DT 1.2.3

GUIDING DOCUMENT TO DEMONSTRATE THE BENEFITS OF IMPLEMENTATION OF REEF 2W PLANTS

30/05/2018

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1. INTRODUCTION

This deliverable gives an overview about the status quo of the 5 pilot sites before and after implementing the REEF2W technologies. The deliverable is also focusing on the benefits by implementing the REEF2W technologies from an economic point of view as well as from an environmental point of view. A template has been developed (see Annex 1) to collect the relevant information useful to properly describe the actual and prospective situation of the pilot sites and to have a better comparability of the sites. A short description of the planned use of technologies, their advantages and disadvantages and also the associated changes to the site are obtained. Benefits regarding economic and environmental points of view are inquired. Information reported in the next paragraphs was provided by each partner filling in the template.

2. PILOT SITE MONTEFELTRO SERVIZI

2.1. Description of Pilot site (actual situation)

The High Valmarecchia, crossed by the river of the same name, is enclosed between Tuscany, the Marche, the Republic of San Marino and Emilia-Romagna of which it is part.

The valley goes from the central Apennine to Rimini, in the heart of the Romagna Riviera, ranging from soft clay hills to sandstone and limestone spikes that rise here and there. It has always been a disputed territory and has a monumental and art heritage among the most singular in Italy, rich in some of the most beautiful fortresses, of boroughs with walls and towers, beautiful churches, small and great stories, linked to fights that saw the big families of Montefeltro and Malatesta antagonistic.

The High Valmarecchia is the ancient heart of Montefeltro: meta and stay since ancient times of famous men, from Dante to San Francesco, from Cagliostro to Ezra Pound; has recently reinforced its tourist attractiveness.

High Valmarecchia offers varied natural landscapes, dense woods, habitat of a rich and characteristic fauna, all enriched by sudden panoramic balconies, where the gaze is lost on the horizon, until you can see the sea. The Natural Park of Sasso Simone and Simoncello, of 4847 hectares, is located in the provinces of Rimini-Pesaro and Urbino, representing the 50% of Pennabilli's municipal territory.

By law no. 117 of August 3, 2009 the municipalities of Casteldelci, Maiolo, Novafeltria, Pennabilli, San Leo, Sant'Agata Feltria and Talamello from the Marche Region were aggregated to the Emilia-Romagna Region, within the province of Rimini, pursuant to Article 132, second paragraph, of the Italian Constitution.

Short description of municipalities of the Valmarecchia

CASTELDELCI

surface area km^2: 49,21

altitude: 436 – 1355

inhabitants: 460

MAIOLO

surface area km^2: 24,40

altitude: 212 – 950

inhabitants: 830

NOVAFELTRIA

surface area km^2: 41,78

altitude: 164 – 883

inhabitants: 7.126

PENNABILLI

surface area km^2: 69,66

altitude: 298 – 1375

inhabitants: 2.850

SAN LEO

surface in km^2: 53,32

altitude: 122 – 787

inhabitants: 2.945

SANT'AGATA FELTRIA

surface area km^2: 79,30

altitude: 174 – 961

inhabitants: 2.130

TALAMELLO

surface area km^2: 10,53

altitude: 213 – 861

inhabitants: 1.088

Figure 1. Map of the High Valmarecchia.

Montefeltro Servizi S.r.l is a public company (in House) with share capital of Euro 119,000.00, owned by the 7 municipalities that are its members.

The administrative headquarters are located in the municipality of Novafeltria while there are three operating venues:

- one located in Novafeltria, we have a garage for all the trucks and operating machines;

- two located in the municipality of Maiolo in Cavallara: the Inter-municipal Environmental Center and the trans-shipment Center.

The Company carries out the following services:

- Environmental hygiene;
- Collection of urban solid waste unsorted and differentiated;
- Management of the Inter-municipal Environmental Center;
- Cemetery Services;
- Public announcements;
- Management of public parks.

The Company consists of a sole Director and 25 employees, of which 4 administrative / technical and 21 operators with different tasks.

The Company carries out its activities in the territory of the 7 Municipal Members which reaches an area of 328,26 Kmq with 17.374 inhabitants, representing 40% of the territory of the Province of Rimini and 5% of the total population of the Province.

The undifferentiated and differentiated collection are managed on six Municipalities of the seven total of High Valmarecchia area; in particular, services are managed for the Municipalities of Novafeltria, San Leo, Talamello, Pennabilli, S. Agata Feltria and Casteldelci, while the municipality of Maiolo performs it with internally, for economic reasons.

Collection of the undifferentiated fraction is carried out through road harvesting, while for the separate collection two systems are adopted: road harvesting through the proximity system and the direct delivery to the Inter-municipal Environmental Center, to which citizens of all Municipalities can directly confer.

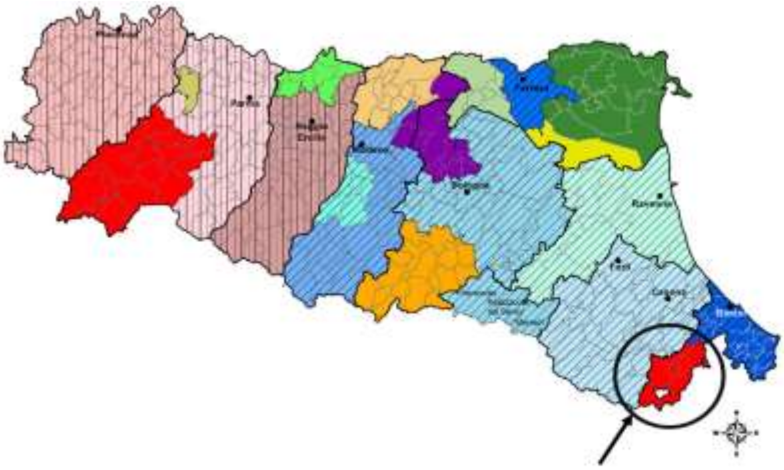


Figure 2. Geographical map of Emilia Romagna. The area covered by Montefeltro Servizi shown at the bottom right.

The collection of organic waste, it is currently carried out in three Municipalities out of seven and precisely Novafeltria, Talamello and San Leo.

Furthermore, Montefeltro Servizi is developing the possibility to manage urban wastewater in order to reduce management costs and disposal costs.

Table 1 below shows the quantities collected annually; it shows a steady increase in waste collected both for organic and for garden pruning and mulching.

Table 1. Total amounts of biowaste by waste codes from 2011 to 2016.

WASTE DIFFERENTIATED		
Year	**Waste Code and Description**	
	200108 - Biodegradable kitchen and canteen waste	**200201** - Biodegradable waste
	Amount of waste [t/year]	
2011	150.019	1.452
2012	193.179	2.307
2013	231.610	15.960
2014	258.119	94.370
2015	253.407	133.080
2016	312.292	195.001

Waste Service

The Integrated Waste Management Service (SGRU) consists of a range of activities to optimize waste management, including road sweeping activities and must be managed in accordance with principles of efficiency, cost-effectiveness, transparency, technical and economic feasibility and in compliance with national and EU standards.

The Integrated Waste Management Service is organized, as envisaged by Legislative Decree 152/2006 "Uniform Text of the Environment" based on the best territorial areas identified by each Region, together with the definition of the specific sphere of government. Government of the area that the Emilia Romagna Region, with Regional Law no. 23/2011 has entrusted to ATERSIR, which, in compliance with national and EU legislation on the reliance of local public services of economic importance, provides, distributes and manages the integrated waste management service.

The functions of ATERSIR relate in particular to the organization of the services, the choice of the management form, the determination of the tariffs to the users in matters of competence, the management and its control.

Waste management takes place in accordance with the hierarchy enshrined in the EU Directive 98/2008 / EU, aiming to identify, in order of priority, the best environmental option.

Since the approval of Regional Law no. 25 of 1999 and until December 31, 2011 the system of regulation and organization of the integrated water service and integrated waste management service in Emilia-Romagna was mainly based on the provincial-level action at the nine Agencies Territorial Optimal, special forms of cooperation between local authorities. Each agency operates on the basis of a convention concluded between all the municipalities of each province and the province.

With L.R. 23/2011, the Emilia-Romagna Region has identified a single optimal territorial area comprising the entire regional territory (and possibly in special cases also external communes adjacent to the regional border) by reassigning the functions of provincial agencies to a new public body with autonomy administrative, accounting and technical services, the Emilia-Romagna Territorial Agency Water and Waste Services (ATERSIR).

2.2. Descipription of Pilot Site inlcuding REEF2W Technologies

Main focus of the REEF 2W technologies are: utilization of biowaste collected in the High Valmarecchia zone, biogas upgrade to the quality of natural gas, and sustainable solution for the produced sludge.

Montefeltro Servizi has need to find a feasible solution for the treatment of collected biowaste.

Costs incurred by the Company to dispose of organic waste, during the year 2017 are:

- cost for organic fraction 90 euro/ton;

- costs for pruning 35 euro/ton;

To date, the Company has not implemented any process within its territory; the amount of waste is low, but growing, according to a better collection and a better sorting of the different fractions of wastes. The easiest way to use organic wastes could be the anaerobic digestion process, but the low amount of wastes available could be a problem for the application of this technology. Being a small reality you could think of other process technologies, such as composting, gasification or hydrothermal carbonization.

The tool that will be implemented within the REEF 2W project will have, therefore, the purpose of clarifying the type and quantity of waste managed, which is the best process on which to invest.

For sure the possibility the anaerobic digestion process can have the advantage of an easy and consolidated technology with no or limited environmental impacts, and with the advantage of the possibility to redistribute in agriculture the residues reach in nutrients (nitrogen and phosphorus).

On the other side other possible technologies like gasification can represent a good alternative with the possibility to recovery energy also with small amounts of biomasses, and with the possibility to use different kinds of biomasses, not only green biomasses as usually request for the anaerobic digestion.

The use of this approach will allow to use the of other biomasses coming not only from the organic waste collection, but also those coming for agricultural and agro-industrial activities that actually are sent at other specialized centres for the treatment.

In the meantime it will be possible to collect also the sludge deriving from the wastewater treatment plants distributed in territory.

In the territory are present ten small treatment plant that dispose their sludge in specialized treatment centers more than 50 km far away.

In the table below the locations of the treatment plants and their potentiality in terms of population served and in terms of filtered sludge production is shown.

The total potentiality of the area served by the Utility is about 1.220 tons/d.

Treatment plant	PE served	Estimated sludge production kg tq/d	kg tss/d
Novafeltria	5.000	500	0,03
Sant'Agata Feltria	1.500	150	0,03
Talamello	800	80	0,03
San Leo	2.500	250	0,03
Casteldelci	150	15	0,03
Pennabilli	2.300	230	0,03

Also this amount is quite limited, but can contribute at the provision of organic matter to be used.

