D.T3.1.2

VALIDATED ISA PROCEDURE TO BE USED IN REEF 2W FEASIBILITY STUDY

Content

1. INTRODUCTION

The main aim of this deliverable is to apply ISA procedure described in D.T3.1.1 to evaluation of 5 pilots tailoring the framework conditions to specific case of each pilot. Results of ISA procedure are evaluated by an expert group of involved partners.

ISA should compare two scenarios:

a) Status quo in evaluated WWTP

b) Situation after REEF 2W technology application, using data of pilots

In the general framework of ISA there was recommended to divide evaluation into the two sections:

The first section contains relevant indicators for the pre-assessment of sustainable REEF 2W solutions, whereas the second section provides a list of specific indicators that can be used for the MCDA. With the final list of indicators, a MCDA can be carried out in order to determine the most sustainable option.

Finally Multi-criteria decision analysis (MCDA) is performed according to general procedure defined in D.T3.1.1.

2. ISA of pilot in the Emilia Romagna region

2.1. Pilot and applied REEF 2W technology specification

As stated in D.T2.3.1, the multi-utility Montefeltro Servizi srl provides environmental services to 7 municipalities in area of the High Valmarecchia valley: Novafeltria, San Leo , Talamello, Maiolo, Casteldelci, Pennabilli, and Sant'Agata Feltria. The High Valmarecchia valley is relatively large and hilly area with a low population density, located between the regions of Tuscany and Marche, the Republic of San Marino and Emilia-Romagna, to which it belongs, with a total population of about 17.000 inhabitants.

Therefore, the implementation of the wide range of technologies and processes encompassed in the REEF 2W integrated approach is strongly limited by the small dimensions of the multi-utility and by the characteristics of the waste collected. Moreover, following a regional reorganisation of waste and wastewater management, the company is no longer involved in wastewater treatment. This new situation that arose after the start of the project, further limited the possible scenarios applicable at the pilot site.

For this reason, as stated in detail in D.T2.3.1, the new model that the company wishes to evaluate is the possibility to gasifying the lignocellulosic material with the aim to produce the electricity and thermal energy necessary to cover the needs of the treatment platform. To increase the renewable energy production, the gasification process will be coupled with about 100 m^2 photovoltaic panels to be installed on the roof of the new headquarters, as required by law in Italy.

This way, it will be possible to produce a consistent amount of renewable energy at the treatment plant, in the forms of both electricity and thermal energy, with a return for the involved municipalities allowing a payback period of ranging from 5 to 10 years

The electricity will be used not only at the pilot site but also by in the 7 municipalities in their territory to partly cover their electricity demand. This will be allowed by an interesting aspect of the Italian legislation for the use of the energy produced by public bodies, with the possibility to produce electricity in any place of the Italian territory and use it in any other place of the Italian territory where the same public body has a utilization point. This is call “scambio sul posto altrove” (exchange on the site elsewhere). In the case of the Italian pilot this could be particularly interesting because the land of the treatment platform is owned by the seven municipalities and the excess of electricity produced could be used by the municipalities for all the necessities of the municipality (public lighting, provide energy at schools, and social centres, etc.).

The produced thermal energy will be only used at the pilot site due to the high costs related to the connection of the treatment area to the possible utilization sites.

2.2. General indicator evaluation

In this section, the status quo of selected Treatment plant of Montefeltro Servizi was compared with the planned REEF 2W technologies. According to D.T2.3.1, for this pre-assessment, the following cases were selected:

- Status quo: the WWTP as described in D.T2.3.1
- Scenario I: use of the biomass already available on the treatment platform without the organic fraction of municipal waste (OFMSW)
- Scenario II: available biomasses has been integrated with exhaust mushroom litter
- Scenario III: integration of all available biomasses including OFMSW

The pre-assessment was done by software tool N1 and N2 and the result are shown in table 3-1.

Table 2-1: General indicators used for the pre-assessment

Sustainability criteria	General indicator	Measurement	Categories	Status Quo	REEF 2W S I	REEF 2W S II	REEF 2W S III
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	> 0	> 0
	Thermal excess energy provision	Difference between thermal energy production and consumption in kWh	> 0 ≤ 0	≤ 0	> 0	> 0	> 0
	Excess digester gas provision	Difference between digester gas production and consumption in m³	> 0 ≤ 0	≤ 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	> 0	> 0
	Excess heat demand	Heat demand in the vicinity of the WWTP and in kWh	> 0 = 0	> 0	> 0	> 0	> 0
	Excess digester gas demand	Digester gas demand in the vicinity of the WWTP and in kWh	> 0 = 0	> 0	> 0	> 0	> 0

As shown in the table above, in the status quo there is no excess of electricity nor of excess of thermal energy whereas a surplus of both electricity and thermal energy is produced in all the envisaged scenarios. As explained in D.T2.3.1 however, SIII is the most favourable one for the produced amounts and allows an investment return time of 5–10 years. Even if the external electricity demand as well as the potential external heat demand are present, only the electricity demand can be (partially) met; the thermal energy instead will be only used at the pilot site.

2.3. Specific indicator evaluation

As explained before, the implementing the REEF 2W technologies (here in Berlin case) changes the energy flows (electric and thermal energy demand and /or production).In the table below (table 3-2), the status quo of the selected WWTP was compared with REEF2W scenarios. The comparison includes a set of indicators, which are split into four types: environmental, social, economic and technical.

Table 2-2: The comparison of sustainability criteria

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W SI	REEF 2W SII	REEF 2W SIII	Weight
Environmental context	CO_2 emissions reduction for consumed electric energy (internal and external)	kg CO2/kWh	< 0.05 1.1-0.05 > 1.1	A B C	C	C	B	B	1
	CO_2 emissions reduction for gas (internal and external)	kg CO2/kWh	< 0.22 > 0.22	A B	B	B	A	A	1
	CO_2 emissions reduction for consumed thermal energy (internal and external)	kg CO2/kWh	< 0.12 >0.23-0.12 > 0.23	A B C	C	C	C	C	1
	Share of renewable electricity (internal and external)	%	> 100 100-40 < 40	A B C	C	A	A	A	1
	Share of renewable thermal energy (external)	%	> 100 100-40 < 40	A B C	C	C	C	C	1
	Share of renewable gas (external)	%	> 100 100-40 >40	A B C	External C (0%)	External C (0%)	External B (100%)	External A(105%)	1

