BONUS RETURN

Reducing Emissions by Turning Nutrients and Carbon into Benefits

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X	PU	Public.
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	RE	Restricted to a group specified by the consortium.
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BONUS RETURN

Turning waste into circular solutions for the Baltic Sea

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Turning waste into circular solutions for the Baltic Sea

EXECUTIVE SUMMARY

The purpose of this manual is to lay out a basic step-by-step process for how to conduct a general sustainability analysis by applying multi-criteria analysis (MCA). This manual is not intended to be a complete resource for how to conduct a general MCA. The focus of this manual is on the use of MCA as a tool for sustainability analysis of ecotechnologies in the context of resource recovery (recovery of nitrogen, phosphorus and organic carbon) from waste and by-products from the wastewater and agricultural sectors. The sustainability analysis method applied within BONUS RETURN consists of the following eight steps, all of which are described in further detail in later sections of the manual:

1. Goal and scope definition,
2. Selection of criteria,
3. Selection of alternatives,
4. Analysis and evaluation,
5. Scoring,
6. Weighting,
7. Interpretation of results,
8. Sensitivity analysis.

Transparency, simplicity and ease of use are important factors to consider in order to increase the acceptance of the results that arise from applying any decision support method. This is particularly important when there is a risk of conflicting interests arising from involving a diverse group of stakeholders. The method applied within BONUS RETURN is relatively simple to apply and intuitive to understand which adds to the methods transparency and usability. Implemented correctly, MCA can become an effective tool for communication not only within a group of decisionmakers but also when disseminating results to a greater group of stakeholders. It is important to keep in mind that a sustainability analysis is context specific and an alternative or solution that is found to be the most sustainable in one setting, area or region might be unsuitable to apply in another. This can be due to different local needs and variations in attitudes towards different aspects or trade-offs that come with specific solutions. As previously stated, sustainability is multi-dimensional and requires multi-disciplinary input for a fair assessment. There is rarely a "one-size fits all" solution to a specific challenge.

In order to make the manual more understandable parts of the Vantaanjoki case study from Del. No 3.3 by Johannesdottir et al. (2019) was included as an example to walk through the steps of the manual. This case study was carried out during the years 2018-2019 with focus on recycling of substrates from the agricultural sector with an addition of source separated blackwater from scattered settlements (on-site sewage systems).

1 INTRODUCTION

The degradation of the Baltic Sea is an ongoing problem, despite investments in measures to reduce external inputs of pollutants and nutrients from both diffuse and point sources. Available technological and management measures to curb eutrophication and pollution flows to the sea have not been adapted adequately to the contexts in which they are being applied. Furthermore, measures are often designed based on single objectives, thereby limiting opportunities for multiple benefits.

In addition, there is a general sense that measures to address the deterioration of the Baltic ecosystem are primarily technologically-driven and lacking broader stakeholder acceptance – the "experts" who define these measures have little engagement with industry, investors, civil society and authorities. This problem is magnified by governance and management, taking place in sectoral silos with poor coordination across sectors.

As a result, research shows that regional institutional diversity is presently a barrier to transboundary cooperation in the Baltic Sea Region (BSR) and that actions to achieve national environmental targets can compromise environmental goals in the BSR (Powell *et al.*, 2013). The regional dimension of environmental degradation in the BSR has historically received weaker recognition in policy development and implementation locally. However, developments in recent years suggest a new trend with growing investments in environmental protection supporting social, economic, and territorial cohesion.

The BSR is an environmentally, politically and economically significant region and like other regions globally, its rapid growth needs to be reconciled with the challenges of sustainable development in a global setting that demands unprecedented reductions in GHG emissions. This poses a truly wicked problem exacerbated by the fact that many of the challenges in the BSR will also magnify in a changing climate. In order to navigate the uncertainties and controversies associated with a transformation towards a good marine environment, BONUS RETURN will enact an innovative trans disciplinary approach for identifying and piloting systemic eco-technologies.

The focus is on eco-technologies that generate co-benefits within other interlinked sectors, and which can be adapted according to geophysical and institutional contexts. More specifically, emphasis is placed on eco-technologies that reconcile the reduction of present and future eutrophication in marine environments with the regional challenges of policy coherence, food security, energy security, and the provision of ecosystem services.

1.1 Project Objectives

The **overall** aim of BONUS RETURN is to improve the adaptation and adoption of eco-technologies in the Baltic Sea Region for maximum efficiency and increased co-benefits.

