D.T3.1.1

# DOCUMENT DESCRIBING GENERAL FRAMEWORK OF CONDITIONS FOR ISA

*“Collection of relevant models in a guiding document to demonstrate in an easy, comprehensive and direct way the benefits (economic and environmental) of implementation of REEF 2W plants”*

## Content

# 1. INTRODUCTION

“The decision support framework for integrated sustainability assessment will be established and shown the use of sustainability indicators via a multi-criteria decision analysis to determine the most sustainable options.”

## 1.1. Background

Integrated Sustainability Assessment (ISA) is an approach to evaluate the complex and multidimensional matter of sustainability, simultaneously requiring a multicriterial approach (Buytaert et al. 2011). In order to better understand the complexity of sustainability assessment an overview with regard to different features, as summarised in Hacking and Guthrie (2008), is presented. According to their study, features of sustainable development can be described on three axes: (1) **Strategicness** of the focus and scope, (2) **Comprehensiveness** of the coverage and (3) **Integratedness** of the techniques and themes. Within in this three-dimensional scheme, the characteristics of sustainability assessment can be described as strategic and broad focused (Feature No.1), covering all sustainability-related ‘themes’ (Feature No.2) and following combined/compared assessment techniques (Feature No.3). In contrast to sustainability assessment and within the same scheme, Hacking and Guthrie (2008) describe “conventional” environmental impact assessments as project-specific with a narrow focus (Feature No.1), covering only the bio-physical environment (Feature No.2) and following a separate assessment technique (Feature No.3). The scheme is visualised in Figure 1.

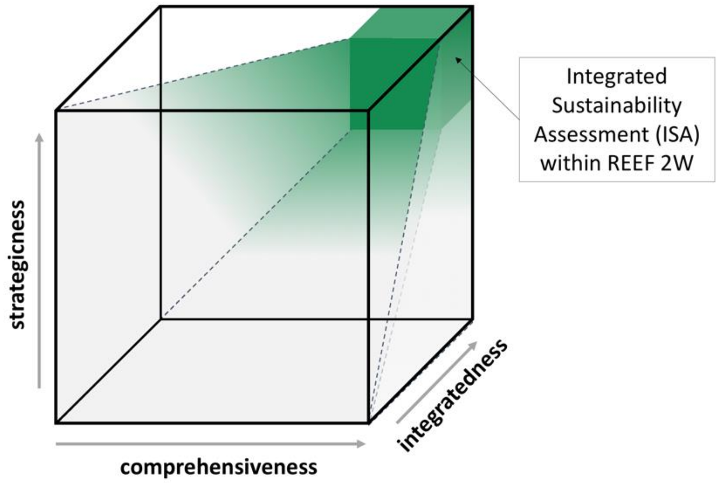


**Figure 1: Scheme features of sustainable development (after Hacking and Guthrie 2008).**

Hence, also the developed ISA-approach in the REEF 2W project follows a strategic assessment, covers multiple aspects of sustainability (including the three-pillar concept) and integrates various assessment techniques e.g. Energy Efficiency (EE) Environmental Assessment (EA), Urban Compatibility Assessment (UCA), etc..

Before defining sustainability in the context of REEF 2W and deriving relevant sustainability indicators for the Multi-Criteria Decision Analysis (MCDA) a brief overview of the multi-perspective approach of the ISA Framework within the research project is given.

## 1.2. ISA framework established for REEF 2W

As described in D.T1.5.1 the ISA approach is based on four perspectives: (1) Energetic, (2) Spatial, (3) Environmental and (4) Economic (see Figure 2 and also see D.T1.5.1). The energetic context of the WWTP can be further split into two parts: Energy Efficiency (EE) and Renewable Energy Sources (RES). The proposed methodology can also be seen as steps on how to examine the feasibility of WWTPs as local energy supply systems. Initially, the energy consumption of the WWTP has to be optimized (see EE section and Software tool N.1) and additional resources at the WWTP have to be used in an efficient way (see RES section and software tool N.1) in order to provide an energy surplus that can be used in the vicinity of the WWTP (see UCA section and software tool N.2) in an economically feasible (CBA section) and environmentally friendly (EA section) way (also see D.T1.4.3 and D.T1.5.4).

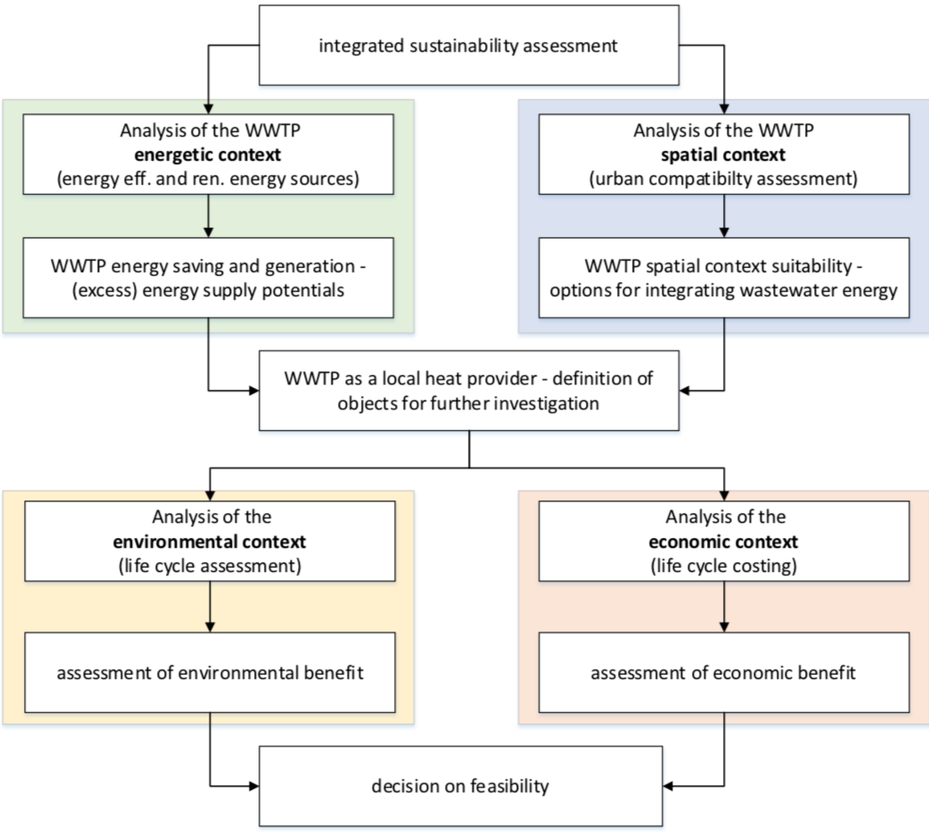


**Figure 2: Overview Integrated Sustainability Assessment – ISA in the REEF 2W project (own illustration)**

The structure of the ISA approach (see Figure 2) is also used for this deliverable. Based on the four ISA-perspectives and the previously developed Software tools the multi-criteria decision analysis (MCDA) can be followed. The methodological approach from the general ISA-concept to the MCDA is presented in this deliverable. Additionally, relevant sustainability indicators are developed at the end of this document.

