D.T.3.3.1 FEASIBILITY STUDY ON "INCREASED ENERGY EFFICIENCY FOR A WASTE TREAMENT PLANT THROUGH BIOGAS PRODUCTION"

Project Title: REEF 2W—Increased renewable energy and energy efficiency by integrating, combining and empowering urban wastewater and organic waste management systems

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1. Introduction

The purpose of this deliverable is to set up a comprehensive feasibility study on the Montefeltro Servizi pilot case by putting together the previous 4 steps: assessment of the soundness of the pilot in terms of renewable energy production and of the suitability of its location, taking into account the urban context as well as relevant environmental and social aspects (steps 1 & 2, see D.T2.3.1); analysis of the financial options for implementing the pilot (step 3, see D.T3.2.1); Integrated Sustainability Assessment (ISA) applied to the pilot (step 4, see D.T3.1.2).

As said in other deliverables, following a renovation at regional level, Montefeltro Servizi no longer manages wastewater treatment plants; therefore, the pilot on "revamping of sludge line in Montefeltro Servizi" proposed in the AF was changed on "Increased energy efficiency for a waste treatment plant through biogas production". Thanks to this approach, the REEF 2W implementation has proved feasible and convenient even in case of a very small multi-utility like Montefeltro Servizi.

2. Background

2.1. The feasibility study methodology

The REEF 2W tool is used to systematically assess technical innovations for energy optimisation of waste management plants and 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 that 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.

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, sales, investment, and maintenance costs.

V: To assess the environmental impacts, a Life Cycle Assessment (LCA) that focuses on CO_2-reduction potentials is carried out for each scenario.

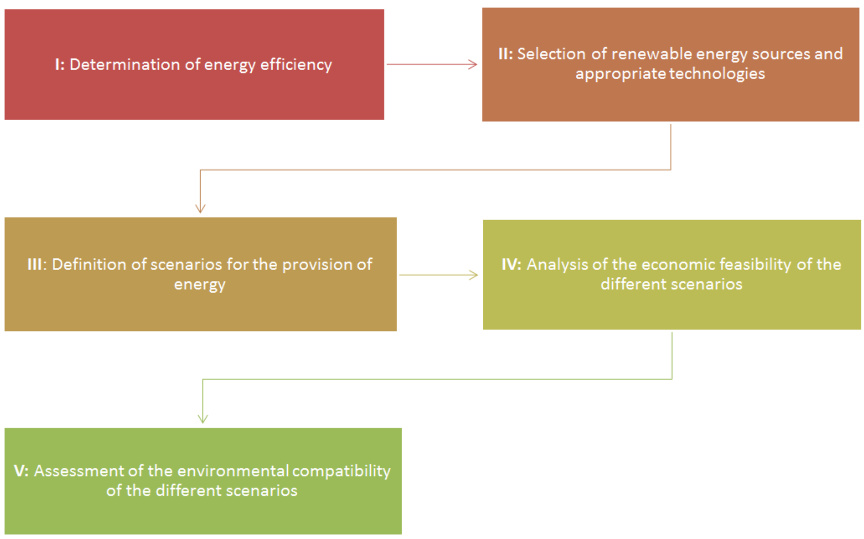

Figure 1: The five steps of the ISA method

2.2. The Expected Benefits

The implementation of REEF 2W 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 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 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 Waste treatment plant

The High Valmarecchia is located between the regions of Tuscany and Marche, the Republic of San Marino and Emilia-Romagna, to which it belongs.

The High Valmarecchia is relatively large and hilly with a low population density.

Montefeltro Servizi is a multi-utility that provides environmental services in the area for all the seven municipalities in the valley with a total population of about 17.000 inhabitants.

Due to a recent change in the 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, determined a modification of the possible scenarios applicable at the pilot site. For this reason, the model presented in the project application form is no more valid.

At present, the company only manages the waste produced in the area and sorts and delivers it to specialised centres for the final disposal. This work is done in an area owned by all the seven municipalities.

The collected waste contains a large proportion of dry organic waste that cannot be used for anaerobic digestion and must be stabilized in the composting process. Composting is a well-known and energy-intensive process that in the specific case of Montefeltro Servizi is conducted in another plant several kilometres away from the collection point. To reduce the number of transports from one end of the valley to the other, and to valorise the energy content of the organic waste, the company has decided to investigate the possibility of using a gasification process to recover thermal and electric energy from the organic waste.

