D.T 3.3.4 - PA4: FEASIBILITY STUDY ON IMPLEMENTATION BIOMETHANE PRODUCTION IN A WWTP; CZ

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

Lead Partner: Veolia*, Cooperating Partner:UCT**

Authors: Ondrej Benes*, Radka Rosenbergova*, Pavel Jenicek**

Submission Date: 01.02.2020

Contact: UCT, Technicka 5, 166 28 Prague, Czech Republic, Email: jenicekp@vscht.cz

Content

1. Introduction 2

2. Background 2

2.1. The feasibility study methodology 2

2.2. The Expected Benefits 3

3. Description of pilot site (status quo) 4

3.1. Characteristics of the WTTP 4

3.2. Technology upgrade of the pilot 5

3.3. Data availability and quality 7

3.4. Evaluation of energy efficiency 7

4. Application of renewable energies and associated energy output improvements 8

4.1. On-site renewable energy generation 8

4.2. Biogas upgrading 8

4.3. Concluding remarks 10

5. ISA of pilot in the region of Prague 11

5.1. Pilot and applied REEF 2W technology specification 11

5.2. General indicator evaluation 12

5.3. Specific indicator evaluation 13

5.4. Suitability of indicators 16

5.5. Multi-criteria decision analysis (MCDA) 16

1. Introduction

The purpose of the deliverable is to finalize the feasibility study by combining of the D.T 2.3.4 Feasibility Study (step 1&2)_Czech Republic and second part described in D.T 3.1.2 Feasibility Study (step 3&4)_Czech Republic.

The aim of D.T 2.3.4 was to analyse the energy efficiency and the potential to produce renewable energy in the project's pilots. This was done using REEF 2W tool. Implementing the first part of the feasibility study allows to understand how much energy the WTTPs currently use, and at what level of efficiency.

In the D.T 3.1.2. Integrated Sustainability Assessment (ISA) was applied to compare status quo and proposed REEF 2W solution. Based on the ISA evaluation a decision maker can evaluate the strong or weak points of proposed innovative solutions in following contexts: environmental, economical, social, technical.

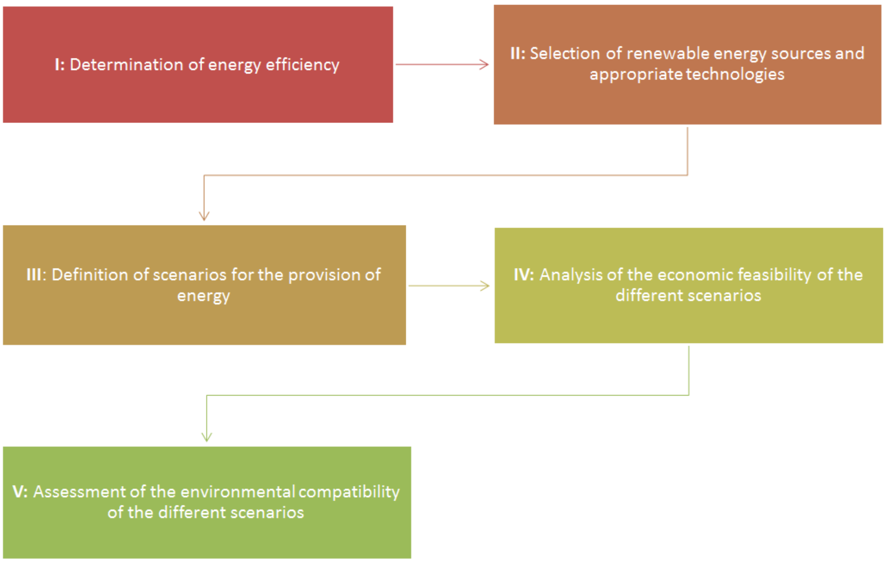
2. Background

2.1. The feasibility study 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 for making predictions about 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:

Figure 1: The five steps of the ISA method



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.