## 1.3. REEF 2W objectives and sustainability assessment

According to Pope et al. (2004) sustainability assessment can be based on the three-pillar concept of sustainability, emphasizing equal importance to (1) environmental, (2) social and (3) economic aspects in decision-making. The basic idea of the three-pillar concept can be used as a starting point to develop relevant sustainability criteria. Thus, the defined criteria in this deliverable can be used for the sustainability assessment and likewise for the multi-criteria decision analysis (MCDA). The same three-pillar concept was also recently applied for a sustainability assessment of wastewater treatment technologies, using a multi-criteria analysis (see Plakas et al. 2016).

By focusing on the central aim of the assessment - "To determine whether or not an initiative is actually sustainable" (Pope et al. 2004, 608) - a detailed definition of sustainability is required beforehand. Also Buytaert et al. (2011) highlight the necessity of defining sustainability beforehand, since different assessment approaches might be relevant, depending on the direction of the research project. In order to define sustainability in the context of the REEF 2W-project, it is essential to revisit the goals of REEF 2W. According to the project proposal the main objective is:

> *"The REEF 2W main objective fully matches the CEU programme's SO2.1 by tackling the integration and processes optimization of wastewater treatment plants and municipal waste management systems. The project is even more ambitious as it aims at making these energy consuming plants not only more efficient or self-sustainable, but also producers of surplus of renewable energy, preferably to be used in local territories becoming key enablers for virtuous low-carbon local communities. This is pursued through an optimization of the cycles (e.g. heat recovery in wastewater drainage and treatment systems, mechanical energy recovery from wastewater flows), and through their integration (e.g. enrichment of the sludge with the bio-degradable fraction of urban waste) for an increased energy production (e.g. biogas, bio-methane, electricity, heat, H2). Relevant contributions can derive from supplies of the agro-food sector or of urban green. The energy surplus can improve energy distribution through specific local networks, or serve as additional energy supply for urban mobility. Legislation and regulation barriers as well as ways to overcome them will also be identified and compared for the different countries to help the decision makers to adopt the best technical and legislative approach to solve the problem. The income generated by energy savings and energy production can be used for improving public services and infrastructures to make our cities better places to live and work in."*
>
> *(also see Application form p. 27)*

Based on the objectives, the following aspects to support sustainability in the research project can be derived (Table 1). The first column of the table presents the various aspects of sustainability derived from the Application form. These aspects were categorised according to the ISA framework (see Figure 2). In addition, the social context was added. This was done, to fulfil the requirements of the three-pillar approach, comprising environmental, social as well as economic aspects.

**Table 1: Overview of aspects towards sustainability in the REEF 2W project.**

| Aspects towards sustainability - collected from the application form | REEF 2W sustainability framework (criteria) | | | | |
|---|---|---|---|---|---|
| | Energetic context | Spatial context | Environmental context | Economic context | Social context |
| Increasing **energy efficiency** of the wastewater and waste cycles (see Application Form p.30) | x | | | x | |
| Shifting energy-consuming processes to **neutral or positive energy** processes (see Application Form p.30) | x | | | x | |
| **Recovering** raw material from waste (see Application Form p.30) | x | | x | | |
| **Reducing** the dispersion of wastes to the environment, reducing the use of landfill for waste disposal and creating the possibility to close the cycle of raw material using the stabilized, sanitized and unpolluted digestate as fertilizer (see Application Form p.30) | | | x | | |
| Producing $CO_2$ from renewable material; reducing the **GHG emissions** compared to fossil fuels (see Application Form p.30) | x | | x | | |
| Degreasing **energy costs**, improving treatments or helping local authorities to develop more **environmentally friendly legislations** (see Application Form p.30) | | x | x | x | x |
| Measuring sustainability and evaluating REEF 2W pilots, based on the ISA procedure including **environmental, economic and social** indicators and a **life cycle** approach (see Application Form p.49) | | x | x | x | x |
| Establishing WWTPs as circular **recycling** factories (see Application Form p.51) | | | x | | |
| Evaluating the most sustainable options by **integrating** sustainability indicators via a **multi-criteria decision analysis** (see Application Form p.49) | x | x | x | x | x |

In line with the REEF 2W objectives, the REEF 2W aspects of sustainability and based on the three-pillar concept, relevant sustainability indicators can be derived and consequently be used for the MCDA. In the following chapter the methodological approach with regard to MCDA is presented, before the actual deduction of sustainability indicators is followed.

## 1.4. Methodological approach multi-criteria decision analysis (MCDA)

A multi-criteria decision analysis is a decision support approach that can be used to support sustainability assessments. MCDA methodologies are capable of dealing with complex situations and problems, uncertainties, conflicting objectives, different forms of available data and information as well as with various interests and perspectives (Buytaert et al. 2011).

For determining evaluation criteria in multi-criteria decision analyses of energy supply systems Wang et al. (2009) emphasize to include technical aspects (4) to the previously presented three-pillar approach (economic, environmental and social). The inclusion of technical aspects in the analysis is especially interesting, since the REEF 2W approach includes the WWTP as a renewable energy supply solution. Additionally, the REEF 2W tools are mainly based on technical evaluations, emphasising the need to include the technical perspective to the previously presented three-pillar approach. Therefore, the final set of indicators is split into four types: (1) Environmental (2) Social (3) Economic and (4) Technical/Others (see chapter 7).

With that in mind, relevant indicators can be classified in accordance to their assessment level. The following illustration (Figure 3) shows the “indicator pyramid” incorporating the three-pillar concept (Stoeglehner and Narodoslawsky 2008). The pre-assessment in a planning process contains indicators that can be used as “filters” to avoid unsustainable alternatives. In the current context, the related indicators refer to energetic and spatial characteristics, derived from software tools N.1 and N.2, respectively. Once this pre-assessment on a strategic level is carried out a detailed assessment can be followed using specific indicators.