	Sludge production change	%	<0 0 >0	A B C	A	A	A	A	1
Social context									
	Affordable energy	%	cheaper +/-10 % more expen	A B C	C	A	A	A	1
	Number of applied technologies for electric energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	C	B	B	B	1
	Number of applied technologies for thermal energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	C	B	B	B	1
	Additional employment	Change of employment, job creation or loss	>0 0 <0	A B C	B	B	A	A	1
	Local environmental welfare	Indication of local welfare change	Positive Neutral Negative	A B C	B	A	A	A	1
Economic context	Return of Investment (ROI)	Years	<3 3-10 >10	A B C	C	C	C	B	1
	Additional income	€	>0 0 <0	A B C	B	B	A	A	1
	Energy costs saving	€	>0 0 <0	A B C	B	A	A	A	1

Technical context (energetic & spatial)	Degree of electric self-sufficiency	Ratio between electric energy production and consumption in %	>75 25-75 <25	A B C	C	A	A	A	1
	Degree of thermal self-sufficiency	Ratio between thermal energy production and consumption in %	>100 20-100 <20	A B C	C	B	A	A	1
	Degree of externally usable excess heat	Ratio between heat production and heat consumption in %	> 0 0	A B	B	B	B	B	1
	Degree of usable excess gas	Ratio between gas production and consumption in %	> 0 0	A B	B	A	A	A	1
	Electric energy consumption at WWTP	kWh/PE120.a	< 20 20 - 50 > 50	A B C	B	B	B	B	1
	Thermal energy consumption at WWTP	kWh/PE120.a	<30 > 30	A B	C	C	B	B	1
	Electric energy generation at WWTP (with anaerobic stabilisation)	kWh/PE120.a	>20 10-20 <10	A B C	N.A.	N.A.	N.A.	N.A.	
	Thermal energy generation at WWTP (with aerobic stabilisation)	kWh/PE120.a	>40 20-40 <20	A B C	N.A.	N.A-	N.A.	N.A-	
	Electric energy generation at	kWh/PE120.a	> 0 < 0	A	N.A.	N.A-	N.A.	N.A-	

	WWTP (with aerobic stabilisation)			B					
	Thermal energy generation at WWTP (with aerobic stabilisation)	kWh/PE_{120}.a	> 0 = 0	A B	N.A.	N.A-	N.A.	N.A-	

The production of renewable energy flow plays an important role for multi-criteria decision analysis (see next section). The increase in energy consumption and production affect directly the economic, ecological and technical criteria.

The weight of the indicators in the table is set equal to 1 (all the indicators have the same relevance). Different values can be set to take into account for different situations or specific needs (see next section 2.4).

2.4. Multi-criteria decision analysis (MCDA)

To have more detailed information, each specific part of ISA (social, environmental, economic and technical) are calculated separately and decision maker can use it for 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 each indicator (in our pilot the weight of indicators is set equal to 1. Appropriated values can be used in case of specific interest from municipalities to better adaptation to their needs).

The result of each ISA criterion is shown in the following table (table 2-3) for scenario 3 that is the most favourable one considering the energetic yield and the return of investment points of view. The quantitative evaluation was made by assigning numerical values to each parameter: 1 for A; 3 for B and 5 for C. The value of each index is calculated by adding the values of all relevant parameters.

A total evaluation value is then calculated by summing the relative values of the single indexes, where the better scenario corresponds to the lower sum.

Table 2-3: the result of multi-criteria decision analysis

Criterion	Composite Index (Status Quo)	Composite Index SIII
General parameters	12	8
Environmental	29	21
Social	21	9
Economic	9	5
Technical	29	15
Total evaluation	100	58

The table shows how the REEF 2W implementation allowing the production of both electricity and heat using all available biomass coupled with photovoltaic panels can improve the present situation (status quo) not only for a best composite index (58 vs 100) but also under all the single aspects: environmental, social, economic, technical.

3. ISA of pilot in the region of Berlin

3.1. Pilot and applied REEF 2W technology specification

The integrated approach envisioned in REEF 2W encompasses a wide range of technological steps and processes. Except the enrichment of sludge through bio-waste to enhance biogas yields, many of them are realized at Schönerlinde. The steps will be established to increase the biogas yield through hydrolysis and to convert biogas into bio-methane. Additionally, facilities will be installed to take lower-value electricity from the grid turning in order to turn it into hydrogen, which will be used together with carbon dioxide from biogas upgrading for generating additional bio-methane. (Figure 3.1)

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

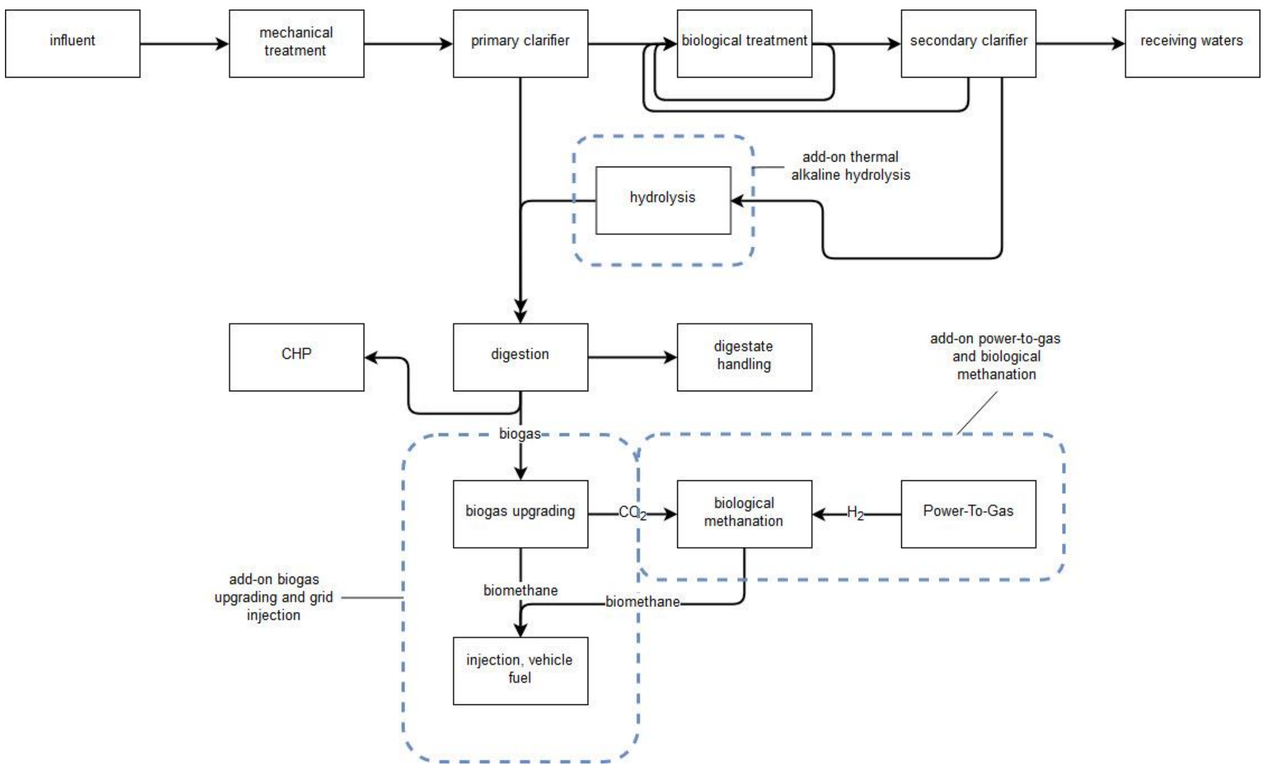


Figure 3.1: schemata of the new pilot site including the new REEF 2W technologies

Thermal Hydrolysis

- 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.

