation has to be done to validate them on consistency and plausibility. They have to be checked formally as well as technically and has to be compared with other plants and their performance characteristics for example with *"the report state and future of benchmarking of WWTPs in Austria"* (Lindtner, 2013) or *"ÖWAV rule sheet 13"* (ÖWAV, 2013) or other master data of a WWTP of same characteristic and size. Further certain comparisons have to be done in the case of input and output values. For example the inlet and outlet amount of wastewater should stand in correlation to each other. The amount of produced sewage gas should be related to the size of the WWTP and also to the digestion tank. The connection size of the current P.E. should lie in the design P.E of the WWTP. The energy consumed should also stand in a certain correlation to the size of the WWTP and so on. Then on the first glance the provided data should be consistent and every necessary data should have been received. After a rough analysis of the evaluated WWTP the detailed evaluation has to be done. The detailed analysis is separated into two main analyses. In the next points it is given on the one hand through mass flow balancing and on the other hand through the energy consume.

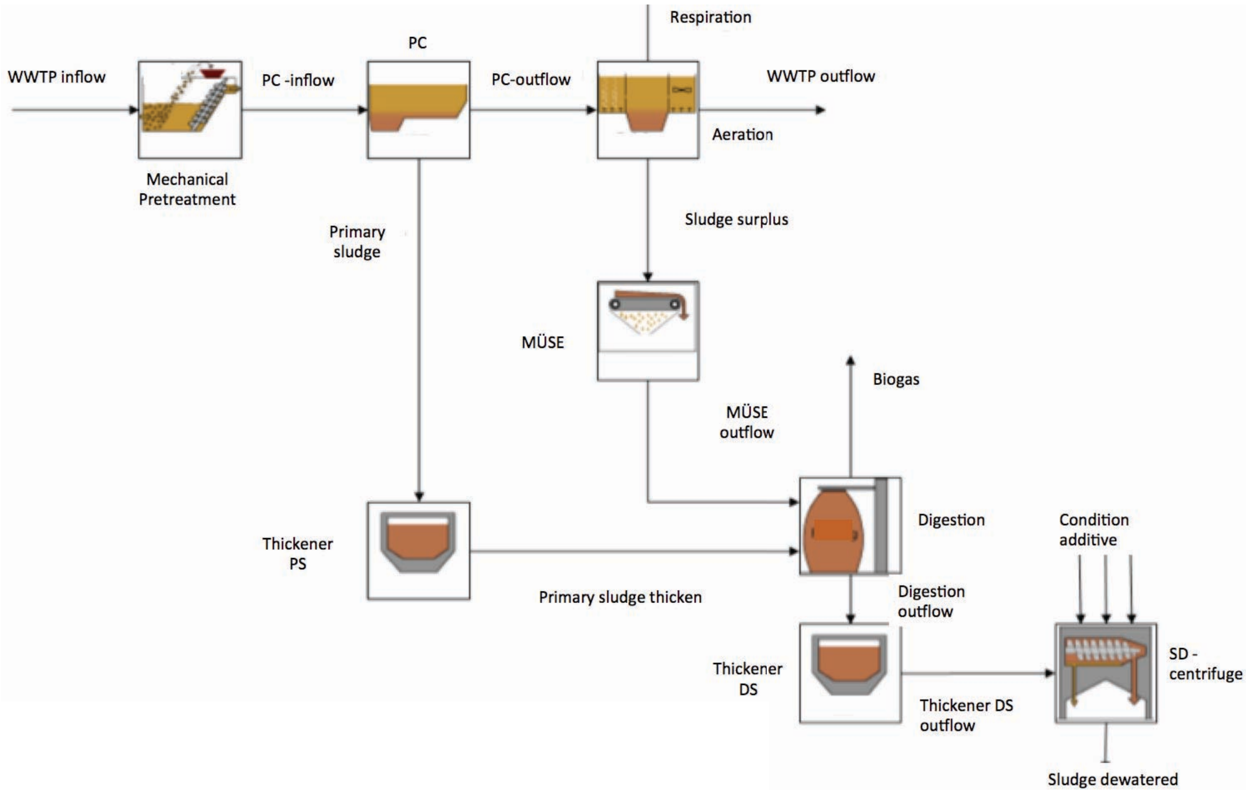

Figure 10: Illustration of the structure of the WWTP in Freistadt (own presentation in eDAB)

4.2.1.2 Detailed analysis of data of WWTP Freistadt

4.2.1.2.1 Mass flow balance analysis through the software eDAB

The software eDAB gives detailed information over the mass flow balance in the WWTP. Through the software it is possible to calculate and control if the right and valid data has been received. The software is only prepared in German but will be explained in English in the next figures.

The software is provided from the company eDAB Entwicklungs- und Vetriebs GmbH. A contact has to be made and a detailed description of the evaluated WWTP has to be send as well to it. After that the company provides a calculation template, which is specially adapted to the investigated WWTP.

Afterwards the received template has to be load into eDAB. This is shown in the figure 11. First the button *"file"* (Datei) has to be clicked and then the button *"build from template"* (Aus Vorlage erstellen). After that eDAB loads the prepared template into itself.

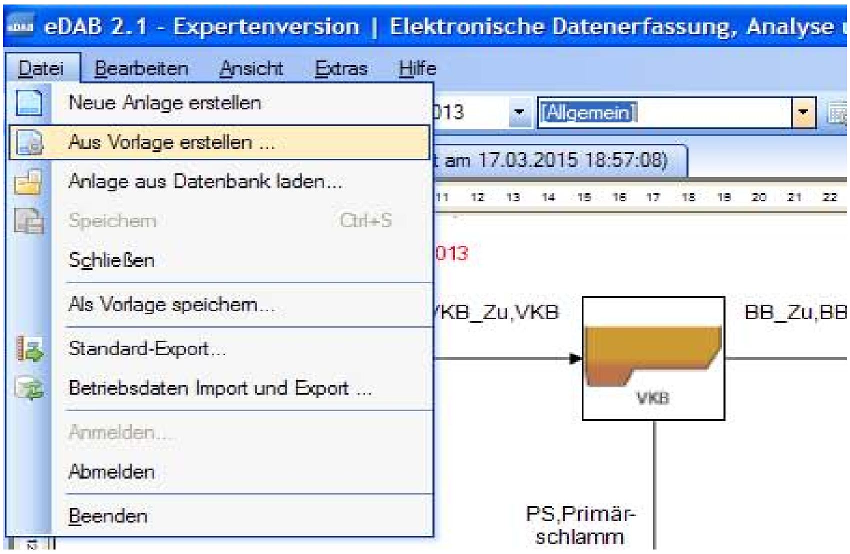

Figure 11: Illustration of loading the prepared template into eDAB (own presentation)

Then a parameter setup has to be done and the imports have to be defined. This parameter setup is illustrated in figure 12. The button *"edit"* (Bearbeiten) has to be clicked and then *"parameter setup"* (Parametersetup). In this parameter setup it is possible to add different characteristics of the evaluated WWTP for example MÜSE or thickener and so on.

Figure 12: Illustration of the parameter setup (own presentation)

Afterwards the operating data has to be taken and a copy has to be made. The copy has to be load into a new excel file. This is presented in figure 13. This file should be named without any numbers. The excel file should consist two work folders. In the first, references should be created to the single operating data, so that eDAB is able to find the data when it is imported. This is illustrated on the left side of figure 13. And in the other folder there have to be the operating data of the evaluated WWTP listed with the date in the first column.

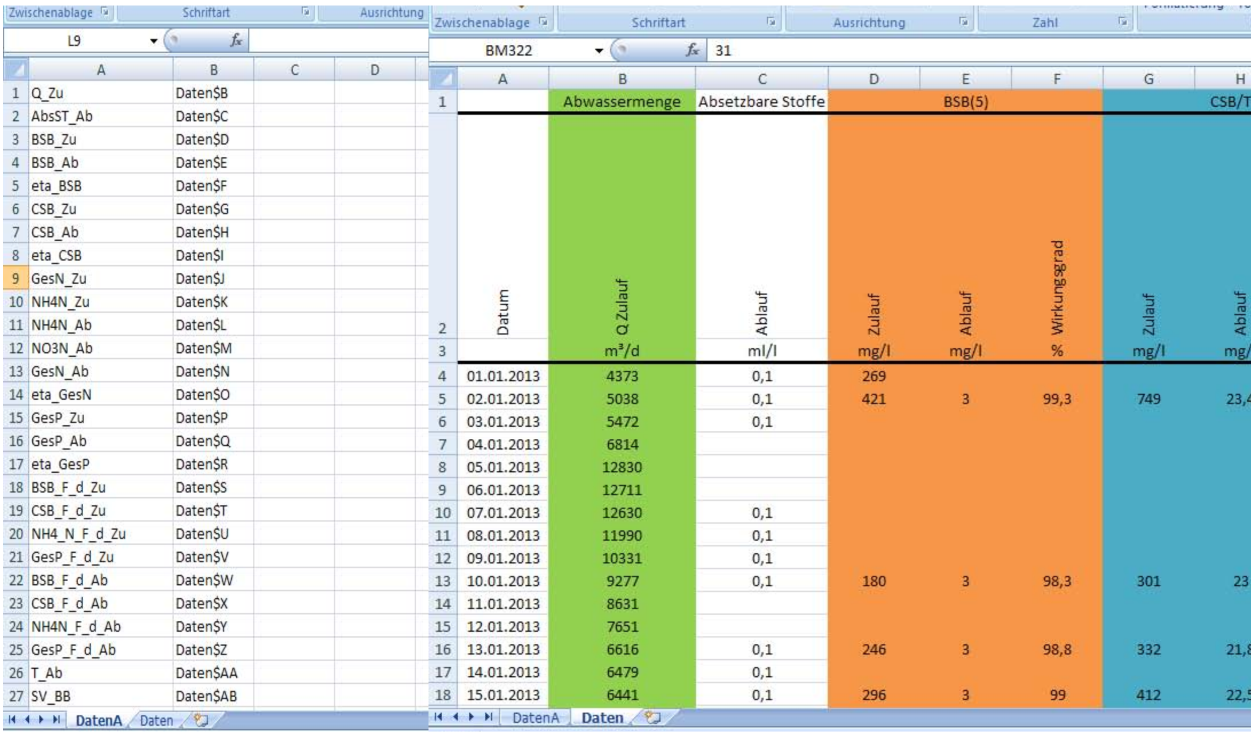

Figure 13: Illustration of operating data that has to be loaded into eDAB (own presentation)

The next step is to go in *"extras"* (Extras) – *"administration"* (Verwaltung) – *"import definition"* (Importdefinitionen) and looks for the predefined assignments in eDAB. Important is that the assignments have to be taken exactly as they are written there. In *"general"* (Allgemein) there the definitions take place. It has to be defined the first column A, the last column CG, date column A, the values start at line 4 and the end of the line 368. This is presented in figure 14.

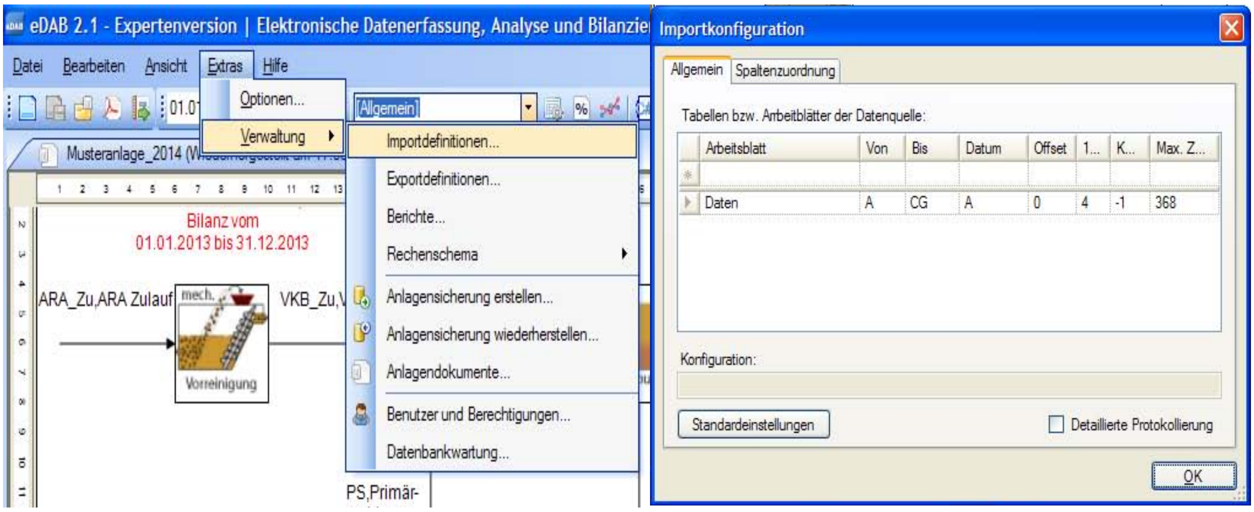

Figure 14: Illustration of the import configuration (own presentation)

Since the operating data is not predefined in the tab. In the button *"edit"* (Bearbeiten) - *"parameter definition edit"* (Parameterdefinitionen bearbeiten) there is the possibility to define own parameters if the predefined parameters are not enough. This is illustrated in figure 15. It is also possible to look up for parameters that someone might has in the operating data but does not know how it is defined.