2.3. Description of economic and environmental benefits by implementing REEF 2W technologies

It is a long period of time that Montefeltro is looking for technologies that could reduce the energetic impact of the waste treatment in Valmarecchia and in the meantime could reduce the road traffic due to the waste transport.

Due at the limited amounts of waste available it will not be possible to implement as planned at the beginning of the project, an anaerobic digestion process, able to grantee the best option for the energy recovery from wastes and reduction of the environmental impact.

For this reason the use of the DSS REEF 2W and the results that will be suggested from it, will help the utility to have a better view of the possible advantages of the different technologies applicable, but also of their costs.

At the moment it seems that the most suitable technology applicable for this pilot site could be the gasification process for its simplicy in the daily management, and for the possibility to use a larger spectrum of biomasses to recovery energy.

The advantage of this technology is also related at the possibility to reduce enormously the amount of treated wastes that can be distribute in the fiesl like ash or biochar.

The economic results will depend about the capacity of the Utility to increase the amount of utilizable biomasses, and in the possibility to increase the valorisation of the energy recovered.

The expected advantage will be mainly the reduction of the transport costs to other treatment centres of the wastes and the possibility to redistribute the collected energy locally for the municipal swimming pool heating or for the production of electricity to use for some public use.

3. PILOT SITE BERLIN SCHÖNERLINDE

3.1. Description of Pilot site (actual situation)

The WWTP Schönerlinde is a part of Berlin's Water Works (Berliner Wasserbetriebe – BWB), which provides 3.7 million people in Berlin and Brandenburg with drinking water, as well as collection and advanced biological wastewater treatment.

The demonstration site WWTP Schönerlinde sewage treatment plant is in operation from 1985 and located in the north of Berlin in Wandlitz, OT Schönerlinde (Figure 1). The effluent from the wastewater treatment plant in Schönerlinde is released into the Nordgraben channel that confluences with the river Tegeler flow. The Tegel lake water is used for bank filtration and artificial groundwater recharge. The treated wastewater portion is close to 50% in the winter period and 33% in the summer half year (Jekel and Gruenheid, 2008). Thus, the WWTP Schönerlinde is one of the important wastewater treatment plants for the water cycle in Berlin with a treatment capacity of 105.000 cubic meters per day (dry weather).

In 2012 BWB installed three wind turbines, each with an output of two megawatts at the wastewater treatment plant Schönerlinde. While the cost of installing the turbines was EUR 11 million each, the three wind turbines combined produce 80-90% percent of total energy required to run the plant, saving BWB significant energy cost (Brears, 2017).

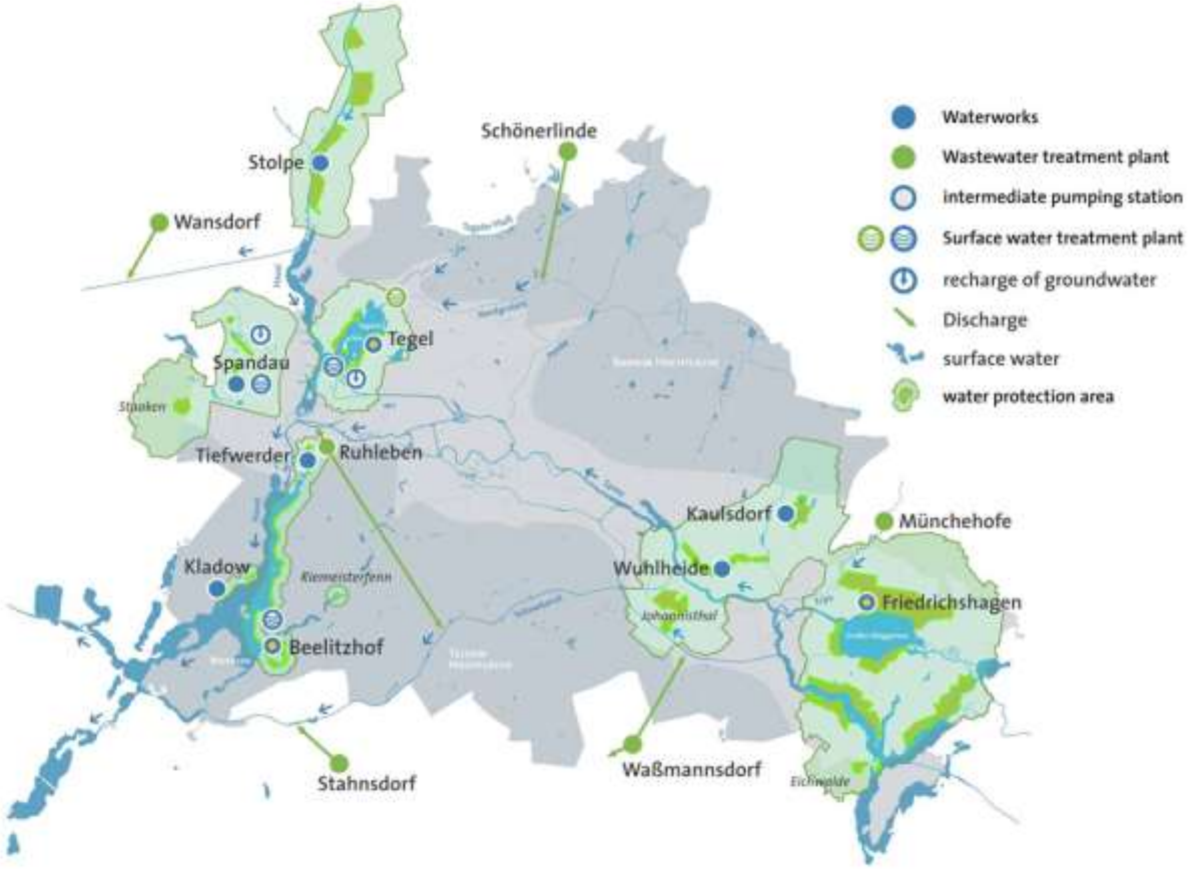


Figure 1: The location of Schönerlinde sewage treatment plant in Berlin (Source: BWB)

TECHNOLOGICAL DESCRIPTION

The wastewater in Schönerlinde is treated by mechanical and biological processes with biological phosphate elimination in combination with nitrification and denitrification. The sewage sludge is digested in digesters with mesophilic digesting at approx. 35°C and subsequently drained in centrifuges. Figure 2 gives an overview of the treatment process at Schönerlinde sewage treatment plant. The following technical dates are from the information sheet of BWB (BWB, 2017a).

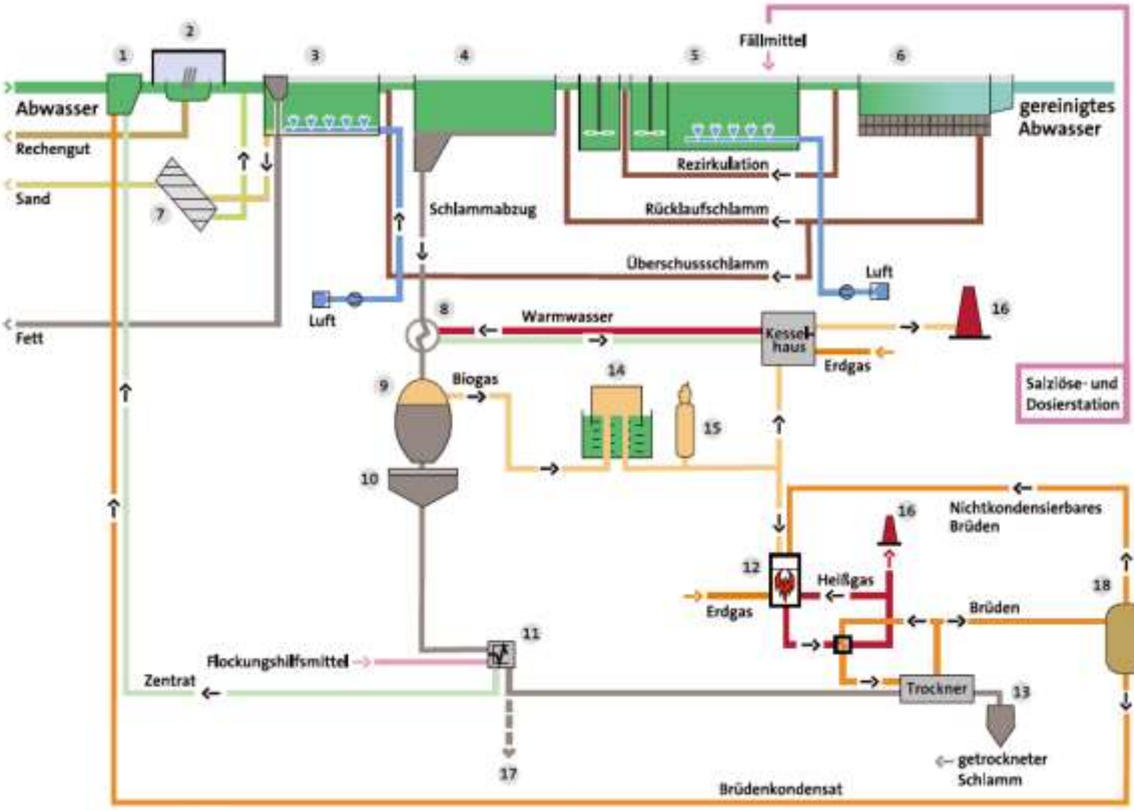


Figure 2: Process scheme of wastewater treatment in Schönerlinde (BWB, 2017a)

Treatment capacity:

105,000 cubic meters per day wastewater (dry weather), approx. 850,000 population equivalent (based on BOD5 value)

Mechanical treatment:

Five rake screens remove 1.5 tons of screenings from the wastewater daily. Three aerated double grit chamber classifier approximately two tons of sand per day. Eight rectangular sedimentation tanks are available as Pre-treatment tanks with a total volume of 14,800 cubic meters.

Biological purification:

The aeration tanks consist of eight basins as anaerobic zone, as well as fourteen basins as anoxic and aerobic zone. These have a total volume of 130,500 cubic meters. Aeration systems installed in the activated sludge tank consists of membrane aerators as well as ceramic aerators. As clarification serve twelve rectangular tanks with a total volume of 42,660 cubic meters and two round basins with a total volume of 10,500 cubic meters. Table 1 gives the key operation parameters at Schönerlinde. sewage treatment plant.

Table 1: operation parameters of Schönerlinde sewage treatment plant (Miehe, 2010)

Parameters	Value	Unit	Parameters	Value	Unit
sludge age	17.8	d	hydraulics retention time (HRT)	22.8	h
sludge load	0.09	kg BOD_5/(kg DM•d)	Flocculants doses	13.7	mg Fe^{2+}/L
volumetric load	0.34	kg $BOD_5/(m^3 \bullet d)$	Oxygen concentration in in activated sludge basin	2.1	mg O_2/L
dry matter in activated sludge basin	3.7	g/L	wastewater temperature	18.9	°C

Biogas utilization:

The produced biogas is stored in two gas containers and used for drying the sewage sludge, for heating purposes and for power generation.