II: Suitable technologies are selected through a potential analysis that compares different renewable energy sources. Emphasis in 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 CO_2-reduction potentials is carried out for each scenario.

2.2. The Expected Benefits

The implementation of REEF2W technologies entails several advantages from an energetic, economic and environmental point of view.

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 cost**s, 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 CO_2-footprint** of WWTPs. Biogas obtained from sewage is a **more environmentally friendly biogas** compared to crop-based feedstocks. Recycling of organic waste in sewage treatment plants **replaces the CO_2-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 WTTP

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 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 new biological treatment line in commissioning phase.

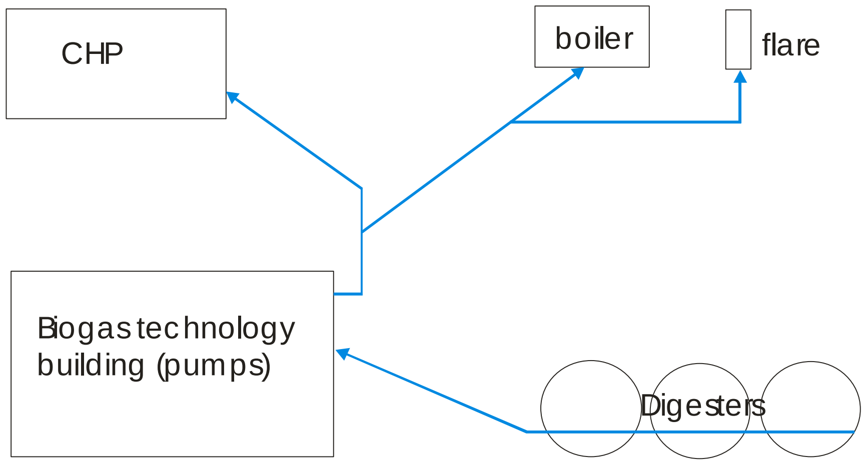
Sludge produced at both treatment lines of Prague WWTP is processed by thermophilic anaerobic digestion (AD). WWTP Prague is the largest biogas production site in Czech Republic. There is:

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



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 (Nm^3/year)	18,066,974
Electricity production (kWh/year)	32,029,000
Plant self sufficiency	75 %
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

For Prague WWTP there is biomethane unit for biogas upgrading and vehicle refuelling station designed. The biomethane plant can positively affect the energy efficiency of WWTP and reduce the air pollution generated by transport.

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

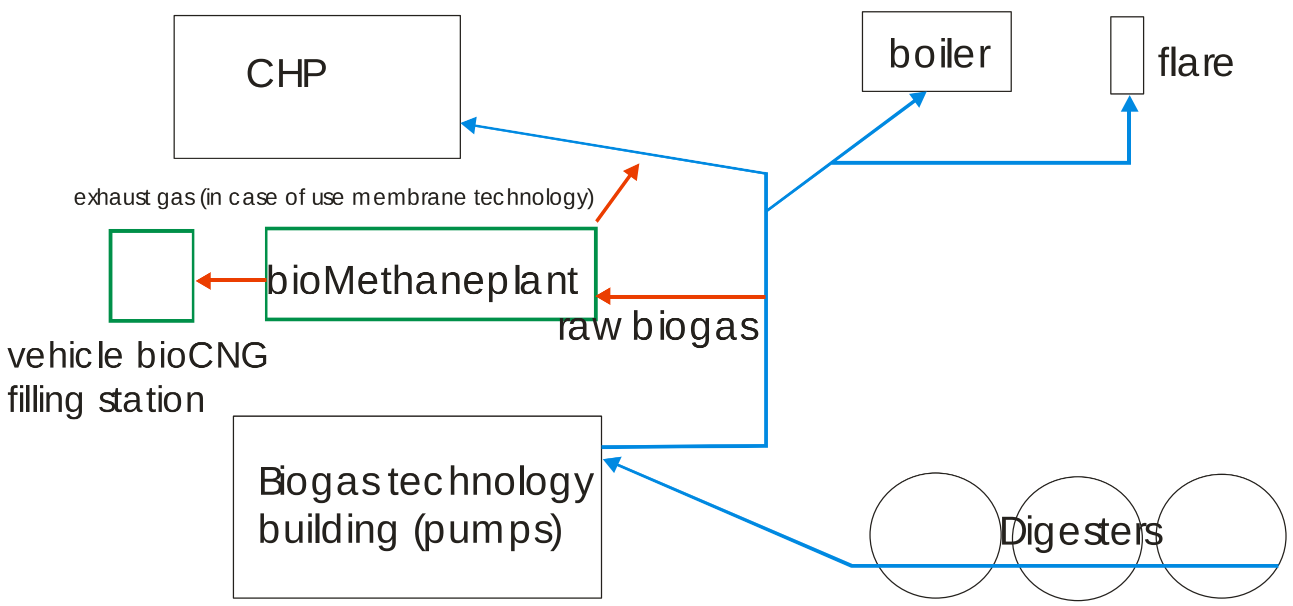
The technology consists of membrane biogas upgrading unit and bioCNG vehicle filling station.