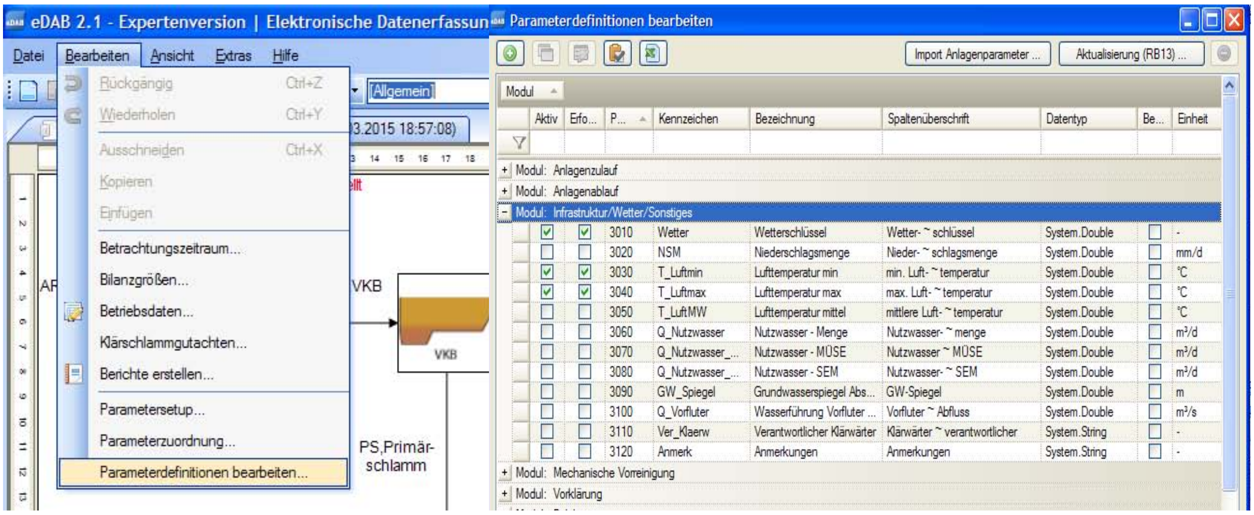

Figure 15: Illustration of the parameter definition edit (own presentation)

Then the two columns of the first work folder have to be copy based and have to be imported into *"extras"* (Extras) – *"administration"* (Verwaltung) – *"import definition"* (Importdefinitionen) – *"column list"* (Spaltenzuordnung) and on the right side there is a button with an excel file picture. This button has to be clicked to import all defined parameters. This is presented in figure 16. The program will notify if there are any problems obtained with the referencing or finding of the data.

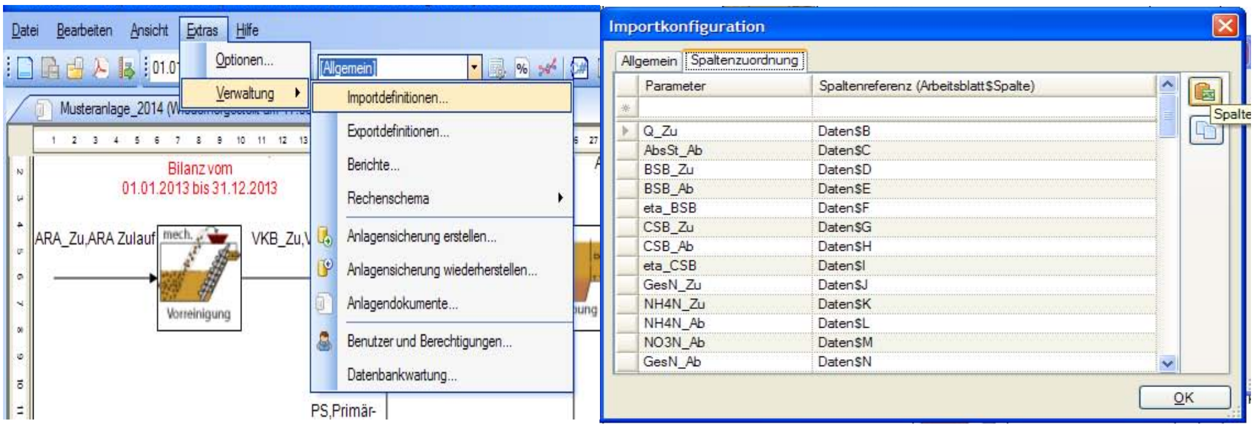

Figure 16: Illustration of the import configurations (own presentation)

Afterwards, the prepared excel file has to be closed and the *"data"* (Datei) - *"operating data import export"* (Betriebsdaten Import und Export) has to be opened. Then *"import"* (Importieren) - *"excel import (direct) GV"* has to be pressed. Then the prepared excel file has to be searched in *"data source"* (Datenquelle). Further the button start has to be clicked to run the program. This is in figure 17 imaged.

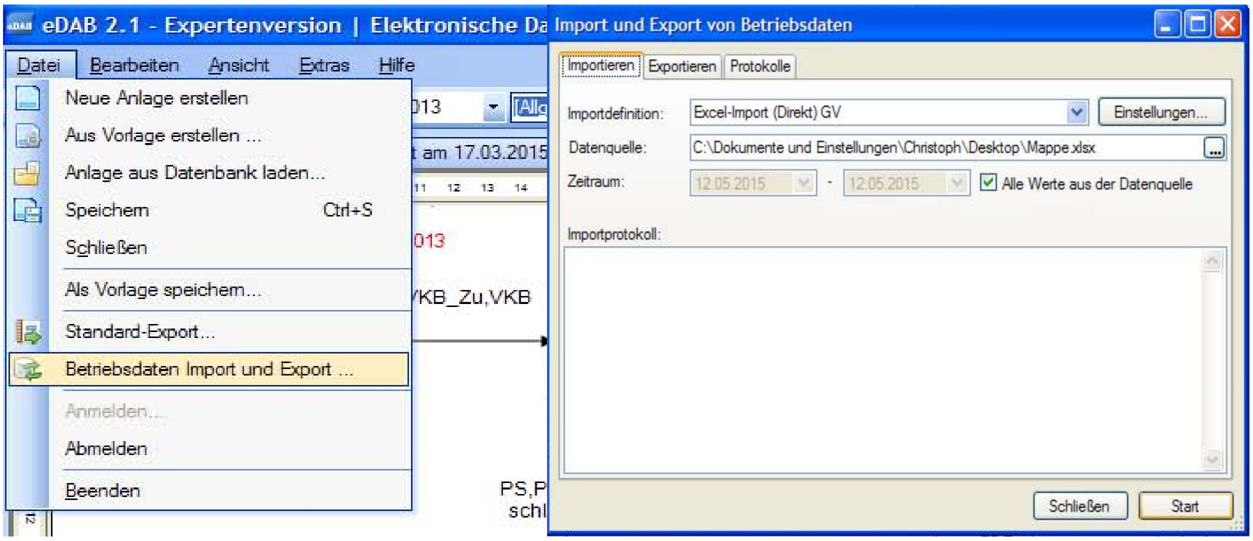

Figure 17: Illustration of the import of the prepared excel file (own presentation)

The software is designed to give information of errors and will list the errors. Through this listing the errors can be corrected.

The next point is to create a sewer sludge report. The button *"edit"* (Bearbeiten) - *"sewer sludge report"* (Klärschlammgutachten) has to be pressed. This sheet provides the information of the different parameters of the sludge. This is pictured in figure 18.

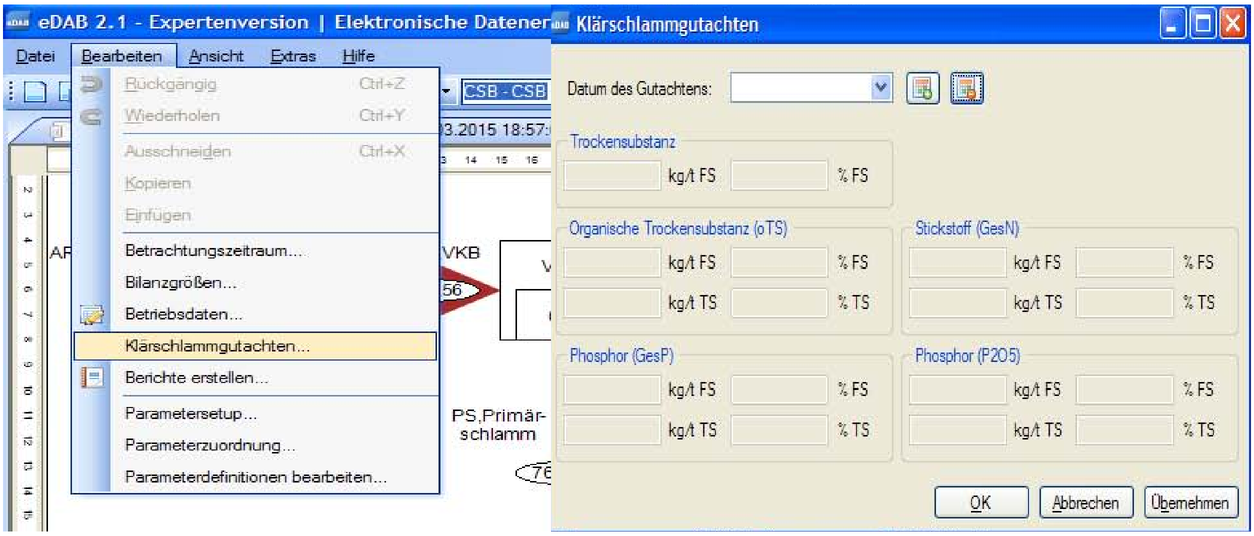

Figure 18: Illustration of the sewer sludge report (own presentation)

After importing, on the main sheet, the balance of the WWTP is presented. Every single mass balance flow has to be checked if it has been calculated with a formula and if the formula has been right by clicking into the provided arrows. In the middle of the calculation bar there is a tab to change the mass flows of different outputs. There is a possibility to select as before mentioned between COD, DS, Phosphorous, Nitrogen and water amount in total and detail. As it has been mentioned in fundamentals the operation boxes and their percentages have to be checked. Through going through of the different in- and outputs and the relations to each other a checkup has been done. It is also possible to receive no result for a mass flow. This happens when the operation data provides no more data to calculate. If this does occur, experience values from the literature have to be taken in this special case. Once more to check the validity of the received mass flows, it is possible to recheck the flows for example through the paper *"energy demand from wastewater treatment plants"* of Kroiss and Svardal (2009). Through this paper it is possible to recalculate the COD for every flow. In the end a plausible and consistent evaluation of the different flows of the evaluated WWTP have to be received.

Further through the evaluation of the COD it is possible to detect via co-digestion possible energy supply on the WWTP. This procedure is mentioned in detail in part energy optimization.

4.2.1.2.2 Energetic analysis and optimization potential of WWTP Freistadt

The energy segment of a WWTP is an important one. The energy guideline (Lindtner, 2008) has been taken to calculate in detail if the data that has been received is consistent and also if there is any energy optimization potential.

The energy guideline is a predefined calculation template in excels for WWTPs. The guideline structure is separated into a current state analysis and comparison with the measurement standards and the deviation analysis. The focus lies on the current state analyses and comparison. The current state is contained in an Excel sheet, which calculates every data and gives a detailed overview of the WWTP.

The first task is to check if all data has been received for the different parts to obtain an assessment. The template is built up that in the part of the electrical energy consumption the single technical processes are summarized in main processes. So, for example, in the part of the mechanical biological wastewater treatment, the part agitator is the sum of all single agitators. In other instances, there have to be summarized every single technical device which is not assignable to the other categories or parts. It is very important that every single consumption is assigned to a part and nothing is forgotten. After checking of all necessary values, the entering starts.

After all the data has been entered, an overview of the evaluated WWTP will be received. In the parts of the plant performance indicators and energy indicators, there is on the right site a part, which is with grey background. In this grey background there are numbers that give a measurement standard. Now the single calculated cells are compared with the measurement standard. The calculated numbers should be in the range of these standards. In most cases they properly follow the standards. But in some cases results are received that are below or above. In this case these results have to be marked. The results could give evidence that the entered values might be wrong or include an energy optimization potential. This is the starting point for further investigation and evaluation.

After the results from the energetic analysis have been received, the optimization of the evaluated WWTP begins. The results have to be evaluated, which are above or below of the measurement standards and have to be validated on plausibility and consistency. They should be not too high or too low. If this is the case, the entered values have to be checked for typing errors. The next part is to create a new excel file where a recalculation of these parts has been made. For the recalculation, values have to be taken, which assure to obtain values that are in the measurement standard. Now these values have to be taken as reference points. The difference between the reference point and the previously entered value is the theoretically saving potential or optimization potential. But the problem in most cases is that nobody really knows if the entered measured value is really right or wrong. A solution is to pursue this problem through a detailed checking of the data.

The next step is to make an appointment at the WWTP for a recheck. Afterwards the operator has to be asked where he generates these data sets and he should be asked about the calculation pathways. Through this process an exclusion of any calculation errors can be made. If no calculation mistakes have been made, the investigation goes on. Subsequent to this step, to be really sure that the single technical devices consume and produce the right values, every suspicious technical part has to be screened. To obtain right values a rough energy consumption calculation has to be made. The different technical parts in an excel file have to be listed and the operator has to be asked about the different technical devices of the WWTP. The next information’s that have to be generated are: annual hours of work, average operating time, nominal capacity and power input. The power input is normally around 80%. The nominal capacities are normally marked on the different devices. And the other data is provided through the operator and his recordings. Now the annual hours have to be calculated through 365 days to obtain the average operating time. Then nominal capacity has to be multiplied by power input through 100 then the real power input has been received. After the calculation the annual hours have to be multiplied with the real power input. The result is the energy consumption of the device in kWh/d.