The **specific objectives** of the project can be divided into six categories presented below. These categories are interlinked but for the purpose of providing a step-wise description, the following overview of each category proves useful. BONUS RETURN is:

1) **Supporting innovation and market uptake of eco-technologies by:**

- Contributing to the application and adaptation of eco-technologies in the BSR through an evidence-based review (systematic map) of the developments within this field.
- Contributing to the development of emerging eco-technologies that have the capacity to turn nutrients and carbon into benefits (e.g. bio-energy, fertilizers), by providing an encompassing framework and platform for rigorous testing and analysis.
- Developing decision support systems for sustainable eco-technologies in the BSR.
- Contributing to better assessment of eco-technology efficiency via integrated and participatory modelling in three catchment areas in Finland, Sweden and Poland.
- Contributing to methodological innovation on application and adaptation of eco-technologies.

2) Reducing knowledge gaps on policy performance, enabling/constraining factors, and costs and benefits of eco-technologies by:

- Assessing the broader socio-cultural drivers linked to eco-technologies from a historical perspective.
- Identifying the main gaps in the policy environment constraining the implementation of emerging eco-technologies in the catchments around the Baltic Sea.
- Informing policy through science on what works where and under which conditions through an evidence-based review (systematic map and systematic reviews) of eco-technologies and the regional economic and institutional structures in which these technologies evolve.

3) Providing a framework for improved systematic stakeholder involvement by:

- Developing methods for improved stakeholder engagement in water management through participatory approaches in the case study areas in Sweden, Finland and Poland.
- Enacting a co-enquiry process with stakeholders into opportunities for innovations in eco-technologies capable of transforming nutrients and pollutants into benefits for multiple sectors at different scales.
- Bringing stakeholder values into eco-technology choices to demonstrate needs for adaptation to local contexts and ways for eco-technologies to efficiently contribute to local and regional developments.
- Disseminating results and facilitating the exchange of learning experiences, first within the three catchment areas, and secondly across a larger network of municipalities in the BSR.
- Establishing new cooperative networks at case study sites and empowering existing regional networks by providing information, co-organizing events and engaging in dialogues.

4) Supporting commercialization of eco-technologies by:

- Identifying market and institutional opportunities for eco-technologies that (may) contribute to resource recovery and reuse of nutrients, micro-pollutants and micro-plastics (e.g. renewable energy).
- Identifying potential constraints and opportunities for integration and implementation of eco-technologies using economical models.
- Facilitating the transfer of eco-technologies contributing to win-win solutions to multiple and interlinked challenges in the BSR.
- Linking producers of eco-technologies (small and medium enterprises – SMEs), to users (municipalities) by providing interactive platforms of knowledge exchange where both producers and users have access to BONUS RETURN's envisaged outputs, existing networks, and established methodologies and services.

5) **Establishing a user-driven knowledge platform and improved technology-user interface by:**

- Developing an open-access database that maps out existing research and implementation of eco-technologies in the BSR. This database will be intuitive, mapped out in an interactive geographical information system (GIS) platform, and easily managed so that practitioners, scientists and policy-makers can incorporate it in their practices.
- Developing methodologies that enact the scaling of a systemic mix of eco-technological interventions within the highly diverse contexts that make up the BSR and allows for a deeply interactive medium of knowledge.

1.2 Project Structure

BONUS RETURN is structured around six Work Packages that will be implemented in three river basins: The Vantaanjoki river basin in Finland, the Słupia river basin in Poland, and Fyrisån river basin in Sweden.

Work Package 1: Coordination, management, communication and dissemination.
Work Package 2: Integrated Evidence-based review of eco-technologies.
Work Package 3: Sustainability Analyses.
Work Package 4: Environmental Modelling.
Work Package 5: Implementation Support for Eco-technologies.
Work Package 6: Innovative Methods in Stakeholder Engagement.

1.1 Deliverable context and objective

The current deliverable (Del. No 3.4) is part of WP (3). The objectives of WP (3) are to evaluate sustainability aspects of eco-technologies selected from WP2 using a decision support-based framework for sustainability analysis for each catchment area. The application of sustainability analysis includes a step-wise systems analysis approach to be carried out together with local stakeholders by: 1) defining system boundaries; 2) selecting criteria covering health and hygiene, environmental issues, economy, socio-cultural dimensions and technical function; 3) selecting and formulating different system alternatives based on the review of eco-technologies from WP2; 4) comparing the different options using the criteria from step 2. The comparison is done by using substance flow-, cost-effectiveness and cost benefit analysis, energy analysis and qualitative assessments. In step 4, a multi-criteria analysis is used for an integrated assessment of all dimensions to reach a complete decision support system for municipalities or regions. A second objective of WP3 is to identify upcoming innovations for reuse (TRL 5 or higher), using the same sustainability criteria as above. The final results of WP3 are a selection of interesting eco-technologies for further development in WP5.

