D.T.2.3.4 FIRST PART OF THE FEASIBILITY STUDY (STEP 1 + 2) FOR THE PILOT PROPOSED – CZECH REPUBLIC

Project Title: REEF2W Increased renewable energy and energy efficiency by integrating, combining and empowering urban wastewater and organic waste management systems

WP Lead: adelphi

Authors: Jenicek Pavel, D.Pokorna (UCT); Z.Varga, O.Benes (Veolia Czech Republic)

Submission Date: 12/2019

Contact:

André Müller

adelphi

Alt-Moabit 91

10559 Berlin, Germany

Phone:+49(30)8900068910

Email: mueller@adelphi.de

Content

1. Introduction

1.1. The REEF 2W Project

In the wake of the “Energiewende”, an increased focus is concentrating on the yet unexploited energy-saving potential of the wastewater sector. Wastewater treatment plants are large consumers of energy and often have key shares in the carbon footprint of municipalities and urban governments. Their energy consumption usually accounts for the bulk of operational costs of wastewater utilities, sometimes up to 60 per cent. Despite being a large source of electricity and heat, sewage is generally not taken into account. In fact, the amount of energy used can be 10 times bigger than what is required to treat it. Lately, an increasing number of wastewater operators have deployed energy-efficiency measures and novel technologies to better harness the energy of sewage. Evaluations of pioneering projects show that utilities are not only capable of becoming energy self-sufficient, but also suppliers of energy diversifying the local mix.

The project Reef 2W recognizes that wastewater is an integral part of the water-energy nexus. The project is funded by the European Development Bank’s Interreg Central Europe Programme and is carried out through 11 research institutes and wastewater utilities from Italy, Czech Republic, Germany, Croatia, and Austria. The project’s main objective is to drive up energy efficiency and renewable energy generation of wastewater treatment plants (WWTPs). It provides an innovative approach in integrating organic waste and wastewater streams and infrastructures. Where beneficial, bio-waste will be used to enrich sewage sludge, helping to elevate outputs of heat and electricity in a process called co-fermentation. To prove that the new technologies can be technically feasible and are economic viable, project partners will develop a comprehensive assessment tool in close collaboration with utility operators in- a series of workshops. Another key task of Reef 2W is to investigate the legal and policy framework conditions and to advocate for policy alternatives that spur the large-scale use of wastewater-to-energy solutions.

1.2. Scope of the deliverable

The purpose of the deliverable is to analyse the energy efficiency and the potential to produce renewable energy in the project’s five pilots. This will be achieved using REEF 2W tool, which is based on the Integrated Sustainability Assessment (ISA). The methodology and its five steps are described in chapter 2 of this document. Implementing the first part of the feasibility study will allow to understand how much energy the WTTPs currently use, and how efficient they are. Furthermore, it will provide a quantitative understanding about the potential to increase energy outputs. In the (fictive) technological upgrades defined for each pilot, these include measures to optimise existing processes and to install new technologies that produce renewable energy (See Figure below).