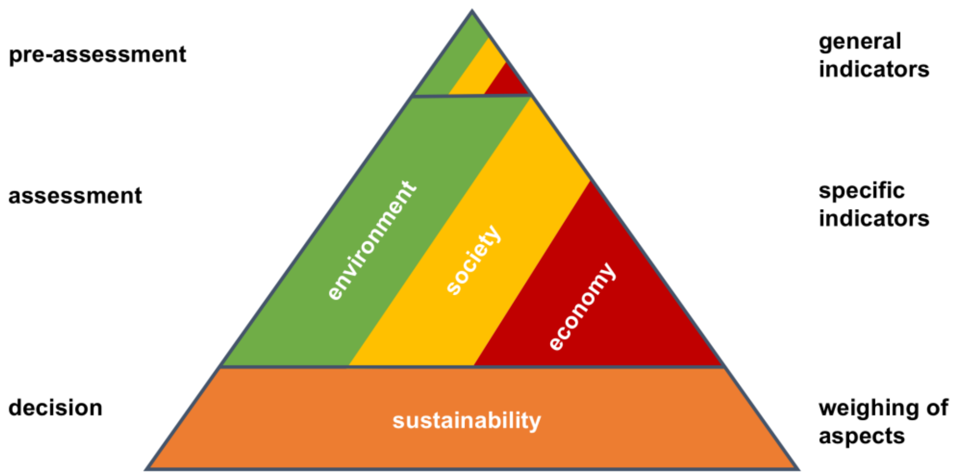


**Figure 3: Illustration of the „indicator pyramid“, adapted after Stoeglehner and Narodoslawsky (2008)**

The developed set of indicators described in this deliverable is split into (a) general indicators and (b) specific indicators (see chapter 7). The specific set of indicators is used for the MCDA, whereas the general indicators represent a first evaluation in order to filter unsustainable solutions.

In general, MCDA requires the identification of indicators, which is carried out in this deliverable. However before starting with the actual MCDA two main methodological approaches concerning MCDA can be distinguished (after Ramón and Mateo 2012): (1) Multi-attribute decision-making and (2) multi-objective decision making. Since the REEF 2W goals concentrate on identifying the most sustainable solution the method of multi-attribute decision-making was chosen.

This deliverable is structured according to the distinctive ISA steps: Energy Efficiency (EE), Renewable Energy Sources (RES), Urban Compatibility Assessment (UCA), Environmental Assessment (EA) and Cost Benefits Analysis (CBA). The last chapter presents the relevant sustainability indicators that can be used for the MCDA (see chapter 7).

# 2. ENERGY EFFICIENCY (EE)

The assessment of energy efficiency (EE) potentials of WWTPs is one objective in the REEF 2W project. It can be seen as a starting point from which further evaluations with respect to potential renewable energy applications and/or excess energy utilisation can be followed. This chapter contains the aim, relevance, framework conditions, system boundaries as well as the main results of the EE assessment (also see Software tool N.1).

## 2.1. Aim of the EE analysis and its relevance

Since the operation of a WWTP requires significant amounts of energy it is necessary to assess and potentially increase its EE. In order to analyse the EE, a comparison between the current electric and/or thermal energy consumption and the actual energetic consumption with pre-defined standard values/ranges is conducted (also see D.T1.5.4 and D.T1.4.3 – Software tool N.1). These benchmarks can be used for a first assessment of the WWTPs energy efficiency.

It is undisputed, that before a WWTP is implemented as a "local energy cell", by providing surplus/excess energy, its own EE hast to be increased first. By optimising the plants potentials, decision-makers can then proceed to implement potential renewable energy sources (RES) at the WWTP and finally decide on how to provide excess energy to the WWTPs surroundings. This is in accordance to the presented ISA approach of D.T1.5.4.

## 2.2. Framework and system boundaries

The EE assessment is split into two components: (1) Analysis of electric energy consumption and (2) analysis of thermal energy consumption. Benchmark values for the analysis (Austrian context) are derived from Lindtner (2008). The EE analysis of electric energy consumption is split into four different parts: (a) Inflow pumping station and mechanical pre-treatment, (b) mechanical-biological treatment, (c) sludge treatment and (d) infrastructure.

The analysis of the thermal energy consumption and performance is conducted with respect to (a) sludge heating, (b) transmission loss (digester tower heating) (c) generation, storage and distribution loss (d) heating for buildings.

Whenever the values for electric and thermal energy consumption are within the standard range, the energetic situation of the WWTP can be considered as efficient. Values beyond standard ranges indicate a possible optimisation potential. Based on that information, decision-makers can continue with the RES analysis.

## 2.3. Main results of the EE analysis

The current version of the software tool compares absolute values for the electric as well as for the thermal energy consumption in kWh per PE120 and year. In the results section the layout corresponds to the framework description in the previous chapter and is split into an electric and thermal assessment. The following table (Table 2) give an overview of the results in the report section of the tool.

**Table 2: Overview of standard ranges of electric energy consumption as one part of the EE assessment.**

| Calculation results | Unit | Standard range | |
|---|---|---|---|
| WWTP total electricity consumption | kWh/PE$_{120}$/a | 20 | 50 |
| Inflow pumping station and mechanical pre-treatment | kWh/PE$_{120}$/a | 2.5 | 5.5 |
| Pumping station | kWh/PE$_{120}$/a | 1.5 | 3.5 |
| Screening | kWh/PE$_{120}$/a | 0.5 | 1 |
| Sand trap and primary clarifier | kWh/PE$_{120}$/a | 0.5 | 1 |
| Mechanical-biological treatment | kWh/PE$_{120}$/a | 14.5 | 33 |
| Aeration | kWh/PE$_{120}$/a | 11.5 | 22 |
| Stirrers | kWh/PE$_{120}$/a | 1.5 | 4.5 |
| Return sludge pumps | kWh/PE$_{120}$/a | 1 | 4.5 |
| Miscellaneous (sec. clarifier) | kWh/PE$_{120}$/a | 0.5 | 2 |
| Sludge treatment | kWh/PE$_{120}$/a | 2 | 7 |
| Thickening | kWh/PE$_{120}$/a | 0.5 | 1 |
| Digestion | kWh/PE$_{120}$/a | 1 | 2.5 |
| dewatering | kWh/PE$_{120}$/a | 0.5 | 3.5 |
| Infrastructure | kWh/PE$_{120}$/a | 1 | 4.5 |
| Heating | kWh/PE$_{120}$/a | 0 | 2.5 |
| Misc. infrastructure | kWh/PE$_{120}$/a | 1 | 2 |

Besides the electric EE evaluation, also the thermal energy consumption and performance is evaluated. Table 3 shows again a sample calculation.

**Table 3: Overview of standard ranges of the thermal energy consumption as a part of the EE assessment.**

| Calculation results | Unit | Standard range | |
|---|---|---|---|
| WWTP total thermal energy consumption | kWh/PE$_{120}$/a | 0 | 30 |
| Sludge heating | kWh/PE$_{120}$/a | 8 | 12 |
| Transmission loss, digester tower heating | kWh/PE$_{120}$/a | 0 | 4 |
| Generation, storage and distribution loss | kWh/PE$_{120}$/a | 0 | 2 |
| Heat for buildings | kWh/PE$_{120}$/a | 0 | 2 |
| Heat for supply air unit | kWh/PE$_{120}$/a | 0 | 10 |

# 3. RENEWABLE ENERGY SOURCES (RES)

Besides the evaluation of energy efficient (EE) operation of the investigated WWTP, the estimation of the energy potential available from renewable energy sources (RES) within the premises of the WWTP are the other important task of energetic assessment (tool 1).

## 3.1. Aim of the RES analysis and its relevance

Analysing and improving the availability and usability of on-site renewable energy in WWTPs is a central aim of the REEF 2W project and in general the potential can substantially contribute to the sustainable energy supply of the WWTP and its surroundings.