Energy consumption and production:

In 2016 WWTP Schönerlinde has a total energy consumption of 22,173,370 kWh and among them 8,283,508 kWh is generated from biogas and sludge (Schwieger, 2017). Based on the values of measuring devices, connection values and operating hours, the following energy consumption of the individual processes were estimated from the WWTP operator (Schwieger, 2017):

- mechanical cleaning 3%,
- biological purification 69.1%
- Sludge utilization (digestion, drainage, drying) 15.5%
- superior 8.9%
- rest 3.5%

3.2. Description of Pilot Site inlcuding REEF2W Technologies

- **Description of your pilot site by including your REEF2W Technologies**
  - **What will be the technologies implemented on your site?**
    - **a) Short description of the REEF2W technologies you will implement**

Alkaline thermal hydrolysis:

The Disintegration of sludge will act as a pre-treatment before anaerobic digestion. Objective is to destroy floc structure and with higher energy input to dissolve cell walls. This disintegration achieves the transformation of non-biodegradable organic substances into bioavailable ones resulting in higher degradation rates of the volatile substances. Result is an increased biogas yield. Figure 3 shows the commercially available PONDUS® process as an example of a full scale application.

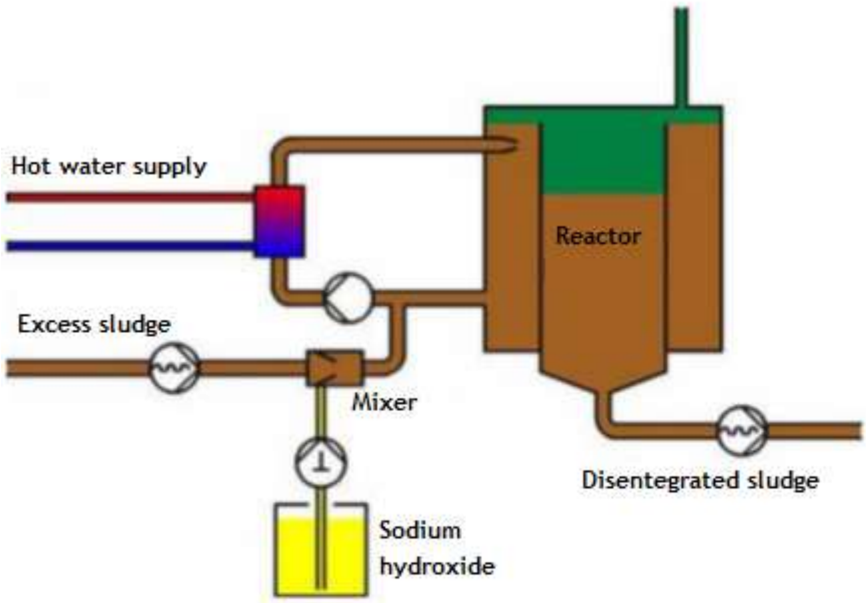


Figure 3: PONDUS® process (PONDUS GmbH)

Biogas upgrading

Biogas from anaerobic digestions contains large amounts of carbon dioxide and smaller amounts of other impurities such water vapour, ammonia and H2S which need to be removed if a high quality biomethane suitable for grid injection is desired. Biogas upgrading separates the raw biogas into a methane rich product stream and a CO2 rich offgas. This is a state of the art process for gas separation with the possibility to use different commercially available technologies to achieve the goal. As there is no technology that fits for every site specific circumstances a careful selection has to be made. Figure 4 shows the general principle of gas separation for biogas upgrading.

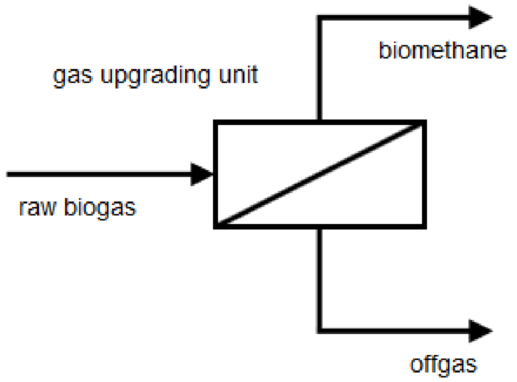


Figure 4: general principle of biogas upgrading

The following upgrading process technologies are considered:

- Pressurized water scrubbing (PWS) is the physical absorption of the carbon dioxide into the inorganic solvent water. Separation principle is the difference in solubility. CO_2 is more soluble in the scrubbing water than methane and therefore removed.
- Amine scrubbing is the chemical absorption into an organic agent containing an amine solution with higher loads and selectivity than water scrubbing. A substantial amount of heat is needed for regeneration of the scrubbing solution. This process will most likely be implemented as there is an existing full scale bio gas upgrading unit at a Berlin waste management facility digesting OFMSW. Because the operating company is in possession of the city of Berlin like the Water Works, it is possible to profit of their experiences.
- Gas separation with membranes uses the different partial pressures of compounds as driving force through materials with favourable selectivity for CH_4/CO_2 separation.
- During Pressure Swing Adsorption (PSA) the separation principle is based on different adsorption behaviours of gas components on solid surface under pressure.

Electrolysis

Electrolysis is process where an electrical current forces water into a redoxreaction at the electrodes resulting in the generation of oxygen and hydrogen. The two main readily available technologies are alkaline and polymer electrolyte membrane (PEM) electrolysis.

In alkaline electrolysis an ion-permeable membrane separates the cathode and the anode from each other. The electrolyte is basically made of water mixed with 20-40% of potassium hydroxide (KOH). In this reaction, the electrical current at the cathode splits the water into hydroxide-ions and hydrogen. The hydroxide ions can migrate through the separator to the anode and oxidise to O2. Both oxygen and hydrogen are released as gas.

During PEM compared with alkaline electrolyser the water is fed at the anode side. As a result the produced hydrogen does not need a water separation. The proton conducting membrane (often sulfonate polymer) separates the anode and the cathode. Electrodes are attached on both sides of the membrane and are treated with platinum group metals. During operation, oxygen is oxidised and electrons are released. The produced H+ ions migrate through the PEM towards the cathode side and are reduced to hydrogen gas.

Biological methanation

In this process biogas or pure carbon dioxide and hydrogen are injected in a separate reactor. Microorganisms of the family of methanogenic Archaea convert the CO2 and injected H2 into methane.

b) Pro and cons of your REEF2W technologies implemented

technology	advantages	disadvantages
Chemical disintegration (PONDUS® process)	Increased biogas yield through increased degradation rate of biological matter Lower hydraulic retention times possible (i.e. smaller vessels) VS reduction (i.e. les digestate)	Heat demand (70°C) Chemical demand (NaOH, 2L/m³) Higher return load of NH_4-N
Biogas upgrading	Biomethane stream as substitute for natural gas (for grid injection or use as vehicle fuel)	Energy input (heat, electrical) Less biogas for local energy production and local use
Electrolysis	Hydrogen stream for grid injection or methanation Electrolyzer as stabilization for electrical energy grid Storing of surplus renewable energy possible (power-to-gas)	High energy demand Energy efficiency Operating times limited by energy market Legal classification regarding energy fees

Biological methanation	Biomethane quality Commercially available Good partial load capability Flexible and robust	External reactor needed Hydrogen less soluble in water than CO_2 Energy demand for mixing and pumping Nutrients for microorganisms needed Excess water as product of reaction

Downside of implementing upgrading biogas for injecting into the public grid is the reduced/omitted local production of electrical energy in the CHP units. The missing energy has to be purchased from the public grid. Because the major part of electrical energy demand of the Schönerlinde WWTP is covered by the wind turbines, this will not be a substantive obstacle.

How will your pilot site change?

a) Schemata of the new pilot site including the new REEF2W Technologies

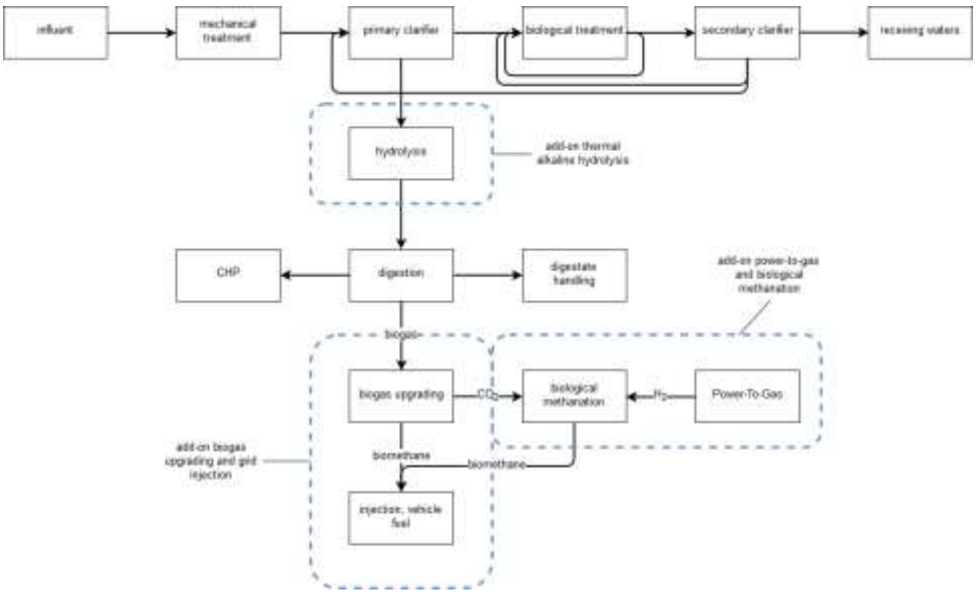


Figure 5: schemata of the new pilot site including the new REEF 2W technologies

b) Description of the "new" pilot site compared to the state-of-the art model

The new pilot site will incorporate a thermal hydrolysis stage which will receive a part or the complete flow of the separated sludge from the primary clarifiers to increase the biogas yield during anaerobic digestion and reduce the overall digestate.

A biogas upgrading unit will receive the biogas produced during anaerobic digestion and valorize the stream into biomethane. Only a small footprint is needed even in the case of upgrading the full biogas stream.

The electrolysis unit will use electrical energy from the grid during low demand times or during surplus of renewable energies and produces a stream of hydrogen. The inevitably simultaneously formed oxygen stream will be fed into the biological treatment of the wastewater.

Hydrogen produced in the electrolysis stage and the carbon dioxide stream from biogas upgrading will be injected into a biological methanation unit producing high quality biomethane. The vessel and it's accessories only have a small footprint.

A grid injection site and required pipelines will be installed. This site is owned and operated by the grid owner who will also be responsible for calorific adjustment, odoration, compression and pressure control.