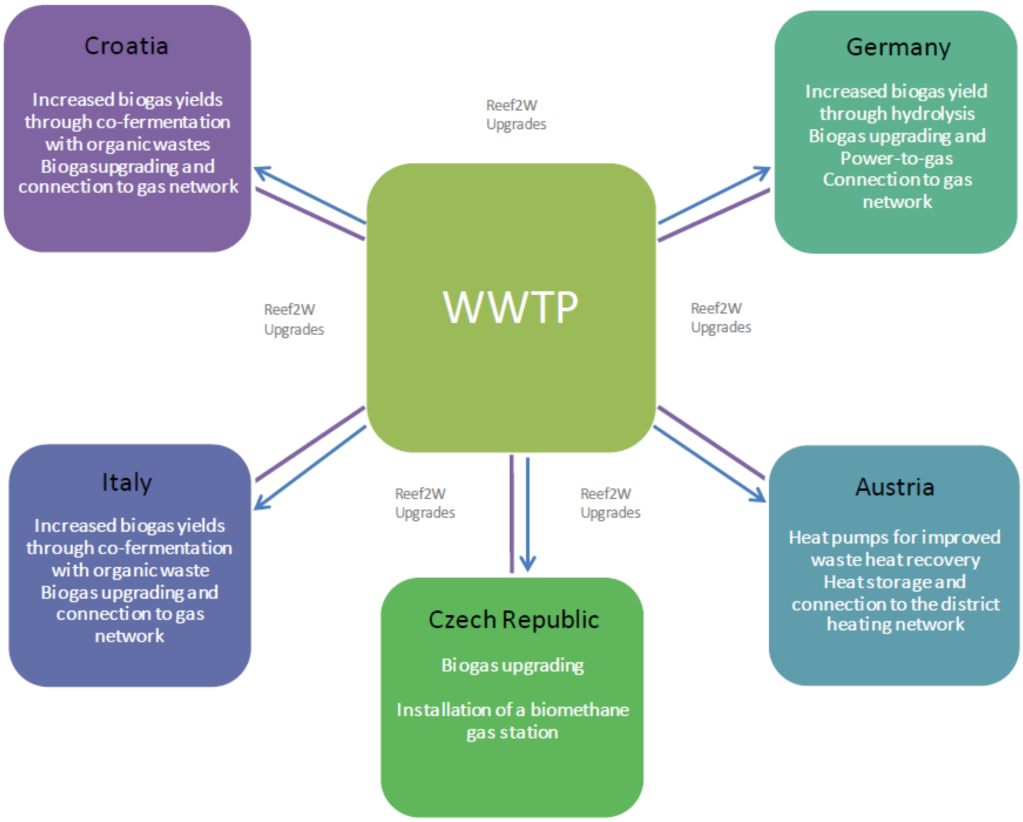

Figure 1: Presentation of the Reef2Water upgrades in the five European pilot plants.

How is it relating to previous deliverables?

The REEF 2W tool has been continuously improved and tested, also by external actors during the training courses. While the feedback gathered from the participants has been integrated, this is feasibility study is the first organised attempt to test the tool for all pilots and document the results. The results for applying these first two tools will provide the data required to conduct the second part of the Feasibility Study (in Work Package 3). The results are also important for other communicational purposes. For example, they provide evidence of the potential of wastewater-to-energy solutions, which is demonstrated in the Regional Strategies (DT2.5.1) and the MOUs (DT.2.5.2).

Structure & Approach

There will be five reports using the following approach. First, the background chapter introduces the ISA-methodology and its five steps, as well as the benefits that can be generally expected of the REEF 2W-solutions. The second part, mostly building on previous deliverables, describes technological characteristics of the WTTP and the envisioned (fictive) upgrade investigated during REEF 2W. Chapter 4 analyses the energy performance of the WTTP and evaluates the current level of energy efficiency. Chapter 5 analyses the energetic yields that result from deploying the renewable energy solutions. Lastly, the final part will distil key results, shortcomings of the methodology and further improvements to be made.

2. Background

2.1. The Integrated Sustainability Assessment (ISA) methodology

The REEF 2W tool is used to systematically assess technical innovations for energy optimisation of wastewater treatment plants (WWTPs) on different sustainability criteria. The instrument allows to make predictions about the potentials to improve energy performance, the technical feasibility or the environmental sustainability of the REEF 2W solutions. For more detailed information, please check DT.1.4.1-3.

The REEF 2W tool, which was developed as an Excel spreadsheet and online tool, comprises five core steps:

I: Energy efficiency is determined through a comparative analysis that measures current energy consumption against recognized efficiency standards. This benchmarking shows the optimization potential for heat and electricity savings.

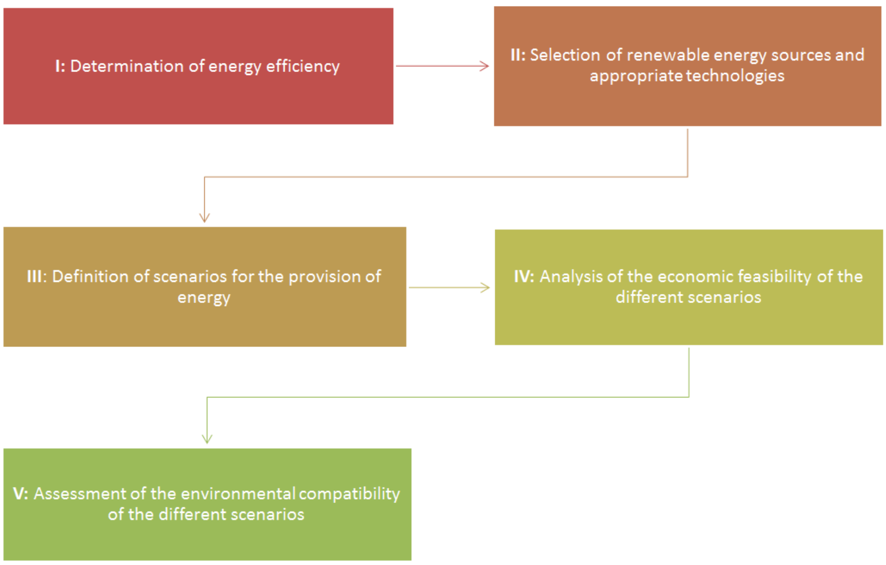

Figure 2: The five steps of the ISA method

II: Suitable technologies are selected through a potential analysis that compares different renewable energy sources. Emphasis on the project is set on improving heat and biogas yields while increasing the efficiency of subsequent uses such as biogas upgrading.

III: Different scenarios demonstrate how excess energy can be used for self-supply of the WWTP and feed-in into the gas, electricity and heat grid. These take into account the amount of available surplus energy, energy consumption and energy demand of neighbouring settlements as well as existing grid infrastructures.