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 - 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 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.



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 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 are 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 REEF2W TOOL.

3.4. Evaluation of energy efficiency

Current energy consumption WWTP Prague is characterized by following data.

Prague WWTP has daily capacity of 290 m^3/day of raw wastewater. Real inflow in PE equates (COD value) is 1,750,000 PE.

Total electricity consumption of the plant is about 44,000,000 kWh/year.

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

Energy 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	%

From 2019 there is new availability for utilizing more biogas in CHPs (due to grid operator agreement about electricity transfers) but we can expect more biogas production from the sludge from new water line of Prague WWTP. The self-sufficiency of WWTP will increase to 85 - 90 %.

4. Application of renewable energies and associated energy output improvements

4.1. On-site renewable energy generation

There is possible to integrate many of traditional renewable energy technologies into a Prague WWTP which can reduce the energy consumption or provide energy neutrality and independence from external energy providers. Some of this technologies are fully operated at Prague WWTP and provides the production of huge amount of renewable energy (AD with biogas production).

Prague WWTP is situated in urban area at island on Vltava river. It is very close to the city centre and residential areas. As result, there is very limited space for installing some of the technologies for renewable energy production at Prague WWTP. Therefore the biomethane production was selected as suitable solution and the feasibility of this solution is evaluated.

Biogas production: Biogas production is fully integrated to WWTP technology and provides high biogas production from sludge anaerobic digestion. Prague WWTP reaches about 75% 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.

Biomethane production:

4.2. Biogas upgrading

At Prague WWTP there is now significant overproduction of biogas that is not possible to use in CHP. CHP also produced more heat than can be used at WWTP and this heat has to be disposed by cooling especially in summer time. Biomethane production can improve energy efficiency of biogas utilisation. 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 now not available at WWTP and new connection to high pressure grid has to be realised.

Gas upgrading technology is the chosen technology for Prague REEF2W pilot and is also the possibility for the future utilisation of all Prague WWTP biogas (16 – 18 mil m^3/year) instead current CHP.

Biogas upgrading separates the raw biogas into a methane rich product stream 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. The energy consumption of these three technologies is calculated in the tool and the results are shown in the following figure.