The entire footprint needed for the intended REEF 2W technologies is manageable as the stages themselves need each about a few standard container sized areas and on the WWTP grounds is enough space for this expansion.

The hydrolysis stage and biogas upgrading can be independently operated and toggled on or off. The electrolysis/methanation stage needs the running biogas upgrading module as CO2 source and for the grid injection. A sole injection of hydrogen into the natural gas grid would in some circumstances be possible, but is not considered.

3.3. Description of economic and environmental benefits by implementing REEF 2W technologies

Economic benefits by changing the state-of-the-art pilot to a REEF2W pilot:

The produced biomethane is a valuable and more versatile product than biogas. It's properties are like the substituted natural gas and by injecting into the grid it is supplied to every connected end user. Applications are for example heating purposes, in the mobility sector, in power plants and the chemical industry (i.e. ammonia and hydrogen synthesis).

The biological methanation of hydrogen and carbon dioxide is a cutting edge technology and the plant will be a trendsetter in an emerging market. Concessions for early adopters may apply.

Supplying the gas grid with locally produced methane is a strategic advantage to be more independent from external gas suppliers.

A power-to-gas plant can act as a stabilizer for the electrical energy grid by being able to quickly change it’s partial load. It is able to harvest renewable energy surpluses and decouple the production from use by storing the energy in the gas grid.

By increasing the biogas yield with thermal hydrolysis more of the profit generating product in form of biogas is generated. Alternatives are reducing the hydraulic retention time in the digester; or using smaller vessels while throughput remains the same. The needed heat can be generated on-site with available biogas.

Environmental benefits by changing the state-of-the-art pilot to a REEF2W pilot:

The direct emissions of the site will decline because less biogas will be burned in the CHPs and by injection of biomethane into the gas grid credits for substituted natural gas are earned. The biomethane is generated from renewable resources and is therefore a “green” gas.

The P2G module offers the possibility of capturing and saving of surplus renewable energy peaks instead of wasting them. The utilization of the storage potential of the natural gas grid makes this possible. A reconversion of the methane into electrical energy is possible albeit the overall efficiency would not be optimal.

A very pure oxygen stream is generated as a side product during electrolysis. It can be used to save on aeration costs during the aerobic biological treatment stage at the WWTP. Due to the higher oxygen content than ambient air less electrical energy for the blowers will be needed to achieve the same oxygen contents in the water.

Through methanation the otherwise untapped potential of the CO_2 from the biogas upgrading process is used as a resource instead of being simply wasted. It is therefore transformed from being a GHG emission into a source for credit.

Thermal hydrolysis enables an enhanced digestion. This means that less digestate in means of dry mass has to be transported off-site therefore saving in emissions for transports. The agricultural use as fertilizer substitution is not substantially impaired.

3.4. References

- Bauer, F., et al. (2013). Biogas upgrading – Review of commercial technologies. (SGC Rapport; Vol. 270), Svenskt Gastekniskt Center AB.

- Brears, R.C., 2017. Berlin transitioning towards urban water security, Urban Water Security. Wiley Online Library, pp. 151-164.
- BWB, 2017a. Infoblatt: Klärwerk Schönerlinde, Modernste Technik für die Abwasserreinigung Berlins. Berliner Wasserbetriebe, www.bwb.de.
- DWA. 2016: DWA-M 302 Klärschlammdesintegration. Hennef, Germany, DWA Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V.
- Franzke, U., 2011. Sewage Sludge Treatment in Large Cities Using the Example of Berlin, in: Pelloni, K.J.T.-K.L. (Ed.), Waste Manage. (Oxford). TK Verlag, Berlin, p. 693 to 698.
- Homann, K., Hüwener, T., Klocke, B., Wernerkinck, U., 2017. Handbuch der Gasversorgungstechnik : Logistik - Infrastruktur - Lösungen (1.ed., gwf edition). München.
- Jekel, M., Gruenheid, S., 2008. Indirect water reuse for human consumption in Germany: the case of Berlin. Jiminez, B.; Asano, T.(Hg.): Water Reuse. An International Survey of current practice, issues and needs. ISBN: 9781843390893. Scientific and Technical Report, 401-413.
- Kabbe, C., Bäger, D., Mancke, R., 2014. Deliverable of project P-Pot: Phosphorus potential in Berlin (in German), http://www.kompetenz-wasser.de/wp-content/uploads/2017/05/20140325-p-pot_bericht_uep2-11400.pdf.
- Miehe, U., 2010. Performance of technical barriers for the removal of anthropogenic trace pollutants - wastewater treatment plants and dual media filtration (in German). Technische Universität Berlin, Berlin.
- Remy, C.; Diercks, K.: POWERSTEP deliverable D3.1: Best practices for improved sludge digestion.2016.
- Schwieger, K., 2017. Personal communication with BWB staff.

4. PILOT SITE RHV TRATTNACHTAL

4.1. Description of Pilot site (actual situation)

The waste water treatment plant serving as the Austrian pilot site is the plant of RHV Trattnachtal, located in Upper Austria (15 km north of Wels) with a capacity of 74.000 PE.

Since 2008 the Biogas Trattnachtal GmbH is running a waste cofermentation on the site of the sewage plant. The Biogas Trattnachtal is 100% owned by the RHV-Trattnachtal. The Biogas Trattnachtal GmbH is the holder of the permit for waste processing (marked green in Figure 1) and the RHV-Trattnachtal holds the permit for the wastewater treatment (marked blue and red). Both permits have to be obtained from the local government but from different departments, which leads to totally different permits concerning involved topics and technical experts.

The waste cofermentation changed the energy need and output of the sewage plant drastically.

Heat demand

Sewage plants with digesters have a considerable heat demand. On the one hand they have to heat the sludge, on the other hand the digesters lose heat due to their surface. Figure 1 shows the map of the wastewater treatment plant of RHV Trattnachtal.

Figure 6: Map of the wastewater treatment plant RHV Trattnachtal (Austrian pilot plant), source: RHV Trattnachtal

Per m^3 sludge that has to be heated the following heat energy is needed:

- 1,16 kWh/m^3 x ($T_{sludge,out} - T_{sludge,in}$)
- The temperature of the outgoing material $T_{sludge,out}$ corresponds with the temperature of the digester (assumed 35°C). The temperature of the incoming material $T_{sludge,in}$ is the average sludge temperature (assumed 15°C). So the sludge must be warmed up by 20K.
- =1,16 kWh/m^3K x 20K = 23,2 kWh/m^3 digested sludge
- The digesters of the RHV Trattnachtal have a volume of 2 x 2000 m^3 and a daily input of 120m^3 sludge
- Heat for warming up the sludge per day: 120 m^3/d x 23,2 kWh/m^3 = 2.784 kWh/d heat energy

- The heat loss of the digesters depends on the size of the surface, its heat insulation and the temperature difference of $T_{sludge,out}$ minus $T_{sludge,in}$
- In the case of the RHV Trattnachtal these are 1000m^2 surface with a heat loss of 1 W/m^2K (although due to the insulation a value of 0.5 kWh/m^2K is also possible – depends if the insulation gets wet) and 24°C temperature difference (average outside temperature = 11°C/a)
- Heat losses: 1000 m^2 x 1 W/m^2K x (35°C-11°C) = 24 kW per digester tower
- This leads to an annual heat demand of: 24h*365*(24 kW x 2) + 2.784 kWh/d x 365 d = 420.480 + 1.016.160 = 1,43 Mio. kWh/a for both digesters

The heat loss through the surface causes app. 30 % of the total heat demand of the digesters of the RHV-Trattnachtal, 70 % of the heat is needed for warming the sludge.

The measurement shows that the digester needed more energy than calculated. The reason is that in 2016, the digestion tower ran at 45°C in average. This is not a necessary temperature level (35°C would be sufficient), but as there is no need for the surplus energy this is a convenient way to get rid of the heat. This example shows that there is a lot of energy optimization potential which is only of relevance if external heat consumers are considered (which is one of the main aims of this case study).

Table 2: Heat energy balance of the wastewater treatment plant RHV Trattnachtal in 2016, source: RHV Trattnachtal

in MWh	heat demand			heat production (CHP)
	digester	rest	total	
Jan	91	30	121	224
Feb	119	21	140	192
Mär	141	30	171	243
Apr	150	18	168	212
Mai	225	17	242	266
Jun	200	14	214	230
Jul	165	19	184	204
Aug	139	14	153	171
Sep	192	23	215	244
Okt	184	28	212	248
Nov	201	36	237	294
Dez	213	39	252	320
year	2020	289	2309	2848

Electricity demand

This is an overview of the power consumption of the RHV-Trattnachtal in the year 2016.

- total electricity need 2016 . 2.000.000 kWh
- the screening and sand trap needed 9,28%
- the aeration needed 24,46%
- the return activated sludge cylce needed 17,33%
- the digesters incl. sludge line needed 10,51%
- diverse consumers 38,44%

The sewage plant has a maximum performance of 74.000 population equivalents and an average performance of 50.000 population equivalents (PE), so this results in an electricity need of:

- 2.000.000 kWh/74.000 PE = **27 kWh per PE maximum performance**
- 2.000.000 kWh/50.000 PE = **40 kWh per PE average performance**

The electricity need can also be calculated in combination to the treated water volume of 2016:

- 2.000.000 kWh electricity for 5.900.000 m^3 waste water = **0,34 kWh per m^3 wastewater**

Table 3: Electricity energy balance in kWh and sludge amount in m³ of the wastewater treatment plant RHV Trattnachtal in 2016, source: RHV Trattnachtal

2016	electricity consumption	electricity production	electricity sold	sludge amount
Jänner	168.899	211.747	58.211	115
Februar	149.077	181.081	53.869	426
März	173.502	383.497	211.333	647
April	148.559	268.447	122.211	393
Mai	160.642	306.903	147.813	357
Juni	161.110	307.335	147.629	394
Juli	174.095	316.455	144.555	286
August	169.399	283.867	117.463	183
September	177.051	338.089	161.318	320
Oktober	178.516	345.993	168.552	401
November	179.390	379.889	200.978	391
Dezember	200.731	421.157	220.799	402
Total	**2.040.971**	**3.744.460**	**1.754.731**	**4.315**
	53%	**100%**	**47%**	

The energy consumption rose significantly by 40% after starting the cofermentation. This is mainly due to the fact that the RHV tried to set up technologies on the plant using the own electricity instead of bought chemicals, so a decanter press and a membrane filtration were put in operation.