Biogas Upgrading

- A biogas upgrading unit will receive the biogas produced during anaerobic digestion and upgrade it into bio-methane. Only a small footprint is needed even in the case of upgrading the full biogas stream.

Electrolysis Unit

- 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 or can be used for the prospective ozonisation step as fourth treatment stage.

Grid Injection

- 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 bio-methane. The vessel and its accessories only have a small footprint.

3.2. General indicator evaluation

In this chapter, the status quo of selected WWTP in Berlin was compared with the implemented REEF 2W technologies. For this pre-assessment, the following cases were selected:

- Status quo: the WWTP as described in the previous section
- Scenario I: integration of thermal hydrolysis for production more biogas in status quo
- Scenario II: integration of biogas upgrading (biomethane injection)
- Scenario III: integration of biogas upgrading and PtG technology (biomethane injection)

The pre-assessment was done by software tool N1 and N2 and the result are shown in table 3-1.

Table 3-1: General indicators used for the pre-assessment

Sustainability criteria	General indicator	Measurement	Categories	Status Quo	REEF 2W S I	REEF 2W S II	REEF 2W S III
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	≤ 0	≤ 0
	Thermal excess energy provision	Difference between thermal energy production and consumption in kWh	> 0 ≤ 0	> 0	> 0	≤ 0	≤ 0
	Excess digester gas provision	Difference between digester gas production and consumption in m^3	> 0 ≤ 0	≤ 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	> 0	> 0
	Excess heat demand	Heat demand in the vicinity of the WWTP and in kWh	> 0 = 0	= 0	= 0	= 0	= 0

	Excess digester gas demand	Digester gas demand in the vicinity of the WWTP and in kWh	> 0 = 0	> 0	> 0	> 0	> 0

As shown in the table above, there is an excess of heat energy in the status quo, especially in summer due to a lower heat demand of the WWTP and overproduction in CHP system. This heat surplus is emitted in the environment, since there are not potential heat consumers and the relevant heat supply network in the vicinity of the WWTP. In the REEF 2W (SII and SIII) scenarios, there is no excess heat. Besides, the potential surplus biomethane generated at the WWTP can be utilised in the surroundings of the WWTP. However, the external electricity demand is increased in both scenarios.

3.3. Specific indicator evaluation

As explained before, the implementing the REEF 2W technologies (here in Berlin case) changes the energy flows (electric and thermal energy demand and /or production).In the table below (table 3-2), the status quo of the selected WWTP was compared with REEF2W scenarios. The comparison includes a set of indicators, which are split into four types: environmental, social, economic and technical.

Table 3-2: The comparison of sustainability criteria

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W SI	REEF 2W SII	REEF 2W SIII	Weight
Environmental context	CO_2 emissions reduction for consumed electric energy (internal and external)	%	> 0 = 0	A C	A (79%)	A (95%)	C (0)	C (0)	0.2
	CO_2 emissions reduction for consumed thermal energy (internal and external)	%	> 0 = 0	A C	A (90%)	A (100%)	C (0)	C (0)	0.1
	Share of renewable electricity (internal and external)	%	> 100 100-0 0	A B C	B (82%)	B (90%)	C (0%)	C (0%)	0.2
	Share of renewable thermal energy (internal and external)	%	> 100 100-0 0	A B C	A (162%)	A (162%)	C (0%)	C (0%)	0.1

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W SI	REEF 2W SII	REEF 2W SIII	Weight
	Share of renewable gas (external)	%	> 100 100-0 0	A B C	External C (0%)	External C (0%)	External B (100%)	External A(105%)	0.3
	Sludge production change	Delta t DM / year	<0 0 >0	A B C	B	A	B	B	0.1
Social context									
	Affordable energy	%	Lower Same (+-10 %) Higher	A B C	B	B	B	B	0
	Number of applied technologies for electric energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	B	B	C	C	0.2
	Number of applied technologies for thermal energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	B	B	C	C	0.2
	Additional employment	Change of employment, job creation or loss	>0 0 <0	A B C	B	B	B	A	0.3
	Local environmental welfare	Indication of local welfare change	Positive Neutral Negative	A B C	B	A	A	A	0.3
Economic context	Return of Investment (ROI)	Years	<3 3-10 >10	A B C	B	B	A	C	0.4

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W SI	REEF 2W SII	REEF 2W SIII	Weight
	Additional income	€	>0 0 <0	A B C	B	B	B	B	0.3
	Energy costs saving	€	>0 0 <0	A B C	A	A	B	C	0.3
Technical context (energetic & spatial)	Degree of electric self-sufficiency	Ratio between electric energy production and consumption in %	>75 25-75 <25	A B C	A (84%)	A (95%)	C(0%)	C(0%)	0.2
	Degree of thermal self-sufficiency	Ratio between thermal energy production and consumption in %	>100 20-100 <20	A B C	B(95%)	A(105%)	C(0%)	C(0%)	0.2
	Degree of externally usable excess heat	Ratio between heat production and consumption in %	> 0 0	A C	C	A (40%)	C	C	0.1
	Degree of usable excess gas	Ratio between gas production and consumption in %	> 0 0	A C	C	C	A	A	0.3

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W SI	REEF 2W SII	REEF 2W SIII	Weight
	Electric energy consumption at WWTP	kWh/PE120.a	< 20 20 - 50 > 50	A B C	B (29)	B (29)	B (29)	B (29)	0.05
	Thermal energy consumption at WWTP	kWh/PE120.a	<30 > 30	A C	A (14)	A (14)	A (14)	A (14)	0.05
	Electric energy generation at WWTP (with anaerobic stabilisation)	kWh/PE120.a	>20 10-20 <10	A B C	A (21)	A (24)	C (0)	C (0)	0.05
	Thermal energy generation at WWTP (with anaerobic stabilisation)	kWh/PE120.a	>40 20-40 <20	A B C	B 25.8	B (29)	C (0)	C (0)	0.05

The change in energy flow plays an important role for multi-criteria decision analysis (see next chapter). The increase / decrease in energy consumption and production affect directly the economic, ecological and technical criteria.