If every information is received, the energy consumption for every single machine has to be calculated. In the end a sum of all devices should be obtained. This sum should be around the sum that has been received from the operator before or not. If it’s not the case then the right value for the consumption or an estimation of the right value has been obtained. But it should be taken into account that this calculation will always have a reasonable calculation error. To perform a meaningful value this calculation error should be under 10 percent.

After this detailed calculation part right values should have been received, which are checked on validity, consistency and plausibility, to close the energy accounting. Now at the end there will be parts where values will exceed or fall below the measurement standards again. In these special cases energy saving potentials or optimization potentials has been received. On the other side if no deviations in the standards appear, this will show that the evaluated WWTP performs good and well.

Energy supply through co-digestion

For the estimation of the co-digestion the following data has to be received out of the consistent and valid operating data. It is needed the volume of the digestion tank, the amount of raw sludge of primary sludge, the amount of sludge surplus, the load data of dry organic matter of the primary sludge, as well as the load data of primary sludge of the COD, the load of dry organic matter in MÜSE of the sludge surplus and also the load data of sludge surplus of the COD. Then this data should be entered in to a new excel file because it is easier to calculate with it. The tables how it could look like for the calculation is in point 5.2.1.2.2 presented. The calculation of the current space loads is the following. The current space load of the dry organic matter is received if the two load data of the primary sludge and the sludge surplus are added and then divided through the volume of the digestion tank. Further the same has to be done with the space load of the COD. And to obtain the value for the current digestion time, the volume of the digestion tank has to be divided by the sum of the two amounts of the primary and surplus sludge. After that the current value has to be subtracted from the normal value. The standard values are given in the paper of Urban and Scheer, (2011) for the different sizes of the WWTPs.

The result that has been obtained is the potential. Likewise the potentials have to be multiplied with the volume of the digestion tank and through this an estimation of the co-substrates can be made and a free potential. If the free potential has been received it has to be compared with table 26 in chapter 5.2.1.2.2 energetic analysis and optimization potential of WWTP Freistadt that is presented in results. In this table it is presented the comparison of properties of different substrates. Afterwards it is possible to say what co-substrate is possible to add and also how much of it or nothing can be added to receive a higher energy supply.

4.2.2 Evaluation of the general suitability of WWTP Freistadt

4.2.2.1 Evaluation of operating data of WWTP Freistadt

For the evaluation of the operating data it is needed as well as before the provided data sets that has been controlled on consistency and validity from the operator. The detailed data that is needed, is mentioned in the chapter fundamentals. First the data of the current P.E. of the evaluated WWTP has to be taken and has to be compared with the P.E. of expansion level. There a difference of the two values will be detected. If the current P.E. is very low and the P.E. expansion level is very high this means that a high difference will be received and further on a high reserve capacity. But on the other hand if this difference is very low, a low reserve capacity will be the result. The difference has been given in percentage and in P.E., so it is easier to demonstrate. Likewise the NH4-N concentration has to be checked. The outlet concentration has to be in the predefined limit of 5 mg/l.
So the average value of the concentration has to be calculated. Then a difference has to be made and should be compared with each other. If the outlet concentration is lower than a higher reserve, capacity has been obtained. If it is not then it is the other way, a low capacity is the result. The next point that should be evaluated is the wastewater temperature of the WWTP. The inlet temperature has to be taken and again an average value out of the whole 5 years has to be made. This value is very important because it informs if there might be a cooling potential in front of the WWTP or not. Further on if the average value is very low and only retains in the predefined limit than this will mean that there will be no or less reserve capacities in this aspect. As well on the other hand again a higher average value of temperature will mean a higher possibility of a reserve capacity. After the evaluation of the operating data has been finished, according to the outcome, a detailed analysis through the contingent calculation is the next point.

4.2.2.2 Contingent calculation according to the guideline of AWEL for the data of Freistadt

The method of the contingent calculation is taken one to one from the AWEL as presented in fundamentals. Since the method has only one part *"the determination of possible cooling"* where legal differences of the two countries appeared. In this case this part of the calculation has been adapted to the Austrian wastewater directive. The requirement as before mentioned, for a contingent calculation, is always a good working WWTP. The AWEL is based on the Swiss wastewater directive. As in the point fundamentals explained before there are differences to the Austrian directive. These differences are once more presented in table 12. The Swiss directive says the discharge water concentration has to be 2 mg/l of nitrogen and the efficiency factor of the treatment should have 90%. Also if the ammonia concentration has bad effects on the water quality of flowing water than the water temperature should have more than 10°C (GSchV, 2014). In Austria the directive says that there should be at least 70% of the total Nitrogen be reduced in WWTP bigger than 5 000 P.E.60 and the maximum outflow concentration in mg/l is 5. Additionally, the emission limit is valid at a wastewater temperature of 12°C in the outflow of the biological treatment in the WWTP (1.AEV, 2014).

Table 11: Difference of the legal guidelines between Austria and Switzerland (own presentation)

Characteristics	Austria	Switzerland
Reduction of total bonded Nitrogen	At least 70% (bigger than 5.000 P.E.60)	At least 90%
Maximum outflow concentration of total Ammonia (mg/l)	5 mg/l (bigger than 5.000 P.E.60)	2 mg/l
Cooling limit without permission	None	0.1 °C Depend on the canton
Design temperature	8°C for nitrification and 12°C denitrification	10°C

<u>Adaptation of the calculation of cooling potential in front of Austrian WWTPs</u>

Further for the calculation of possible cooling potential in front of Austrian WWTPs the formula [11] has been adapted to their legal requirements. Since as before shown the discharge limit of the Swiss is 2 mg/l. But in Austria the discharge limit is 5 mg/l the formula has been adapted to this requirement. So the adapted formula is the following:

$$\Delta T = (\ln (NH_4\text{-}N_{,\text{new Austrian}} / NH4\text{-}N_{,\text{measured}}))/0.33 \qquad [11]$$

Thereby for the NH_4-$N_{,\text{new Austria}}$ term, the valid discharge limit value of 5.00 mg/l is used.

For example:

$\Delta T = (\ln (5.00/1.11))/0.33 = 4.6$ °C or Kelvin

In this case a cooling potential is obtained for this WWTP of around 4.6 °C or Kelvin.

The data that is normally needed is provided from the WWTP operator of the evaluated WWTP. The following data sets have to be received: the outlet concentration of Ammonia, the inlet amount of dry weather flow and the inlet wastewater temperatures of the WWTP. To be sure to obtain a significant result, it is recommended that the data should be actual and from the last 5 years. It is possible to take the data of only one year but the accuracy and validity of the calculation will be not that high. Again the easiest and precise way is to create a new excel file where all received data has been entered. Such an excel file how it could look like is presented in point 5.2.2.1

In the AWEL guideline it is declared that through the contingent calculation very often results are received that might be too high. To recheck the result and to be really sure that the value is right that has been calculated, another calculation before has to be done. A reference temperature has to be calculated.

At first the inlet wastewater temperatures of the 5 years have to be counted that are under 6°C. In some cases a few values will be received. This value has to be entered in the excel sheet. The easiest way is to take the COUNTIF function to determine these values out of 1825 for 5 years. This procedure should be done for every degree Celsius till 12. The next step is to calculate the percentage of the 6°C values and the others. At the end for every degree Celsius a percentage of the total sum should be obtained. Then it should be checked, which percentage is lower than 5 percent. The value has to be taken, which is as close as possible to 5 but does not exceed 5. The value that is received is the reference temperature. For example it is reached the 5 percent at a degree of 9°C than 8°C has to be taken, as the reference temperature. Finally the reference temperature has to be calculated minus 6 and an end result is obtained. It is 6 because under 6°C it is not economical any more to cool down the temperature in front of a WWTP. As before mentioned it can happen that the WWTP has very low wastewater temperatures in winter months because for example the winter has been very hard and cold. This will mean that the percentages will be above 5 already at the beginning. Further on this will also mean that the reference temperature will be 0. For this reason there will be no cooling potential in front of the WWTP. But if a positive reference temperature has been received the next steps have to be made.

After that the real calculation of the contingents of the evaluated WWTP has to be made. A new sheet in the excel file has to be created. The 5-year values of the outlet concentration of ammonia have to be taken and the average has to be created. Next the formula for the determination of the possible cooling potential in front of the WWTP has to be taken. This formula is given in the chapter 3.4.2 contingent calculation according to the guideline of AWEL [9]. The natural logarithm has to include the value of the average concentration divided by the legal predetermined concentration of ammonia of Austria. Further this value has to be divided by 0.33 the microbial degradation. The value that has been received is the temperature that is possible to cool down in front of the WWTP. Now the calculated temperatures have to be compared with each other. For the further contingent calculation the smaller value that has been calculated has to be taken. The smaller value has to be taken in order to be on the safe side and thereby to reduce the risk of possible emerging problems in the context of wastewater energy recovery.

After the value has been obtained it has to be entered in the formula for the calculation of the contingents. The formula is given in detail in chapter 3.4.2 contingent calculation according to the guideline of AWEL [10]. The other single parameters are given in the guideline and are predefined. The only part that has to be calculated as well is the amount of the average dry weather flow. Since the operator provides again for every day a value of dry weather flow the average flow of the 5 years has to be calculated. Then the average value has been received in the unit m^3 per day. The next step is to calculate this value in liters per second. When everything has been converted the value has to be inserted into the formula. The result is the possible contingents in front of the WWTP in the unit Watt. Through the formula it is also possible to calculate a possible contingent in the outlet of the WWTP. For this purpose it should be insert into the formula, instead of the reference temperature, the maximal possible cooling temperature of 4°C or 5°C. These values are also predefined in the AWEL. In this case it is sometimes possible that the calculated energy is normally higher than the energy that has been gained through cooling in front of the plant. As before quoted it depends always on the possible cooling temperature. In the guideline it is mentioned explicit that a theoretical wastewater heat recovery is only economical when the result is over 100 kW.

As previously mentioned, if the result of the detailed analysis through the contingent calculation is marginal then a more detailed analysis is recommended. In this case a statically and hydro dynamically modeling would be recommended. Since this method is very time consuming and needs a high effort it has not been taken into consideration in this master thesis.

4.2.2.3 Modeling statically or hydro dynamically with the data of WWTP Freistadt

Since as in point 3.4.3 modeling statically or hydro dynamically before mentioned a statically and hydro dynamically modeling is very time consuming and needs a lot of measured data. In this case the modeling has been discarded because it would have gone beyond the scope of this master thesis. Nevertheless it is recommended for the evaluation of a general suitability of a WWTP.

4.3 Evaluation and optimization of the standardized approach

If the process of the approach is precisely followed then a good overview of the evaluated WWTP should be obtained. Further on it has been deemed important that the approach should be as user-friendly as possible for the evaluation of the WWTPs in Austria. There is no optimization potential in the context of the standardized approach. Although the software tool eDAB at the first glance will need dedication and time. So regarding to this an easier handling and a quicker structure would be preferable.

5. Results and discussion

5.1 Illustration of the theoretical standardized approach (flowchart)

Through careful consideration and development of the standardized approach the following flowchart has been resulted. This flowchart shows in detail how to proceed to obtain a certain result in the context of wastewater heat recovery in the sewer system.

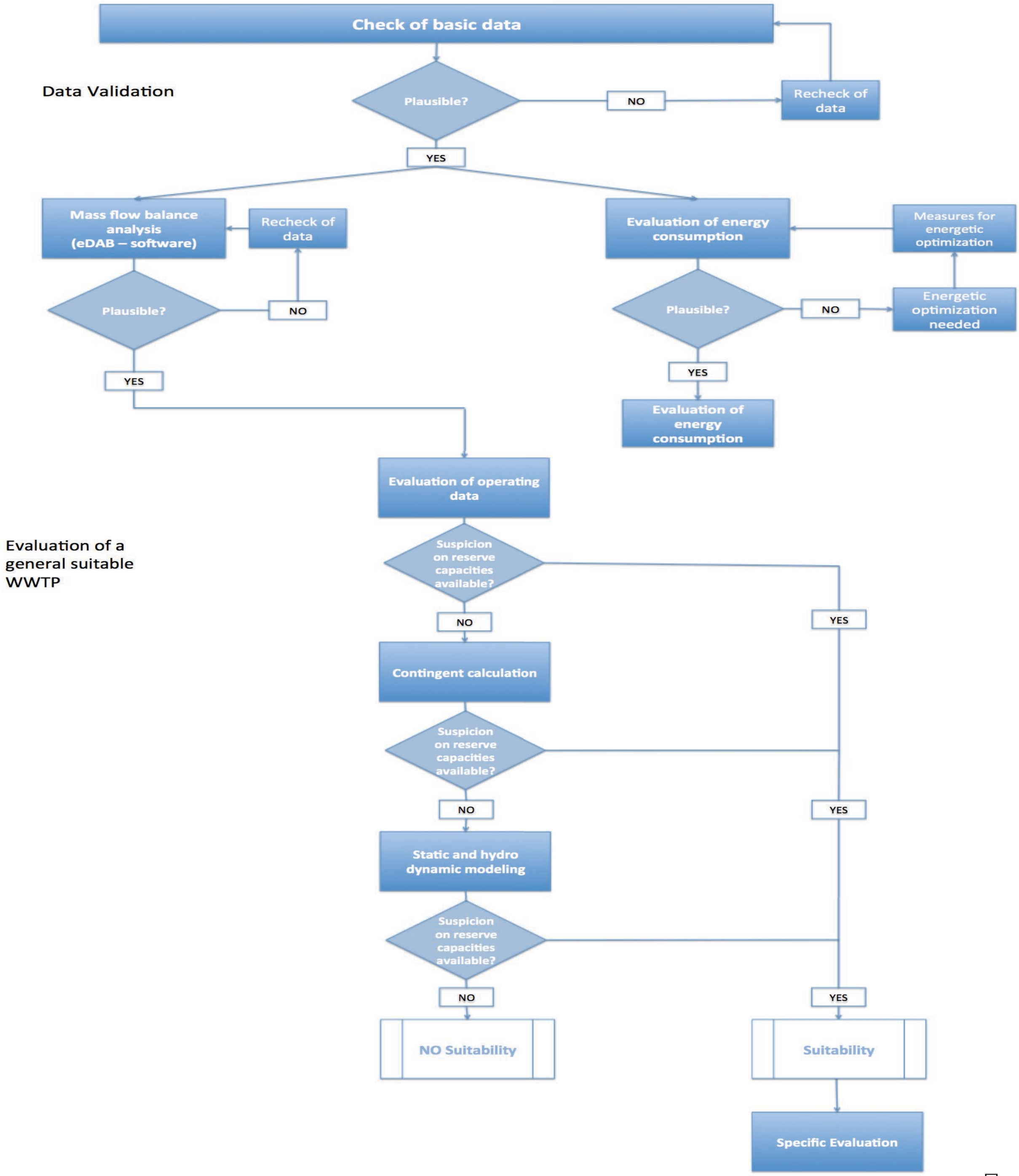

Figure 19: Illustration of the flowchart to detect a general suitable WWTP with regard to wastewater heat recovery (own presentation)