There is a variety of usable RES such as biogas, thermal energy from wastewater, solar energy, wind energy and hydropower. The analysis is based on only few parameters which shall be easily accessible to stakeholders such as authorities from the municipality, technical staff of the WWTP, etc. who shall, with the help of the REEF 2W tool, have the ability to decide which approach is the most beneficial for the concrete WWTP and surrounding area. While a detailed approach, including high temporal resolution (e.g. hourly data) would of course deliver more precise results, the selected low-barrier approach ensures a wider usability and is beneficial to maximize the project impact. The results of this analysis can further be used for assessing the potential of the WWTP to serve as a “local energy cell”, i.e. delivering energy surpluses to adjacent buildings and the environmental as well as the economic feasibility of this approach.

## 3.2. Framework and system boundaries

All resources (wastewater, digester gas, sewage sludge, solar and mechanical energy) that are available at the WWTP can be considered as energy source. On the one hand the resources in the wastewater itself (thermal energy, height difference in the WWTP effluent, biogas) are of relevance. On the other hand, the premises of the WWTP represents a location which can be used for the installation of solar and wind power plants.

The energy sources included in the REEF 2W approach are

- biogas for
  - CHP
  - gas motor heat pump or
  - grid injection
- thermal energy from wastewater used by
  - an electric and/or
  - a gas motor heat pump
- solar energy
  - solar thermal collectors
  - PV collectors
  - PVT collectors (photovoltaic-thermal)
- hydropower

Wind energy cannot be included, as the wind conditions are too specific to be based on easily available parameters as the topography and surrounding buildings, trees, etc. influence the wind conditions to an extent that does not allow general assumptions. Also, legal restrictions regarding the minimum distance from large wind power plants to residential houses are locally different. Small wind power plants are easier to implement from a legal point of view, but even more dependent on the local wind conditions.

If there are more options for using one energy source, the operator can, by variation of the input parameters, find an optimum. This optimum can be understood in different ways: maximizing the energy output, maximizing CO2-reduction or maximizing the economic benefit. The first approach is covered by the RES tool, the second by the EA tool and the latter by the CBA tool. Side conditions as available budget or legal restrictions can complicate finding the ideal solution, where the tool can also be a support.

## 3.3. Main results of the RES analysis

In the RES tool a monthly balance in kWh per month of available energy potential is calculated and moreover a total annual balance is provided. The balance is split into a thermal and an electrical part; furthermore the biogas balance is given. The potential amount of surplus energy throughout the year, which is obtained by subtracting energy generation and consumption, shows the potential of the WWTP to serve as an energy source for external use. The (concrete) energy consumption of buildings and processes (heating, cooling, warm water, industrial applications, etc.) in the vicinity of the WWTP that can theoretically be covered by the WWTP resources is in detail calculated in the UCA analysis.

# 4. URBAN COMPATIBILITY ASSESSMENT (UCA)

This section starts with a brief description of the aims and relevance of the Urban Compatibility Assessment (UCA). Based on this first section, the framework and system boundaries of the UCA are highlighted. In order to derive relevant sustainability indicators a quick overview of the calculated results in the UCA is presented beforehand.

## 4.1. Aim of the UCA and its relevance

The main goal of the UCA is to carry out a comprehensive evaluation of the spatial and energetic situation in the vicinity of the investigated WWTP. The UCA is necessary, since potential surplus/excess energy generated at the WWTP like excess heat, electricity and/or gas can be utilised in the surroundings of the WWTP.

Electricity and gas can be transported across large distances, allowing the utilisation of the energy further away from the WWTP. In other words, energy consumers can be located far from the WWTP itself. However, due to heat losses the transportation of excess heat is limited to the local context – requiring an assessment of potential heat consumers in the immediate vicinity of the WWTP.

By evaluating potential heat consumers and the relevant heat supply network (in the case of excess heat a district heating network), the UCA supports decision makers to get a first impression of potential energy consumers and relevant infrastructure requirements. Overall the relevance of the UCA can be seen in supporting the objective to establish WWTPs as “local energy cells” and to support decision makers in utilising excess energy from the WWTP in the vicinity of the treatment plant.

## 4.2. Framework and system boundaries

Depending on the availability of energy supply networks and the possibility of feeding into these networks (like existing gas grids or district heating networks), the distance to the next feed-in point is essential (only for heat and possibly for biogas, but not for electricity. It is assumed that all WWTPs are connected to the electricity grid and, at least a large majority of those equipped with digester towers, also to the gas grid). Due to the previously described nature of thermal energy and its limited transportation distance, the construction of additional infrastructure (in this case a district heating network for the thermal energy supply) is also incorporated in the UCA.

In order to evaluate the required district heating network lengths, the status-quo of the heat demand in the vicinity of the WWTP has to be calculated first. Based on different settlement types, the overall gross development area and the distances between the single settlements and to/from the WWTP, the final infrastructure requirements as well as the total thermal energy demand can be calculated. Figure 4 illustrates the general approach of the UCA.

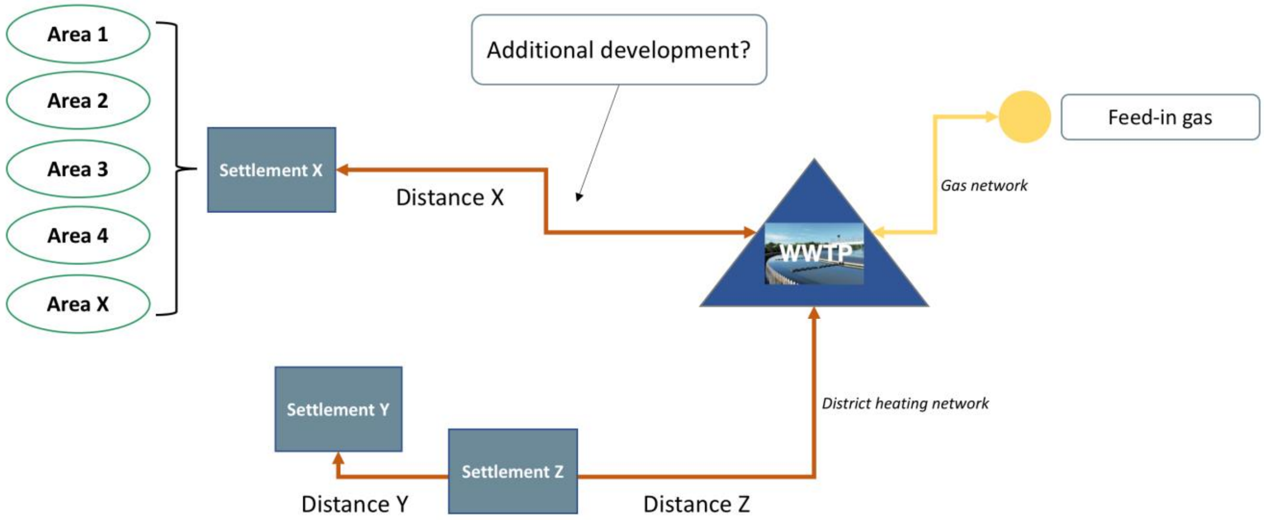


**Figure 4: Simple illustration of the framework concerning the UCA (own illustration)**

The UCA analysis serves as a basis for both, status-quo and future scenario calculations. A first assessment run usually concerns the current situation while the following runs apply different modifications of set data (boundary conditions). These scenario calculations can include variations in the