An important part of the above table is the weighting of the selected indicators.

3.4. Multi-criteria decision analysis (MCDA)

To have detailed information about specific parts of ISA (social, environmental, economic and technical) will be calculated separately and decision maker can use it for own analysis and decision (see chapter 8). 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 (table 3-3).

Table 3-3: the result of multi-criteria decision analysis

Criterion	Composite Index (Status Quo)	Composite Index	Composite Index SII	Composite Index

		SI		SIII
Environmental	2.8	2.8	4.2	3.6
Social	3	2.4	3.2	2.6
Economic	2.4	2.4	2.2	4.4
Technical	3.4	2.4	3.5	3.5

Considering the comprehensive energetic, social and economic analysis, scenario SI (CHP + thermal hydrolysis) is recommended as the most sustainable and future-proof option for the selected WWTP. As shown in the table above, the scenario SI has the best composite index in these categories, which means, both technologies (CHP and thermal hydrolysis) could bring additional benefits in all views. From an ecological point of view, biogas upgrading will become more interesting in the future to contribute to climate policy. The net GWP is heavily influenced by the electrical consumption from the grid and its substitution depending on the used energy mix. Electrical energy generated by using biogas in the CHP unit (status quo) is more beneficial in GWP than the biomethane credits generated from the same amount of biogas (SII). Similarly, PtG (SIII) is not worthwhile in environmental terms, also because biogas use for electricity production is more beneficial than substituting natural gas in the grid.

It is also observed that a combination of PtG technology (SIII) in the selected WWTP offers the investor no advantage over the scenarios without this technology. This technology severely increases the investment risk. Currently, the lack of support scheme for this technology makes this concept uneconomical.

4. ISA of pilot in the region of Linz

4.1. Pilot and applied REEF 2W technology specification

The REEF 2W pilot site in Austria is located approximately 200 km west of Vienna and 40 km south-west of Linz, comprising the municipalities of “Wallern an der Trattnach” and “Bad Schallerbach”. North-east of the village centre of Wallern an der Trattnach the Wastewater treatment plant (WWTP with 74,000 PE) “RHV Trattnachtal” is located. The pilot site, including the WWTP and its surroundings, serves as an example to realize the REEF 2W solution of recovering thermal excess energy from WWTPs.

In this context, figure 4.1 illustrates a simplified scheme of the REEF 2W solution. Currently there are two digester towers in operation, providing biogas to a CHP unit. Considering the annual energy balance, the WWTP provides surplus electricity as well as thermal energy. Due to this fact surplus electricity (provided by the CHP unit) could be used to operate a heat pump, thus recovering thermal energy from the effluent of the WWTP. Since an initial evaluation of the energetic context in the two municipalities already showed that there is sufficient head demand in the surroundings, the REEF 2W solution of installing a heat pump in the effluent of the WWTP was followed and is evaluated in more detail in the subsequent ISA.

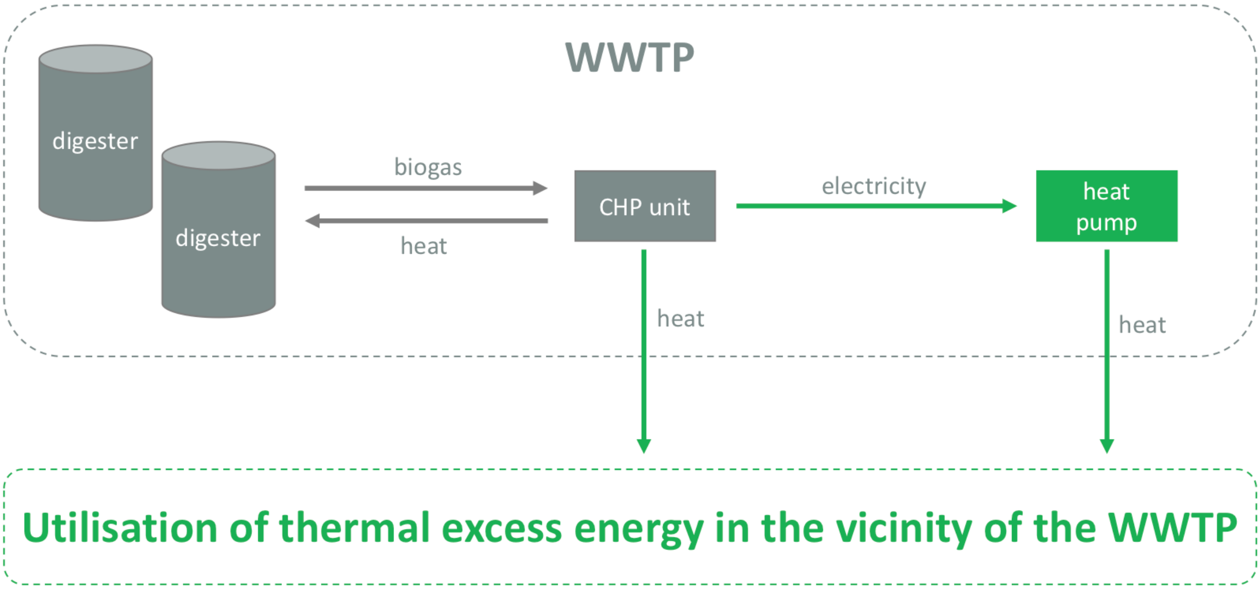


Figure 4.1: Simplified scheme for the REEF 2W solution at the pilot site in Austria

The following subchapters start with a pre-assessment evaluating general indicators presented and described in Deliverable 3.1.1., followed by a calculation of specific indicators and a corresponding multi-criteria analysis. Derived data for the evaluation can be found in the previous REEF 2W deliverables and in the recent publications by Neugebauer et al. (2019) and Zach et al. (2019).

4.2. General indicator evaluation

As described in D.T3.1.1 the “indicator pyramid” serves as a basis for the hierarchical approach of the ISA. On the pre-assessment level general indicators are evaluated which are presented in the following table (see table 4.1). Further, the results are differentiated between the Status Quo (current situation) and the applied REEF 2W solution at the pilot site.