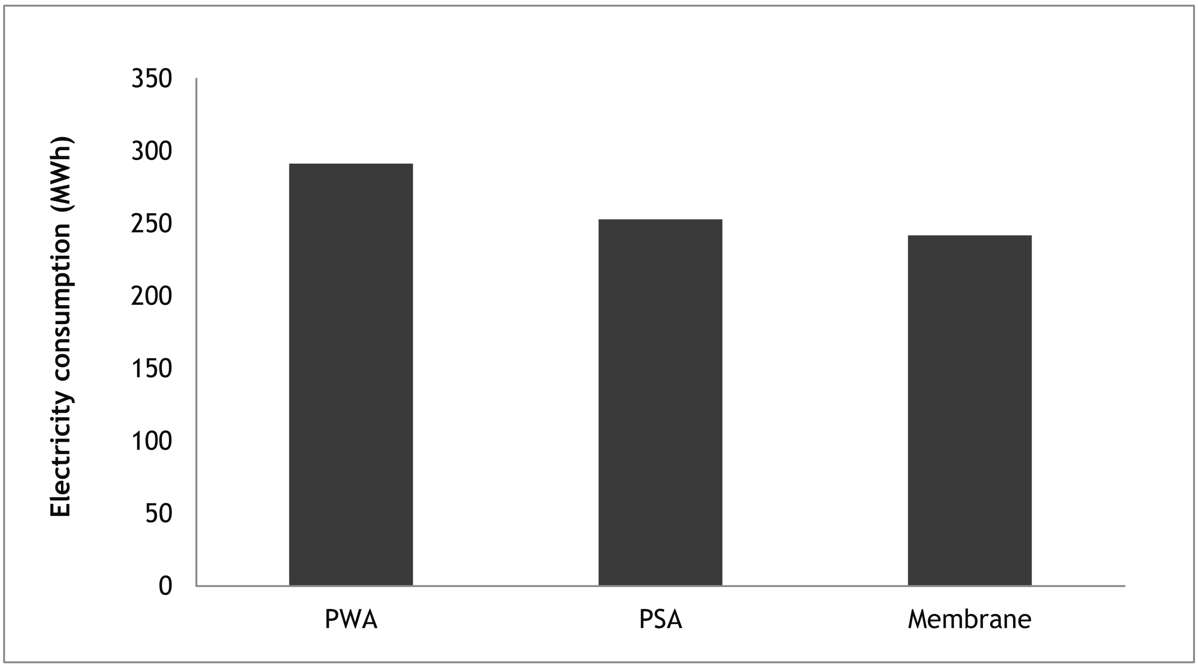


Figure 2: Comparison of electricity consumption of all three technologies

Figure 10 shows electricity consumption calculated by the TOOL of biogas upgrading unit for in pilot scale (capacity of 250 Nm^3 of biomethane).