- degree of connected heat consumers (variation of total thermal energy demand due to an increase or decrease of connected heat consumers)
- degree of developed areas (this scenario reflects potential energy consumers that are not yet there; it incorporates, if additional areas are developed and heat consumers are located in the vicinity of the WWTP)
- share of refurbished buildings (reducing the total thermal energy demand of buildings) and
- share of renewable energy sources within the settlements (e.g. solar thermal panels on buildings which cover a certain amount of heat demand in the settlement).

For each calculation run (scenario) the REEF 2W provides the user with a result report. These reports can then be compared to evaluate the performance of the applied scenarios.

## 4.3. Main results of the UCA

The current version of the UCA tool can consider the WWTP external supply with electricity, biogas and heat. While a supply of the former two usually does not require any detailed spatial analysis as WWTPs are expected to being connected to the public electricity grid and in most cases also to the local gas supply network, thermal energy supply is considered more complicate. In this context, the tool calculates the overall energy demand (MWh/a) in the vicinity of the WWTP. Putting the overall heat demand in relation to the supply area the heat demand density expressed in MWh/ha*a can be calculated. Besides the heat demand and heat demand density, the necessary district heating network in metres is obtained. Through the comparison of heat demand and network length the indicator occupancy density/connection density can be calculated, resulting in provided thermal energy per meter grid length [MWh/m.a], also taking into account the heat loss of the district heating network.

By adapting input parameters after a calculation (e. g. adapted future heat demand and correspondingly also an adapted connection density), alternative supply scenarios can be investigated. Based on the calculated results of the UCA as well as from previous tools, relevant sustainability indicators for this section can be derived.

For additional information on the calculations, data requirements, results and system boundaries of the UCA also see D.T1.4.1, D.T1.4.2 and D.T1.4.3. The current version of the excel tool provides results for the UCA as follows (Table 4).

**Table 4: Overview of calculated results in the UCA**

| Calculation results | Unit |
|---|---|
| Heat demand in the WWTP surrounding | MWh/a |
| Grid length (district heating) | m |
| Connection density | MWh/m*a |
| Heat loss (district heating network) | MWh |
| Distance to next feed-in point (gas and district heating) | m |

# 5. ENVIRONMENTAL ASSESSMENT (EA)

## 5.1. Aim of the EA and its relevance

A life cycle assessment is a method in the EA and is an environmental protocol of a product or a process and provides knowledge about their impact on the environment.

The goal of EA is to analyse the potential environmental impacts of different products or process configurations and to compare them with each other. Consequently, EA can help to develop more environmental-friendly products. (Yoshida & et. el., 2014) For REEF 2W project, the life cycle assessment was used to recognize the environmental impacts of each process.

The following Figure 1 illustrates the framework of LCA according to ISO14040.

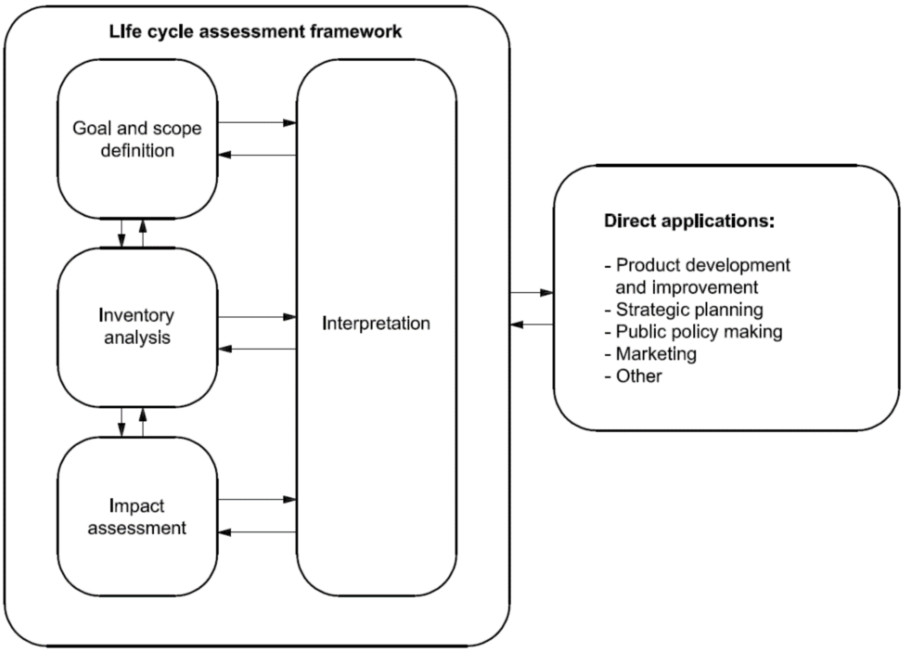


Figure 1: the framework of LCA according to ISO14040

Different dedicated commercial as well as open source software can be used for the EA. One of the well-known software is Umberto that is also used in Kompetenzzentrum Wasser Berlin gGmbH. With this software, a complex LCA model for EA can be implemented. Figure 2 shows a detail of a complex model containing a combined heat and power (CHP) unit in the context of a wastewater treatment plant.

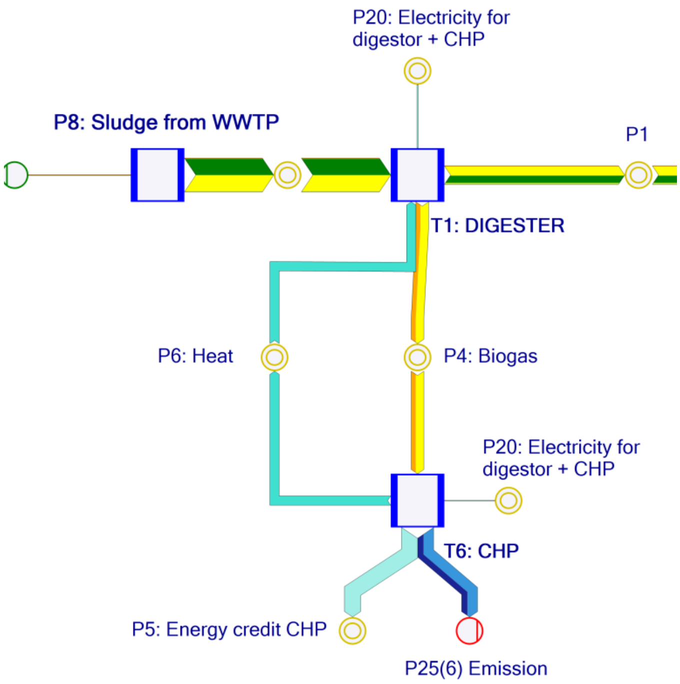


Figure 2: detail of a model created with Umberto software

The figure above shows the different units that form a material and energy flow network to calculate the environmental impact of a CHP system. In the model above, the green circles are input material, the green one shows auxiliary material and the red one represents the output. The square symbol indicates a process or transition. Finally, the lines show the material flows to the each processes.