Table 4.1: General indicators used for the pre-assessment at the pilot site in Austria

Sustainability criteria	General indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W solution	Explanations on classification
Availability of excess energy (Software tool N.1)	Electric excess energy provision	Difference between electric energy production and consumption in kWh	> 0 ≤ 0	A B	A	B	Staus Quo: 1.7 GWh excess electricity REEF 2W solution: 3.1 GWh additional external electricity demand
	Thermal excess energy provision	Difference between thermal energy production and consumption in kWh	> 0 ≤ 0	A B	A	A	Staus Quo: 0.5 GWh REEF 2W solution: 14.5 GWh
	Excess digester gas provision	Difference between digester gas production and consumption in m^3	> 0 ≤ 0	A B	B	B	In both scenarios surplus is not available, due to the utilisation of gas for thermal energy
Availability of energy consumers (Software tool N.2)	Excess electricity demand	Electricity demand in the vicinity of the WWTP and in kWh	> 0 = 0	A B	A	A	The WWTP is connected to the electricity grid and electricity demand is given in the municipalities and settlements nearby.
	Excess heat demand	Heat demand in the vicinity of the WWTP and in kWh	> 0 = 0	A B	A	A	Heat demand is already given within a radius of 1 km from the WWTP. First spatial assessments indicate more than 10 GWh/a heat demand in selected hotspots in the neighbouring municipalities.
	Excess digester gas demand	Digester gas demand in the vicinity of the WWTP and in kWh	> 0 = 0	A B	A	A	Gas demand in the vicinity of the WWTP is given. Additionally, gas networks stretch across the two pilot municipalities.

It can be seen that in the status-quo a surplus of electricity is given (“A” rating). If a heat pump is applied, additional electricity will be needed resulting in a “B” rating for the REEF 2W solution. However, due to the heat pump application, even more thermal excess energy can be provided in the future. The produced digester gas by the CHP unit is entirely used for thermal energy provision, therefore there is no excess digester gas available. Electricity, heat as well as gas demand is above zero in all scenarios.

4.3. Specific indicator evaluation

Based on the pre-assessment level the actual assessment using specific indicators is followed. Results of the general assessment indicates that a further evaluation of the specific criteria can be followed. Table 4.2 shows the evaluated sustainability criteria that are split into: Environmental, social, economic and technical criteria. Unfortunately, it was not possible to assess each indicator in “Status Quo” due to the character of some indicators that imply a “change” in order to be evaluated. In this context, the column “Comments on indicator application” specify the emerging problems during the indicator evaluation.

Table 4.2: Results of specific sustainability indicators for the pilot in Austria

Sustainability criteria	Indicator	Measurement	Categories	Grad-uation	Status Quo	REEF 2W solution	Explanations on classification	Comments on indicator application
Environmental context	CO_2 emissions reduction for consumed electric energy (internal and external)	%	> 0 = 0	A B		A	Status-Quo: no tool result REEF 2W solution: 0.59 kg CO_2/kWh (tool result)	Alternative categories (also previously agreed on): <0.05 kg CO_2/kWh; 1.1-0.05 kg CO_2/kWh; 1.1 kg CO_2/kWh. Regarding the Graduation, the “C” was changed to “B”

Sustainability criteria	Indicator	Measurement	Categories	Grad-uation	Status Quo	REEF 2W solution	Explanations on classification	Comments on indicator application
	CO_2 emissions reduction for consumed thermal energy (internal and external)	%	> 0 = 0	A B		A	Status-Quo: no tool result REEF 2W solution: 0.23 kg CO_2/kWh (tool result)	Alternative categories (also previously agreed on): <0.22 kg CO_2/kWh; > 0.22 kg CO_2/kWh Regarding the Graduation, the "C" was changed to "B"
	Share of renewable electricity (internal and external)	%	> 100 100-0 0	A B C	A	B	Status-Quo: Result "A" due to the surplus of electricity provided by the CHP unit REEF 2W solution: Due to the additional electricity demand caused by the heat pump, the share of renewable electricity will be below 100% - considering the national electricity mix.	Share of renewable electricity "external" is not possible. Alternative categories (also previously agreed on): >100; 100-40; <40
	Share of renewable thermal energy (internal and external)	%	> 100 100-0 0	A B C	A	A	Status-Quo: Result "A" due to the surplus of heat provided by the CHP unit REEF 2W solution: After applying the heat pump, even more surplus heat can be provided.	Alternative categories (also previously agreed on): >100; 100-40; <40
	Share of renewable gas (external)	%	> 100 100-0 0	A B C				Since CO_2 emissions reduction for Gas was also removed, it is suggested to also remove this indicator.
	Sludge production change	Delta t DM / year	<0 0 >0	A B C	N/A	B	Due to heat pump application there is no change in sludge production.	There can be no change in the status quo.

Sustainability criteria	Indicator	Measurement	Categories	Grad-uation	Status Quo	REEF 2W solution	Explanations on classification	Comments on indicator application
Social context	Affordable energy	%	Lower Same (+-10 %) Higher	A B C	N/A	N/A		Before applying this indicator, It is necessary to specify energy (electricity, heat). The wording of the categories suggests a "change". Comparison to EU or national specific? From our point of view, it is not possible to compare both.
	Number of applied technologies for electric energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	B	B	Status Quo: Currently only CHP unit at the WWTP REEF 2W solution: Also, in the future only CHP unit at the WWTP	
	Number of applied technologies for thermal energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	B	B	Status Quo: Currently only the CHP unit at the WWTP REEF 2W solution: Besides the CHP unit also heat pump application to recover heat from the effluent	
	Additional employment	Change of employment, job creation or loss	>0 0 <0	A B C	N/A	B	Status Quo: N/A REEF 2W solution: Based on cautious considerations it is assumed that there will be no additional employment	There can be no "additional employment" in the current situation.
	Local environmental welfare	Indication of local welfare change	Positive Neutral Negative	A B C	N/A	A	Status Quo: N/A REEF 2W solution: Due to central heat supply via district heating no additional emissions at consumer site resulting in a positive rating.	Same as previous indicator, there can be no "local welfare change" in the current situation.

Sustainability criteria	Indicator	Measurement	Categories	Grad-uation	Status Quo	REEF 2W solution	Explanations on classification	Comments on indicator application
Economic context	Return of Investment (ROI)	Years	<3 3-10 >10	A B C	N/A	C	Status Quo: N/A REEF 2W solution: Based on experience from previous heat recovery applications (e.g. Amstetten, Austria) the ROI is estimated to be slightly above 10 years.	It is not possible to assess this indicator, because there is no investment in the status quo. Evaluation in tool still missing
	Additional income	€	>0 0 <0	A B C	N/A	A	Status Quo: N/A REEF 2W solution: It is assumed that if heat is recovered that there will be additional income due to selling the heat to heat consumers in the vicinity of the WWTP.	The wording "additional" income implies a change; hence the calculation is not possible in Status Quo. Evaluation in tool still missing
	Energy costs saving	€	>0 0 <0	A B C	N/A	A	Status Quo: N/A REEF 2W solution: Currently the digester towers are refurbished (insulation). Hence, energy costs will be saved. Also, excess energy from heat recovery will be sold after applying the REEF 2W solution.	The wording implies a change; N/A in Status Quo. Evaluation in tool still missing
Technical context (energetic & spatial)	Degree of electric self-sufficiency	Ratio between electric energy production and consumption in %	>75 25-75 <25	A B C	A	B	Status Quo: Excess electricity available (1.7 GWh) REEF 2W solution: Considering the future electricity consumption of the heat pump, a degree of electric self-sufficiency of 55% can be reached.	
	Degree of thermal self-sufficiency	Ratio between thermal energy production and	>100 20-100	A B	A	A	Status Quo: 0.5 GWh surplus REEF 2W solution: 14.5 GWh surplus	