This deliverable, 3.4, contains a manual for application of sustainability analysis adapted for BONUS RETURN. An example is also included taken from the case study of Vantaanjoki catchment area.

1.2 Outline of the report

This report is structured as follows: First a brief introduction to sustainability and multi-criteria analysis is given. Following the introduction is a basic step-by-step description of how to conduct a sustainability analysis using the same multi-criteria analysis method that was applied in BONUS

RETURN (Del No. 3.3) by Johannesdottir et al. (2019). The method can be broken down into eight steps, namely: 1) Goal and scope definition, 2) Selection of criteria, 3) Selection of alternatives, 4) Analysis and evaluation of criteria, 5) Scoring, 6) Weighting, 7) Interpretation of results and 8) Sensitivity analysis, see Figure 1.

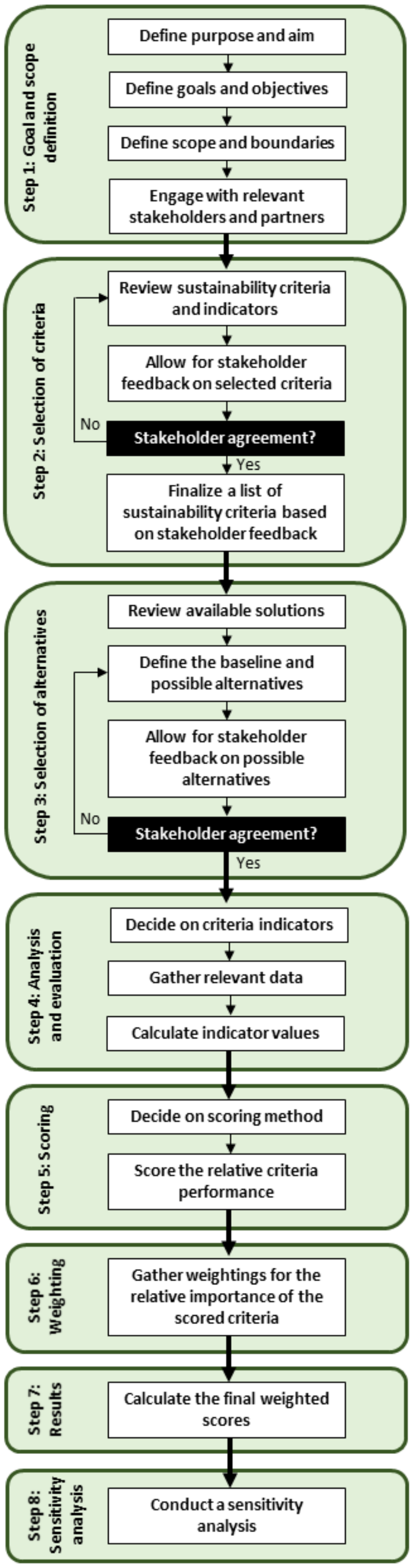

Figure 1. A general flow chart describing the different steps and sub-steps in the MCA method.

2 MANUAL FOR ASSESSING SUSTAINABILITY OF ECO-TECHNOLOGIES

2.1 General method: Sustainability and multi-criteria analysis

The term *sustainability* encompasses a wide range of aspects and can in broad terms be said to have three main dimensions, namely *environmental*, *economic* and *social* sustainability, all of which can be assessed by applying different indicators. In some applications the inclusion of *technical function* and *health and hygiene* as two additional sustainability dimensions can also be found (Johannesdottir et al., 2019). When conducting a sustainability analysis it is necessary to evaluate all dimensions of sustainability that are relevant for the question in hand before a fair assessment can be given.

As an example, we can look to the energy sector and at renewable energy production from wind and solar parks. Which mode of production is more sustainable? Some metrics such as annual revenue or the amount of pollutants that are released during production are relatively straightforward to assess, but how should these metrics be compared to social aspects of sustainability such as acceptance of changing esthetics arising from the installations or from the effect on local communities where necessary rare earth metals are mined? Annual revenue might be more interesting to investors, whilst potential environmental effects of mining might be more interesting to the sectors of recreation and tourism and effects on local communities might be more important to nearby residents, both in case of mining the metals and the construction of the parks. There are a multitude of different factors that ultimately need to be considered before a conclusive answer can be given. Sustainability is multi-dimensional and non-trivial to assess without introducing significant bias.