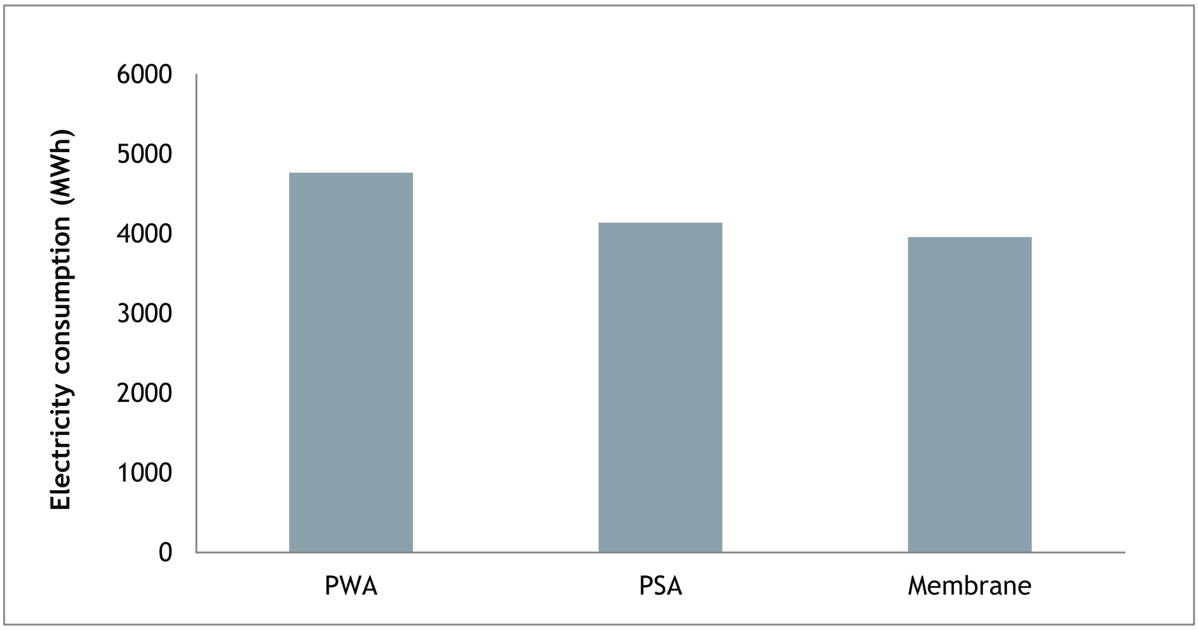


Figure 11: Comparison of electricity consumption of all three technologies

Figure 11 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.

There is significant difference between TOOL data and some case studies. Results of the TOOL favoured membrane technology in any cases despite upgrading unit capacity.

4.3. Concluding remarks

The first part of the tool (EE) can provide easy and rapid performance analysis. 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, simplified energy performance of the WWTP as well as gas production and consumption were evaluated. The result of the first part of this analysis shows that the energy consumption in Prague WWTP is within specified energy range. It is also quite interesting to observe that the calculated amounts of biogas excellently corresponds with the real production.

The second part of this analysis compared and evaluated the combination of different renewable energy technologies. The result shows that a solar plant could improve electrical energy self-sufficiency, but in very limited scale. Two other renewable technologies (solar thermal and hybrid) increase the thermal energy generation, but WWTP has already enough heat from the CHP system. The integration of renewable energy technologies can improve the energy self-sufficiency of Prague WWTP but not in current status with CHP biogas utilisation. Higher value of renewable energy can be obtained in case of remove CHP.

Thermal hydrolysis can boost the biogas production and so the energy production. Upgrading of biogas to biomethane allow the highest efficiency levels to be achieved, both in the production of electricity and in direct heat utilisation. In case of biogas upgrading technologies the tool favoured membrane technology in any case. There we can note, that in big installations, PWA and PSA are still fully competitive to membrane technologies. In case of Prague, there was case study of PSA system with 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 the WWTP. Besides, the energy neutrality can be reached by increasing energy production using new technologies such as thermal hydrolysis.

The results gained by using of the developed 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 tool cannot asses also other aspects of renewable energy sources installations – wind, solar, P2G which are affected by local conditions (river valley WWTP position, urban regulations etc.).

5. ISA of pilot in the region of Prague

5.1. Pilot and applied REEF 2W technology specification

For Prague WWTP there is biomethane unit for biogas upgrading and vehicle refuelling station designed. The biomethane plant can positively affect the energy efficiency of WWTP and reduce the air pollution generated by transport.

Due to the priorities of the project, the membrane biogas upgrading method was selected for Prague project because of lower investment costs of this technology. The technology consists of membrane biogas upgrading unit and bioCNG vehicle filling station.

Simplified scheme of status quo and Reef technology scenario is shown in Figure 5.1.