Sustain ability criteria	Indicator	Measurement	Categories	Grad-uation	Status Quo	REEF 2W solution	Explanations on classification	Comments on indicator application
		consumption in %	<20	C				
	Degree of externally usable excess heat	Ratio between heat production and consumption in %	> 0 0	A B	B	A	Status Quo: Currently the excess heat is not sufficiently used. REEF 2W solution: After applying a district heating network and supplying external consumers the degree of usable excess heat will be >0	The term “externally usable excess heat” should be changed. Regarding the Graduation, the “C” was changed to “B”
	Degree of usable excess gas	Ratio between gas production and consumption in %	> 0 0	A B	B	B	Status Quo: No biogas upgrading or feed-in station REEF 2W solution: No biogas upgrading or feed-in station planned	Regarding the Graduation, the “C” was changed to “B”
	Electric energy consumption at WWTP	$kWh/PE_{120}.a$	< 20 20 - 50 > 50	A B C	B	N/A	Status Quo: 41 $kWh/PE_{120}.a$ maximum performance REEF 2W solution:	The benchmarks according to Lindtner are values for conventional WWTPs, not including technologies like co-fermentation or heat pump applications. The question is how to implement benchmarks for the REEF 2W solution.
	Thermal energy consumption at WWTP	$kWh/PE_{120}.a$	<30 > 30	A B	B	N/A	Status Quo: 46 $kWh/PE_{120}.a$ maximum performance REEF 2W solution:	Regarding the Graduation, the “C” was changed to “B” The benchmarks according to Lindtner are values for conventional WWTPs, not including technologies like co-fermentation or heat pump applications. The question is how to implement benchmarks for the REEF 2W solution.

Sustain ability criteria	Indicator	Measurement	Categories	Grad-uation	Status Quo	REEF 2W solution	Explanations on classification	Comments on indicator application
	Electric energy generation at WWTP (with anaerobic stabilisation)	$kWh/PE_{120}.a$	>20 10-20 <10	A B C	A	N/A	Status Quo: 75 $kWh/PE_{120}.a$ maximum performance REEF 2W solution:	The benchmarks according to Lindtner are values for conventional WWTPs, not including technologies like co-fermentation or heat pump applications. The question is how to implement benchmarks for the REEF 2W solution.
	Thermal energy generation at WWTP (with anaerobic stabilisation)	$kWh/PE_{120}.a$	>40 20-40 <20	A B C	A	N/A	Status Quo: 57 $kWh/PE_{120}.a$ maximum performance REEF 2W solution:	The benchmarks according to Lindtner are values for conventional WWTPs, not including technologies like co-fermentation or heat pump applications. The question is how to implement benchmarks for the REEF 2W solution.

From an environmental point of view, additional electricity is required for the operation of the heat pump. However, the amount of excess heat of 14.5 GWh (mainly from heat recovery) can be interpreted as the main environmental benefit of the REEF 2W solution. Simultaneously the social benefits of the REEF 2W scenario outweigh the current situation. For example, the number of applied technologies for thermal energy provision increases or the local environmental welfare is positively influenced. Although additional income, due to the disposal of surplus heat in the REEF 2W scenario, will be generated, the Return on Investment (ROI) of the heat pump application shows a rather poor rating “C”.

4.4. Multi-criteria decision analysis (MCDA)

The following table (table 4.3) shows the results of the first ISA application for both "Status Quo" and the "REEF 2W solution". The assigned colours were used to underline the alphabetical graduation in order for decision makers to easily identify where improvements are required or on the contrary where the WWTP is performing comparably well. The results indicate that the performance of the WWTP is already promising. For instance, the heat pump application of the REEF 2W solution only affects the electric excess energy provision.

Table 4.3: Overview and visualisation of general indicator results for the pilot in Austria

General indicator	Categories	Graduation	Status Quo	REEF 2W solution
Electric excess energy provision	> 0 ≤ 0	A B	A	B
Thermal excess energy provision	> 0 ≤ 0	A B	A	A
Excess digester gas provision	> 0 ≤ 0	A B	B	B
Excess electricity demand	> 0 = 0	A B	A	A
Excess heat demand	> 0 = 0	A B	A	A
Excess digester gas demand	> 0 = 0	A B	A	A

Table 4.4 shows the results of the specific indicators. Some cells are empty, because either the indicator description or the categories were not clear enough for a detailed evaluation. Cells, containing the abbreviation "N/A", are subject to other complications, details described in table 4.3 in the reference column "Comments on indicator application".

Table 4: Overview and visualisation of indicator results for the pilot in Austria

Indicator	Categories	Graduation	Status Quo	REEF 2W solution
CO_2 emissions reduction for consumed electric energy (internal and external)	> 0 = 0	A B		A
CO_2 emissions reduction for consumed thermal energy (internal and external)	> 0 = 0	A B		A
Share of renewable electricity (internal and external)	> 100 100-0 0	A B C	A	B
Share of renewable thermal energy (internal and external)	> 100 100-0	A B	A	A

Indicator	Categories	Graduation	Status Quo	REEF 2W solution
	0	C		
Share of renewable gas (external)	> 100 100-0 0	A B C		
Sludge production change	<0 0 >0	A B C	N/A	B
Affordable energy	Lower Same (+-10 %) Higher	A B C	N/A	N/A
Number of applied technologies for electric energy provision (*Resilience*)	3 1-2 0	A B C	B	B
Number of applied technologies for thermal energy provision (*Resilience*)	3 1-2 0	A B C	B	B
Additional employment	>0 0 <0	A B C	N/A	B
Local environmental welfare	Positive Neutral Negative	A B C	N/A	A
Return of Investment (ROI)	<3 3-10 >10	A B C	N/A	C
Additional income	>0 0 <0	A B C	N/A	A
Energy costs saving	>0 0 <0	A B C	N/A	A
Degree of electric self-sufficiency	>75 25-75 <25	A B C	A	B
Degree of thermal self-sufficiency	>100	A	A	A

Indicator	Categories	Graduation	Status Quo	REEF 2W solution
	20-100 <20	B C		
Degree of externally usable excess heat	> 0 0	A B	B	A
Degree of usable excess gas	> 0 0	A B	B	B
Electric energy consumption at WWTP	< 20 20 - 50 > 50	A B C	B	
Thermal energy consumption at WWTP	<30 > 30	A C	B	
Electric energy generation at WWTP (with anaerobic stabilisation)	>20 10-20 <10	A B C	A	
Thermal energy generation at WWTP (with anaerobic stabilisation)	>40 20-40 <20	A B C	A	

A weighing of each indicator and an aggregation to a single resultant value is not followed for the Austrian case study. Considering one final resultant value implies that an inferior rating can be compensated by a better rating. For instance, a good rating in the "sludge production change" could overrule a bad performance in "share of renewable thermal energy". Therefore, the decision maker should consider all individual results of the indicators. In this context it is possible to consign the decision entirely to the decision maker.