Multi-criteria analysis (MCA), also referred to as multi-criteria decision analysis, is a broad group of decision support methods that can be applied to facilitate systematic and transparent assessment of alternatives during a decision-making process and can be applied for sustainability analysis. MCA can be used to aggregate different sustainability aspects, that do not necessarily lend themselves to straight forward comparison, into more easily comparable metrics. MCA can be applied when there is an interest or a need to incorporate qualitative stakeholder perspectives with more conventional quantitative dimensions in a decision-making process. MCA has seen applications in numerous fields, ranging from the water sector (Sjöstrand et al., 2018) to healthcare (Frazão et al., 2018) and financing (Zopounidis et al., 2015), which all have their specific challenges and priorities. These different priorities have in turn led to the development of multiple MCA methods. In their review on available MCA methods Diaz-Balteiro et al. (2017) found 15 different MCA methods that had been applied in four or more scientific papers. More recently, in their work to provide a generalized framework to guide practitioners to select suitable MCA methods Wątróbski et al. (2019) found that a total of 56 different MCA methods had been described in the scientific literature.

The method applied within BONUS RETURN was a weighted sum method, sometimes also referred to as simple additive weighting or linear additive method, mainly based on the *Strategic Planning of Sustainable Urban Water Management* method by Malmqvist et al. (2006). This sustainability analysis approach has been applied as a decision support method in more than 20 applications in the areas of water supply, wastewater and solid waste management. The approach has a generic structure but is also flexible, transparent and evaluates five dimensions of sustainability, namely *environmental*, *social*, *economic*, *technical* and *health and hygiene.* In Sweden, the method has been applied for choosing innovative water and wastewater systems in new city districts such as Norra Djurgårdsstaden in Stockholm and H+ in Helsingborg. It has also been applied for long term strategic planning of wastewater and organic waste systems in Gothenburg and for the selection of peri-urban water and wastewater management in coastal areas of Southern Sweden.

The purpose of this manual is to lay out a basic step-by-step process for how to conduct a general sustainability analysis by applying the same MCA method that was used in BONUS RETURN by Johannesdottir et al. (2019). This manual is not intended to be a complete resource for how to conduct a general MCA. More complete general introductions to MCA and related methods can be found in Dodgson et al. (2009) or in textbooks such as Bouyssou et al. (2006). The focus of this manual is on the use of MCA as a tool for sustainability analysis of ecotechnologies (as defined in Haddaway et al. 2018) in the context of resource recovery (recovery of nitrogen, phosphorus and organic carbon) from waste and by-products from the wastewater and agricultural sectors. The sustainability analysis method applied within BONUS RETURN consists of the following eight steps, all of which will be described in further detail in later sections of the manual:

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In conjunction with this manual a simple Microsoft Excel-based tool for sustainability analysis based on MCA has been developed, see BONUSRETURN.EU for more information.

3 SYSTEMATIC STEP-BY-STEP SUSTAINABILITY ANALYSIS DESCRIPTION

In general terms we are using sustainability analysis as a tool to address a *challenge.* To address this *challenge,* we are looking for different *solutions.* These *solutions* can be added and combined into different *alternatives* which in turn can be applied to address the *challenge.* We want to assess the sustainability of these *alternatives* by applying multiple *indicators* that can be used to evaluate different *sustainability criteria.* Evaluating these *indicators* is done through *scoring* whereby the *alternatives* relative performance on these *indicators* is rated based on if the performance is better or worse than a *baseline alternative.* Through stakeholder engagement the relative importance of these *criteria* will be determined by adding *weights* to the *scores* that where calculated for the different *indicators.* The calculated sum of these *weighted scores* for all the evaluated *indicators* is then the total *sustainability score* for the *alternative*. In context of BONUS RETURN, the *challenge* addressed was the deterioration of the Baltic Sea due to marine and land-based pollution. To address the *challenge* some of the *solutions* that were applied were different eco-technologies for recovering organic carbon, nitrogen and phosphorus from wastewater and agricultural wastes. These different eco-technologies together with the necessary surrounding infrastructure were the different *alternatives* that were evaluated in the different case studies. The sustainability of these *alternatives* was evaluated by examining different *sustainability criteria*. An example of one of the evaluated sustainability criteria was *eutrophication potential*, where the amount of nutrients (nitrogen and phosphorus) entering the air and a receiving waterbody per annum was used as an *indicator*. The *baseline* in these case was chosen to be “business-as-usual” where none to very little resource recovery was conducted and the *score* for the *indicator* was based on the relative difference in the amount of nutrients entering the receiving waterbody per annum.