Data validation

For the data validation, the first step is to do a rough analysis of the basic data. The rough analysis should give an overview about the performance level and consistency of the received data. For the check of the basic data, every bit of information is needed. As previously mentioned in the point fundamentals, the informations should contain all basic data, which is written there. For example it should contain a detailed description of the plant, structural main technical characteristics and so on. The data should be as actual as possible. Further on there should be an overview made of the collected data and a collating should be done. This sorting out is very important for the next steps of the evaluation, assessment and comparison.

The next point is to compare different basic data sets and control them if they are consistent or not. They have to be compared formally on possible calculation mistakes and technical in the context of plausibility of performance characteristics with other plants. The data of different other plants is given in the *"ÖWAV rule sheet 13"* or in the paper "*the report state and future of benchmarking of WWTPs in Austria"*. The data have to be plausible and comprehensible. The best solution against incomprehensible data is to create own excel files and offset the data. Likewise the compilation of inlet, outlet, sewer gas amount and sludge has to be checked and has to be controlled with another WWTP with similar characteristics. If the rough analysis is consistent and valid, in the flowchart it is presented with *"Plausible?"* - "*Yes",* then the next step has to be made. If it is not possible to receive valid and consistent results it is *"No"* than it has to be gone to the next box *"Recheck of data"*. The basic data sets are once more controlled on possible data gaps and measured errors. In the case that the data gaps cannot be closed a consultation with the operator should be considered to receive plausible data.

If *"Plausible"* data has been received, the next point is the detailed analysis through the mass flow balance analysis through the software eDAB. There the data is checked more precisely if it is consistent. Further the evaluation of the energy consumption can be also made to check the consistency. Afterwards if again *"Plausible?"* - *"Yes"* data has been obtained than the arrow down has to be followed to the evaluation of a general suitable WWTP in the case of the mass flow analysis. If the results are *"No"* than again a recheck of the data has to be done. This is presented in figure 19 through the arrow up to the *"Recheck of data"*. In this case the whole process once more is checked precisely and like before a consultation day with the operator should be considered. On the other hand if the evaluation of the energy consumption is *"Plausible?"* - "*Yes"* this means the energetic optimization has been achieved. In this case it is observable where optimization potential is situated. But if *"No"* results are obtained energetic optimization is needed. Further through measures it should be possible to overcome the implausibility to evaluate once more the energy consumption and get then *"Plausible?"* - "*Yes"* results.

Evaluation of the general suitability of a WWTP

The next point is to evaluate and detect a general suitable WWTP in the context of wastewater heat recovery in the sewer system. There are three steps to analyze reserve capacities for a suitable WWTP. The start is with the evaluation of operating data. For example through the evaluation of the operating data it has been received a *"Suspicion of reserve capacities available?"* - *"Yes"*. In this case *"Suitability"* will be obtained. This will mean that the evaluated WWTP is general suitable for wastewater heat recovery in the sewer system. A more detailed analysis will not be necessary. For this typical case the authorities have to decide if the rough analysis with the evaluation of operating data will be enough or to proof the result, a detailed analysis should be done. Further if it is received through the rough analysis only "*Suspicion of reserve capacities available?"* - "*No"* then it is recommended to make the detailed analysis via the *“Contingent calculation”*. This is also presented in figure 19. Likewise if only *“Suspicion of reserve capacities available?”* - *“No”* has been obtained again then an evaluation is recommended through *“Static and hydro dynamic modeling”*. But if results are obtained through the contingent calculations that have *“Suspicion of reserve capacities available?”* - *“Yes”* then again as before mentioned an evaluation through the models will not be necessary. After the analysis there is the point where the evaluated WWTP is suitable or not suitable for the wastewater heat recovery in the sewer system.

The static and hydrodynamic modeling has not been taken into account in this master thesis because it would have gone beyond the scope of this thesis.

If a general suitability of the WWTP is obtained after the evaluation a further specific evaluation has to be done. This specific evaluation will take a more detailed investigation. Since this evaluation is dependent on the planed heat extraction amount (extraction volume, wastewater amount and wastewater temperature at extraction point, distance to WWTP, etc.) it is not part of this thesis.

However to summarize the evaluation process for every analysis the responsible water authorities have to be conform to the result. The more marginal the result for the suitability is the more detailed is the proof.

5.2 Practical application of data validation and performance evaluation for the case study Freistadt

5.2.1 Data validation

5.2.1.1 Rough analysis of the data of the WWTP Freistadt

The application of the guideline according to the WWTP delivers the following results:

The results of the first part the data validation and performance evaluation of the data sets of the WWTP have been valid. The sortation and validation have shown that the received data sets have been complete and consistent. In order to confirm this a rough comparison with the WWTP of Gleisdorf has been done and is shown in table 12. The WWTP of Gleisdorf has nearly the same master data like the WWTP of Freistadt.

Table 12: Results of rough comparison of WWTP master data (own presentation)

Characteristics	WWTP Freistadt	WWTP Gleisdorf
Expansion size	30.000 P.E.	32.000 P.E.
Actual size	22.000 (P.E. 120)	23.000 (P.E. 120)
Wastewater amount inlet	5.000 m^3/d	7.400 m^3/d

Inlet COD load	2.600 kg/d	2.800 kg/d
Inlet BOD_5 load	1.560 kg/d	1.650 kg/d
COD outlet concentration	22,4 mg/l	18,0 mg/l
BOD_5 outlet concentration	3,1 mg/l	4,1 mg/l
Energy supply	1.661 kWh/d	2.688 kWh/d
Sewer gas amount	473 m^3/d	272 m^3/d*
Sludge amount	31 m^3/d	29 m^3/d

* The value of the gas amount is smaller because the WWTP in Gleisdorf has a smaller sludge tank (450m^3) than the WWTP in Freistadt (1000m^3)

Further the table 12 gives evidence that data is valid, consistent and lies in the preferred range. The compilation of inlet and outlet, sewer gas amount and sludge amount are similar to other plants of that size. The energy supply is higher in the case of WWTP Gleisdorf due to the fact that they don´t produce own electrical energy. Further on they have more than twice smaller sludge tank as WWTP Freistadt.

5.2.1.2 Detailed analysis of data of WWTP

5.2.1.2.1 Mass flow balance analysis through the software eDAB

The results of the COD mass flow balance are the following. The COD mass flow has been chosen because it is one of the most meaningful mass flows and has been recalculated and compared with the experience values from the literature of Kroiss and Svardal (2009) to proof the consistency and validity of the data.

In figure 20 there is shown the COD of the total balance from the WWTP of the observed year of 2013. The back flows of the sludge treatment are not considered in this case. All mass flows have the unit kg per day. Through the total balance of the mass flow of COD a deviation can be observed that has a result of -0.04 percentages. This gives information that the balance of the COD is consistent and valid. All mass flows that have been calculated in eDAB of the total balance have been recalculated and compared with the experience values of the literature. All values are valid and consistent and are discussed and presented on the next pages.

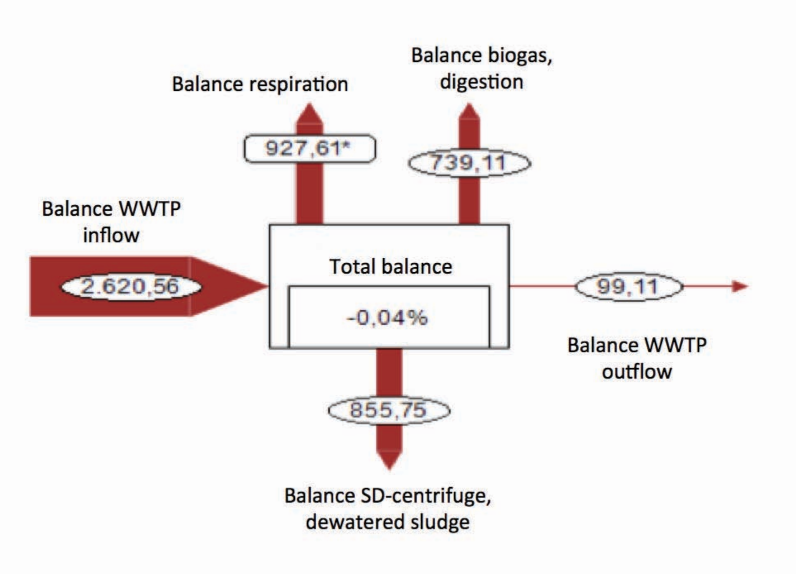

Figure 20: The total overview of the COD mass flow calculated in eDAB (observed year 2013)

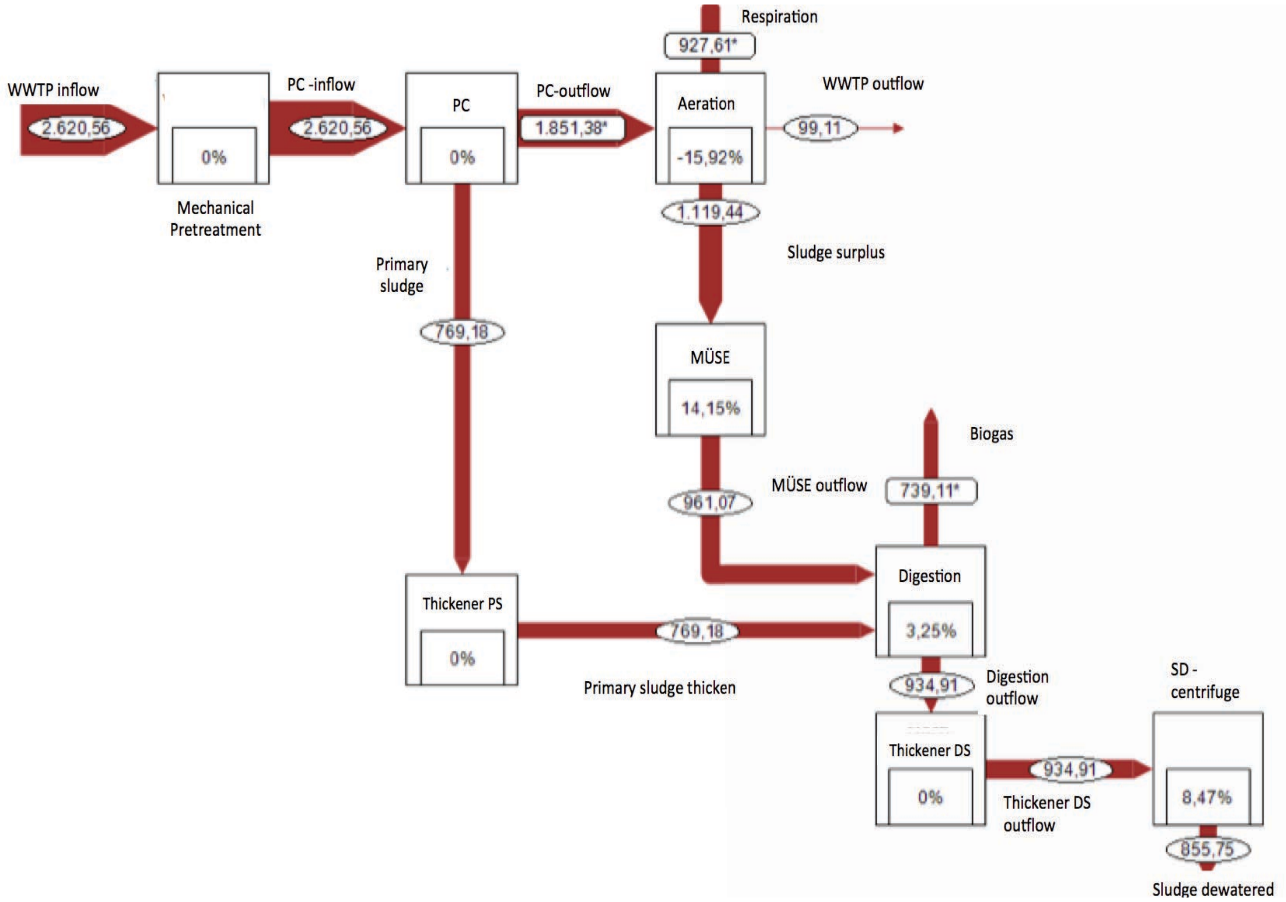

Figure 21: The detailed overview of the COD mass flow calculated in eDAB (observed year 2013)

The figure 21 gives the detailed overview of the COD mass flows. All values that have a star beside them are calculated values with the help of experience values. In this case for these values no measured data have been available. The inflow of the COD is a measured value that's why there is no deviation in the mechanical preliminary screen. The box shows a result of zero percentage. Further in the primary clarifier there is also no deviation of the flows. Although the flow to the aeration basin has been calculated, the other mass flow of the primary sludge has been added into eDAB one to one because it is a measured data. This data that has been received has been also compared and recalculated with the experience values of the literature of Kroiss and Svardal (2009). The literature value that has been obtained is around 800 kg per day. The following box, which is named Thickener PS is the thickener of the primary sludge. If the two flows are compared with each other than it can be observed that they are the same. Due to the fact that the operator does not remove the cloudy water, but uses it just as a temporary storage. So the primary sludge flows more or less directly into the digestion.