To increase the energy production potential, not only the collected dry organic material was considered, but also the availability of other lignocellulosic materials collected from agricultural or industrial activities.

For this reason, 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.

3.2. Technology upgrade of the pilot

At this moment, any environmental technology is applied to reduce the energetic impact of the treatment technologies at the treatment site.

In the meantime, there is a plan by the company to reallocate different working sites and offices in one place to optimise space and working time. For this reason, there is a strong interest in the evaluation of the possibility to identify technologies capable of recovering energy from collected wastes. Gasification technology represents one of the most probable options, as it can be used with locally available material, offers the possibility of combining electricity and heat recovery, and can be switched on and off as required.

The other interesting aspect of the gasification process is that the end products are ash and biochar. The advantage of this treatment technology is the reduction of volume and weight of the input material during the treatment. The ashes could provide inorganic elements that can be reused in agriculture. If this is not possible, the ash could also be disposed as a stable material in landfills or used as an inert material in building or road construction.

Biochar, on the other hand, is a carbon concentrate that can be used in agriculture to return the carbon to neighbouring lands.

The electricity produced could be used for the different appliances in the treatment platform. The heat could be used for heating the offices during winter time and all year round to warm up the water in the worker's sanitary facilities.

At this stage, it is not yet decided which specific gasification technology will be applied. This will strongly depend on the current evaluation. But it is clear that gasification is the only possible technology that can be applied at the pilot site at this moment under the conditions under consideration.

The organic material available for gasification at that moment will consist of the organic fraction of the municipal solid waste, the excess sludge of the WWTPs, and brushwood. The available amount of these materials is not very large and for this reason the company has carried out a survey of the territory to evaluate alternative available substrates.

3.3. Data availability and quality

Since Montefeltro Servizi is in charge of waste collection at local level, the company have an historical data collection of the available quantities of different types of waste collected. For the organic waste some data are summarized in the following table.

Type of waste	Tons per year
MFOSW	405,98
Prunings	261,51
Exhaust vegetal oil	1,58

The company has already conducted a survey of the energy consumption (electricity and heat) of the different production facilities and offices. The result of the survey highlighted the following average values per year: 17.247 kWh of electricity and 2117 SCM of methane, equivalent to about 80400MJ or 22.400 kWh.

As already mentioned, due to the limited amount of available waste and the level of investment costs, the company conducts a survey on the availability of other sources for organic waste in the territory. One of the best options offered by a farm that produces cultivated mushrooms. This farm generates every week about 16 tons of exhaust litter that must be disposed. At the moment, these 16 tons are distributed directly to the surrounding cultivated fields. But, as the costs for transport, spreading, and burial of the litter are relatively high, the farm is looking for alternative solutions. As the litter consists mainly of lignocellulosic materials, the opportunity to use the litter in a gasification process seems interesting.

3.4. Energy performance of pilot

The assessment of the energy performance is obtained by comparing the current situation with the expected one after the realization of the pilot.

The current energy consumption at the Montefeltro Servizi treatment plants is as follows (see the previous paragraph 3.3):

Total electricity consumption of the plants is about 17.247 kWhe/year;

Total thermal energy consumption of the plants is about 22.400 kWht/year, produced by using about 2.100 cubic meters of methane.

Presently, there is no energy production at the plant. The expected situation after the pilot implementation is completely different (see below): the production of about 1070 MWhe will allow Montefeltro Servizi to become from consumer to net producer of energy. In particular, the production of 19,52 MWh of photovoltaic will cover practically all its electricity needs, allowing to use the production of 1050 MWhe from biogas for other needs, whereas the production of about 1200 MWh of thermal energy will cover all the thermal energy needs in the absence of external users.