This chapter of the manual will present a general step-by-step walkthrough of the basics that needs to be considered when conducting a sustainability analysis. The described MCA- and sustainability analysis method is flexible, generalizable and can be applied in different contexts. This manual is written for decisionmakers who are interested in the process of conducting sustainability analyses and for consultants and professionals who are interested in expanding their toolboxes. For illustrative purposes an example will be given in the context of results produced within the multi-criteria analysis part of the BONUS RETURN project by Johannesdottir et al. (2019) in chapter 4.

3.1 Step 1: Scope definition

Good decisions require clear goals and need to be based on accurate and useful information. As with any type of project an important first step in a sustainability analysis is to clearly, and in no ambiguous terms, define the purpose and goals of the project in plain language so that all participants can understand what is needed. A good definition sets the basis for clear communication with all participants and helps with setting the expectations for everyone involved. A good definition should include well-defined boundaries that set a clear scope for the analysis, it should be explicit with the questions that the analysis sets out to address and lastly it should state what is to be achieved for the project to be considered successfully carried through.

3.1.1 Define the purpose and aim

The purpose of the sustainability analysis should be as concise as possible and stated in a few sentences. The purpose should include why the analysis is being conducted in the first place and the challenges to be addressed. A clearly defined purpose helps the analysis to stay on track, reduces risks of potential scope expansion (so called "scope creep") and simplifies the assessment of whether or not the analysis has achieved what it set out to accomplish once it has concluded. The usefulness of results from the sustainability analysis will ultimately depend on how well formulated the aim is.

3.1.2 Define the goals and objectives

To ensure that the analysis can be successfully carried through there needs to be clearly defined goals for everyone involved to work towards. With clear and explicitly defined goals it is possible to keep the work effort focused on reaching the goals. Well formulated goals should ideally be specific, measurable, achievable, realistic and time bound.

3.1.3 Define the scope and boundaries

The boundaries of the analysis need to be explicit as these will help guide the work that is being done by all project participants. Without clearly defined boundaries it is likely that time and project resources are spent inefficiently or misguidedly, and it is also possible that work is accidentally left out. It should be stated what amount of time and resources can be allocated to different parts of the analysis.

3.1.4 Engage with relevant stakeholders and partners.

During the definition step, a list of potential stakeholders should be compiled, and the ones deemed most relevant for the success should be given opportunities to get involved, see Figure 2. Subject matter experts, such as researchers or consultants, could be tied to the analysis through the creation of a consortium and local stakeholders and decisionmakers could be part of reference groups whose input can be used to assess qualitative aspects of social sustainability for the different criteria that are to be assessed.

Figure 2: For a fair sustainability analysis all relevant stakeholders should be given an opportunity to interact. Some examples of different stakeholders that can be included when working with introducing resource recovering eco-technologies are, from left to right: farmers, decisionmakers, consultants, lawyers, and researchers.

3.2 Step 2: Selection of criteria

It is necessary to consider what aspects of sustainability are important to evaluate to be able to address the challenges. Some aspects and dimensions of sustainability can be more or less relevant when considering a challenge by challenge basis, some criteria might be easier to assess than others, and there is no objectively right or wrong choice of criteria nor a right or wrong way to assess these.

Sustainability criteria can broadly be separated into two distinct categories, namely *quantitative criteria* such as *operational costs* or *amount of pollutants produced over time*, which are quantified through a numerical value*;* and *qualitative criteria* such as *social acceptance*, typically assessed and graded in terms of likelihood or scale of potential impact.

3.2.1 Review sustainability criteria and indicators

A good starting point for the analysis can be a review of the scientific literature to see what types of sustainability criteria have previously been successfully applied to analyze similar challenges and how these different criteria have been assessed. By doing this it is possible to get a sense of what criteria and aspects might be relevant to assess within the analysis and the set boundaries. A literature review can also ensure that no important aspects are accidently left out of the analysis. A large set of sustainability criteria that have previously been applied for sustainability analysis within the wastewater and agricultural sectors has been compiled in a previous deliverable of the BONUS RETURN project (Del. No 3.3 by Johannesdottir et al. (2019)) and is summarized in the Appendix of this manual. The compiled criteria were divided into five sustainability dimensions: *environmental, economic, socio-cultural, technical function*, and *health & hygiene,* a selection these criteria is presented in Table 1.