IV: The economic feasibility assessment of planned measures will be carried out through a life-cycle cost analysis incorporating generated revenues from energy savings and sales, and investment and maintenance costs.

V: To assess the environmental impacts, a Life Cycle Assessment (LCA) focusing on CO2-reduction potentials is carried out for each scenario.

2.2. The Expected Benefits

The implementation of REEF 2W technologies entails several advantages from an energetic, economic and environmental point of view.

Table 1: Energetic, economic and environmental benefits of the REEF 2W technological solutions

Energy optimization	Economic feasibility	Environmental sustainability
Additional process steps such as thermal hydrolysis or co-fermentation with organic substances increase biogas yields. **Additional heat production is achieved by heat pumps in the sewer.** **A more efficient utilization of biogas is achieved by Combined Heat and Power or biogas upgrading.** **More efficient energy consumption, increased energy yields and the production of storable biomethane increase system security and flexibility.**	Energy savings and self-supply of energy and heat lead to a reduction in operating costs. Sales of excess heat, electricity and biomethane allows for additional revenues. Reduced sewage sludge volumes reduce disposal costs, especially where cost-intensive waste incineration is the only option. Optimized economics of wastewater treatment plants lead to financial savings for municipalities.	Energy savings and reduced use of fossil fuels result in a lower CO2-footprint of WWTPs. Biogas obtained from sewage is a more environmentally friendly biogas compared to crop-based feedstock. Recycling of organic waste in sewage treatment plants replaces the CO2-intensive disposal on landfills. The wastewater sector increases its contributions to a sustainable energy transition and climate protection.

3. Description of pilot site (status quo)

3.1. Characteristics of the wastewater treatment plant (WWTP)

Prague is the capital of Czech Republic and the city area is placed on river Vltava and hilly country around. It is situated in the central part of Czech Republic. Prague´s population is 1,280,500 inhabitants. Central Prague WWTP is a large site with the capacity of 1,641,000 PE, WWTP is the mechanical-biological system with the thermophilic anaerobic digestion of sludge. WWTP is situated on the northern part of Prague at river island, very close to residential areas. Now, there is a new biological treatment line in commissioning phase.

Figure 3: Central WWTP Prague - illustration photography

Sludge produced at both treatment lines of Prague WWTP is stabilizeded by thermophilic anaerobic digestion (AD). WWTP Prague is the largest biogas production site in Czech Republic. It consists of:

5 x 4,380 m^3 digester (1stage)

5 x 4,000 m^3 digester (2 stage)

5 x 6,000 m^3 gas storage

3 x 0.95 + 2 x 1.25 MWel CHP

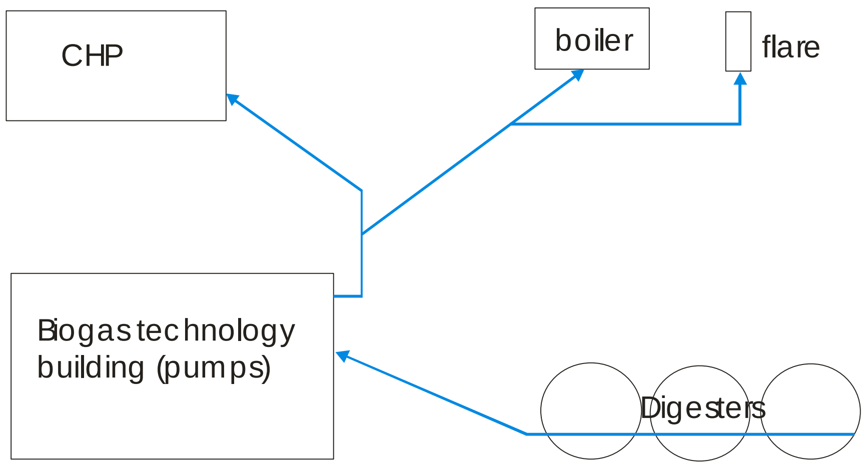

Figure 4: Scheme of the current gas management

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

Table 1: Biogas production at WWTP Prague

Biogas production (Nm^3/year)	18,066,974
Electricity production (kWh/year)	32,029,000
Biogas for other purposes (Nm^3/year) (now burned on flares without purpose)	1,150,000
Methane content of raw biogas	61 %

3.2. Technology upgrade of the pilot

A biomethane plant for biogas processing and a vehicle filling station were designed for the Prague WWTP. This biomethane plant can positively affect the energy efficiency of WWTP and reduce the air pollution generated by transport.

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

The technology consists of membrane biogas upgrading unit and bioCNG vehicle filling station.

The upgrading plant is connected to the existing raw biogas pipeline from digesters to current CHP. It contains a unit for additional special biogas pre-treatment (removal of H_2S), 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, length = 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. The filling station is placed in the container similar to container of membrane separation unit and is covered by own dispenser stand with the payment terminal (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 installation of the biogas upgrading unit causes only minor changes to the WWTP site. The installed technology is small and compact situated in standard containers. Only small part of produced biogas (currently not used) will be upgraded.