4. Application of renewable energies and associated energy output improvements

4.1. On-site renewable energy generation through traditional technologies

Among the variety of traditional renewable energetic technologies, such as photovoltaic, biogas production, wind energy, hydropower, hybrid collectors, and solar thermal available on the market, at this moment at the OFMSW in Novafeltria only photovoltaic and gasification technologies are applicable. Photovoltaic is a technology that can be considered because the probable available roof space in the new building will be sufficient to install this technology. The feasibility of using the gasification process has already been discussed on the previous chapters, and is directly related to the new situation the company is facing in these years. On the other hand, this new situation determines the need to evaluate the possibilities to reduce costs and environmental impacts, where the REEF 2W Tool can help.

Photovoltaic: At this moment, there aren’t possibilities to install photovoltaic panels as well as to do an assessment of their installation, because it doesn’t exist a draw of the new space availability for the new productive site of the company. One can only assume that photovoltaic technology will be installed on the roof of the new headquarters, as required by law in Italy. The area available for installation should be about 100 m^2.

Biogas production: due to the amount and quality of the waste collected this is not a technology that can be considered for the near future.

Wind energy: local legislation doesn't allow the installation of wind turbines in the valley according to the environmental evaluation. Furthermore, the valley doesn't have a very interesting wind profile. Due to these considerations, this technology will not be applied.

Hydropower: After wastewater treatment plant operation separation, there is no more for the company of the sewage wastewater available, furthermore in any case the limited amount of wastewater collected doesn't allow to consider this kind of technology applicable.

Solar hybrid collector: It is feasible to equip the roof surfaces that were intended for the installation of photovoltaic panels with hybrid collectors. Hybrid collectors have the advantage that they produce heat at the same time as electricity. However, this is in competition with the recoverable heat from the gasification process. Since only a limited amount of heat is required on the WWTP, the authors recommend limiting the technology upgrade to photovoltaic panels to keep investment costs low.

Solar thermal energy: For the same reasons as for solar hybrid collectors, this technology is not considered.

Gasification: The gasification process is the only evaluable process with the data available. The general consideration done on the applicability of this process at the pilot site are related to the quality of biomass available and the possibility to switch it on and off in a very short time. Compared to other technologies, this provides the possibility to produce energy when it is requested, without having to store it or feed it into the public grid.

4.2. Evaluation of renewable energy generation.

This section will provided a brief analysis on the advantages of renewable energy use in the treatment platform of Montefeltro Servizi according to the results obtained using the REEF 2W Tool.

As already mentioned, the results are based on the actual energy consumption provided by the company and take into account the possibility of installing photovoltaic panels on the roof area of $100m^2$ and a gasification system that can be used with the available organic waste. Three different scenarios are considered:

- In the first scenario, only the biomass already available on the treatment platform without the organic fraction of municipal waste (OFMSW) has been considered.
- In the second scenario, available biomasses has been integrated with exhaust mushroom litter.
- In the third scenario, all available biomasses including OFMSW were considered.

At the moment energy consumption of the pilot is limited by the public supplier due to the limited availability of gas and electricity. The following graph shows the total energy consumption in kWh and in standard cubic meters (SCM). For a simpler comparison of the two values, SCM is given in kWh equivalent.

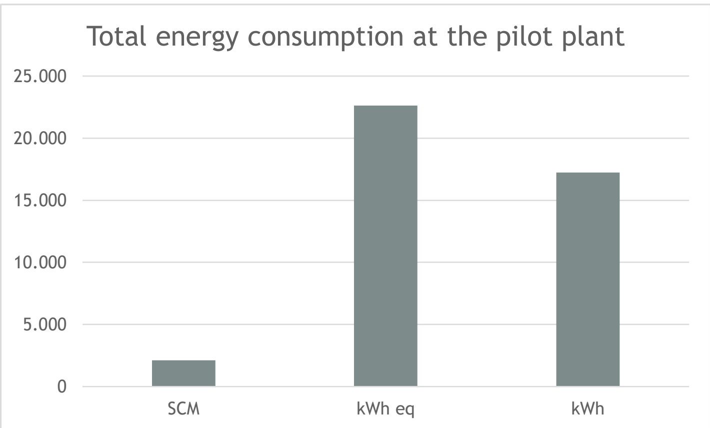

Fig. 1: Actual energy consumption at Pilot plant

Applying the tool to the Italian pilot site, taking into account the already available biomass and the energy production from the possibility to install photovoltaic panels, the following result is obtained:

The changes in energy generation are shown in the following figures according to the tool results:

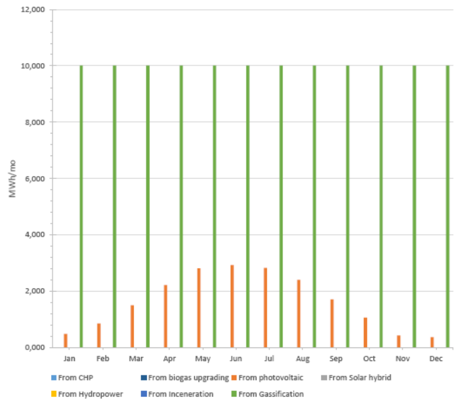

Fig. 2: Results of the energy production from available biomasses without OFMSW

The potential energy produced by photovoltaic panels could reach the value of 19.52 MWh per year. This amount would be sufficient to cover almost four fifths of the company's total energy consumption.

Furthermore, the energy recoverable from biomass gasification is 10.08 MWh per year in form of electricity and 19.80 MWh year in form of thermal energy.

Considering all values, the total energy producible in the pilot site could be 127 MWh per year in form of electricity and 119 MWh year in form of thermal energy.

In the second scenario, an integration of the already mentioned biomasses with the mushroom litter was considered.

In the second hypothesis, with the integration of mushroom litter, the results are the following:

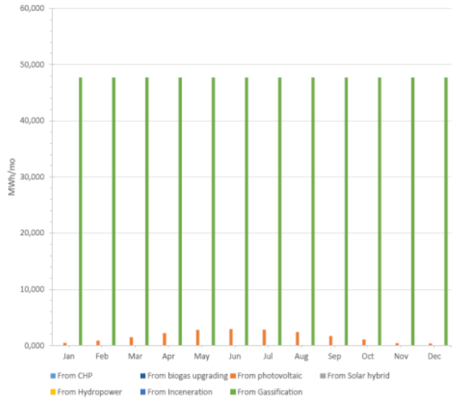

Fig. 3: Results of the energy production from available biomasses plus the litter

The total available energy could be about 515 MWh per year in form of electricity and about 570 MWh per year in form of thermal energy.

For the third scenario, which also includes OFMSW in the process, the results are presented in the following graphic:

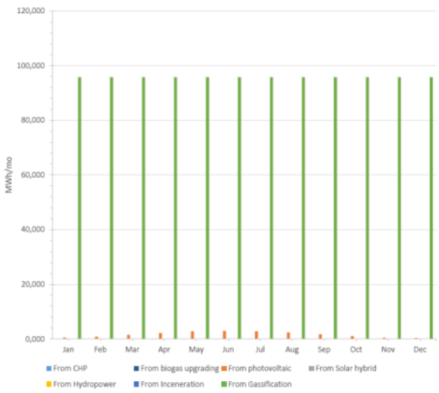

Fig. 4 Results of the energy production from available biomasses

From the latter scenario it can be seen that a potential energy production of about 1025 MWh per year in form of electricity and 1136 MWh per year in form of thermal energy would be possible.

5. Evaluation of further assessment

5.1. Spatial Assessment

If the possibility to sale the electric energy at the grid it is possible and it could provide an economic advantage, the possibility of selling the generated thermal energy to third parties is much more complicated due to the orographic situation of the valley and the long distances that must be overcome. From the different evaluation done, the maximum connection density obtained is 1.5 MWh/m. This value requires further and more detailed analysis.

No data are available for the industrial areas nearest to the plant, so a specific heat release value of 1200 MWh/y was assumed for the two identified areas.

The total length of the pipeline is about 3.5 km serving two different industrial areas of 5 and 20 ha.

These scenarios result in a connection density of about 0.31MWh/(m y), which is significantly lower than the suggested values necessary for a more deep evaluation of the application.

As can be seen, the reason for this difficulty is directly related to the length of the connection necessary to connect the treatment area with the nearest industrial area. Unfortunately, at the moment there is any other possibility to use the produced heat.

5.2. Environmental assessment

The environmental assessment of the considered solutions shows a strong advantage in terms of reduction of carbon emissions. In the assessment, only the electric energy produced and eventually introduced in the grid has been considered. The reason for this choice is directly related to the spatial assessment done that reports a strong disadvantage for the use of heat. Consequently, considering only this aspect, more than 19.000 tons of CO_2eq could be removed, if the gasification of the biomasses can be applied.