Table 1. Examples of sustainability criteria separated into the five different dimensions of sustainability.

Environmental	**Economic**	**Socio-cultural**	**Technical function**	**Health & hygiene**
Greenhouse gas emissions	Life cycle cost	Acceptance	Flexibility	Work environment
Reuse of resources	Capital/investment costs	Laws and policies	Reliability	Health risks
Emission of pollutants	Operation and maintenance costs	Attitudes and behaviours	Technical complexity	Spreading of diseases
Impact on biodiversity	Economic lifetime	Cultural and aesthetic values	Robustness	Exposure to toxic substances

By conducting a literature review and starting the analysis procedure by looking into sustainability criteria in a broad context it should then be easier to narrow down the potentially relevant sustainability criteria into a smaller subset that should be presented to the involved stakeholders.

3.2.2 Review of selected sustainability criteria by involved stakeholders

Once a subset of relevant criteria has been selected, it should be presented to involved stakeholders for comments and feedback before any further analysis is conducted. The stakeholders should be given an opportunity to give input on which sustainability criteria they consider the most important for the studied object and the challenges that are to be addressed, preferably in an open forum where the relevance of criteria can be discussed. It is advisable that the total number of criteria used in the analysis are kept at a manageable level, within BONUS RETURN the limit was set at a maximum of ten different criteria. A large number of criteria can significantly increase the amount of work when gathering data and evaluating different alternatives, and it can also increase the total effort needed to complete the sustainability analysis.

3.2.3 Finalize a list of sustainability criteria for analysis

Based on stakeholder feedback a short list of relevant criteria that are to be applied in the sustainability analysis should have been produced in the previous sub-step where all the criteria deemed irrelevant by the stakeholders should have been removed. The criteria in each category (environmental, economic, socio-cultural, technical function and health & hygiene) identified as the most important by stakeholders should be given priority in the final selection of criteria to be used in the sustainability analysis. However, criteria should be suitable to the scope of the assessment and to the proposed alternatives before a final list of criteria can be decided upon. To maximize the usefulness of the assessment, redundant criteria or criteria that cannot be assessed should be excluded. Once the final criteria and alternatives are determined, further revisions should only be made if problems arise with data availability which might limit the possibility to compare the different alternatives.

3.3 Step 3: Selection of alternatives

Once criteria are selected, it is necessary to explore the alternatives available to address the challenge within the boundaries that are set by both the selected sustainability criteria and the goals and boundaries that where formulated during the definition step. It is important to be mindful that all the included alternatives have the same net function and should be comparable (e.g. they are all able to treat the same amount of water if the comparison is between different wastewater treatment solutions), as this is the only way to ensure a fair comparison between different alternatives. Alternatives are, in the context of this manual, one or a more solutions that combined with the necessary surrounding infrastructure can constitute/describe the same functional unit.

3.3.1 Review available solutions

As with the selection of sustainability criteria a good starting point for looking into available solutions is to conduct a review of the literature on the subject. A literature review can provide the necessary background information of available solutions and guidance towards finding possible solutions that are applicable in the decision-making context. Within BONUS RETURN a systematic map of eco-technologies for the recovery and reuse of nutrients and carbon within the Baltic Sea region was conducted in Del. No 2.3 by Macura et al. (2018). This deliverable was later used as the basis for selection of technological system components and overall system alternative design in the case studies in Del. No 3.3 by Johannesdottir et al. (2019). The systematic map by Macura et al. (2018) can serve as a suitable starting point when reviewing available eco-technologies that might be of interest in the implementation context. A compilation of the most promising solutions found during the literature review should be presented to the stakeholders for comments and feedback.

3.3.2 Define the baseline and the possible alternatives

The proposed MCA-method uses the relative performance of the different alternatives compared to a baseline alternative as part of its overall sustainability scoring method. The baseline alternative can be seen as the standard to which the other alternatives are compared to or the benchmark to reach. Current practices, or "business as usual", is commonly used as a baseline alternative and is often a suitable choice as it is frequently of interest to know how much better or worse a certain alternative would be relative to what already exists or is implemented. It is of course also possible to use another alternative as the baseline as only relative performance differences between the alternatives are of interest for this particular type of analysis and not any absolute performance numbers.