In the aeration basin box it can be observed that there is a deviation of -15.92 percent. In this case there is a lower input than an output. Simply speaking the three mass flows WWTP outflow, respiration and sludge surplus, which are going out of the box, are higher than the flow, which goes into it. Likewise the respiration flow has been calculated through the sewer sludge report, the oxygen yield and the aeration energy consumption. But in spite of that the experience values in the literature give evidence, that when a result has been received that is fifty-fifty in the context of the respiration amount and the sludge surplus amount, than a consistent and valid result has been received (Kroiss and Svardal, 2009). Another flow that goes out of the aeration basin box is the discharge of the WWTP. The result that has been received is around 100 kg per day. This value is a measured value and compared to the data of the literature far too low. According to the literature values a value of around 240 kg per day should be obtained. In this context the value that has been measured is not really consistent. The next mass flow is to the box MÜSE. There it can be observed a result of 14.15 percentages. This result shows that the data that has been measured in the context of the surplus sludge amount is not that consistent. The value that has been measured and calculated from the measurement is 1119.44 kg per day. According to the literature experience values there should be a result obtained of about 800 kg per day of sludge surplus (Kroiss and Svardal, 2009). Since this value is taken and is entered into the balance, the aeration basin box that has been discussed before would have a better deviation. This deviation would be closed to zero.

After the box MÜSE a mass flow has been obtained with a value of 961.07 kg per day. This value has been also measured and looks like, with regard to the next box digestion, as a consistent value. The box digestion supplies the result of a deviation of 3.25 percent. Although there are two mass input flows and two mass output flows the deviation is not that high. As before has been discussed the input flow of the primary sludge after thickener is consistent and valid. Further the two input flows should have, according to the experience values, a sum of around 1.600 kg per day. This amount has been nearly reached. The sum of the data that has been measured is around 1.700 kg per day. So there is a little deviation in this connection, which can be seen as before mentioned in the box of digestion. The output flow of the sewer gas has been calculated through the CO2 concentration of the plant, which has been provided from the operator’s data. The result that has been calculated has a value of 739.11 kg per day. Once more this value has been compared with the experience values of the literature and the result is that this mass flow is consistent and valid.

The last part of the overview of the COD mass flow is the mass flow of the outflow of the digestion. This flow has a result of 934.91 kg per day and has been measured on the WWTP. This value should be consistent with regard of the other mass flows, which are consistent, that has been going in and out of the digestion box. Furthermore the box of the following thickener shows a result of zero percentage. Due to the fact that the input flow has the same amount like the output flow. Both mass flows have been measured and should be also to some extent consistent according to the literature. The last box of the scheme is the sludge dewatering machine which has a little deviation of around 8.5 percent. The 8.5 percent have been received because the input flow is way higher than the output flow. The output flow has a value of 855.75

kg per day and has been measured. The measured value is a little bit too high in the context of the experience values from the literature. The value, which has been obtained through literature, is around 800 kg per day. But nevertheless this gives information that the measured value is consistent.

All in all, the results that have been obtained through the calculation of the software eDAB have shown that the data, which has been received, is consistent, plausible and valid. Although the measured value of the surplus sludge amount is not that consistent and should be put under further investigation. Further the COD discharge flow of the WWTP shows also an inconsistency.

5.2.1.2.2 Energetic analysis and optimization potential of WWTP Freistadt

The next part is the results and discussion of the energy guideline that has been applicable for the verification of consistency and validity of the received data of Freistadt.

Table 13: Specific energy sources of the WWTP in Freistadt (operating data from 2013)

Energie sources	Amount		Energy content		usable electrical energy		usable thermical energy	
Sewer gas total	***537***	***m³/d***	3.199	***kWh/d***	**513**	***kWh/d***	**2.011**	***kWh/d***
Sewer gas CHP	473	m³/d	2.819	kWh/d	733	kWh/d	1.669	kWh/d
Sewer gas / gas engine	0	m³/d		kWh/d		kWh/d		kWh/d
Sewer gas heating	64	m³/d	380	kWh/d			342	kWh/d
Sewer gas torch		m³/d		kWh/d				
Natural gas total		***m³/d***	***0***	***kWh/d***	**0**	***kWh/d***	**0**	***kWh/d***
Natural gas CHP		m³/d		kWh/d		kWh/d		kWh/d
Natural gas / gas engine		m³/d		kWh/d		kWh/d		kWh/d
Natural gas heating		m³/d		kWh/d				kWh/d
Liquid gas total		***kg/d***		***kWh/d***		***kWh/d***		***kWh/d***
Liquid gas CHP		kg/d		kWh/d		kWh/d		kWh/d
Liquid gas / gas engine		kg/d		kWh/d		kWh/d		kWh/d
Liquid gas heating		kg/d		kWh/d				kWh/d
Heating oil		l/d		kWh/d				kWh/d
Solar energy PV	48	kWh/d		kWh/d	48	kWh/d	0	kWh/d
Solarthermy		kWh/d		kWh/d	0	kWh/d	0	kWh/d
Sum electrical or thermical energy produced on WWTP					**561**	**kWh/d**	**2.011**	**kWh/d**
Energy from PSC or district heating bought in addition					1.100	kWh/d	0	kWh/d
Energy provided to PSC or district heating						kWh/d	0	kWh/d
Energy supply WWTP					**1.661**	**kWh/d**	**2.011**	**kWh/d**

The next table 13 gives the specific energy sources. This table shows that the received data is valid and consistent. But one value, which is calculated through the template, is too high. This value is the usable electrical energy value of the sewer gas CHP. In this case the value that has been calculated 733 is higher than the value, which has been obtained from the operator. Since the operator has provided a file where all measured values have been given from the WWTP. Further on in this case it can be detected that there might be an optimization potential of the production of sewer gas CHP. Likewise an investigation in this process has shown that the recommended efficiency level of the micro turbine is not been reached. And through this a lower production of electrical energy is the result.

Another consideration has been made through consultation of the operator, the transfer of the sewer gas could be switched at an early stage from electrical energy to thermic energy usage. A higher amount of gas is used for the production of thermic energy although electrical energy has a higher economic benefit. Further the sewer gas heating produces a heat of 342 kWh/d, which is in this context good. Likewise the WWTP has also a Photovoltaic energy that creates 48 kWh/d. The energy that is produced on the WWTP has a value of 561 kWh/d. This value is received through the sum of the sewer gas in total and the solar energy. The plant receives also energy of about 1.100 kWh/d from the power supply company. The WWTP supplies additional 1.661 kWh/d electrical energy for it's operation. On the other side, it produces 2.011 kWh/d only thermical energy. This production of the thermal energy is in the context of other plants very good.

Further on the next table 14 shows the total electrical consumption of the whole plant with the data that has been provided from the operator before the consultation day.

Table 14: Total electrical consumption of the WWTP in Freistadt before the consultation day (operating data from 2013)

1) Intake pumping station and mechanical pre- treatment	**61**		**kWh/d**
1.1 Outlet pumping station		0	kWh/d
1.2 Rakes		57	kWh/d
1.3 Grit chamber and fat trap		4	kWh/d
2) Mechanical-biological wastewater treatment	**928**		**kWh/d**
2.1 Aeration		82	kWh/d
2.2 Agitator		435	kWh/d
2.3 RS-pumps		264	kWh/d
2.4 Others (PSB, ASB,…)		147	kWh/d
3) Sludge treatment	**167**		**kWh/d**
3.1 MÜSE and stat. Thickener		7	kWh/d
3.2 Digestion (energy digestion/heating)		106	kWh/d
3.3 Sludge dewatering		54	kWh/d
4) Infrastructure	**282**		**kWh/d**
4.1 Heating (factory building/infrastructure)		138	kWh/d
4.2 other infrastructure		144	kWh/d
WWTP total	**1.438**		**kWh/d**

The 0 given in point 1.1 is because the WWTP has no outlet pumping station so it is consistent and valid. At the first glance other interesting points are the grit chamber and the fat trap because they have seemed really low compared to other plants. Likewise in the mechanical and biological part the aeration has seemed far too low and on the other hand the agitators seemed too high. So in these two cases something is wrong. In the sludge treatment the value for MÜSE and the stationary thickener has seemed far to low at the first glance and has been also marked and put under further investigation. All other values have seemed to be correct and valid. Conformation about these inconsistent values is given in the next table 15 the specific electrical energy consumption.

Table 15: Specific electrical energy consumption of the WWTP in Freistadt before the consultation day (operating data from 2013)

			measurement standard	
WWTP total	**24.0**	**kWh/PE120/a**	**20**	**50**
1) Intake pumping station and mechanical pre- treatment	**1.0**	kWh/PE120/a	**2.5**	**5.5**
1.1 Outlet pumping station	0.0	kWh/PE120/a	1.5	3.5
1.2 Rakes	1.0	kWh/PE120/a	0.5	1
1.3 Grit chamber and fat trap	0.1	kWh/PE120/a	0.5	1
2) Mechanical-biological wastewater treatment	**15.5**	kWh/PE120/a	**14.5**	**33**
2.1 Aeration	1.4	kWh/PE120/a	11.5	22
2.2 Agitator	7.3	kWh/PE120/a	1.5	4.5
2.3 RS-pumps	4.4	kWh/PE120/a	1	4.5
2.4 Others (PSB, ASB,…)	2.5	kWh/PE120/a	0.5	2
3) Sludge treatment	**2.8**	kWh/PE120/a	**2**	**7**
3.1 MÜSE and stat. Thickener	0.1	kWh/PE120/a	0.5	1
3.2 Digestion (energy digestion/heating)	1.8	kWh/PE120/a	1	2.5
3.3 Sludge dewatering	0.9	kWh/PE120/a	0.5	3.5
4) Infrastructure	**4.7**	kWh/PE120/a	**1**	**4.5**
4.1 Heating (factory building/infrastructure)	2.3	kWh/PE120/a	0	2.5
4.2 other infrastructure	2.4	kWh/PE120/a	1	2

Here it can be observed on the right sight the measurement standard that gives evidence if a device consumes normal, too much or too less. The intake pumping station and mechanical pre-treatment consume only 1 kWh/PE$_{120}$/a, which is low compared to the measurement standard. The rakes are still in the measurement standard with 1 kWh/PE$_{120}$/a but as before mentioned the grid chamber and fat trap are far below the measurement standard. The devices have only an energy consumption of 0.1 kWh/PE$_{120}$/a. This has been noticed and has been put under further investigation through a consultation day with the operator. As before has been discussed the aeration is far too low and the agitator is far too high so in this case they might have been mixed up or have been measured wrong. Further the devises in point 2.4 others consume as well also too much energy and have been marked. Once more MÜSE and the stationary thickener obtain a result of 0.1 kWh/PE$_{120}$/a which is 0.4 kWh/PE$_{120}$/a under the measurement standard. So it has been also notified. In the end point 4.2 other infrastructure is a little bit higher than the measurement standard of around 0.4 kWh/PE$_{120}$/a. This has also been marked and put under further investigation

After checking the specific electrical energy consumption the plant performance indicators are the next. The next table 16 gives in detail the calculated values of the performance of the plant, which have been supplied through the main data.

Table 16: Plant performance indicators of WWTP in Freistadt (operating data from 2013)

			measurement standard	
PE_{120}	21.842	E		
PE_{60}	25.950	E		
$PE_{Ntotal11}$	20.873	E		
$PE_{NH4N6,5}$	18.929	E		
$PE_{Ptotal1,7}$	21.765	E		
PE-digested sludge-oDS22 (PE_{oDS22})	21.667	E		
N/COD	0.09	-	*0.07*	*0.1*
BOD/COD	0.59	-	*0.4*	*0.6*
spec-DS-load stabilized sludge	40	g DS/PE_{120}	*35*	*50*
spec-ODS-load digested sludge	22	g ODS/PE_{120}	*20*	*30*
spec. Sewer gas amount per PE_{120}	25	l/PE_{120}	*15*	*22*
spec. Sewer gas amount per PE_{oDS22}	25	l/PE_{ODS22}	*15*	*22*
DS-sludge dewatering	30	%	*25*	*35*

This table has shown that all values, which have been received, are valid and consistent and correspond to the provided measurement sheet of the operator. But the sewer gas amount per $P.E._{120}$ as well as the amount per $P.E._{ODS22}$ are too high and exceed the measurement standard. These to values correlate to the sewer gas amount in total that has been discussed in table 13 and can be related to the two viewpoints.