5.3. Economic assessment

The pilot case in the Emilia Romagna region was conceived by Montefeltro Servizi in the framework of a general renovation plan of both the waste collection service and the internal organization. The objectives of the renovation plan are as follows:

Improvement of the waste collection service taking into account the peculiarities of the territory, with a door-to-door collection, thereby overcoming the percentage of separate waste collection envisaged by the regional plan: from the present 43,7% to 74,0%.

Development and valorization of the society, equipping it with facilities for the management of integrated waste cycle;

Optimization of the collection rates undertaking in the same time the whole waste cycle management.

The plan includes investments for new vehicles and facilities for about Euro 2.300.000, covered by bank loans at an annual rate of 3%, repayable in 7 years.

The pilot case proposed by Montefeltro Servizi fits wery well in this context. From one hand the renovation plan improves both the quantity and the quality of the organic waste, from the other hand the REEF 2W installation, as can be seen in the next paragraphs, has the potential for producing an amount of renewable energy to generate savings that can contribute to lower the collection rates. This way, the Emilia Romagna pilot can represent a sustainable model for small multi-utilities serving dispersed communities.

5.3.1. Estimation of costs for the pilot plant

With reference with D.T2.3.1 where three different scenarios are assessed for the gasification of biomass and production of electricity and thermal energy, in the present analysis we consider scenario III only. In fact, scenario III optimizes the quantity of biomass available for the gasification process integrating all the biomass available: the organic fraction of municipal waste (OFMSW), prunings deriving from the maintenance of public green and from mowing of brushwood along the banks of rivers, exhaust mushroom litter coming from an enterprise of the territory, the excess sludge of three small WWTPs. Moreover, this is the only scenario with the potential of generating a substantial economic return.

In addition, the proposed pilot is completed by about 100 m^2 of photovoltaic panels to be installed on the roof of the Montefeltro Servizi headquarters, as required by law in Italy. In recent years, in Italy photovoltaic plants have had a rapid drop in costs due to booming market growth and have now stabilized. Features and costs of a plant like that under consideration are as follows:

Surface	100 m^2
Power peak	20 KW
Energy produced yearly	19,52 MWh
Cost of plant	Euro 32.000
Cost of the accumulation system	Euro 13.000
Other costs	Euro 5.000
Total cost	Euro 50.000

The cost of a system for the production of syngas starting from biomass, aimed at producing both electricity and thermal energy, greatly depends on the specific features of the system. We have made a careful market analysis concerning the major producers in Italy, the results of which are shown below for a system matching the requirements of the Emilia Romagna pilot:

Nominal electric power	150 KW
Annual operating hours	7000
Biomass drying system	yes
Flue gas filtering system	yes
Electricity yearly production	1050 MWhe
Thermal energy yearly production	1200 MWht
Cost of plant	Euro 600.000
Installation cost	Euro 200.000
Total cost	Euro 800.000

Therefore, the estimation of the total cost of the plants for the pilot in Emilia Romagna is of Euro 850.000.

5.3.2. Estimation of revenues/savings

The economic return of a plant producing renewable energy strongly depends on the level of incentives and from the legislative framework.

Considering the electricity production, economic advantage can be generated by selling the electric energy at the grid or directly use it. For the Emilia Romagna pilot the most favourable option is to directly use it thanks to a specific measure provided by the Italian legislation called "scambio sul posto altrove" (exchange on the site elsewhere). Based on this regulation, public bodies can produce electricity in any place of the Italian territory and use it in any other place where the same public bodies have a utilization point. In our case of the place where the electricity will be produced, that is the Montefeltro Servizi treatment platform is directly owned by the seven municipalities and the excess of electricity produced can be used by the same municipalities for all their electricity needs (public lighting, provide energy at schools, and social centres, etc.).

The present yearly average electricity consumption of Montefeltro Servizi to run the offices and the treatment facilities is of about 17,25 MWh and even the future needs can be mainly covered by the electricity produced by photovoltaic plant.