3.3.3 Finalize a list of alternatives for analysis based on stakeholder feedback

Stakeholders should be given opportunities to present input and feedback on the proposed alternatives before any further analysis is conducted. Stakeholder feedback should be used to rule out alternatives that are deemed undesirable or irrelevant in the implementation context. This feedback should result in a shortened list of feasible or desirable alternatives to go forward with in the analysis.

3.4 Step 4: Analysis and evaluation

Once the baseline and the possible alternatives are decided, their relative performance needs to be evaluated by looking into different measurements or indicators linked to the sustainability criteria. For a criterion such as *Life cycle cost* a straightforward and obvious choice of indicator would be the calculated total costs over the life cycle of the alternative in question, but for a criterion such as *Air quality* the choice is less obvious. For *Air quality* suitable indicators could be the emissions of atmospheric aerosol particles, nitrous oxides or sulfur dioxide resulting from operating a certain process, but the preferred indicator is ultimately context specific. This highlights the need to apply indicators that are relevant to the specific analysis and situation.

3.4.1 Decide on suitable indicators or measurements to assess

The choice of indicators to be used for assessing criteria is crucial as this will affect the degree of uncertainty and the final interpretation of the analysis. It is advisable that the assessments based on qualitative data are based on the largest possible sample size, and consensus if applicable, as this will decrease the amount of sampling bias which can influence the results of the analysis. For a fair assessment it is also necessary to ensure that no included or selected criteria are dependent upon another so that the same criteria are not effectively accounted for twice (or more). To give some guidance on the choice of applicable indicators a selection of previously applied sustainability criteria and proposed indicators is presented in the Appendix. The choice of indicators should be relevant to the purpose of the analysis and in line with the views that have been presented by the involved stakeholders earlier in the process.

3.4.2 Gather relevant data for evaluation of criteria

Depending on the criteria selected for the analysis it will likely be necessary to gather both qualitative and quantitative data. Depending on the scope of the analysis and the resources available, quantitative background data may be gathered from scientific literature, by conducting necessary experiments or from consulting experts. Qualitative background data should be gathered from local stakeholders. Relevant data could include personnel or land costs which can have large regional variations. Extrapolations or interpolations might be necessary for some types of data and information, for example data regarding the performance of an eco-technology observed in a different scale and different context compared to the one in the actual analysis. Data will likely not be available for the exact same size installations as would be necessary for the analysis, so some assumptions, such as a constant cost per connected person or per treated volume of water, will be necessary. These assumptions will introduce uncertainties into the scoring. These uncertainties should be addressed by conducting a sensitivity analysis, which will be briefly described in a later section of the manual.

3.5 Step 5: Scoring

3.5.1 Scoring the relative performance of criteria

For each alternative that is being assessed, all of the applied criteria are to be scored relative to the performance of the baseline alternative. For the baseline alternative all criteria are scored as 0, and scores for the other alternatives are then calculated based on their performance relative to the baseline. The proposed method scores the criteria with integer scores between -2 and +2, where +2 is given for highest performance and -2 for the poorest performance as described in Table 2.

Table 2: Proposed method and cut-off thresholds for assigning scores when evaluating the relative performance of criteria.

Quantitative criteria	**Qualitative criteria**
Over 40% worse than baseline: -2	Most likely negative impact compared to baseline: -2
Up to 40% worse than baseline: -1	Possible negative impact compared to baseline: -1
Within 20% of baseline: 0	Negligible or no impact compared to baseline: 0
Up to 40% better than baseline: 1	Possible positive impact compared to baseline: 1
Over 40% better than baseline: 2	Most likely positive impact compared to baseline: 2

It is important to keep in mind that if the score is 0 it does not mean that the performance of the alternative regarding the criterion in question is 0. For example, if the baseline alternative is given the score 0 for "*Total costs*" this does not mean that the total costs are 0; it means that the cost for the baseline system has a relative middle value. The performance of the baseline alternative is neutral in comparison to itself. The other alternatives are compared in relation to the performance of the baseline alternative. So, if an alternative has a 30% higher total cost than the baseline alternative it would be assigned a score of -1.

Based on previously made assumptions and the quality of available data and information it is likely that some amount of uncertainty has been introduced into the analysis which can affect the computed scores for the evaluated criteria, particularly when the evaluated metrics come close to any of the cut-off thresholds for assigning a particular score. Uncertainties should be clarified in the analysis and be accounted for in the final assessment by conducting a sensitivity analysis (see section 3.8)

3.6 Step 6: Weighting

3.6.1 Gather weightings for the relative importance of the sustainability criteria

Stakeholder input to the weighting process can be gathered by hosting physical meetings (e.g. through interactive workshops), by sending out questionnaires (electronically or by mail), or by conducting phone interviews. Weightings should be gathered from as many relevant groups of stakeholders as possible as this will allow for some statistical analysis and uncertainty analysis of the obtained weights and final results. By enabling stakeholder interaction (e.g. by conducting workshops), it is possible to gather weightings based on informed discussions which should increase the consensus between the stakeholders and allow for a fairer weighting procedure, see Figure 3. Weighting in small groups (e.g. decisionmakers, experts, residents or mixed groups) is one possibility and whole group consensus is another.