The energy production rose by nearly 400% after starting the cofermentation, so the biogas plant can now easily provide the needed electricity for the sewage plant. The biogas plant is selling the electricity for 12c/kWh to the RHV Trattnachtal and the surplus electricity is sold to the grid. The market price for electricity is quite low and fluctuating between 3 and 6 c/kWh over the last 6 years. In 2016 nearly half of the produced electricity was sold, so it is a much better option to get a subsidized tariff (usually around 8-10 c/kWh) from the state if there is one. The natural gas costs were below 5.000€ (mainly measuring and net costs) in 2016, the price for electricity from the grid summed up to app. 20.000€ (mostly measuring and net costs). One negative aspect is the massive increase of sewage sludge (it nearly doubled) because of the waste fermentation.

4.2. Description of Pilot Site inlcuding REEF2W Technologies

The strategies in order to optimize the energy balance (electricity and heat) consist of three main fields of action:

- Reducing the energy demand of the wastewater treatment plant
- Optimizing the energy output by using the resources that are available on-site
- Developing strategies to use the surplus (heat) energy at surrounding consumers' sites

REDUCING THE ENERGY DEMAND OF THE WASTEWATER TREATMENT PLANT

As it was shown by cofermentation the wastewater treatment has already a more than 100% self-supply in electricity as well as in heat. In order to use this surplus heat and therefore make a heat grid profitable, it is desirable to increase this surplus (in this respect also electricity is relevant as it can be used for heat pumps). As a rough rule 1 MW of heat power allows to install a heating grid of 1 km. For electricity already small amounts are useful if they can be fed into the grid, still maximizing the surplus makes sense due to environmental and economic reasons.

There are several options to reduce the demand of electricity and heat which can be of interest for RHV Trattnachtal.

<u>Reducing heat demand</u>

Insulation of the digester towers

An important option to reduce the heat demand is the insulation of the two digestion towers. At the moment they are insulated with a 9 cm glass wool layer. Under normal circumstances this should lead to an insulation value of about 0,45 W/m²K. Glass wool is in principle quite resistant against humidity, but if it is kept between two layers and water can enter, the thermal insulation quality of glass wool decreases rapidly.

There are two options of enhancing the insulation quality

1.) If the problems of humidity is relevant in this case, the glass wool layer should be kept dry. This is a low cost investment.

2.) In any case extending the thickness of the insulation layer from 9 to 12 cm would result in better insulation values of about 0,18 W/m²K (using PIR), but this is of course a larger investment. Using biological insulation materials will be another option to be compared.

Optimize temperature in the digester tower

Another possibility is to optimize the temperature in the digester towers. Presently there is no need to reduce the heat demand as the surplus energy cannot be used anyhow. But as soon as there is a heat grid installed, optimization of heat demand in the digester is a key issue.

Minimizing water amount in the sludge

The larger the dry matter content in the sludge the less water needs to be warmed up. Therefore the sludge should be as dry as possible (ensuring that pumps can still work).

<u>Reducing electricity demand</u>

Aeration

One possible strategy to reduce heat demand is the optimization of aeration. Either the amount of oxygen per time can be adjusted or time can be designated in which there shall be no aeration at all. Moreover it depends on the amount and quality of the actual wastewater how much oxygen has to be pumped into the wastewater basins.

Other opportunities can be found by checking benchmark values of Austrian wastewater treatment plants.

OPTIMIZING THE ENERGY OUTPUT BY USING THE RESOURCES THAT ARE AVAILABLE ON-SITE

The two main energy sources on a wastewater treatment plant are:

- The thermal energy of the treated wastewater – can be used for low temperature heat up to app. 65°C
- The energy in the sewage sludge (digester gas) – can be used for electricity and heat

Other forms of locally available non-fossil energy sources are:

- Electricity:
  - Wind energy
  - Solar energy
  - Water power by using a height difference between wastewater treatment plant and “Vorfluter”.
- Heat:
  - Solar energy

The pilot example will deal with wastewater energy and optimized use of the digester gas.

<u>Thermal energy of wastewater</u>

The mean wastewater flow through the wastewater treatment plant is 688 m³/h or 191 l/s in the years 2016 and 2017.

Analysis of the effluent wastewater on an hourly basis shows that 120 l/s are available permanently.

With a delta T of 2K an energy amount of 120 l/s*4,18 kJ/kgK*2K = 1 MW (1 kg corresponds to 1 liter of water) could be extracted from the wastewater permanently, resulting in an electric energy consumption for heat pumps (using a COP of 4) of 250 kW. In annual average the wastewater treatment plant has an electric surplus energy of 200 kW (the seasonal variations will be of importance as in January and February show the lowest surplus). This means that – using heat storages with an appropriate volume – most of the energy for heat pumps can come from the surplus energy of the wastewater treatment plant. Taking into account that strategies for reducing the electric energy demand and maximizing the electric energy consumption are available and will be investigated regarding their practicability on this pilot plant, an even higher fraction of the electric energy for the heat pumps is realistic. Table 3 shows the detailed data for the amount of wastewater and its temperature.

Table 4: Wastewater amount and temperature in the pilot plant in the 2016 and 2017 average, source: RHV Trattnachtal

	m³ waste water	T effluent °C
Jan	505.787	9,6
Feb	468.334	10,3
Mär	542.247	11,4
Apr	555.607	12,9
Mai	647.611	15,0
Jun	444.780	18,3
Jul	472.397	19,2
Aug	451.656	19,4
Sep	417.945	17,1
Okt	460.046	15,0
Nov	455.621	12,4
Dez	602.284	10,6
year	6.024.315	14,3

Digester gas (from sewage sludge and cofermentation)

Optimizing the energy output from digester gas is a task that will be investigated.

In the development of energy supply strategies the digester gas plays a completely different role compared to the wastewater energy explained before:

- it can be used for heat supply without using electric energy (e.g. for heat pumps)
- it can be used for heat at a high temperature level (contrary to wastewater heat)
- and can additionally be used for electricity production

Therefore the two resource groups serve for different heat demands (which are: low temperature domestic heat, high temperature domestic heat, domestic warm water, digester heat, etc.).

Stratified storage tanks can store thermal energy from both sources. An optimized storage strategy will help to cover all different heat energy needs.

DEVELOPING STRATEGIES TO USE THE SURPLUS (HEAT) ENERGY AT SURROUNDING CONSUMERS' SITES

WWTPs demand significant amounts of energy for the treatment process, but are at the same time interesting from an energetic point of view, as they can provide thermal energy and electricity. While electricity can be fed into an existing electricity network, the provision of thermal energy requires a district heating network. The spatial context of the WWTP and the presence of existing or future heat consumers, determine the potentials for an efficient integration of surplus heat into local energy supply concepts.

For a first analysis of the spatial context, the CORINE land cover (Coordination of information on the environment) program of the European Commission can be used. The CORINE land cover program comprises different land-use categories, from which the following three categories can be used for an initial analysis: (1) "Continuous urban fabric" – built structures with little coverage of vegetation and bare soils; (2) "Discontinuous urban fabric" – mixture of built structures and vegetated areas; (3) "Industrial or Commercial units" – built environment with few vegetated areas. This is an interesting approach to get a first idea about the spatial context of the WWTP and the location of possible heat customers in the surrounding area (Neugebauer et al. 2015). Based on this first analysis a rough classification of the pilot site can be undertaken. According to Neugebauer et al. (2015) three different types of WWTPs can be distinguished: (1) WWTPs "within the settlement"; (2) WWTPs "near to the settlement" and (3) WWTPs "far from the settlement". As illustrated in Figure 2, the pilot site in Wallern an der Trattnach, can be classified as "near to the settlement".

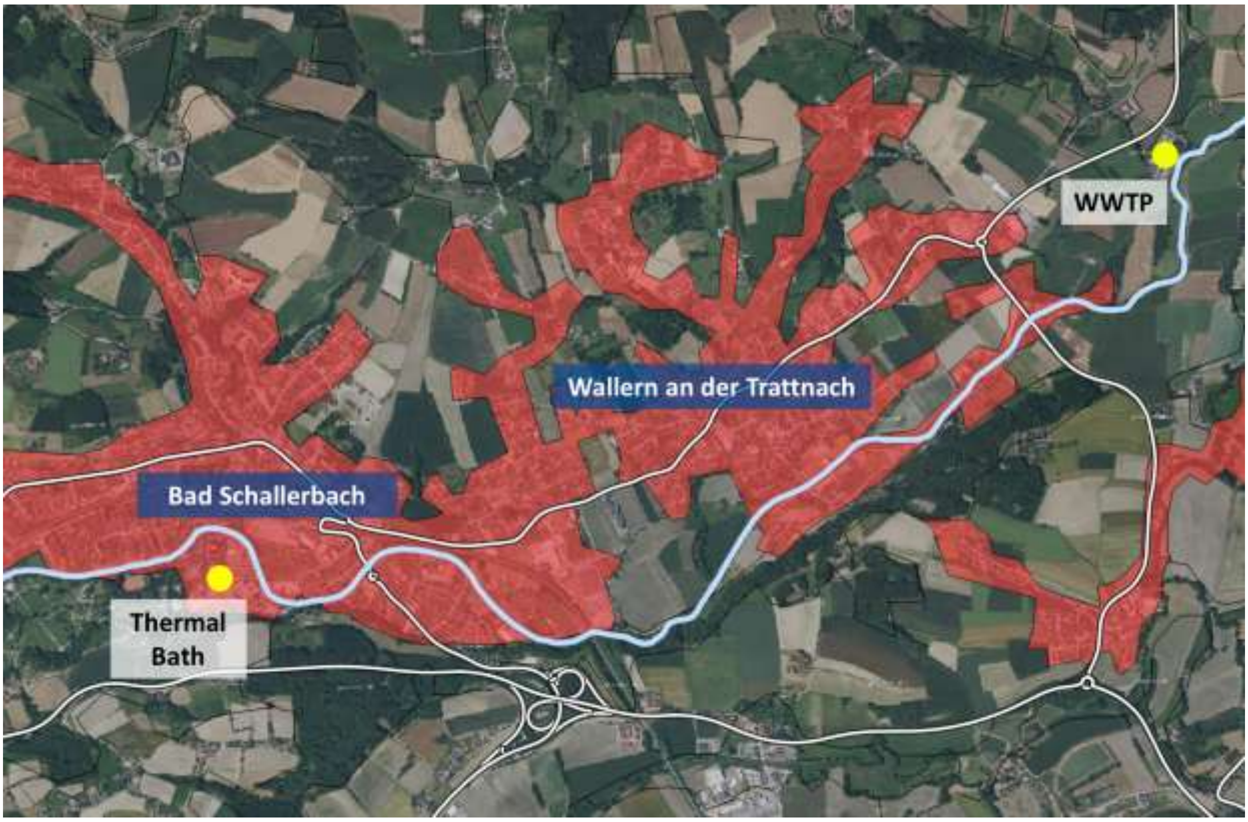


Figure 7: Visualization of the case study municipalities Bad Schallerbach and Wallern an der Trattnach, including CORINE land-cover category "discontinuous urban fabric" and two heat sources: WWTP and the Thermal Bath.