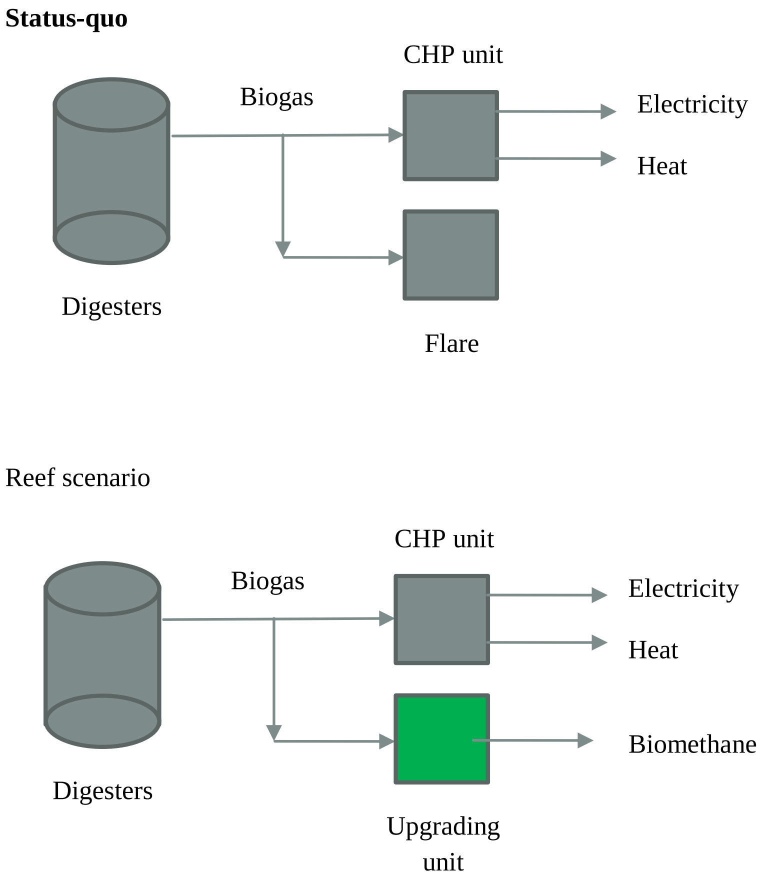


Figure 5.1. Simplified scheme of status quo and Reef technology scenario of Prague's pilot

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 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, 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 - 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 m3.

The 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.

Biogas upgrading unit will operate with 250 Nm3/hour of raw biogas. Biomethane production will be 160 Nm3/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 – currently unused biogas.

5.2. General indicator evaluation

Table 1.1: General indicators used for the pre-assessment

Sustainability criteria	General indicator	Measurement	Categories	Status Quo	REEF 2W
Availability of excess energy (Software tool N.1)	Electric excess energy provision	Difference between electric energy production and consumption in kWh	> 0 ≤ 0	≤ 0	≤ 0
	Thermal excess energy provision	Difference between thermal energy production and consumption in kWh	> 0 ≤ 0	> 0	≤ 0
	Excess digester gas provision	Difference between digester gas production and consumption in m^3	> 0 ≤ 0	≤ 0	> 0
Availability of energy consumers (Software tool N.2)	Excess electricity demand	Electricity demand in the vicinity of the WWTP and in kWh	> 0 = 0	> 0	> 0
	Excess heat demand	Heat demand in the vicinity of the WWTP and in kWh	> 0 = 0	= 0	= 0
	Excess digester gas demand	Digester gas demand in the vicinity of the WWTP and in kWh	> 0 = 0	= 0	> 0*

* biomethane in this case

Table 5.1 shows that evaluated WWTP has actually excess of heat (in some periods of the year) and part of biogas is burnt in flares. Balance of other energy sources such as electricity is negative.

Implementing biomethane production the surplus heat production for which no demand exists will be eliminated. However, biomethane will be produced which can be beneficially used for gas grid injection or as fuel in public transport.

5.3. Specific indicator evaluation

Table 2.2: Specific indicators used for ISA and their weights

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo		Weight
Environmental context	CO_2 emissions reduction for consumed electric energy (internal and external)	%	> 0 = 0	A C	C 0.69	C 0.62	0,1
	CO_2 emissions reduction for consumed gas (internal and external)	%	> 0 = 0	A C	C 0	A 0,301	0,1
	CO_2 emissions reduction for consumed thermal energy (internal and external)	%	> 0 = 0	A C	C 0.24	C 0.24	0,1
	Share of renewable electricity (internal and external)	%	> 100 100-40 <40	A B C	B 70	B 70	0,2
	Share of renewable thermal energy (internal and external)	%	> 100 100-40 <40	A B C	A	A	0,2