The EA model for the REEF 2W project must be realised with spreadsheet software Excel. However, it is almost impossible to implement such a complex system with a huge database behind in an excel tool. Hence, this tool is simplified enough to be implemented. Figure 3 shows an example of the implementation into an Excel spreadsheet.

| | | | |
|---|---|---|---|
| | | Case1<br>(base case) | |
| **Energy** | | | |
| | Electricity mix for EU | 0,390 | [kg CO2-eq/kWh] |
| | net_elec_energy_demand | 8.500.000 | [kWh] |
| | carbon footprint elec. Energy | **3.315.000** | [kg CO2-eq] |
| | | | |
| | Natural gas | 0,234 | [kg CO2-eq/kWh] |
| | net_th_energy_demand | 57.000 | kWh |
| | carbon footprint th. Energy | **13.338** | [kg CO2-eq] |

Figure 3: EA implementation into a spreadsheet

The figure shows the different emission factors (CO2 equivalent) for electricity consumption as a function of the electricity mix. For example, a consumption of one kilowatt hour of natural gas produces 0.234 kg of CO2.

## 5.2. Framework and system boundaries

A prominent impact of energy generation from fossil sources is the emission of greenhouse gases (GHG) such as fossil $CO_2$. “Greenhouse gases (GHG) such as $CO_2$, $CH_4$ and $N_2O$ trap heat in the atmosphere at different capacities due to radiative forcing. Global warming potential (GWP) refers to the equivalent amount of GHG released to the atmosphere from a process, expressed in terms of kg $CO_2$eq.” (Vo, Rajendran, & Murphy, 2018)

The implemented LCA considers the energetic aspects (electricity and heat demand) of all processes at a WWTP. The use of sewage gas replaces and reduces the electricity and heat demand of WWTP and was considered in the REEF 2W tool. Using the surplus energy (e.g. heat and electricity) for the adjacent settlement structures was also taken into account in the REEF 2W tool.

In addition, all processes necessary for wastewater treatment as well as chemicals required for the process of each plant were included in this analysis. The boundary also includes REEF 2W schemes such biogas upgrading and power to gas.

According to Remy, the infrastructures, construction and dismantling of facilities do not have a huge impact on global warming potential of WWTP and were neglected in the REEF 2W tool. (Remy, 2012)

A GWP is calculated over a specific time horizon, commonly 20, 100, or 500 years. The time horizon used for the REEF 2W tool is based on GWP 100. The target group of the LCA tool primarily includes professionals and decision makers in the water and wastewater sector, energy sector and municipalities (operators, engineering companies, and regulators) who are related to planning, construction/upgrading, and operation of plants. They should be informed about innovative WWTP schemes and their potential benefits in environmental terms compared to the conventional process.

## 5.3. Main results of the EA

This EA tool should enable a simple analysis of relevant effects of the REEF 2W schemes, including GWP impacts of the innovative approach on the life cycle of a WWTP. This perspective can help to identify benefits and drawbacks of different scenarios.

The main result of the tool is global warming potential ($CO_2$ equivalent) of different scenarios.

The $CO_2$ reduction potential can be reached:

- by reduction of energy demand from external supply (e.g. grid electricity) by exploiting the internal chemical energy potential of the incoming wastewater,
- by substitution of fossil supply with renewable energy sources and
- by increasing the energy self-sufficiency.

# 6. COST-BENEFIT ANALYSIS (CBA)

## 6.1. Aim of the CBA and its relevance

The evaluation of economic benefits of REEF 2W technologies includes necessarily also economic evaluation. The aim of Cost-benefit analysis (CBA) is to estimate the strengths and weaknesses of alternatives (innovative solutions of REFF 2W in this case). It is used to determine options which provide the best approach to achieving benefits while preserving savings. A CBA may be used to compare potential (or completed) projects, or to estimate (or evaluate) the value against the cost of a decision, project, or policy. It is commonly used in policy decisions (especially public policy) and project investments.

In our case the CBA is used to determine if an investment induced by the innovation decision is sound, ascertaining if and how much its benefits outweigh its costs.

## 6.2. Framework and system boundaries

The evaluation is based on simple comparison of basic state and state after application of innovative REEF 2W technology using cost analysis.

The costs are expressed in the following items:

- Investment (technical installations incl. supply grids)
- Operating costs (installations for energy generation)
- Operating incomes (sell of excess energy)

Data provided by other partners, pilot operators, will be used for this economic analysis.

It will be identified and calculated the operating incomes related to:

- Higher biogas production
- Electricity from biogas, photovoltaics and hydropower
- Heat from biogas
- Heat from wastewater and solar thermal
- More effective biogas utilization
- Lower sludge production and sludge disposal costs
- Disposal of OFMSW (organic fraction of municipal solid waste)

Sum of the operating incomes will be compared with the investment and operational costs to calculate economic benefit and payback period.

## 6.3. Main results of the CBA

For our purpose to define economic parameter simple to calculate and understand it was selected **Return on investment** (**ROI**) as the main result of the CBA.

ROI is a basic economic parameter expressed as a ratio between the net profit and cost of investment and in context of REEF 2 W project seems to be an optimal decision tool which will be calculated in software tool developed in D.T1.4.3.

General character and the simplicity of the parameter allowed to users freely select the suitable variables such as what variables are used to calculate income or cost components.

On the other hand it is necessary to mention that the use of ROI as an indicator for prioritizing investment projects is risky since also other economic and noneconomic parameters are playing important role, therefore also other indicators are integrated in ISA.

# 7. RELEVANT SUSTAINABILITY CRITERIA FOR MCDA

The following chapter is split into 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.

## 7.1. General indicators for pre-assessment

In this first section a list of general indicators used for the pre-assessment in the REEF 2W context is presented (see Table 5). These indicators are in accordance with the first two evaluation steps of the ISA framework (energetic context: software tool n.1 and spatial context: software tool N.2). At first the energetic context is examined with respect to the degree of energy (electric and thermal) self-sufficiency. The next step is to evaluate the spatial context by assessing the degree of usable excess energy (electricity, heat and gas). On the pre-assessment level annual values will considered for the calculations.