After the rough CORINE-analysis a selective identification of “key” heat customers in the WWTP’s surrounding should be carried out. Energy demand can arise from heating and cooling of

- Residential buildings
- Public buildings (e.g. schools, kindergarten, public swimming pools, hospitals, etc.)
- Commercial or industrial buildings

Additional thermal energy demand is generated by agriculture and forestry, as summarized in Neugebauer and Stöglehner (2015):

- Dewatering of wood chips, crops, medicinal or spice plants
- Heating and cooling of barns (e.g. for piglet breeding)
- Heating of greenhouses for the production of fruits, vegetables etc.
- Heating of aquaculture (for breeding fish or growing micro-algae)

If a district heating network should be developed, the distances between the heat source and the heat sink should be as short as possible. For the heat supply, two different supply systems can be distinguished: Warm district heating and cold district heating. Depending on the supply temperature, there are less heat losses in a cold district heating system, which means that greater distances can be covered. However, the closer the heat consumer is located to the WWTP the better, also for the economic feasibility of a district heating grid. Table 4 shows a rough estimation of the maximum distance between the WWTP and the energy consumer, depending on the particular heat capacity.

Table 5: Rough estimation of the economic feasibility, depending on the distance to the heat consumer (after Abwasserenergie 2017).

Estimating the economic feasibility	Dimension of energy consumer (Heat capacity in kW)				
	250 kW	500 kW	1000 kW	2000 kW	3000 kW
Maximum distance in m	100 m	500 m	1000 m	2000 m	3000 m

Depending on the consumer, different temperature levels might be necessary (e.g. high temperatures for industrial use and rather low temperature for new buildings with residential use). Furthermore, an optimization of spatial structures in order to enhance the overall heat demand can be carried out. In this context, the following questions arise: Is it possible to add additional buildings on open space? Is it possible to add additional storeys to already existing structures? Planners and authorities should also think about future agricultural or industrial/commercial developments close to the WWTP. Specifically, in our case-study, the town of Bad Schallerbach is known for its thermal spring. Therefore, this potential heat source located in appr. 4 km distance to the WWTP could be used to support and feed the district heating network.

After the initial rough analysis, more detailed analyses can be carried out. There are two main options for a more detailed identification of the energy demand: (1) Settlement related heat demand identification and (2) Buildings related heat demand identification. Using the first option, specific heat demand is allocated to a certain settlement type. Each settlement type is characterized by a particular building arrangement (e.g. density or population), building type (single family house, multi-storey building, etc.) and utilization (residential, commercial, mixed use, etc.). For the second option, a detailed calculation of the heat demand for every single object in the vicinity of a WWTP is carried out. For instance, heat demand values ($kWh/m^2.a$) dependent on building types and construction periods can be used in order to estimate the heat demand of residential buildings. The specific heat demand can be multiplied with the energy related area (e.g. m^2 of living space) which results in a total heat demand of a building.

4.3. Description of economic and environmental benefits by implementing REEF 2W technologies

Environmental benefits of the REEF2W solutions

Using waste water as a thermal energy source can significantly reduce the environmental impacts, (expressed in terms of CO_2 emissions, ecological footprint calculations or global warming potential – GWP) compared to the use of fossil energy sources like natural gas. In order to generate thermal energy from waste water, heat exchangers and heat pumps are needed. For the operation, electricity is required and therefore an electricity mix that mainly consists of renewable energy sources should be used.

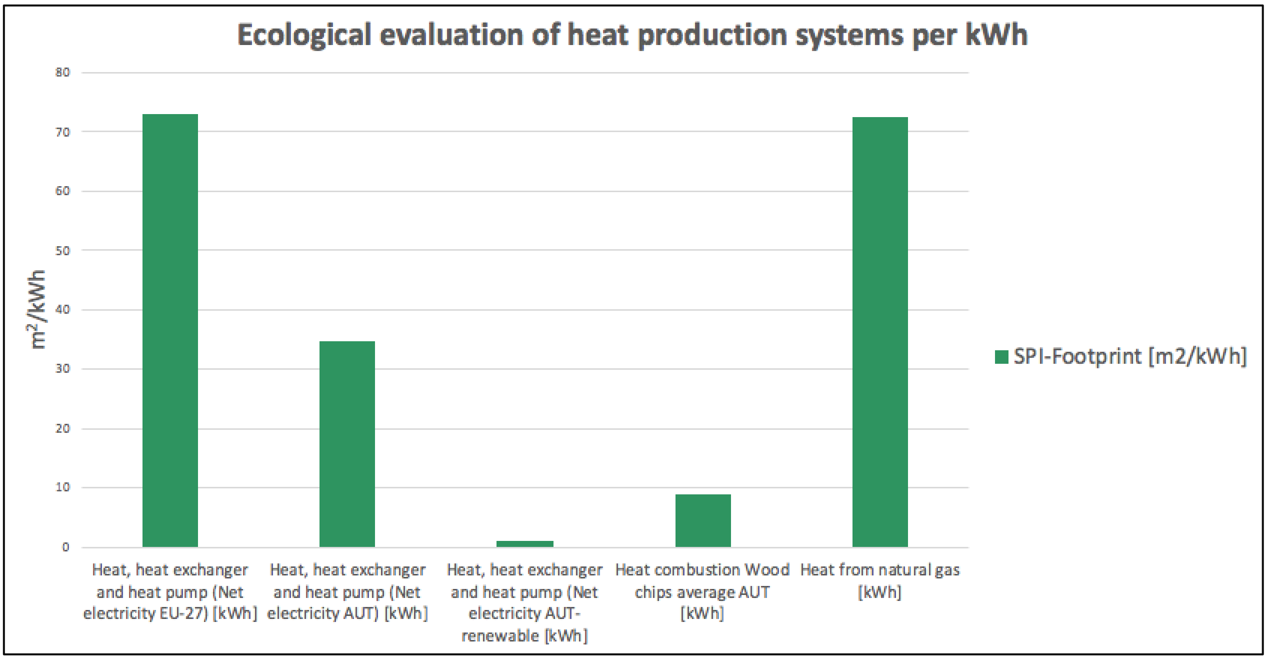


Figure 8: SPI calculations for different heat production systems (after Neugebauer et al. 2015)

Figure 3 illustrates a comparison between different heat production systems, that shows the influence of the electricity mix on the environmental impacts of the respective waste water related heat generation systems. Neugebauer et al. (2015) used the Sustainable Process Index (SPIonWeb) to calculate the ecological footprint of different heat production systems. The SPI is part of the ecological footprint family and is compatible with the EN ISO 14040 (ISO 2006). It asses the life cycle impact and can therefore be used to evaluate environmental pressure. In figure 3 it can be seen that heat generated with heat exchangers and heat pumps, using a typical Austrian renewable electricity mix features the lowest footprint (m^2/kWh). In this case, the applied electricity mix has a huge impact on the footprint calculations.

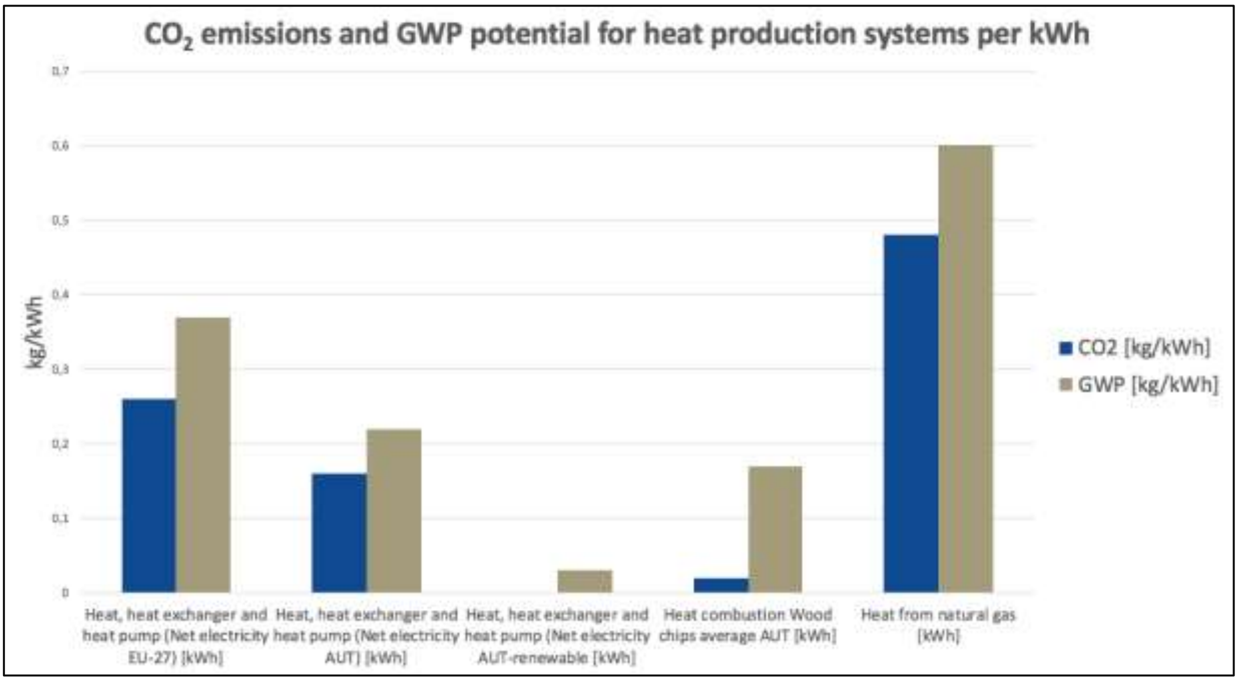


Figure 9: Calculation of CO_2 emissions and global warming potential for different heat production systems (after Neugebauer et al. 2015).

In figure 4, CO_2 emissions and GWP of different heat production systems are presented. Also in this case, heat produced with heat exchangers and heat pumps, using a typical Austrian renewable electricity mix is the most environmentally friendly option, especially compared to heat produced from natural gas.

A substitution of fossil energy sources is possible, if an economically feasible concept for a heating grid can be developed. As the rough energy potential from the wastewater treatment plant is 1 MW from wastewater + 0,25 MW electricity from renewables (resulting in 11,7 GWh/a) and approx. 1 GWh/a from digester gas (energy surplus after optimization), about 13 GWh/a of fossil energy consumption can be replaced by renewables from the wastewater treatment plant.

Economic benefits of the REEF2W solutions

For the wastewater treatment plant the installation of a heating grid will be a completely new business (although already now one nearby building is supplied with surplus heat). The economic feasibility of the grid is not yet calculated. However, an amount of 13 GWh/a at a price of 6 ct./kWh would mean a net turnover of € 780.000 per year.