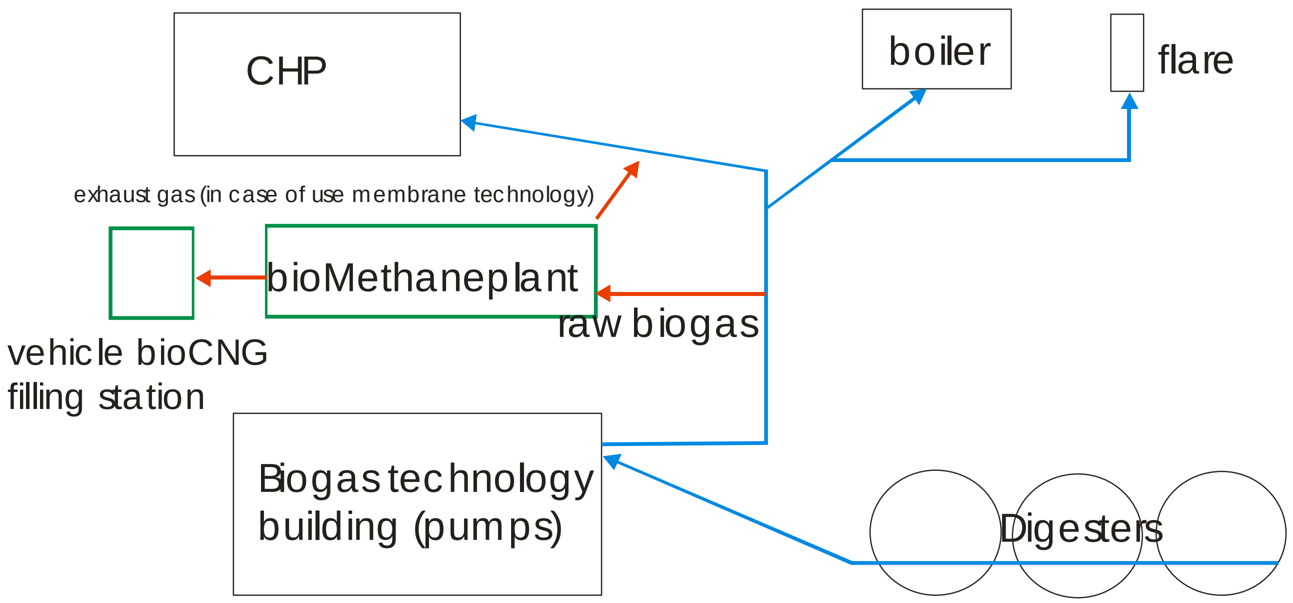

Figure 5: Scheme of the future gas management

Biogas upgrading unit will operate with 250 Nm^3/hour of raw biogas. Biomethane production will be 160 Nm^3/hour. It means that 2,500 kg of CNG per day will be produced. By energy It means 1,370 kWh of green energy will be produced from – now unused biogas.

3.3. Data availability and quality

Veolia collects detailed pool of operational data for all large WWTP´s operated including Prague WWTP (about 600 parameters per plant). This data is available for a 10 years period.

There are available data about quality and efficiency of treatment process in all indicators (influent/effluent quality, treatment process parameters, chemicals consumption, etc.). Very detailed data is also available about energy (heat and electricity) production, consumption (electricity) and sludge production and quality.

Part of the data is generally confidential, but there are enough to evaluate the calculations of pilot and also REEF 2W TOOL.

4. Energy performance of pilot WTTP

4.1. Current energy consumption and production

Prague WWTP has daily capacity of 290 m^3/min of raw wastewater. Real inflow in PE equates (COD value) is 1,750,000 PE. The total electricity consumption of the plant is about 44,000,000 kWh/year.

Table 2: Electricity consumption at WWTP Prague

Electricity consumption - raw water pumping station	%	6.7
Electricity consumption - sludge line	%	24.4
Electricity consumption – water line – air blowers (activated + regenerated tank)	%	55.1
Electricity consumption - dewaterïng of digested sludge	%	4.3
Electricity consumption - thickening of excess sludge (include desintergation)	%	7.3

Table 3: Electricity production at WWTP Prague

Biogas production	18,000,000	Nm^3/year
Biogas used by CHP	16,000,000	Nm^3/year
Biogas used by boiler	1,000,000	Nm^3/year
Biogas burned by flare	1,000,000	Nm^3/year
Electricity production	32,000,000	kWh/year
Heat production	45,500,000	kWh/year

Plant self-sufficiency (electricity)	78	%
Plant self-sufficiency (heat)	more than 100	%

4.2. Evaluation of energy efficiency

As shown in Table 3 current WWTP self-sufficiency (electricity) is in average 78 % as regards electricity and more than 100 % as regards heat. From 2019, probably even more electricity would be produced, because of minimization of biogas amount burned in flare and it is expected higher biogas production from the sludge from new water line of the WWTP in Prague. The self-sufficiency of the WWTP could increase to 85 - 90 %.