**Table 5: List of general indicators used for the pre-assessment**

| Sustainability criteria | General indicator | Measurement | Description | Categories | Graduation | Source | Relevant Tools |
|---|---|---|---|---|---|---|---|
| Availability of excess energy (Software tool N.1) | Electric excess energy provision | Difference between electric energy production and consumption in kWh | This indicator describes the amount of electricity provided by the WWTP in relation to consumed electricity. | > 0<br>≤ 0 | positive<br>negative | Own definition | EE & RES |
| | Thermal excess energy provision | Difference between thermal energy energy production and consumption in kWh | This indicator describes the amount of thermal energy provided by the WWTP in relation to consumed heat. | > 0<br>≤ 0 | positive<br>negative | Own definition | EE & RES |
| | Excess digester gas provision | Difference between digester gas production and consumption in $m^3$ | This indicator describes the amount of digester gas provided by the WWTP in relation to the amount internally consumed. | > 0<br>≤ 0 | positive<br>negative | Own definition | EE & RES (digester sheet) |
| Availability of energy consumers (Software tool N.2) | Excess electricity demand | Electricity demand in the vicinity of the WWTP and in kWh | This indicator describes the electricity demand in the vicinity of the WWTP. | > 0<br>= 0 | positive<br>negative | Own estimation | UCA |
| | Excess heat demand | Heat demand in the vicinity of the WWTP and in kWh | This indicator describes the heat demand in the vicinity of the WWTP. | > 0<br>= 0 | positive<br>negative | Own estimation | UCA |
| | Excess digester gas demand | Digester gas demand in the vicinity of the WWTP and in kWh | This indicator describes the digester gas demand in the vicinity of the WWTP. | > 0<br>= 0 | positive<br>negative | Own estimation | UCA |

## 7.2 Specific sustainability indicators for the MCDA

The following list of indicators is split into four parts, including the three pillars of sustainability (environmental, social and economic) as well as technical indicators. The indicators are based on the REEF 2W goals that were specified in the introduction section of this document. Additionally, the calculated results in the respective sections of the software tool (EE, RES, UCA, LCA and CBA) are used to develop the final set of relevant sustainability indicators.

Social criteria are introduced because they are playing extremely important role at decision making process. The selected social criteria include following factors related to REEF 2W technologies introduction: potential of energy price decrease, increase of resilience and diversity of energy resources, additional employment and as general umbrella indicator the improvement of local environmental welfare including many aspects (air quality, tap water, energy supply, sewerage service, waste collection service, neighbourhood parks, environmental disease prevention, environmentally vulnerable and dangerous regions, eco-tourisms etc.) (Hoi-Seong J., 2013)

The derived list of indicators is subsequently used for the execution of the MCDA.

**Table 6: List of indicators applicable for MCDA**

| Sustainability criteria | Indicator | Measurement | Description | Categories | Graduation | Source | Relevant Tools |
|---|---|---|---|---|---|---|---|
| Environmental context | $CO_2$ emissions reduction for consumed electric energy (internal and external) | % | This indicator compares the $CO_2$ emissions of a current REEF 2W electricity supply scenario with a just fossil based supply of the investigated (REEF 2W) area (effect of substituting fossils by REEF 2W energy). | > 0<br>= 0 | A<br>C | Own estimation | EA |
| | $CO_2$ emissions reduction for consumed gas (internal and external) | % | This indicator compares the $CO_2$ emissions of a current REEF 2W gas supply scenario with a just fossil based supply of the investigated (REEF 2W) area (effect of substituting fossils by REEF 2W energy). | > 0<br>= 0 | A<br>C | Own estimation | EA |
| | $CO_2$ emissions reduction for consumed thermal energy | % | This indicator compares the $CO_2$ emissions of a current REEF 2W heat supply scenario with a just fossil based supply of the investigated (REEF 2W) | > 0<br>= 0 | A<br>C | Own estimation | EA |

| Sustainability criteria | Indicator | Measurement | Description | Categories | Graduation | Source | Relevant Tools |
|---|---|---|---|---|---|---|---|
| | (internal and external) | | area (effect of substituting fossils by REEF 2W energy). | | | | |
| | Share of renewable electricity (internal and external) | % | This indicator expresses the ratio between internal and external renewable electricity provision compared to total electricity consumption in the investigated (REEF 2W) area. | > 100<br>100-0<br>0 | A<br>B<br>C | Own estimation | EE & RES, UCA |
| | Share of renewable thermal energy (internal and external) | % | This indicator expresses the ratio between internal and external renewable thermal energy provision compared to total thermal energy consumption in the investigated (REEF 2W) area. | > 100<br>100-0<br>0 | A<br>B<br>C | Own estimation | EE & RES, UCA |
| | Share of renewable gas (internal and external) | % | This indicator expresses the ratio between internal and external biogas provision compared to total gas consumption in the investigated (REEF 2W) area. | > 100<br>100-0<br>0 | A<br>B<br>C | Own estimation | EE & RES, UCA |
| | Sludge production change | t DM / year | This indicator expresses the change of amount of sludge produced in WWTP. | <0<br>0<br>>0 | A<br>B<br>C | Own estimation | EE & RES, UCA |
| Social context | Affordable energy | % | This indicator compares the current energy price (EU and national specific) with the price of provided energy from the WWTP. | Lower<br>Same (+-10 %)<br>Higher | A<br>B<br>C | Own estimation | CBA |

| Sustainability criteria | Indicator | Measurement | Description | Categories | Graduation | Source | Relevant Tools |
|---|---|---|---|---|---|---|---|
| | Number of applied technologies for electric energy provision (*Resilience*) | Quantity | This indicator counts the total number of applied technologies for electricity provision at the REEF 2W WWTP (e.g. CHP, hydropower and PV). | 3<br>1-2<br>0 | A<br>B<br>C | Own estimation | EE & RES |
| | Number of applied technologies for thermal energy provision (*Resilience*) | Quantity | This indicator counts the total number of applied technologies for thermal energy provision at the REEF 2W WWTP (e.g. CHP, heat recovery and solar thermal). | 3<br>1-2<br>0 | A<br>B<br>C | Own estimation | EE & RES |
| | Additional employment | Change of employment, job creation or loss | This indicator counts the change of total number of employees related to introduced REEF technology | <0<br>0<br>>0 | A<br>B<br>C | Own estimation<br>Colijn B. (2014) | - |
| | Local environmental welfare | Indication of local welfare change | Examples of local welfare change: reduction of traffic, cheeper or renewable heat delivery, minimizing of odour production etc. | Positive<br>Neutral<br>Negative | A<br>B<br>C | Own estimation,<br>(Hoi-Seong J., 2013) | - |
| Economic context | Return of Investment (ROI) | Years | This indicator considers the investment and operational costs of different technologies in ratio to financial benefits (additional income and cost savings) from an investment of some resources | <3<br>3-10<br>>10 | A<br>B<br>C | Own estimation | CBA |
| | Additional income | € | This indicator considers additional income due to external sell of generated energy (electricity, heat and gas) at the WWTP. | >0<br>0<br><0 | A<br>B<br>C | Own estimation | CBA |