4.4. Literature

Abwasserenergie 2017. Abwasserenergie – Die Kläranlage als regionale Energiezelle. Available online: http://www.abwasserenergie.at/fileadmin/energie_aus_abwasser/user_upload/Broschuere_Abwasserenergie_2017.pdf (accessed on 4 June 2018).

CORINE land cover 2012 for Austria. Available online: http://www.umweltbundesamt.at/umweltsituation/umweltinfo/opendata/oed_landbedeckung/ (accessed on 4 June 2018).

ISO. ISO-Norm, 2006. Environmental Management - Life Cycle Assessment - principles and Framework ISO 14040:2006; ISO: Geneva, Switzerland.

Neugebauer, G., Kretschmer, F., Kollmann, R., Narodoslawsky, M., Ertl, T., Stoeglehner, G., 2015. Mapping Thermal Energy Resource Potentials from Wastewater Treatment Plants. Sustainability 7, 12988–13010. https://doi.org/10.3390/su71012988.

Neugebauer, G., Stöglehner, G., 2015. Realising energy potentials from wastewater by integrating spatial and energy planning. Sustainable Sanitation Practice 22, 15-21.

SPIonWeb (Sustainable Process Index on Web). Available online: http://spionweb.tugraz.at/de/spi (accessed on 05 June 2018).

5. PILOT SITE PRAGUE

5.1. Description of Pilot Site (actual situation)

Prague is situated in central part of Czech republic. It is the capital of Czech rep. and city area is placed on river Vltava and hilly country around. Prague population is 1280500 inhabitants. Central Prague WWTP is large site with capacity of 1.641.000 PE, WWTP is mechanical-biological system with thermophilic anaerobic digestion of

sludge. WWTP is situated on the northern part of Prague at river island, very close to residental areas. Now, there is new biological treatment line in construction.

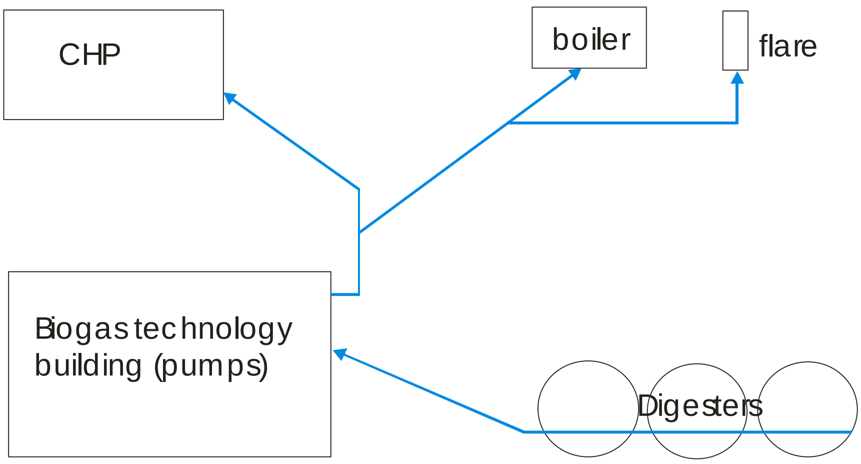
Sludge produced at Prague WWTP is processed by thermophilic anaerobic digestion (AD). WWTP Prague is the largest biogas production site in Czech republic. There is:

5 x 4380 m3 digester (1stage)

5 x 4000 m3 digester (2 stage)

5 x 6000 m3 gas storage

3 x 0,95 + 2 x 1,25 Mwel CHP



Veolia operates Prague central WWTP including sludge line with AD thermophilic process. The biogas is now incinerated at CHP plant 5 MW of electricity (gas piston engines) with limited heat utilizing, which affected overall energy efficiency.

Prague: anaerobic digestion of WWTP sludge

Biogas production (Nm3/year)	18 066 974
Electricity production (kWh/year)	32 029 000
Plant self sufficiency	75 %
Biogas for other purposes (Nm3/year) (now burned on flares without purpose)	1 150 000
Methane content of raw biogas	61 %

5.2. Description of Pilot Site inlcuding REEF2W Technologies

As REEF 2W technology is considered to be biogas upgrading unit situated at WWTP close to digesters and current biogas utilisation (CHP). The biomethane plant can positively affect energy efficiency of WWTP and reduce air pollution generated by public transport.

After detailed case-study there was choice between PSA and membrane technology. PSA has higher price, but lower operation cost, membrane technology hal lower investment cost and higher operation costs. Due to priorities of the project, the membrane biogas upgrading method was selected for Prague project.

Technology consists of membrane biogas uprgrading unit and bioCNG vehicle filling station.

The bioCNG own station is connected to the existing raw biogas transport pipeline (pipeline to CHP). It contains a unit for additional special biogas pretreatment (removal of H2S), gas drying and cooling unit, a compressor unit with filtration, a membrane separation unit itself, and a pressure control device for further distribution. The membrane separation unit is situated in a standard ISO20 container - width = 2,438 m, lengh = 6,058 m, height = 2,2348 m (or other according to the technology supplier), the container is mounted at the level of the terrain on the concrete blocks.

The filling station for vehicles contains compressor, gas drying device, balancing pressure container - these again in the container version and also covered its own dispenser stand with the payment terminal (here again the assumption of automatic unmanned operation).

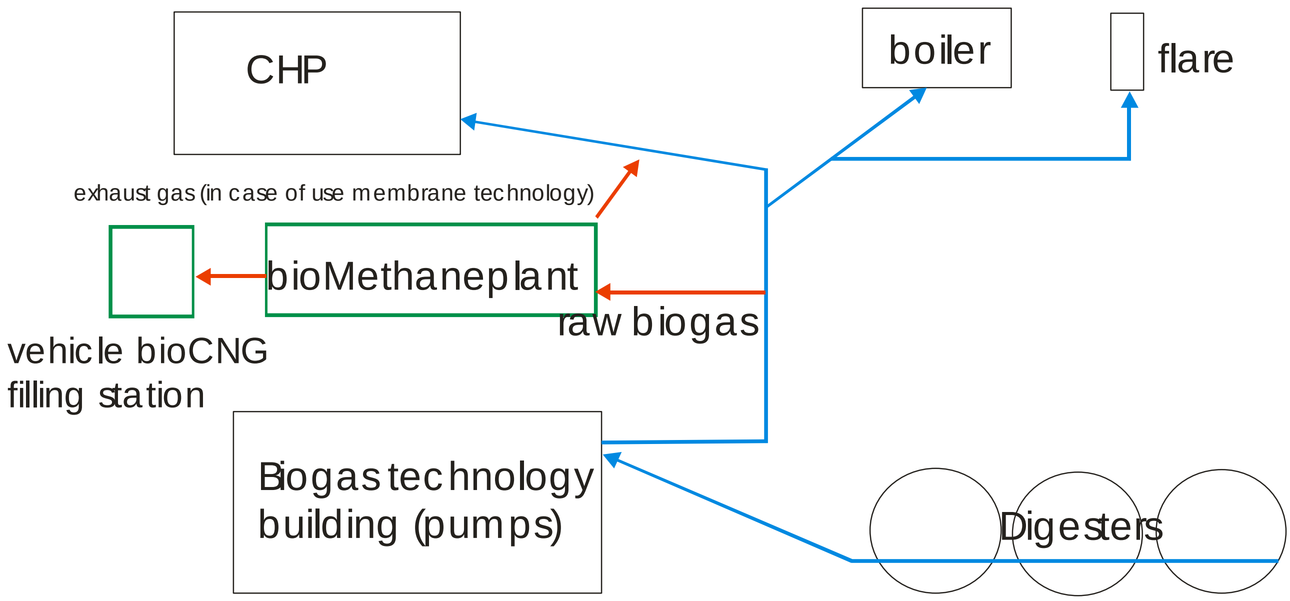
For compressed gas filling stations for motor vehicles, TDG G 304 02 of the Czech Gas Association is available, which specifies the conditions for the location, execution, testing and operation of CNG fast-moving stations for motor vehicles if the inlet pressure does not exceed 0,03 MPa, the compressor does not exceed 20,3/h and the compressor internal volume does not exceed 0.5 m^3.

The necessary space for the bioCNG station is approximately 12 x 8 m.

Pros: Biomethane plant will use now unused biogas, It rise efficiency of energy use at WWTP Prague, membrane unit has low investment cost and sufficient efficiency, upgraded biogas – biomethane is possible to use as bioCNG as vehicle fuel (primary use), or as biomethane injected to public natural gas grid (now considered as future variant of development).

Cons: In compare to PSA technology, there are higher operation costs, generally – biogas upgrading technology is complicated and high pressure device with high maintenance and operation standards demand. In Czech Republic is now not guaranteed biomethane price or subsidy for bioCNG vehicles.

Installation of biogas upgrading unit causes only minor changes to WWTP site. Installed technology is small and compact situated in standard containers. Only small part of produced biogas (now not used) will be upgraded.



5.3. Description of economic and environmental benefits by implimenting REEF2W Technologies

Economic point of view

Biogas upgrading unit will operate with 250 Nm^3/hour of raw biogas. Biomethane production will be 160 Nm^3/hour. It means that 2500 kg of CNG per day will be produced. By energy It means 1370 kWh of green energy will be produced from – now unused biogas.

Prague biomethane is designed for utilisation raw biogas – now burned without any benefit. Current investment cost to biomethane unit is so high and there is no any "green energy" bonus for biomethane, so in current state of art, the biomethane price is the same as for common CNG. By common commercial investment evaluation methods, the project is not very valuable. There is positive economical balance, but there is longer return time of investments.

Investment cost	EUR	2234000
Revenue from bioCNG selling	EUR/year	844800
Costs of input biogas	EUR/year	96000
Amortization	EUR/year	279250
Operation costs	EUR/year	129436
Simple payback	years	6,6

For the biomethane production, there is big synergy with current operation of large WWTP with anaerobic digestion – there is source of raw biogas, biogas infrastructure and possibility to process exhaust gas from biogas upgrading technology.

Biomethane production (without operational subsidy) is not competitive to biogas utilisation in CHP with guaranteed electricity price (price with green subsidy).

Environmental point of view

By daily production, 15 – 100 vehicles (buses, cars) can be filled at filling station. The plant is not big, but It is the first bioCNG plant in Prague and (now also Czech Republic) and there is big potential of positive publicity for both city of Prague and Veolia.

There can be strong effect for positive publicity, where the biogas production at Prague WWTP has poor image as source of odour, noise (from CHP) and anaerobic sludge production. CHP and also sludge production is not affected by biomethane project, but for future, biomethane can be showed as way for future main biogas utilisation with higher technology standard than CHP.

6. PILOT SITE ZAGREB ZCH

6.1. Description of Pilot site (actual situation)

Waste Management

City of Zagreb is the largest city in Croatia with approximately 800,000 inhabitants and a density of 1,200 inh/km². With the surrounding areas, total population of the City is around one million of inhabitants. Food and beverage processing is traditional and one of the most important local branches of industry, and it achieves the highest total revenue and employs the most people.