5. Application of renewable energies and associated energy output improvements

5.1. On-site renewable energy generation through traditional technologies

There is a variety of traditional renewable energy technologies such as photovoltaic, biogas production, wind energy, hydropower, hybrid collectors, and solar thermal, that could potentially installed at the WWTP in Prague. These have the potential to reduce the energy consumption, generate renewable energy, thereby improving local energy security and independence from external energy providers. Some of the technologies are fully operated at Prague WWTP and provide the generation of large quantities of renewable energy (AD with biogas production). Some can theoretically be implemented, but the WWTP in Prague is situated on the riverine island of Vltava in close proximity to the city centre and residential areas. As a result, there is limited space for installing additional technologies for renewable energy generation.

Photovoltaic: There is the possibility to install solar panels on the roofs of the WWTP facilities. Their total area amounts to 2,500 m^2, which could result in electric output of about 370 kWel theoretically which is only few percent (see Figure 8) of current electricity production from biogas. There is also the possibility to place solar plants at covered installations of newly constructed part of activated sludge tanks, where the area is about 5,000 m^2 for solar installation (700 kW). This is the possibility for future development of WWTP energy generation but there are also other criterions beside energy efficiency connected to city building rules and environmental impact of larger solar installations which does not support the solar panel instalation.

Biogas production: Biogas production is fully integrated to WWTP technology and provides high biogas production from sludge anaerobic digestion. Prague WWTP reaches about 78% of self-sufficiency with electric energy and more than 100% in heat self-sufficiency. There is no possibility for co-fermentation of other wastes because of full loading of current AD technology. The current volume of digesters does not allow the addition of external substrate to increase biogas production

Wind energy: The plant is situated into the deep valley of Vltava river in city urban area. It is not feasible to install wind turbines due to the low appearance of winds, close urban areas (noise emissions from wind turbines) and Prague city heritage and monument protection area. Such solution is totally unacceptability by population of the Prague city.

Hydropower: The WWTP is situated close to river water level. Effluent is pumped up to river water level and as there is not a sufficient gradient in the effluent channel. Any energy cannot be produced.

Solar hybrid collector: There is the possibility to install similar area of hybrid collectors as in the case of photovoltaic. The plant overproduces heat generated from CHP unit. In addition a heat distribution grid is not available in urban areas close to WWTP. The social acceptance of a solution inducing the building of a heat transport system in heavily populated part of city is low.

Solar thermal energy: The plant overproduces heat generated from biogas. After new technology of biomethane productionIt will be introduced the amount of heat produced will decrease. But still the production of heat will be higher than consumption. Without finding of a reasonable use of the heat the installation of solar heat panels
is ineffective. One of the discussed options is use of the heat for solar dryers of sludge which seems to be very good solution because of expected change of final disposal route to incineration. However nowadays there is not enough space in the WWTP area and it is not feasible to realise solar dryers out of the WWTP because of extremely high price of the land in Prague.

5.2. Other technologies

5.2.1. Thermal hydrolysis process (THP)

There was feasibility study conducted for a possible improvement of the anaerobic digestion system at the WWTP Prague by thermal hydrolysis of the sludge. One of the most successful THP technology is the Cambi process and the application of the process in Prague WWTP was evaluated.