References

Neugebauer, G., Lichtenwöhrer, P., Kretschmer, F., Stöglehner, G., Langergraber, G. (2019) Integrale Bewertung von Kläranlagen als lokale Energiezellen. Wiener Mitteilungen 251, I1-I12.

Zach, F., Lichtenwöhrer, P., Neugebauer, G., Kretschmer, F. (2019): REEF 2W Machbarkeitsstudie - Fallbeispiel RHV Trattnachtal. Wiener Mitteilungen 251, K1-K11.

5. ISA of pilot in the region of Prague

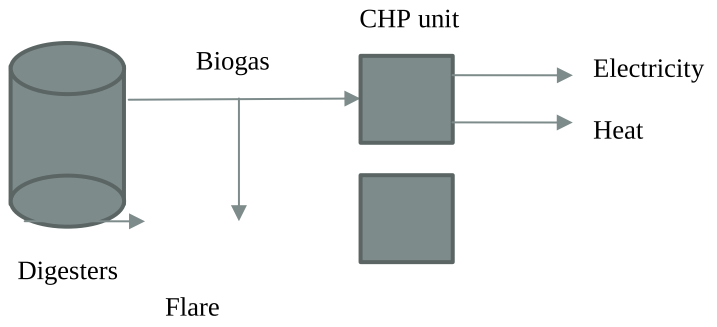
5.1. Pilot and applied REEF 2W technology specification

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.

Status-quo



Reef scenario

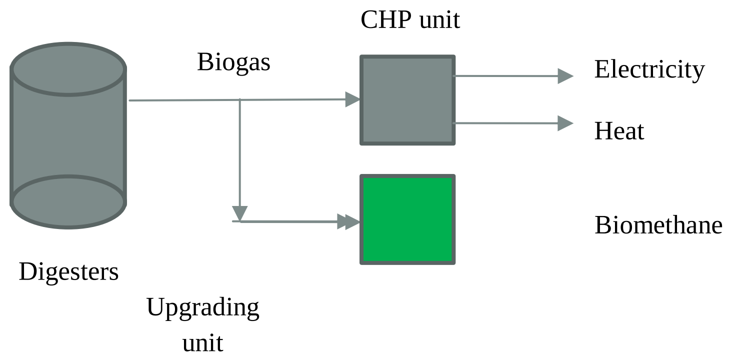


Figure 5.1.

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 5.1: 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 6.2: Specific indicators used for ISA and their weights

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W	Weight
Environmental context	CO_2 emissions reduction for consumed electric energy (internal and external)	%	> 0 = 0	A C	C 0.69	C 0.62	
	CO_2 emissions reduction for consumed gas (internal and external)	%	> 0 = 0	A C	C 0	A 0,301	
	CO_2 emissions reduction for consumed thermal energy (internal and external)	%	> 0 = 0	A C	C 0.24	C 0.24	
	Share of renewable electricity (internal and external)	%	> 100 100-40 <40	A B C	B 70	B 70	
	Share of renewable thermal energy (internal and external)	%	> 100 100-40 <40	A B C	A	A	
	Share of renewable gas (internal and external)	%	> 100 100-40 <40	A B C	B	A	
	Sludge production change	Delta t DM / year	<0 0 >0	A B C	B	B	
Social context	Affordable energy	%	Lower	A B	B	B	

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W	Weight
			Same (+-10 %) Higher	C			
	Number of applied technologies for electric energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	C	C	
	Number of applied technologies for thermal energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	B	B	
	Additional employment	Change of employment, job creation or loss	<0 0 >0	A B C	B	A (1-2)	
	Local environmental welfare	Indication of local welfare change	Positive Neutral Negative	A B C	B	A	
Economic context	Return of Investment (ROI)	Years	<3 3-10 >10	A B C	C default	B (6,6)	
	Additional income	€	>0 0 <0	A B C	B	A (300000 EUR/year)	
	Energy costs saving	€	>0 0 <0	A B C	B	B	
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)	
	Degree of thermal self-sufficiency	Ratio between thermal	>100 20-100	A B	A	A	

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W	Weight
		energy production and consumption in %	<20	C			
	Degree of externally usable excess heat	Ratio between heat production and consumption in %	> 0 0	A C	A	A	
	Degree of usable excess gas	Ratio between gas production and consumption in %	> 0 0	A C	A	A	
	Electric energy consumption at WWTP	kWh/PE_{120}.a	< 20 20 - 50 > 50	A B C	B (23,6)	B (23,6)	
	Thermal energy consumption at WWTP	kWh/PE_{120}.a	<30 > 30	A C	A	A	
	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)	
	Electric energy generation at WWTP (with aerobic stabilisation)	kWh/PE_{120}.a	>0 0	A C	NA	NA	
	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	
	Thermal energy generation at WWTP (with aerobic stabilisation)	kWh/PE_{120}.a	>0 0	A B	NA	NA	

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.

6. ISA of pilot the region of Zagreb

6.1. Pilot and applied REEF 2W technology specification

The WWTP Zabok is in its construction phase and will be built in 2020 with the capacity of 36.940 PE, and will be consisted of these stages:

- *Prior purification* – separation of particles
- *Second stage* - consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface.
- *Third stage* - removes dissolved and suspended biological matter, as well as dehydration of the sludge.

The schematic overview of the WWTP Zabok is presented in the figure 6.1.