Therefore, the excess production of 1050 MWhe from the gasification plant will be used by the 7 municipalities. Presently, they collectively use about 6722 MWh per year, with a cost of Euro 1.210.000 and an average cost of Euro 0,18 per KWh. The pilot plant can thus generate savings for about Euro 189.000 per year.

Concerning the thermal energy produced by the gasification plant, the configuration of the territory and the distribution of possible utilization points the make it not convenient to distribute the heat towards public buildings/facilities or private users. Therefore, it will be used only partly in the Montefeltro Servizi facilities.

5.3.3. Funding opportunities

The Energy Efficiency Directive encourages Public Administrations to use Energy Performance Contracts (EPC) when planning energy efficiency initiatives. This kind of Public Private Partnerships between local public administrations and energy service companies (ESCO) is also supported by the Emilia Romagna regional administration (see http://energia.regione.emilia-romagna.it/low-carboneconomy/temi/imprese-energetiche-esco/esco).

However, after contacting some regional ESCOs, and after considering the services offered by those companies, Montefeltro Sertvizi, in agreement with the 7 municipalities decided not to use EPC for the possible implementation of the pilot.
Indeed, the most convenient option seems to be to negotiate with the same bank that granted the mortgage necessary for the renovation plan a further mortgage for additional Euro 850.000. In this case, with a five-year mortgage at the same conditions, the annual

repayment installment should be of Euro 185.000, easily covered by the annual saving for the electricity costs, with a payback period of 5 years.Estimation of revenues/savings

6. ISA of pilot in the Emilia Romagna region

6.1. 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.Discussion & Conclusion

6.2. General indicators 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 5-1.

Table 5-1: 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

6.3. Specific indicators evaluation

As explained before, the implementing the REEF 2W technologies changes the energy flows (electric and thermal energy demand and /or production). In the table below (table 5.2), the status quo of the selected waste plant in Emilia-Romagna was compared with REEF2W scenarios. The comparison includes a set of indicators, which are split into four types: environmental, social, economic and technical.

Table 5.2: Specific indicators used for ISA and their weights

Sustainability criteria	Indicator	Measurement	Categories	Gradution	Status Quo	REEF 2W SI	REEF 2W SII	REEF 2W SIII	Weight
Enviental 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 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/PE$_{120}$.a	< 20 20 - 50 > 50	A B C	B	B	B	B	1
	Thermal energy consumption at WWTP	kWh/PE$_{120}$.a	<30 > 30	A B	C	C	B	B	1
	Electric energy generation at WWTP (with anaerobic stabilisation)	kWh/PE$_{120}$.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/PE$_{120}$.a	>40 20-40 <20	A B C	N.A.	N.A-	N.A.	N.A-	
	Electric energy generation at WWTP (with aerobic stabilisation)	kWh/PE$_{120}$.a	> 0 < 0	A B	N.A.	N.A-	N.A.	N.A-	
	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 5.4).

6.4. 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.

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

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 5-3) 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 5-3: 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

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100) but also under all the single aspects: environmental, social, economic, technical.

7. Discussion & Conclusion

The analysis with the REEF 2W tool and methodologies shows that the pilot in Emilia-Romagna proposed by the multiutility Montefeltro Servizi can produce an excess of renewable electricity by using a local gasification system fed by already available biomass, coupled with a photovoltaic plant.

The analysis also shows that the excess thermal energy produced by the power unit can be only be used to a small extent, for the internal needs of Montefeltro Servizi, because the lack of users in the immediate vicinity of the pilot and the high installation costs make its use not convenient considering the quantities involved.

The most favourable option for the pilot is the direct use of the excess electricity by the seven municipalities that own the plant thanks to a specific measure provided by the Italian legislation called “scambio sul posto altrove” (exchange on the site elsewhere). Based on this regulation, public bodies can produce electricity in any place of the Italian territory and use it in any other place where the same public bodies have a utilization point. In our case of the place where the electricity will be produced, that is the Montefeltro Servizi treatment platform is directly owned by the seven municipalities and the excess of electricity produced can be used by the same municipalities for all their electricity needs (public lighting, provide energy at schools, and social centres, etc.).

This makes particularly convenient the investment of the pilot, for which the investment costs will be easily covered by the annual saving for the electricity costs, with a payback period of 5 years.