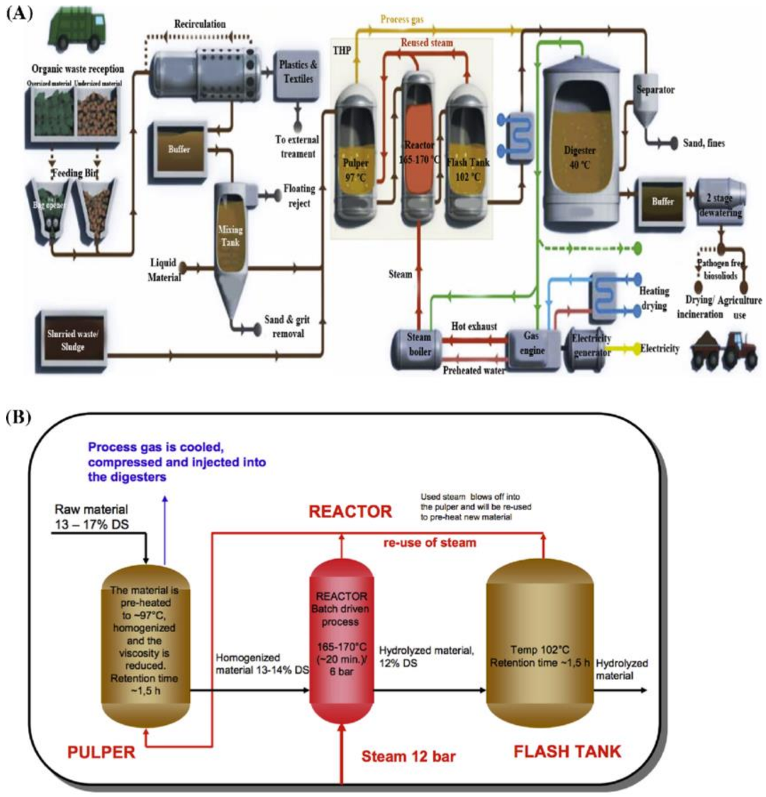

Figure 6: Scheme of the THP (thermal hydrolysis process) technology

After installation of the THP technology, it can be expected that the degradability of residual activated sludge cells will be improved. This, in turn, can lead faster biogas production which can result in higher biogas production by 10 – 20% according to (*Mills, N., Panter, K., Fountain, P., Shana, A., Martinicca, H., Nilsen, P. J., ... & Thorpe, R. (2014). Second generation thermal hydrolysis processes. Proceedings of the Water Environment Federation, 2014(2), 1-13.*). However, the installation of THP at the WWTP in Prague is a complex project with great affect to all parts of WWTP technology. Energetically, it provides more biogas production, but there is necessary to produce steam for THP reactor heating. , It will affected energy consumption because higher Nammon concentration in sludge liquor, sludge dewatering, final sludge quality etc. Final decision about THP application will be determined by selection of technology for future sludge disposal which was not yot done.

Figure 7: visualization of the THP technology

THP installation at Prague WWTP has estimated costs about 20 million EUR and the feasibility of the project is currently assessed. There is a link to the new water treatment line (now commissioning) and changes in sludge amount and quality.

5.2.2. Biogas upgrading

At the WWTP in Prague, there is a surplus of biogas that cannot be used in the CHP facility. The CHP facility also produced more heat than can be used for self-supply and this heat has to be disposed by cooling, especially in summer time. Biomethane production, through a biogas upgrading facility, offers a way to make use of that surplus biogas. Biomethane can be used as fuel in transport (there is large city transport bus hub close to WWTP) or injected to grid. Natural gas pipelines are not available at WWTP and new connection to high pressure grid has to be realised.

5.2.3. Power to Gas

At Prague WWTP, there is relatively constant generation and consumption of electric energy. Energy is consumed by WWTP technology (mainly air blowers at water treatment line) and generated from biogas by CHP unit. The capacity of AD is fulfilled and the system does not allow any H_2 injection (as P2G with biotechnology concepts). For new reactors and also for additional storage capacity for gas, there is not enough space.

5.2.4. Heat Pump

Using a heat pump is theoretically possible, especially at WWTP effluent, where installation of the technology can be easy. There was also a project plan to install a heat pump at the Prague sewer system (ENERGIDO PROJECT -

https://www.veolia.com/en/newsroom/thematic-reports/veolia-committed-climate/our-climate-solutions/wasterwater-green-energy-energido), but because of technical problems with maintenance of the heat exchangers it was cancelled. For the future heat pump application can be feasible when heat transport system and heat use will be satisfactorily solved.

5.3. Evaluation of renewable energy generation.

This section provides a brief analysis on the comparison of renewable energy use in the tool. To compare the results, the area of 500 m^2 was used for all three technologies. In the first part, three renewable energy technologies are compared with the status quo. The changes in energy generation are shown in the following figures.

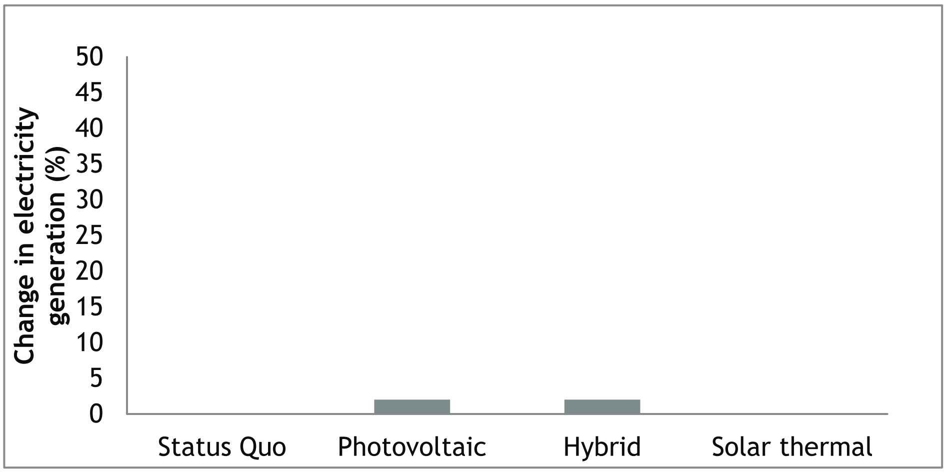

Figure 8: Change in electrical energy generation (in %) achieved through different renewable energy technologies compared with status quo