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo		Weight
	Share of renewable gas (internal and external)	%	> 100 100-40 <40	A B C	B	A	0,2
	Sludge production change	Delta t DM / year	<0 0 >0	A B C	B	B	0,1
Social context	Affordable energy	%	Lower Same (+-10 %) Higher	A B C	B	B	0,2
	Number of applied technologies for electric energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	C	C	0,1
	Number of applied technologies for thermal energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	B	B	0,1
	Additional employment	Change of employment, job creation or loss	<0 0 >0	A B C	B	A (1-2)	0,2
	Local environmental welfare	Indication of local welfare change	Positive Neutral Negative	A B C	B	A	0,4
Economic context	Return of Investment (ROI)	Years	<3 3-10 >10	A B C	C default	B (6,6)	0,5

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo		Weight
	Additional income	€	>0 0 <0	A B C	B	A (300000 EUR/year)	0,3
	Energy costs saving	€	>0 0 <0	A B C	B	B	0,2
Technical context (energetic & spatial)	Degree of electric self-sufficiency	Ratio between electric energy production and consumption in %	>75 25-75 <25	A B C	B (71)	B (71)	0,2
	Degree of thermal self-sufficiency	Ratio between thermal energy production and consumption in %	>100 20-100 <20	A B C	A	A	0,2
	Degree of externally usable excess heat	Ratio between heat production and consumption in %	> 0 0	A C	A	A	0,1
	Degree of usable excess gas	Ratio between gas production and consumption in %	> 0 0	A C	A	A	0,1
	Electric energy consumption at WWTP	$kWh/PE_{120}.a$	< 20 20 - 50 > 50	A B C	B (23,6)	B (23,6)	0,1
	Thermal energy consumption at WWTP	$kWh/PE_{120}.a$	<30 > 30	A C	A	A	0,1

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo		Weight
	Electric energy generation at WWTP (with anaerobic stabilisation)	$kWh/PE_{120}.a$	>20 10-20 <10	A B C	B (16,7)	B (16,7)	0,1
	Electric energy generation at WWTP (with aerobic stabilisation)	$kWh/PE_{120}.a$	>0 0	A C	NA	NA	0
	Thermal energy generation at WWTP (with anaerobic stabilisation)	$kWh/PE_{120}.a$	>40 20-40 <20	A B C	C 18,7	C 18,7	0,1
	Thermal energy generation at WWTP (with aerobic stabilisation)	$kWh/PE_{120}.a$	>0 0	A B	NA	NA	0

5.4. Suitability of indicators

In case of Prague's pilot all indicators were used, except of "Electric and thermal energy generation at WWTP with aerobic stabilisation". These two indicators are alternatively used when anaerobic digestion could not be used which is not the case of Prague's WWTP.

Calculation of values for final indicators evaluation was done partly by using of REF 2W tools, partly by using of real data from WWTP Prague

5.5. Multi-criteria decision analysis (MCDA)

To have detailed information about specific parts of ISA (social, environmental, economic and technical) are calculated separately to be used by decision makers for their own analysis and decision. The following formula was used for the evaluation of each criterion.

$$CI_{s,en,ec,tech} = \sum_{i=1}^{n} w_i \, u_i$$

where CI is the composite index of the ISA for social, environmental, economic and technical segment, w is value of indicator and u is weight of indicator.

The result of each ISA criterion is shown in the following table 5.3.

Table 5.3.: The result of multi-criteria decision analysis

Criterion	Composite Index (Status Quo)	Composite Index REEF 2W Technology
Environmental	3.2	2.4
Social	3.2	2.0
Economic	4.0	2.4
Technical	2.2	2.2

Considering the comprehensive environmental, social, economic and technical analysis, the REEF 2W technology – introduction of biomethane production - is beneficial for the selected WWTP. As shown in the table 6.3, REEF 2W scenario has the better composite index in three categories and it is equal in one of them, which means, that implementation of proposed REEF 2W solution could bring additional benefits in these fields.