| Sustainability criteria | Indicator | Measurement | Description | Categories | Graduation | Source | Relevant Tools |
|---|---|---|---|---|---|---|---|
| | Energy costs saving | € | Financial savings due to WWTP internal energy efficiency measures. | >0<br>0<br><0 | A<br>B<br>C | Own estimation | CBA |
| Technical context (energetic & spatial) | Degree of electric self-sufficiency | Ratio between electric energy production and consumption in % | This indicator describes the percentage of electricity provided by the WWTP in relation to consumed electricity. | >75<br>25-75<br><25 | A<br>B<br>C | Own definition | EE & RES |
| | Degree of thermal self-sufficiency | Ratio between thermal energy production and consumption in % | This indicator describes the percentage of thermal energy provided by the WWTP in relation to consumed heat. | >100<br>20-1<br><20 | A<br>B<br>C | Own definition | EE & RES |
| | Degree of usable excess heat | Ratio between heat production and consumption in % | This indicator describes the percentage of available excess heat in relation to the heat demand in the vicinity of the WWTP. | >100<br><100 | A<br>C | Own estimation | EE & RES, UCA |
| | Degree of usable excess gas | Ratio between gas production and consumption in % | This indicator describes the percentage of available excess gas in relation to the gas demand in the vicinity of the WWTP. | >100<br><100 | A<br>C | Own estimation | EE & RES, UCA |
| | Electric energy consumption at WWTP | $kWh/PE_{120}.a$ | This indicator expresses the electric energy consumption of the WWTP in kWh/PE.a compared to a standard range defined in literature. | < 20<br>20 - 50<br>> 50 | A<br>B<br>C | (Lindtner 2008) | EE & RES |
| | Thermal energy consumption at WWTP | $kWh/PE_{120}.a$ | This indicator expresses the thermal energy consumption of the WWTP in kWh/PE.a compared to a standard range defined in literature. | <=30<br>> 30 | A<br>C | (Lindtner 2008) | EE & RES |

| Sustainability criteria | Indicator | Measurement | Description | Categories | Graduation | Source | Relevant Tools |
|---|---|---|---|---|---|---|---|
| | Electric energy generation at WWTP (with anaerobic stabilisation) | $kWh/PE_{120}.a$ | This indicator expresses the electric energy provision of all applied technologies (CHP, hydropower and PV). | >20<br>10-20<br><10 | A<br>B<br>C | (Lindtner 2008) | EE & RES |
| | Electric energy generation at WWTP (with aerobic stabilisation) | $kWh/PE_{120}.a$ | This indicator expresses the electric energy provision of all applied technologies (Hydropower and PV). | >0<br>0 | A<br>C | Own | EE & RES |
| | Thermal energy generation at WWTP (with anaerobic stabilisation) | $kWh/PE_{120}.a$ | This indicator expresses the thermal energy provision of all applied technologies (CHP, heat recovery and solar thermal). | >40<br>20-40<br><20 | A<br>B<br>C | (Lindtner 2008) | EE & RES |
| | Thermal energy generation at WWTP (with aerobic stabilisation) | $kWh/PE_{120}.a$ | This indictor expresses the thermal energy provision of all applied technologies (Hydropower and PV). | >0<br>0 | A<br>B | Own | EE & RES |

# 8. Multi-criteria decision analysis (MCDA) model construction

The complex ISA evaluation is based on determining sustainability indicators definition and using of these indicators for calculation of final composite index which is integrating all aspects of ISA.

Firstly, all indicators are normalized (dimensionless value score within the range of 1-5) allowing the comparison without scale effects (A=1, B=3, C=5).

Secondly, the indicators are aggregated in accordance with the relative importance of each indicator – see Table 7 and then the composite index are calculated as follows.

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.

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

where *CI* is the composite index of the ISA for social, environmental, economic and technical segment

*w* is value of indicator

*u* is weight of indicator

*n* is 6 for environmental indicators, 5 for social indicators, 3 for economic indicators and 6 for technical indicators.

**Table 7: Indicators for MCDA and applied weight factors**

| Sustainability criteria | Indicator | Weight |
|---|---|---|
| Environmental | $CO_2$ emissions reduction for consumed electric energy (internal and external) | Defined by stakeholder, Range (0-1) so that the sum of the weights of all environmental criteria is equal to 1 |
| | $CO_2$ emissions reduction for consumed gas (internal and external) | dtto |
| | $CO_2$ emissions reduction for consumed thermal energy (internal and external) | dtto |
| | Share of renewable electricity (internal and external) | dtto |

| Sustainability criteria | Indicator | Weight |
|---|---|---|
| | Share of renewable thermal energy (internal and external) | dtto |
| | Share of renewable gas (internal and external) | dtto |
| | Sludge production change | dtto |
| Social | Affordable energy | Defined by stakeholder,<br>Range (0-1)<br>so that the sum of the weights of all social criteria is equal to 1 |
| | Number of applied technologies for electric energy provision (*Resilience*) | dtto |
| | Number of applied technologies for thermal energy provision (*Resilience*) | dtto |
| | Additional employment | dtto |
| | Local environmental welfare | dtto |
| Economic | Return of Investment (ROI) | Defined by stakeholder,<br>Range (0-1)<br>so that the sum of the weights of all economical criteria is equal to 1 |
| | Additional income | dtto |
| | Energy costs saving | dtto |
| Technical/others | Degree of electric self-sufficiency | Defined by stakeholder,<br>Range (0-1)<br>so that the sum of the weights of all technical criteria is equal to 1 |
| | Degree of thermal self-sufficiency | dtto |
| | Degree of usable excess heat | dtto |
| | Degree of usable excess gas | dtto |
| | Electric energy consumption at WWTP | dtto |
| | Thermal energy consumption at WWTP | dtto |
| | Electric energy generation at WWTP (with anaerobic stabilisation) | dtto |
| | Electric energy generation at WWTP (with aerobic stabilisation) | dtto |
| | Thermal energy generation at WWTP (with anaerobic stabilisation) | dtto |
| | Thermal energy generation at WWTP (with aerobic stabilisation) | dtto |

Two main possibilities exist for the evaluation team, for comparing the merits of the different interventions using scoring:

- multi-criteria analysis by compensation or
- multi-criteria analysis based on outranking.

Outranking does not always produce clear conclusions; whereas analysis based on compensation it is always conclusive. From a technical point of view, the compensation variant is also easier to implement. The most pragmatic way of designing the multi-criteria evaluation matrix is for the evaluation team to design scoring scales to all the evaluation conclusions, whether quantitative or qualitative. The multi-criteria evaluation matrix is then equivalent to the impact scoring matrix. Usually the compensation method is used unless members of the steering identify a problem which might justify the use of the veto system.

Therefore it was decided to use analysis by compensation, however for each case of innovative REEF 2W technology application must be identified if there are specific criterions which disqualify the technology to such extent that veto system needs to be used if they are ranked below certain threshold level.

# 9. Literature


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