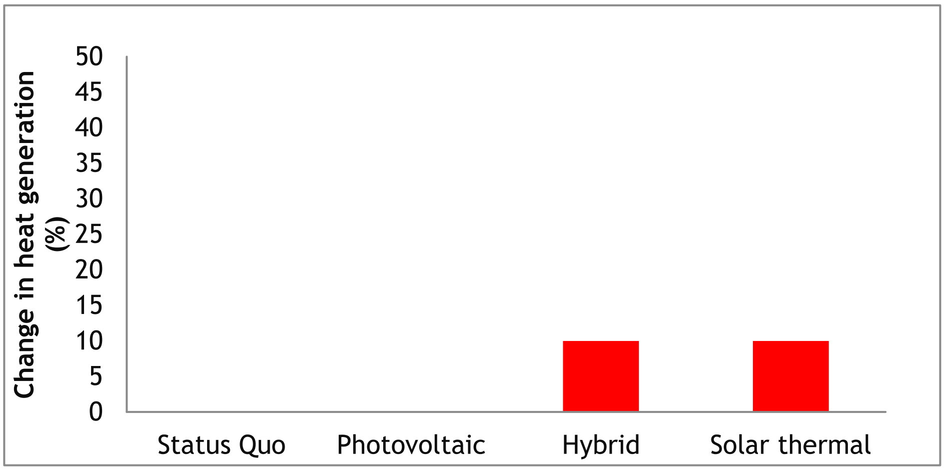

Figure 9: Comparison of thermal energy generation with status quo

Compared to the status quo, electric self-sufficiency is increased by up to 2% due to the integration of renewable energy technologies. Thermal energy cannot be used on the site. There is now overproduction of heat which has to be cooled.

In summary, the combination of photovoltaic or solar plant with the current combined heat and power production from biogas could be used to increase electrical self-sufficiency and is the feasible option for the selected WWTP. Generally the impact of these technologies is small due to the current large electricity and heat production from biogas and limited area for their installation.

5.4. Evaluation of further technologies

5.4.1. Thermal Hydrolysis

Installing thermal hydrolysis (THP)is a big issue for Prague WWTP. It is sure that the experience and recommendations of the REEF 2W project will be used here in future.

The efficiency of anaerobic digestion of sludge is very high in Prague WWTP because the lysate thickening centrifuge is used for the sludge disintegration and high rae thermophilic digestion (55 ºC operational temperature) is applied.

At such specific conditions some effects of THP are impossible to evaluate by the REEF 2W-tool. Pilot scale evaluation of technology will be necessary to estimate affecting of wastewater treatment process by sludge water, affecting of dewatering, heat balance, hygienisation effect etc. We can expect higher heat consumption and higher operational costs because of more complex technology on the other hand an increase of the biogas yield and dewaterability improvement are promising benefits.

Using the REEF 2W-tool we cane roughly estimate the effect of thermal hydrolysis application effect in Prague WWTP. The user can select between two options: Thermo-chemical (65˚C) and Thermo-pressure (165˚C). Figure 7 shows how the gas production of the WWTP could be increased if the thermal THP technology is installed.

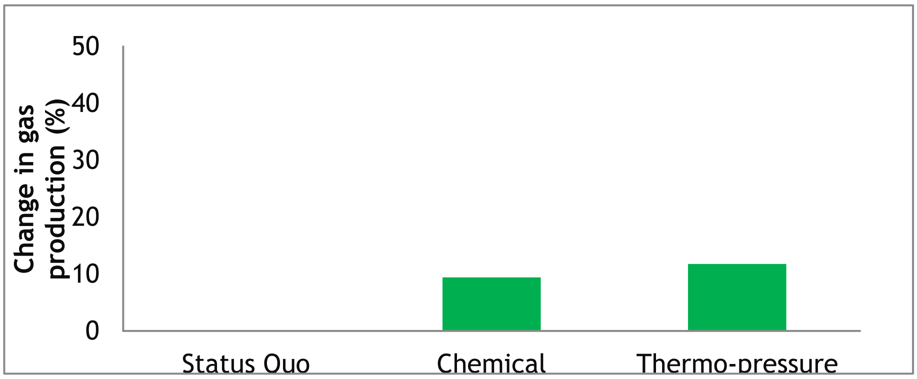

Figure 10: Comparison of biogas production using different thermal hydrolysis technologies

The figure above compares the biogas production by using two different technology types of thermal hydrolysis in the selected WWTP. Compared to status quo, biogas production in the digester is increased by up to 9.4 % through the use of thermo-chemical hydrolysis and up to 11.8 % through thermo-pressure technology. Both technologies are suitable for this WWTP. However, the thermo-pressure technology requires approximately two times more thermal energy. This is not a crucial problem as Prague WWTP has an excess of heat but , there is the low temperature heat 70/90°C and THP requires +180°C high temperature heat.