According to the sewer gas amount the next table 17 gives evidence that the electrical supply of the WWTP is to low.

Table 17: Energy indicators - specific thermical energy supply of the WWTP in Freistadt (operating data from 2013)

			measurement standard	
therm. energy produced from sewer gas	33.6	kWh/PE/a	*20*	*40*
other therm. Energy produced on WWTP	0,0	kWh/PE/a	-	-
therm. energy provided to PSC	0,0	kWh/PE/a	-	-
therm. energy provided	**33.6**	**kWh/PE/a**	*0*	*40*

Further on in this table 17 it can be observed that the thermal energy produced from sewer gas is in the measurement standard. But it is in the higher range of the standard. So from this point of view this table again demonstrates that the thermal energy that is produced from the sewer gas is a little bit too high. The other factors are all 0 since there is no thermal energy, which is provided to PSC as well there are no other thermal energies, which are produced on the WWTP.

Table 18: Energy indicators - other thermical indicators of the WWTP in Freistadt (operating data from 2013)

		measurement standard	
Therm. efficiency level CHP plant	59 %	50	65

This table 18 emphasizes once more that the thermal energy supply of the WWTP is really good. This is underlined through the thermal efficiency level of the CHP plant. It reaches a 59 percentage, which is in the upper level of the measurement standard.

The following table 19 gives main information of the specific energy consumption after the consultation day with the operator of the WWTP. And will highlight the specific technical characteristics.

Table 19: Specific electrical energy consumption of the WWTP in Freistadt after the consultation day (operating data from 2013)

			measurement standard	
WWTP total	**30.8**	**kWh/PE$_{120}$/a**	20	50
1) Intake pumping station and mechanical pre- treatment	0.3	kWh/PE$_{120}$/a	2.5	5.5
1.1 Outlet pumping station	0.0	kWh/PE$_{120}$/a	1.5	3.5
1.2 Rakes	0.2	kWh/PE$_{120}$/a	0.5	1
1.3 Grit chamber and fat trap	0.1	kWh/PE$_{120}$/a	0.5	1
2) Mechanical-biological wastewater treatment	**23.4**	kWh/PE$_{120}$/a	14.5	33
2.1 Aeration	9.1	kWh/PE$_{120}$/a	11.5	22
2.2 Agitator	8.1	kWh/PE$_{120}$/a	1.5	4.5
2.3 RS-pumps	3.9	kWh/PE$_{120}$/a	1	4.5
2.4 Others (PSB, ASB,...)	2.2	kWh/PE$_{120}$/a	0.5	2
3) Sludge treatment	**2.8**	kWh/PE$_{120}$/a	2	7
3.1 MÜSE and stat. Thickener	0.1	kWh/PE$_{120}$/a	0.5	1
3.2 Digestion (energy digestion/heating)	1.8	kWh/PE$_{120}$/a	1	2.5
3.3 Sludge dewatering	0.9	kWh/PE$_{120}$/a	0.5	3.5
4) Infrastructure	**4.3**	kWh/PE$_{120}$/a	1	4.5
4.1 Heating (factory building/infrastructure)	2.3	kWh/PE$_{120}$/a	0	2.5
4.2 other infrastructure	2.0	kWh/PE$_{120}$/a	1	2

The first point the intake pumping station and mechanical pre-treatment decreased its consumption from 1 kWh/PE$_{120}$/a to 0.3 kWh/PE$_{120}$/a after the consultation day and is not in the range of the measurement standard. Since on the one hand the plant has no outlet pumping station and on the other hand the grid chamber and the fat trap had really that low values. Through the recalculation another consumption had been corrected the point 1.2 rakes. As in table 15 presented the rakes consumed 1 kWh/PE$_{120}$/a. Now after the detailed investigation the rakes consume only 0.2 kWh/PE$_{120}$/a, which is around 0.8 kWh/PE$_{120}$/a lower than before. The consultation day with the operator, where all suspicious values have been recalculated, had shown that this values really consumed only that much energy. So from the energy optimization point of view the first part of the WWTP works really efficient and the values that have been obtained are consistent and valid now.

The next part of the table is the mechanical-biological wastewater treatment section.

In this section the main correction of the provided data took place. The first change that can be observed is the higher total consumption of the section. Before a value of 15.5 kWh/PE_{120}/a has been reached and now it has a value of 23.4 kWh/PE_{120}/a. This increase correlates to the corrected values of the other devices. But still is this value in the measurement standard. Further in point 2.1 aeration a value of 9.1 kWh/PE_{120}/a has been obtained through the detailed investigation. As before mentioned in table 15 only 1.4 kWh/PE_{120}/a had been received. Through the investigation the aeration consumes still less energy than is defined in the measurement standard but is valid and consistent now. Likewise this gives significance that this device works very efficient. The next device the agitator consumed before the consultation day 7.3 kWh/PE_{120}/a, which was far too high. After the investigation the agitator consumes more as before. The value that is now obtained is 8.1 kWh/PE_{120}/a. Through this the valid and consistent value is 3.6 kWh/PE_{120}/a over the measurement standard. So today's status is that the agitator has a high optimization potential and should be set under further investigation. Further for the RS-pumps the value has been also corrected. Before in table 15 there has been reached a value of 4.4 kWh/PE_{120}/a and now it has been reached a value of 3.9 kWh/PE_{120}/a. So 0.5 kWh/PE_{120}/a have been corrected in this context. But still this device lies in the measurement standard. The last point in this section is the point 2.4 others. After the consultation, a lower value has been obtained. In this connection 2.2 kWh/PE_{120}/a have been obtained, which is still 0.2 kWh/PE_{120}/a too high compared to the measurement standard. Through this a small optimization potential can be recognized.

The next section of table 19 is the sludge treatment. In this section only the devices MÜSE and stationary thickener have been recalculated. Since the other devices in this section have not been suspicious for a further investigation. The output that has been generated is that there is a wrong measurement of MÜSE and stationary thickener and not all aggregates have been taken into account into the operator's data set. So the received value of 0.1 kWh/PE_{120}/a has been wrong in both tables.

Further in the last section there has been also an adjustment made. Before the consultation day the section infrastructure exceeded the measurement standard of around 0.2 kWh/PE_{120}/a. After the detailed investigation the section is now in the measurement standard. Since the point 4.2 other infrastructure has been corrected. Now it consumes 2.0 kWh/PE_{120}/a, which lies in the range but is situated close to the maximum of the standard. So in this case a reconsideration of all electrical devices should be done to reduce possibly the electrical consumption in this section.

But all in all the total electrical consumption of the WWTP is totally in middle of the measurement standard. Before the consultation day a value of 24 kWh/PE_{120}/a has been obtained. And after the day there has been a value obtained of 30.8 kWh/PE_{120}/a, which is a little bit higher than the value before but still in the measurement standard.

Table 20: Energy indicators - specific electrical energy supply of the WWTP in Freistadt (operating data from 2013)

			measurement standard	
el. energy produced from sewer gas	8.6	kWh/PE$_{120}$/a	***10***	***20***
other el. energy produced on WWTP	0.8	kWh/PE$_{120}$/a	-	-
el. energy bought in addition	18.4	kWh/PE$_{120}$/a	***10***	***50***
el. energy provided to PSC	0.0	kWh/PE$_{120}$/a	***0***	***20***
el. energy provided	27.8	kWh/PE$_{120}$/a	***20***	***50***

The table 20 gives significance and proves that the electrical energy that is produced from the sewer gas is a little bit to low. In this case a value of 8.6 kWh/PE$_{120}$/a has been received, which is highlighted with red in the upper table. So from this point view there is an optimization potential of at least 1.4 kWh/PE$_{120}$/a. But the other calculated values are in the measurement standard. The electrical energy bought in addition from the power supply company is in the lower part of the predefined measurement standard. On the other hand this value says that the plant is far from being autarkic. This case is supported by evidence through the next value of the table. The value electrical energy provided to PSC is 0. The last value, which is shown in the table is the electrical energy provided which obtains a value of 27 kWh/PE$_{120}$/a. This result highlights that the supply of electrical energy is in the measurement standard but has opportunity to be increased.

Table 21: Energy indicators - specific thermical energy consumption of the WWTP in Freistadt (operating data from 2013)

			measurement standard	
WWTP total	**19.7**	**kWh/PE/a**	***0***	***30***
Sludge heating (Qs)	13.4	kWh/PE/a	***8***	***12***
Transmission loss, digester tank heating (Q_T)	2.7	kWh/PE/a	***0***	***4***
Production-, storage- and distribution loss (Q_D)	1.6	kWh/PE/a	***0***	***2***
Heating quantity for buildings ($Q_{buildings}$)	1.0	kWh/PE/a	***0***	***2***
Heating quantity for supply air device ($Q_{supply\ air}$)	1.1	kWh/PE/a	***0***	***10***

Table 21 gives information of the specific thermical energy consumption. In this case it can be seen that the WWTP in total operates good with 19.7 kWh/PE/a. On the other hand in the next point sludge heating there can bee seen an exceeding of the measurement standard of around 1.4 kWh/PE/a. So the heating for the sludge consumes too much energy. There is an optimization potential of around 1.4 kWh/PE$_{120}$/a. The other indicators are totally in the range of the measurement standard.

Table 22: Electrical consumption - other electrical energy indicators of the WWTP in Freistadt (operating data from 2013)

			measurement standard	
cover of own electricity	34	%	***0***	***100***
EL-circulation pumps	#DIV/0!	%	***30***	***70***
spec. agitator energy	4.0	W/m³	***1***	***2,5***
load specific energy consumption from aerate+agitate	0.4	kWh/kg$_{\mathrm{CODbiology\ to}}$	***0.3***	***0.6***
Electrical efficiency level CHP	26	%	***24***	***38***

In this table 22 it can be observed that one part the EL-circulation pumps are not calculated. Since the WWTP has no outlet pumping station, the calculation has to calculate with 0. Through this one parameter that is 0 the calculation template is not able to calculate. So it is not possible to receive a finding in this case. Another factor that jumps to once eye is that the specific agitator energy is far too high. Once more as before has been discussed in the table 19 the agitator consumes too much energy in this case it has a value of 4.0 W/m^3 which is 1.5 over the predefined measurement standard. So this table gives evidence again that the agitator has a high-energy optimization potential. The cover of the own electricity is with 34 percentages that is ok for the size of the WWTP but is also developable. Further on the load specific energy consumption from aerate and agitate is totally in the range of the measurement standard because the aeration on the one hand is a little bit low. On the other the agitator is far to high, thus they equalize each other and so the value is in the range. The last point in this table is the electrical efficiency level of the CHP plant, which is in the range but as before discussed not as recommended and so it has again an optimization potential.

Energy supply and optimization through co-digestion

In table 23 it can be seen the measured operating data. Through this data it has been possible to calculate and estimate the free volume in the digestion tank.

It has been possible to detect an additional energy supply through the estimation of the co-digestion. In the case of Freistadt there is an additional capacity of around 1m^3 per day for adding for example grease into the digestion tank. This is presented in table 24 the free potential. In table 26, grease has a high-energy content and is in high demand. But it has to be carefully added since it could happen that through a too high dosage operation problems could occur. This will mean more energy can be produced on the WWTP. The digestion time can be also reduced because it is 3 days higher than the normal limit.

Table 23: The measured operating data (operating data from 2013, own presentation)

Volume digestion tank	1000	m3
Q raw sludge PS	13	m3/d
Q raw sludge SS	17	m3/d
PS		
Load data dry organic matter	408	kg/d
Load data COD	769	kg/d
SS MÜSE		
Load data dry organic matter	876	kg/d
Load data COD	991	kg/d

Table 24: Calculated potential of the different space loads and digestion time (operating data from 2013, own presentation)

Parameter	Unit	Current	Normal	Potential
Space load dOM	[kg dOM /m3]	1.3	1.5	0.2
Space load COD	[kg COD /m3]	1.7	2.5	0.8
digestion time	[d]	33	20-30	3-13

Table 24 gives the current state of the space loads of dry organic matter and COD and the digestion time of the sludge in the tank. It can be observed that the space load of the dry organic matter has a current value of 1.3 kg dOM/m³. The normal value is usually 1.5 kg dOM/m³, which means that there is a potential of 0.2 kg dOM/m³. Further in the next line of the COD space load there it is received a current value of 1.7 kg COD/m³ compared to the normal value it is obtained a potential of 0.8 kg COD/m³. Likewise what can be also detected that the digestion time has a current value of 33 days and the normal value is between 20 and 30 days. So there can be seen a potential of 3 to 13 days less digestion time, which means a more efficient output.

In the next table 25 there it can be observed the estimation of the co-substrates and through that the free potential in kg per day. In the first line the free potential that has been received of dOM is 216 kg per day. For the COD it has been received a value of 829 kg per day. These received values are important for the table 26 to look for different properties of substrates that could be added.

Table 25: Estimation of co-substrates and free potential (operating data from 2013, own presentation)

Estimation co-substrates	
	free potential
	kg/d
dOM	216
COD	829

As before mentioned table 26 gives information about the properties of the different substrates that could be added. Here it can be observed that for example black water has low values of properties which means also low energy contents and through this a higher load with 83 m³ per day of COD. As mentioned earlier grease has a high-energy content and through that it has also higher properties. This means that the permitted load that can be added into the digestion tank is only 1 m³ per day.