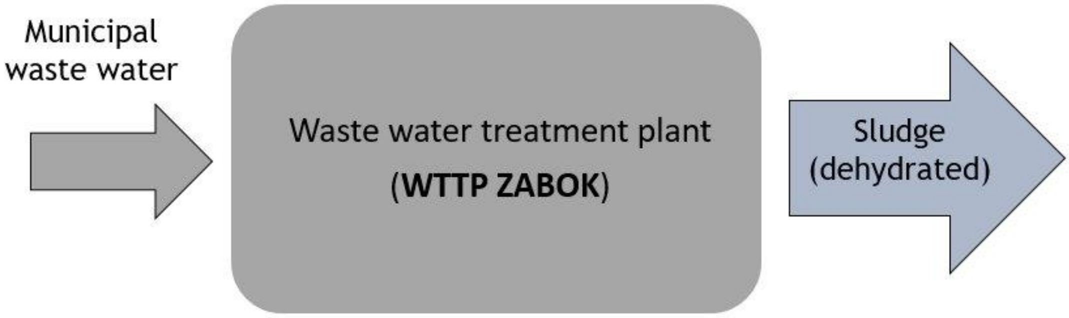


Figure 6.1. Overview of the WWTP Zabok

Within the REEF2W solution, a pilot case has been developed in order to utilize the separately collected biowaste, as well as the sustainable usage of produced sludge. The WTTP in its full capacity will be producing 1.117,5 tonnes of dehydrated sludge. The proposed REEF2W solution is presented in the figure 6.2. Main aspects of this proposal are: possibility to use biowaste fraction of municipal waste, anaerobic treatment, utilization of biogas, and application of digestate as a soil improver.

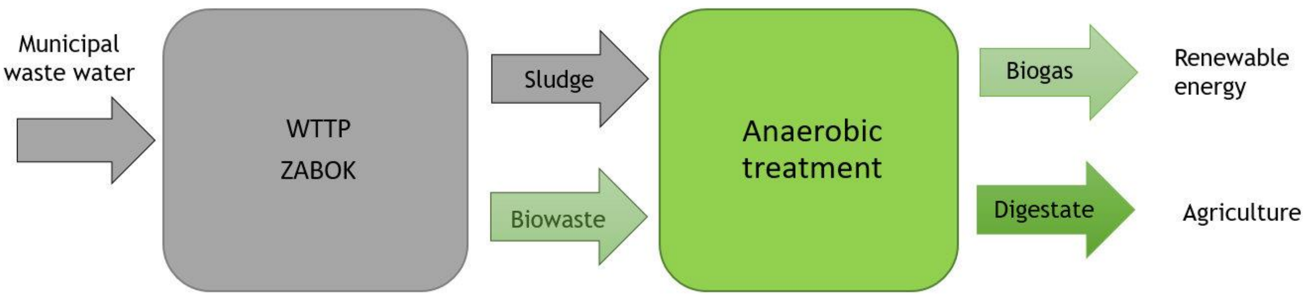


Figure 6.2. REEF2W solution for WWTP Zabok

The combined treatment of waste and waste water is one of the main benefits of the proposed REEF2W solution. The main idea behind this proposal is to successfully utilize separately collected biowaste with current waste water treatment. This extension will also result in a production of renewable energy.

6.2. General indicator evaluation

Table 6.1: 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

6.3. Specific indicator evaluation

Table 6.2: Specific indicators used for ISA and their weights

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W	Weight
Environmental context	CO_2 emissions reduction for consumed electric energy (internal and external)	%	> 0 = 0	A C	C	A	0,1
	CO_2 emissions reduction for consumed gas	%	> 0 = 0	A C	C	A	0,1

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W	Weight
	(internal and external)						
	CO_2 emissions reduction for consumed thermal energy (internal and external)	%	> 0 = 0	A C	C	A	0,1
	Share of renewable electricity (internal and external)	%	> 100 100-40 <40	A B C	C	B	0,2
	Share of renewable thermal energy (internal and external)	%	> 100 100-40 <40	A B C	C	B	0,2
	Share of renewable gas (internal and external)	%	> 100 100-40 <40	A B C	C	C	0,2
	Sludge production change	Delta t DM / year	<0 0 >0	A B C	B	C	0,1
Social context	Affordable energy	%	Lower Same (+-10 %) Higher	A B C	B	B	0,1
	Number of applied technologies for electric energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	C	B	0,25
	Number of applied technologies for thermal energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	C	B	0,25

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W	Weight
	Additional employment	Change of employment, job creation or loss	>0 0 <0	A B C	B	A	0,30
	Local environmental welfare	Indication of local welfare change	Positive Neutral Negative	A B C	B	B	0,1
Economic context	Return of Investment (ROI)	Years	<3 3-10 >10	A B C	C	C	0,4
	Additional income	€	>0 0 <0	A B C	B	B	0,3
	Energy costs saving	€	>0 0 <0	A B C	B	A	0,3
Technical context (energetic & spatial)	Degree of electric self-sufficiency	Ratio between electric energy production and consumption in %	>75 25-75 <25	A B C	C	B	0,2
	Degree of thermal self-sufficiency	Ratio between thermal energy production and consumption in %	>100 20-100 <20	A B C	C	B	0,2
	Degree of externally usable excess heat	Ratio between heat production and consumption in %	> 0 0	A C	C	C	0,1
	Degree of usable excess gas	Ratio between gas production and consumption in %	> 0 0	A C	C	C	0,1

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W	Weight
	Electric energy consumption at WWTP	$kWh/PE_{120}.a$	< 20 20 - 50 > 50	A B C	B	B	0,1
	Thermal energy consumption at WWTP	$kWh/PE_{120}.a$	<30 > 30	A C	A	A	0,1
	Electric energy generation at WWTP (with anaerobic stabilisation)	$kWh/PE_{120}.a$	>20 10-20 <10	A B C	C	B	0,1
	Thermal energy generation at WWTP (with anaerobic stabilisation)	$kWh/PE_{120}.a$	>40 20-40 <20	A B C	C	C	0,1

All indicators were or calculated using REEF 2W tool or using the data provided by WWTP operator, except of the social indicators which were determined or estimated based on proposed technological changes.

6.4. 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 (table 6.3.).

Table 6.3.: The result of multi-criteria decision analysis

Criterion	Composite Index (Status Quo)	Composite Index REEF 2W Technology
Environmental	4.8	3.0
Social	4.0	2.4
Economic	3.8	3.2
Technical	4.4	3.4

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

7. Summary

Suggested ISA procedure proposed In DT 3.1.1 was validated in five countries for five different technologies. It was proved that ISA is suitable tool for evaluation of the sustainability of proposed solution.

However in each specific case the ISA must be modified according specific local conditions, limitations. On the other hand this flexibility of ISA and opportunity of tailor-made tool are the main advantages of the ISA.

It was found that further improvement of ISA is possible regarding the indicators for the reduction of CO_2 emissions, the definition of the indicators is still not fully clear (indicator description, measurement and classification), there occur differences between the several approaches.

Concerning the set of specific sustainability indicators the addition of a new column in table 2 for further comments is proposed in Austrian chapter, the first column with comments contains explanations on the classifications and the second comments on the indicator application, where some further adaptations are still possible.

This improvements will be applied in Feasibility studies DT 3.3.1-2-3-4-5.