5.4.2. Biogas Upgrading

Biogas upgrading is the technology verified by the Prague pilot which has been selected to be a evaluated in theREEF2W project. At present it is available about 3 mil m^3/year surplus biogas that can be “upgraded” into biomethane. In the future there is the possibility for the utilisation of total production of biogas (16 – 18 mil m^3/year) instead of CHP technology, which are currently used.

Biogas upgrading separates the raw biogas into a methane-rich product and a CO_2-rich off-gas. Three main separation technologies can be selected in the tool: PWS (water scrubbing), PSA (pressure swing absorption) and membrane separation. The energy consumption of these three technologies is calculated in the tool and the results are shown in the following figure.

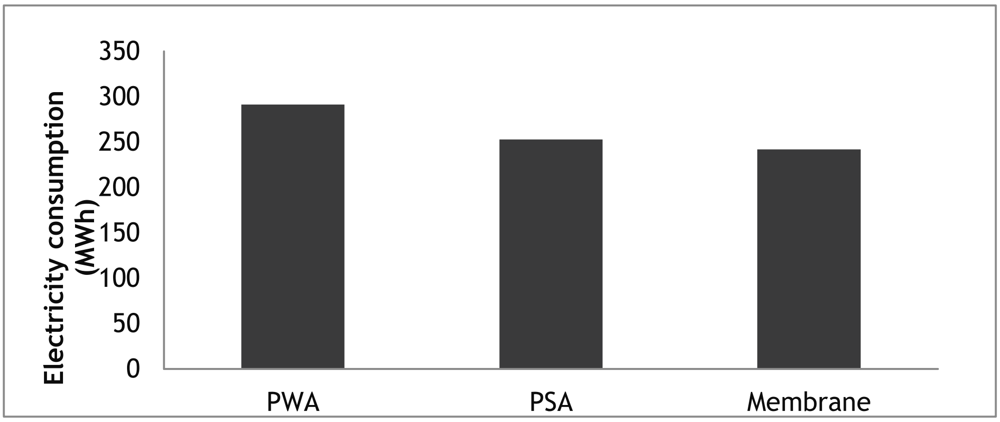

Figure 1: Comparison of electricity consumption of all three technologies(capacity of 250 Nm3/h of biomethane)

Figure 11 shows electricity consumption calculated by the REEF 2W tool of biogas upgrading unit for in pilot scale.

Figure 12: Comparison of electricity consumption of all three technologies (at upgrading of total biogas production)

Figure 12 shows electricity consumption calculated by the TOOL of biogas upgrading unit for in case of all biogas processing to biomethane. In this case, due to the complete biogas upgrading, the plant operator must cover the entire energy demand by external suppliers because own electricity production will not take place.

5.5. Discussion & Conclusion

The first part of the tool (EE) provides a simple analysis of the energetic performance of the WWTP. For the evaluation of this part, it is important to use good quality and real data from a WWTP. However, detailed information regarding individual process steps and equipment such as pumps, motors and screens were not available for comparison. Therefore, the energy performance as well as gas production and consumption were evaluated for the plant as a whole. The result of the first part of this analysis shows that Prague WWTP is 75 % self-sufficient in energy productin which is very good result. It is also quite interesting to observe that the estimated yields of biogas roughly equate to the real production based on the data.

The second part of this analysis compared and evaluated the combination of different renewable energy technologies in the WWTP pilot. The result shows that a solar plant can improve electrical energy self-sufficiency, but to a very limited extent. Two other renewable technologies (solar thermal and hybrid) would increase the thermal energy generation, but the WWTP already generates sufficient heat through the CHP system. The integration of renewable energy technologies can improve the energy self-sufficiency of Prague WWTP. Another way how to improve the renewable energy management is the optimization of biogas utilization. Less or no biogas can CHP biogas can be used for combined heat and electricity production and more or all biogas can be used for biomethane production.

Thermal hydrolysis can boost the biogas production and the energy generation. Upgrading of biogas to biomethane allows the highest efficiency levels to be achieved, both in the generation of electricity and in direct heat utilisation. In case of biogas upgrading technologies the tool favoured membrane technology in any case. We can note, that in large WWTP, PWA and PSA still can compete with the membrane technologies. In case of Prague, there was elaborated a case study of PSA system (internal document of Veolia) showing lower operation cost than membrane system, but higher investments.

Comparing the result of both parts of the tool indicates that the integration of renewable energies could lead to energy neutrality of WWTP in Prague. The energy neutrality can be reached by increasing energy generation using new technologies such as thermal hydrolysis or by codigestion. However energy neutrality is not only possible aim, other promising ssines case is bussines case foccussed in external use of biomethane.

The results of the tool are acceptable and sufficient for the first analysis. However, the results are not sufficient for detailed planning and analysis, as all calculations are based on monthly and annual averages. The REEF 2W-tool cannot assess also other aspects of renewable energy sources installations – wind, solar, P2G which are affected and sometimes excluded by local conditions (river valley WWTP position, urban regulations etc.).