Summarizing the above, it can be said that through the estimation a free potential of 1 m³ per day of grease could be added further through this a sewer gas amount of around 260 m³ per day will be received. This will mean at complete conversion into electricity an output of 360 kWh per day can be received.

Table 26: Comparison of properties of different substrates (Source: Urban and Scheer, 2011, adapted).

	Properties		Permitted loads of		
Substrates	COD	dOM	digestion time	dOM	COD
	kg/m3	kg/m3	m3/d	m3/d	m3/d
Raw sludge	46	28	20	8	18
Flotation sludge (grease)	680	350	20	1	1
Black water	10	12	20	18	83
Beer	100	-	20	-	8

5.2.2 Evaluation of the general suitability of WWTP Freistadt

5.2.2.1 Evaluation of operating data of WWTP Freistadt

The next part are the results of the evaluation of operating data to detect reserve capacities for heat recovery in front of the WWTP. For the reserve capacity there has been calculated a percentage of 26.67 in relation to P.E.120. These percentages are in total 8001 P.E.120. The end result is shown in table 27 and the performance indicators in table 28. Further on because of the development of the area and constructions of industries there will be an increase in the next years of 1000 P.E. This aspect has also been taken into account since the reserve capacities will decrease around 3, from 26.67 to 23.33 percent.

Table 27: Result of reserve capacities of the WWTP in Freistadt (operating data from 2013)

WWTP	Reserve Capacities (%)	Reserve Capacities (P.E.)	Development	Comment
Freistadt	26,67	8001	Expansion Industry	WWTP 2009 extended
			about 1000 P.E. additionally	

Table 28: Performance indicators of the WWTP in Freistadt (operating data from 2013)

Performance Indicators	(P.E. 120)	(%)	year
Actual	22.000	73,33	
Expansion size	30.000	100	
Last expansion			2009
Expansion size difference	8001	26,67	2013

Likewise the outlet concentration of NH4-N is very low. The average outlet concentration is 0.74 mg/l per day. So this means that a high reserve capacity is obtained. Further on through investigating and comparing of the inlet temperature a result has been obtained that the WWTP performs well. The average value is 11.59 °C. But in comparison with other WWTP the average temperature is rather low.

So through the evaluation of the operating data it can be pointed out that in the context of reserve capacities of P.E.120 there is no cause for concerns. Further the load concentration of NH4-N is very small, so there should be no problems with respect to the remove of heat and thus a lowering of the reduction performance of NH4-N. As before mentioned the average value of the inlet temperature is a little bit too low. Following the AWEL guideline there it is mentioned that the average inlet temperature should have a value of around 12°C. So according to this the inlet temperature is an exclusion criterion not to use the thermal heat recovery in front of the WWTP in Freistadt. This will be presented and calculated in detail and shown in the next point.

5.2.2.2 Contingent calculation according to the guideline of AWEL for the data of Freistadt

The next tables will give the results of the calculated reference temperatures.

Table 29: Calculated reference temperature for the years 2009-2013 of the WWTP in Freistadt

(2009-2013)

Temp/Days	Appearance	(%)
< 6°C / % days	26	1%
< 7°C / % days	121	7%
< 8°C / % days	355	19%
< 9°C / % days	537	29%
< 10°C / % days	659	36%
< 11°C / % days	780	43%
< 12°C / % days	925	51%
Numbers of measurements	1826	100%
Reference temperature	6	°C
Difference reference temperature	0	°C
Difference reference temperature	6-6-> 0	°C

In this table 29 it can be observed that the output of the calculation has been 6°C. In this case there is no cooling potential. Since as given in fundamentals, the 5% correspond to 2.5 weeks of a year and should not be exceeded. So in the range between 2009-2013, 26 days have had a lower temperature of the inlet wastewater than 6°C, which makes a percentage of 1% of the total 1826 days. The next line shows 121 days have been lower than 7°C which makes a percentage of 7. In this connection the 5% has been exceeded around 2% and through that the 6°C has to be taken as the reference temperature. As before mentioned in the chapter methods everything that is below 6°C is not economical. So the result of the calculation is the predefined 6°C minus the calculated as well 6°C. The result is the reference temperature and that is 0. So for the years between 2009-2013 there is no cooling potential through this approach.

Table 30: Calculated reference temperature for the years 2010-2014 of the WWTP in Freistadt

(2010-2014)

Temp/Days	Appearance	(%)
< 6°C / % days	8	0%
< 7°C / % days	65	4%
< 8°C / % days	267	15%
< 9°C / % days	470	26%
< 10°C / % days	618	34%
< 11°C / % days	749	41%
< 12°C / % days	903	49%
Numbers of measurements	1826	100%
Reference temperature	7	°C
Difference reference temperature	1	°C
Difference reference temperature	7-6-> 1	°C

Now in this table 30 the inlet temperatures have been taken from 2010 to 2014. In these 5 years it can be observed that the temperature has changed and a reference temperature of 7°C has been obtained, which means in the end a cooling potential of 1°C. In this table 30 it can be seen that the appearance of values that are fewer than 6°C are only 8 times and make a percentage of 0. Furthermore, on values under 7°C have appeared 65 times and make a percentage of 4, which lies still in the 5%. But then there is a quit a high jump from the 7°C to the 8°C. Since less than 8°C, 267 values have appeared and make a percentage of 15 that exceed far the 5%.

So if the two tables are compared with each other it can be detected that in table 29 there is no cooling potential and in table 30 there is one. This result comes from the fact that 2009 has been a very cold year.

Table 31: Calculated reference temperatures for the years 2004-2014 from the WWTP in Freistadt

Temp/Days	Appearance	(%)
< 6°C / % days	190	4,73%
< 7°C / % days	419	10,43%
< 8°C / % days	796	19,82%
< 9°C / % days	1124	27,98%
< 10°C / % days	1428	35,55%
< 11°C / % days	1638	40,78%
< 12°C / % days	1887	46,98%
Numbers of measurements	4017	100%
Reference temperature	6	°C
Difference reference temperature	0	°C

Difference reference temperature	6-6->	0 °C

This table 31 shows the calculation of the total outlet temperature values for the years 2004 to 2014. But this table is not really comparable with the other ones because the data by which is calculated is the outlet temperature of the WWTP. However it shows like in table 29 that the reference temperature is 6°C with 190 appearances and has a percentage of 4.73. This result shows again that there is no cooling potential. So in this context in these 11 years a cooling potential in front of the WWTP has not been able to reach although it should be taken into account that this is for the outlet temperature.

Table 32: Detection of possible cooling potential for the years 2009-2013 from the WWTP in Freistadt

NH4N-daily discharge MV	(2010-2014)			
0,74	mg/l			
discharge conditions NH4-N Austria			Calculation:	(ln(5/0,74))/0,33
5	mg/l			
Detection of possible cooling potential				
ΔT =	5,8	➔	5,8	°C possible cooling

This table 32 the detection of possible cooling potential shows that average daily discharge of NH4N is 0.74mg/l in the years of 2009 to 2013. As before mentioned in fundamentals the value 0.33 is predefined as well as the 5 mg/l. Further on through the calculation a possible cooling potential of 5.8 °C has been received in front of the WWTP.

Table 33: Contrast of possible cooling potential and reference temperature for the years 2009-2013 from the WWTP in Freistadt

WWTP	Possible cooling according to AWEL-guideline 2013 (°C or kelvin)	Difference reference temperature up to 6°C (maximum °C or kelvin)
Freistadt	5.8	0

In the table 33 it can be detected that there is a big difference between the calculation of the possible cooling potential and the calculation for the reference temperature. In this case the result of the cooling potential is 5.8 °C and the reference temperature is 0 °C. So as in chapter methods given the smaller value has to be taken for the further calculation.

Table 34: Calculation of the contingents for the years 2009-2013 of the WWTP in Freistadt

Calculation of the contingent			Calculation after WWTP	
Q'=V'*ρ*c*ΔT				
ρ =	998	kg/m3		
ΔT =	0	°C or K	1	°C or K
c =	4,18	J/K*g		
V' =	14,5	l/s		
Q' =	0	W	60488,78	W

In this table 34 it can be observed that through taking of the reference temperature 0 °C and entering in the formula the result that is obtained is 0. On the right site of the table it is also possible to calculate, through this formula, possible cooling potentials after the WWTP. Since there is no cooling potential in front of the WWTP it is defined through the guideline that it is allowed to take a maximum of 1-2°C after the WWTP. However through this 1 °C only 61 kW has been obtained. This method has been mentioned before as wastewater heat recovery makes only sense when a value of 100 kW is received. In this connection it is not the case.

Table 35: Overall result of the calculation of the contingents for the years 2009-2013 of the WWTP in Freistadt

WWTP	Qddw l/s	Possible cooling ΔT (rounded)	Contingent in front WWTP (rounded) kW	Usable potential after WWTP (rounded; ΔT 1 - 5 °C) kW
Freistadt	14.5	0	0	60

Table 35 has summarized the whole results of the calculation that has been made. So for the investigation of the years from 2009 to 2013 the result is that a wastewater heat recovery especially in front of the WWTP is neither possible nor economical.

Table 36: Detection of possible cooling potential for the years 2010-2014 of the WWTP in Freistadt

NH4N-daily discharge MV	(2010-2014)			
0.77	mg/l			
discharge conditions NH4-N Austria			Calculation:	(ln(5/0.77))/0.33
5	mg/l			
Detection of possible cooling potential				
ΔT =	5.7	➔	5.7	°C possible cooling

In this table 36 it can be seen that compared to the table 32 the possible cooling potential is only 5.7 °C. This result has been generated through the fact that the NH4N daily discharge concentration has been increased from 0.74 to 0.77 mg/l.

Table 37: Contrast of possible cooling potential and reference temperature for the years 2010- 2014 of the WWTP in Freistadt

WWTP	Possible cooling according to AWEL-guideline 2013 (°C or kelvin)	Difference reference temperature up to 6°C (maximum °C or kelvin)
Freistadt	5.7	1

Table 37 gives again the comparison between the two values that have been calculated. Here it can be observed that the cooling potential as before mentioned is 5.7 °C and the reference temperature is 1 °C. In this case again the smaller value 1 °C must be taken for the calculation of the contingents to receive a valid result.

Table 38: Calculation of the contingents for the years 2010-2014 of the WWTP in Freistadt

Calculation of the contingent			Calculation after WWTP	
$Q'=V'*\rho*c*\Delta T$				
ρ =	998	kg/m3		
ΔT =	1	°C or K	2	°C or K
c =	4,18	J/K*g		
V' =	14,4	l/s		
Q' =	60071,616	W	120143,232	W

In this table 38 a result has been obtained for the wastewater heat recovery in front of the WWTP of around 60 kW. Since there is a reference temperature of 1 °C. What has also changed (compared to table 34) is the dry weather discharge V´. In the years of 2009 to 2013 there has been a discharge of 14.5 l/s and in the years of 2010 to 2014 the discharge has decreased a little bit to 14.4 l/s. That is why it has been received, for the same reference temperature in table 34 on the right site, a lower usable heat recovery of only 60 kW. On the other side because of the receiving of the 1 °C of reference temperature it is possible to calculate the contingents after the WWTP with a value of 2 °C. In this connection a higher value has been obtained than in table 34 before. The result of this calculation is 120 kW. It is more or less doubled.

Table 39: Overall result of the calculation of the contingents for the years 2010-2014 of the WWTP in Freistadt

WWTP	Qddw l/s	Possible cooling ΔT (rounded)	Contingent in front WWTP (rounded) kW	Usable potential after WWTP (rounded; ΔT 1 - 5 °C) kW
Freistadt	14.4	1	60	120

This overall table 39 shows the differences between the contingents in front of the WWTP and the usable potential after the WWTP. Again it can be detected that in front of the WWTP a result has been obtained that is only 60 kW. So in both tables, table 34 and 38, a wastewater heat recovery in front of the WWTP is not economical. Although the NH4-N concentration in both cases is very low and through that they have a very high reserve capacity. But the wastewater temperatures are in total too cold to install such a system. However on the other side it shows that if there is a warmer year a wastewater heat recovery system would be economical after the WWTP.

So in this point of view a wastewater heat recovery system should be only installed after the WWTP. Likewise through the table 31, where the outlet wastewater temperatures have been detected from the years 2004 to 2014, it is known that under 6 °C a percentage of 4.73 has been reached. And so if a wastewater heat recovery system will be installed, it sometimes will be more economical in warmer years and sometimes less economical in colder years.

5.3 Evaluation and optimization of the method

The investigation of the theoretical part of the standardized approach has revealed that the approach, which has been created, is practicable for Austrian WWTPs. The structure of the approach is built on several methods. Some of the methods are simple to handle and can be followed without any problems. Others, like the software eDAB are a bit complicated at first but when someone starts to get familiar with it, it gets more and more user-friendly. But a major problem will always occur if available and consistent data is not received. Then the application of the approach will not be possible. In this context considerations should be taken into account to overcome this problem. Further the application of the approach; mainly the mass flow balancing and the energy optimization guideline need for a detailed overview a lot of data to check the consistency and plausibility. In this case maybe it is possible to take other methods or tools into consideration which need not that much data set and time to evaluate them.