Municipal wastes in the city of Zagreb are managed by a Zagreb Holding – Čistoća (ZCH). It is a city owned company whose purpose is the realization of public cleaning service, collection, transportation, treatment and disposal of MSW within the City of Zagreb. For the processes of treatment, recovery and disposal landfill site Jakuševec – Prudinec is in use.

As in any other EU country, largest portion of mixed municipal solid waste (MSW) is biowaste. It is mostly kitchen and green waste with an average of 30 percent of total amounts. The main figures regarding the waste amounts in the City of Zagreb are shown in the table Table 6. Most of the produced biowaste in the City is being landfilled, which is one of the main challenges in the future for the implementation of sustainable waste management.

Table 6: Main figures regarding the waste amounts in the City of Zagreb (ZCH 2015)

City of Zagreb	
Amount of collected municipal solid waste in 2015 (t)	215,373
Potential amount of municipal biowaste in 2015 (t), 30% of total amounts	64,612
Amount of collected biowaste by ZCH in 2015 (t)	4,674

In the City of Zagreb, ZCH is certain amounts of the kitchen waste collecting from a number of restaurants and hotels, and delivering to the composting plants where it is mixed with the garden waste collected from public areas. Larger waste producers, including food and beverage industry and shopping malls, are also separating biowaste, as well as market places in the City (total number of markets in the City is 18). These actions have led to the increase of total biowaste amounts sent to the composting plant (Figure 10).

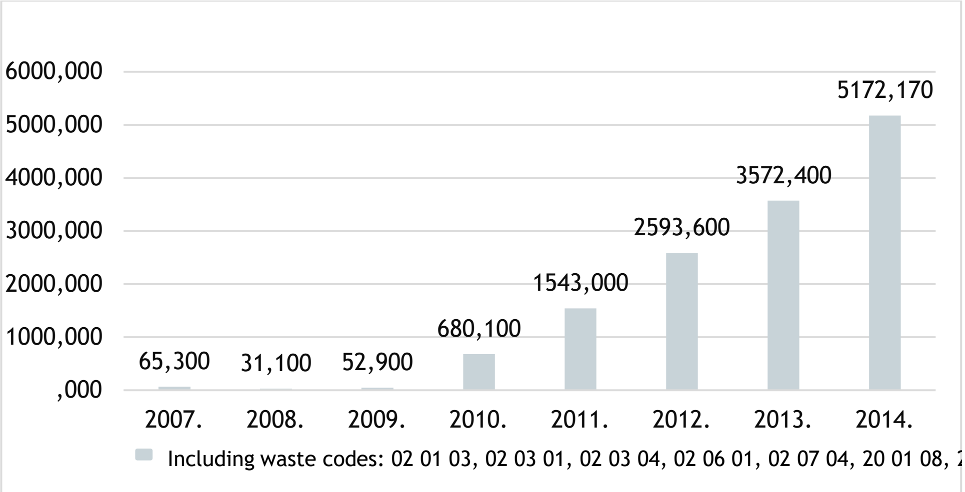


Figure 10: Increase of collected biowaste in the City of Zagreb (2007-2014)

As mentioned before, the largest portion of above presented quantities is from marketplaces within the City. Having in mind the total potential of produced biowaste in the City, these amounts are still not that significant and complete biowaste production needs diversification from the landfill. In 2018, due to the legal obligations, City will start to implement door-to-door separate collection of biowaste from households.

Waste Water Treatment Plant

The company ZOV (Zagreb wastewater Ltd.) is responsible for construction and operation of the Central wastewater treatment plant Zagreb (CWWTZ) and related infrastructure. The CWWTZ project is the first concession for a wastewater treatment plant in Croatia that enabled the City of Zagreb to harmonize and be in compliance with the environmental standards of European Union in the field of environmental and water protection. Pursuant to the Concession Agreement between the City of Zagreb and ZOV, ZOV designed and completed the construction of CWWTZ in 2007, and now is responsible for the management and operation of the facilities and regular maintenance.

The CWWTZ has mechanical and biological treatment (AD) and total capacity is 1.2 mil PE and demand of 27,790 m3/h (BOD 90,000 kg/day). More than 70% of electricity demand is settled from its own production in biogas plant. Also, around 50.000t of sludge is annually produced during the waste water treatment, which is being landfilled at the site. The location of the CWWTZ is presented in the Figure 11, and the overview of the plant in Figure 12.

Figure 11: Location of the CWWTZ

Figure 12: Overview of the CWWTZ

6.2. Description of Pilot Site including REEF 2W technologies

It has been previously elaborated that City of Zagreb needs to implement sustainable waste management through energy utilization of biowaste, as well as to improve current waste water treatment process.

In this sense, the focus of the REEF2W technology is on: utilization of biowaste collected in the City of Zagreb, biogas upgrade to the quality of CNG, and sustainable solution for the produced sludge (Figure 13).

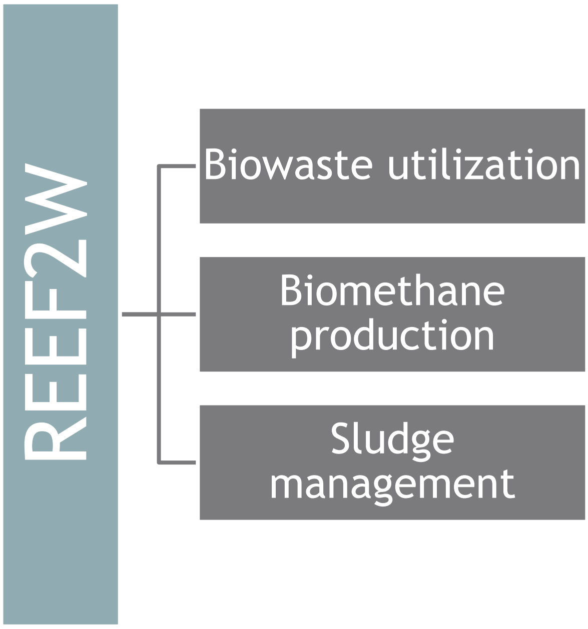


Figure 13: Proposed REEF2W technology in Zagreb

Biowaste utilization

City of Zagreb has a need to find a feasible solution for the treatment of collected biowaste. In this sense, location of the CWWTZ is highly suitable due to assess the city urban zoning and land use. In the case of the proposed location, city's urban plans have classified this area and communal, which allows further steps in the development of biowaste facility and biogas and biomethane production. Another important issue in choosing this location is the fact it might be the most suitable one considering public acceptance. Also considering transportation routes and logistics for future biowaste trucks, this location is one of the best ones. The location is easily accessible from the main city's road. The location is also relatively easy assessable from the main city's highway bypass (Figure 14).

Figure 14: Zoning regulation around CWWTZ

Biomethane production

Proposed location already serves as the city's wastewater treatment plant and has the initial infrastructure necessary for accepting a biogas and biomethane plant, both from transportation and logistical point of view (Figure 14). Also, the proposed location is excellent as the pilot site for biomethane plant because the main natural gas high pressure pipeline passes right next to the location. This means the produced biomethane could be easily injected into the natural gas grid.

Nevertheless, City of Zagreb and Zagreb Holding already have certain fleet of CNG busses for public transportation (around 60). Therefore, the consumption of produced compressed biomethane should be assured.

Sludge management

The one of main issues that CWWTZ is facing is regarding the sustainable management of waste water sludge, which is landfilled at the location. According to available data on sludge amounts, an average amount is approximately 50,000t per year, containing approximately 30% of dry matter average. Proposed solution is regarding the utilization of sludge on agricultural soils as effective way for treatment where the cycle of substance circulation is satisfied. However, seasonal restrictions on the application to agricultural land (e.g. flood, frozen soil or vegetation season) require careful planning between the production and application of sludge as fertilizer in agricultural production. Likewise, when sludge does not meet the agricultural application standard, it requires an alternative way of using, for example, composting or incineration.

6.3. Description of economic and environmental benefits by implementing REEF 2W technologies

Energy utilization of biowaste will gain biogas production at the CWWTZ and therefore increase the total energy production at site. The utilization of biomethane as a biofuel will have also many benefits. It is especially interesting due to the fact previously mentioned that City of Zagreb already has certain CNG fleet of busses, ant intent to increase the total number of different CNG vehicles.

Different EU legislations address the issue of sustainable biowaste and sludge management since it is a priority to have high human and environmental protection standards during the whole waste management process.

Separate collection of municipal biowaste will divert biodegradable waste from landfill and have positive impact on overall employment. Biogas production through anaerobic digestion in closed systems with proper control measures will generate high yields of biogas/biomethane. Anaerobic digestion has become a standard technology for the treatment of separately collected digestible organic fraction of municipal waste in many countries, producing biogas/biomethane which can be used as a renewable biofuel, as well as digestate which can be used as a plant fertilizer. Also, utilization of sludge can be as a soil improver or fertilizer. All of these options will be elaborated during the implementation of REEF2W technology for the City of Zagreb.

These actions are for sure a step towards more sustainable waste management as it allows waste recovery and recycling, as well as the preservation of the natural resources.

The REEF 2W solutions implemented within CWWTZ will provide various economic, environmental and social benefits as outlined below:

1. **Environmental:**
    - reduction of greenhouse gas emissions
    - preserves landfill capacity
    - provision of carbon-neutral forms of energy
    - reduced requirements for new energy sources

- reduction of water pollution methane emissions from landfills

2. **Social:**
    - protects human and environmental health
    - provides opportunities for teaching, training and employment and
    - provision of local, sustainable employment in new industries based on recovering resources such as biofuels from waste

3. **Economic:**
    - production of new sources of revenue for communities to offset infrastructure cost;
    - reduces harmful emissions
    - provides new environmental-based, direct and indirect employment opportunities
    - provides cost savings by reducing fossil

To realize energy savings and emissions reductions necessary to address climate change, decision makers have to consider tapping into behavioral transformation strategies. Behavior change is of central importance in bringing about significant reductions in energy end use and reduction of waste, although in most cases this issue is often treated separately and secondary to technological development. This has changed over the years and there is now a growing need for systematic approach to these interrelated topics. The European Union has officially addressed issues of consumer awareness and behavior in its Green Paper by stating that half of the energy targets set by 2020 could be reached by so called "soft measures". It is important to keep on mind that sustainable waste management model in the city of Zagreb cannot be treated simply as a technical, environmental, or economic project because waste management requires a collaborative approach, with strategic partnerships between government, local authorities, experts, and general public. Waste can be prevented only by involving the public because people should be encouraged to separate more quantities of municipal solid waste for recycling or composting. For that reason, it is necessary to organize permanent and comprehensive education of the public and governmental institutions about the benefits of abandoning landfilling as a current situation and solution for waste in the region of the City of Zagreb.