6. Conclusion and outlook

Municipal and state authorities in each of the surveyed countries have different legal capacities and oversight responsibilities. After analyzing various jurisdictional authorities and their approaches to wastewater heat recovery, a wide range of approaches and solutions appear. The Swiss are able to remove heat from the sewer of 0.1 °C without a permit depending on the canton. In Germany it is possible to remove heat without permit of 0.5 K as long as the temperature is not lower than 10 °C in the sewer system. And in Austria it is not allowed to remove heat without a permit. Funding differences occur with respect to wastewater heat recovery. The Swiss are committed to increase renewable energies and energy efficiency. Network operators are committed to take the electricity that is produced from renewable energies and refund them. The Germans also have different financial funds, which operate in the context of renewable energies. Austria has mandated laws requiring energy efficiency.

For the further evaluation of a general suitability of a WWTP with regard to the wastewater heat recovery in the sewer system the method of the Swiss has been taken. Since the Swiss have the longest experience.

However before it is possible to do a suitability evaluation, valid and consistent data is needed. In this case two methods are utilized. Through these two methods it has been possible to evaluate in detail, data of the WWTP, by correlation of the wastewater heat recovery in the sewer system. Both methods have been demonstrated on the national case study in Freistadt. The rough analysis gives just an overview of the performance level of the WWTP. All basic data has been compared with each other. It has also been evaluated with other WWTPs of same size to measure the consistency and plausibility of the provided data. This has been done to detect some data gaps and errors. This method is a very simple and easy one and can be applied without any problems. However to evaluate the data in detail two other methods are necessary.

One is the mass flow balance via the software eDAB. Through this method it is possible to obtain different mass flows to detect if the measured data has been measured correct or not. Further it is possible to identify data errors or measurement errors. Results were obtained through the application on the WWTP in Freistadt. These data points were measured and validated. The other method has been the application of the energy guideline. This guideline detects the energy production and consumption of the WWTP in detail. They detect energy optimization potentials and the possibility to detect different operation problems, which can be sorted out immediately. In the case of the evaluated WWTP some energy optimization potential has been detected. Utilizing this method it has been possible to fulfill the objective. In the case of eDAB software usage it must be considered that extra time is necessary to yield *"precise"* software results.

As part of the first investigation of the survey it has been possible to identify a general suitable WWTP in the context of wastewater heat recovery and reserve capacities. This can be achieved through an evaluation of the operating data. It can be quickly evaluated if the WWTP has reserve capacities and is suitable for wastewater heat recovery or a more detailed analysis should be performed. If a more detailed analysis is necessary, the contingent calculation has been applied. Since this method was perfected by Swiss regulatory authorities it has been adapted in Austria considering its legal requirements. This method detects and calculates reserve capacities thus identifying general suitable WWTPs in Austria. If low reserve capacities are identified then another method has to be done. These other methods have to be used like the proof by design calculation (ATV-DVWKA A 131, 2000) or dynamically modeling (software based). The latter method is a very detailed method for the detection of a general suitable WWTP. However it has since discarded because it needs too much time and goes beyond the scope of this master thesis.

All these methods that have been previously mentioned have been combined to receive a standardized approach (flowchart). Further if a general suitable WWTP is detected through the standardized approach (flowchart), which is presented in point 5.1, then an essential foundation for a further specific evaluation has been developed. This specific evaluation will take a more detailed investigation. Since this evaluation is dependent on the planned heat extraction amount (extraction volume, wastewater amount and wastewater temperature at extraction point, distance to WWTP, etc.) it was not part of this thesis.

Having evaluated the operating data of WWTP Freistadt, reserve capacities have been detected. However the average inlet temperature has been too cold. This information has been an exclusion criterion for wastewater heat recovery in the sewer system. This has been confirmed through the calculation of the contingents. In this case it has been pointed out that Freistadt is not a general suitable WWTP for the usage of wastewater heat recovery in the sewer system. Further a specific evaluation in the context of wastewater heat recovery after the WWTP would be recommended. Energy optimization potential has also been detected.

The standardized approach (flowchart) that has been developed through this master thesis consists of all points that have been presented in the point *"Material and methods"* to come to a positive output. Through this thesis' methodology it should be possible to detect if a WWTP in Austria is general suitable for wastewater heat recovery.

The outlook is that through this standardized approach that has been created and developed stakeholders, authorities and technical engineering offices should be able to evaluate a general suitable WWTP in Austria. However it should be considered if there are problems with available and consistent data then the approach is not applicable. In this context it should be analyzed whether other possibilities exist to prove consistent data in the future despite apparent data gaps.

System variables must always be measured from WWTP to WWTP because they are always different. Public authorities must decide if the calculation and estimation of the contingents and method will be accepted in this context or not. They might need further investigation and more details or will accept it like it is. Likewise through the augmented application in future the approach and process will be optimized and adapted. The methods illustrated in this thesis are theoretical, but from a basis for further study. For a more detailed evaluation and investigation of a WWTP it is recommended the use of a statically and hydro dynamically modeling. Through this usage of such a model it is possible to investigate the smallest detail.

7. Summary

Dependence on fossil fuel energy resources inevitably leads to energy scarcity and qualitative environmental decline via pollution, global warming and increases of carcinogens in Earth's atmosphere. These environmental warning signs can be abated and mitigated by utilizing concepts espoused in this master thesis.

The European Union counteracts these problems by defining five strategies to enhance energy efficiency. The first strategy mandates that renewable and efficient energy should be increased by 20 percent until the year 2020 (European Commission, 2012). Numerous methods have been developed to attain this target. Most notable is the increase of renewable energy by capturing wastewater heat recovery in advance of entry into the WWTP system.

This method is not a new achievement it is an application employed by Swiss companies and wastewater utilities for 30 years. In Austria the same method was initiated beginning in 2012 with its first project. The success of this first project allowed Austria to connect this advanced methodology to many others and hope to require it in all future Austrian WWTP projects.

This master thesis has developed a standardized approach on the feasibility evaluating a general suitable WWTP with regard to wastewater heat recovery in the sewer system.

The guiding principle of wastewater heat recovery is to take heat energy from the wastewater through a heat exchanger. The process allows a heating pump to bring the obtained energy to a higher energy level that can be utilized to cool or heat buildings. In general the more it is cooled down the more energy is gained. There are three different options for obtaining energy from wastewater. One is after the WWTP, before the plant and in the building (Ochsner et al., 2013). Focus of this master thesis has been on the wastewater heat recovery in front of the WWTP. But the problem of this method is that it has possible negative effects on the cleaning performance of the WWTP. The removal of heat through the lowering of temperature has negative impacts on the reduction of ammonia and carbon. So for the installation of a wastewater heat recovery plant in the sewer system a permit by responsible water authorities is required.

Lack of experience in Austria, the WWTP energy recovery paradigm, require analysis and assessment of WWTP energy recovery methodologies in other nations in Europe wherein these innovations and technologies have been successfully implemented in the past.

The Swiss have employed some of these innovations for the past 30 years in the detection of suitable WWTP energy recovery sites (Schmid and Müller 2005). It is not possible to compare *"outright"* one WTTP method with another because of different legal statutes and regulations governing WWTP facilities in each country. Because of this incongruity, only methods that pertain to the Austrian regulations were considered and evaluated.

But before an evaluation of a general suitable WWTP can be done, consistent and valid data is needed. So the focus of the approach has been to find possibilities for data validation and performance evaluation of a WWTP with regard to wastewater heat recovery in the sewer system. There have been two procedures identified. One has been the rough analysis and the other has been the detailed one. The rough analysis includes a check of the basic data of the evaluated WWTP. Further the detailed analysis includes the mass flow balance via the software tool eDAB and similarly the evaluation of the energy consumption. Via these two analyses, it has been possible to obtain plausible data. Energetic analysis, which comes via the *"detailed"* analysis process, allows to detect an energy optimization potential of a WWTP. Further through the application of the contingent calculation it has been possible to evaluate if a general suitability of a WWTP is present or not in the context of wastewater heat recovery in the sewer system. A further method which was also considered has been the statically and hydro dynamically modeling method. This method is a very detailed method for the detection of a general suitable WWTP. However it has since discarded because it needs too much time and would have gone beyond the scope of this master thesis.

All these methods that have been previously mentioned have been summarized to receive a standardized approach (flowchart). Further if a general suitable WWTP is detected through the standardized approach (flowchart) an essential foundation has been developed for a further specific evaluation. This specific evaluation will take a more detailed investigation. Since this evaluation is dependent on the planned heat extraction amount (extraction volume, wastewater amount and wastewater temperature at extraction point, distance to WWTP, etc.) it was not part of this thesis.

In order to demonstrate that the approach is also practicable and not only theoretical it has been applied at the WWTP in Freistadt. Freistadt has been selected because it is part of a national project in the context of *"Energie aus Abwasser"*. The application of the standardized approach has demonstrated that no obstacles for the detection of general suitable WWTPs in Austria remain with regard to wastewater heat recovery in the sewer system.

In the case of the data validation and performance evaluation, consistent and plausible data has been obtained. Through the application of energy guidelines, WWTP optimization can be scientifically proven. With respect to Freistadt it has been determined that cooling potential directly in front of the WWTP is not warranted and that Freistadt is not a general suitable WWTP with regard to wastewater heat recovery in the sewer system. Examination of the results yield highly different energy characteristics between cold and warm years.

Evaluation of contingent calculations has shown that 2009 was a cold year. This has been confirmed through mean temperature calculations from years 2009 through 2013. Throughout this five year time span, only 0 degrees of cooling potential and 0 kilowatt of energy would have been possible to recover. The same evaluation taken one year later, a possible cooling potential of 1 °C would have been measured, meaning an energy output of 60 kW.

Nevertheless to receive an economical benefit out of the wastewater heat recovery in front of the WWTP it is important to obtain an energy output of 100 kW (AWEL, 2010). Since only 1 °C can be achieved with an energy output of around 60 kW, an installation of a wastewater heat recovery plant in front of the WWTP is not desirable. Consideration of such a plant in Freistadt should only occur after the WWTP.

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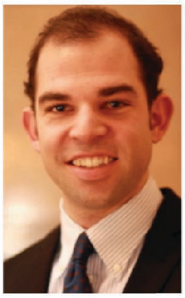
9. Curriculum Vitae

Personal details:



Name	Christoph Hofer BSc
Address	Riemergasse 12/7 1010 Vienna
Telephone	0660/ 40 38 571
E-mail	christoph.hofer@x-dsl.at
Nationality	Austrian
Date of birth	15.02.1988

School- and university education:

2012 – after date

University of Natural Resources and Life Sciences - Vienna
University of Life Sciences - Prague
(Double Degree Master: International Master in Natural Resources Management and Ecological Engineering)

2007 - 2012

University of Natural Resources and Life Sciences - Vienna
(Bachelor Environment and Bio-Resources Management)
Fields of knowledge: nature-, economic-, social-, and legal sciences as well as engineering sciences and technology

Bachelor thesis:

- Comparison of the acceptance of nature protection measures of farmers inside and outside of the national park Kalkalpen
- The meaning of long term orientation for investment- and divestment decisions in on the resource based branches of wood: paper-, wood-based panel industry and energy industry;

2006 - 2007

Civilian service
(Red Cross Wiener Neustadt)

2006

High-school certificate, Bundesrealgymnasium Zehnergasse in Wiener Neustadt

Further skills:

English	Very good (business fluent)
French	Good
Spanish	Basic knowledge
MS Office	Very good knowledge
Acrobat Reader	Very good knowledge
Auto Cad	Basic knowledge
Adobe Photoshop	Good knowledge
eDAB-Software	Very good knowledge

Professional experience:

08/2015 – after date

Aquaconsult GmbH
Sales Engineer

- Technical consulting
- Planning / Assessment of diffuser systems for WWTPs
- Technical order processing
- After sales service

04/2015 – 07/2015

University of Natural Resources and Life Sciences – Vienna
Institute of Sanitary Engineering and Water Pollution Control (SIG)

- Research Assistant in the national project of "wastewater heat recovery"

01/2015 – 04/2015

OMV Austria E&P GmbH
Intern in the department HSSE – Health, Safety, Security and Environment

- Analysis of the actual market trend of the energy branch,
- Support of the gas, power and CO2-expert,
- Support of the environment expert for generating different monthly and yearly accountings (waste-, CO2-, energy),
- Support of the implementation of the energy efficiency law,
- Monitoring of companies, project competings and industry indexes,
- Summarize of surveys and analysis for intern briefing,
- Screening of weekly and quarterly financial key figures and calculation of KPIs

10/2013 - 08/2014

uniforce Consulting GmbH (Junior Enterprise),
Junior consulting company; Business Unit Sales

- Project management,

- New- and old costumer acquisition,
- Data research

12/2012 - 07/2013

Stuhlindustries
Environment- Wastewater- and Water management
- Field service (wastewater treatment plants)
- Assistant of the general manager,
- Data research, costumer service and acquisition,
- Project management

07/2012 - 10/2012

Unlimited Ideas - The Advisory & Advertising Company
Intern in Management Consulting, Innovation Consulting und Project/Process Management
- Research,
- Business correspondence,
- Data preparation

07/2010 - 08/2010

Bilfinger Berger Baugesellschaft mbH
Intern in the department environmental engineering
- Project calculation,
- Solar- as well as Biogas,
- Data research for sanitation of waste disposals

07/2009 – 08/2009

Lallemand GmbH
Intern in the laboratory
- Baking tests,
- Chemical and microbiological analysis

Training:

2012: IELTS – International English Language Testing System (Academic) Ergebnis: 7,5

2005: one month as a sports teacher in Uganda

2005: certified fitness instructor

2004: certified healthy sports instructor

Hobbies:

Soccer, tennis, snowboard, skiing, producing music, meet friends…

10. Affirmation

I certify, that the master thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

21.08.2015 Christoph Hofer