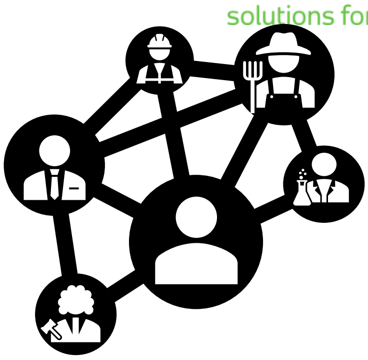

Figure 3: The purpose of the multi-criteria analyst should be to facilitate, and promote, the interaction between involved stakeholders to allow for a nuanced weighting procedure.

The proposed weighting scheme is to allow for individual or groups of stakeholders to assign weights from 0-100 for each of the evaluated criteria based on their perceived relative importance. Summed across all criteria the assigned weights should add up to 100 for each individual or group of stakeholders assigning the weights. In this scheme an assigned weight of 0 would mean that a criterion is deemed entirely unimportant, and conversely an assigned weight of 100 would mean that the weighted criterion is the only criteria that is deemed important. One difficulty in the weighting process is to decide how the weights are going to be assigned as different stakeholders will assign their weights differently. To gather and aggregate stakeholder weightings it is recommended to conduct workshops where the attending stakeholders are divided into weighting groups as heterogeneously as possible based on affiliation (e.g. decision-maker, subject matter expert, resident etc.). By creating heterogenous groups it is possible to include different perspectives and allow for broad discussions on the topic which, ideally, will produce more nuanced weighting. Once the discussions have concluded each group member should be allowed to proceed with the weightings which then should be averaged into a combined group weight. These group weightings can then be further aggregated by averaging across all attending groups, as seen in Table 3, and applied later in the analysis. The weighting aggregation scheme should be presented transparently to the stakeholders *a priori* so that no bias is introduced in the aggregation procedure.

Table 3: Example of how the weighting procedure can be structured in spreadsheet software. The assigned weights by j stakeholder groups and the computed average weights for criteria 1 to k for alternative i.

Criteria	**Weights assigned by stakeholder group 1**	**…**	**Weights assigned by stakeholder group j**	**Average weight**
Criteria 1	$W_{1,1}$	…	$W_{1,j}$	$W_1 = \frac{1}{j}\sum_{i=1}^{j} W_{1,i}$
Criteria 2	$W_{2,1}$	…	$W_{2,j}$	$W_2 = \frac{1}{j}\sum_{i=1}^{j} W_{2,i}$
…	…	…	…	…
Criteria k	$W_{k,1}$	…	$W_{k,j}$	$W_k = \frac{1}{j}\sum_{i=1}^{j} W_{k,i}$

3.7 Step 7: Interpretation of results

3.7.1 Calculate final weighted scores for each criteria and system

Applying the information that is gathered in step 5 and step 6 the sustainability score of each of the analyzed alternatives is calculated using the weighted sum method as described in equation (1).

$$S_i = \sum_{j=1}^{k} W_j C_j = W_1 C_1 + W_2 C_2 + \ldots + W_k C_k \qquad (1)$$

In equation (1) S_i is the overall sustainability score of the i:th alternative that is being assessed and it is computed as the weighted sum of k different criteria. W_j is the weight assigned to the j:th criterion in step 6 and C_j is the score calculated for the j:th criterion in step 5. Put simply, the sustainability score is calculated by multiplying the score for each evaluated criterion with the corresponding weight and then adding up all the resulting products. The sustainability scores for the evaluated alternatives are then easily comparable and ranked according to their relative sustainability.

Previous results from BONUS RETURN (Del. No 3.3 by Johannesdottir et al., 2019) show that the alternative deemed most sustainable in two case studies (Fyriså and Słupia catchments), was different even though the analyzed system alternatives were composed of largely the same eco-technologies. This exemplifies that the weights that are determined in the implementation context by the involved stakeholders are integral components of sustainability assessments which determine the final result.

3.8 Step 8: Sensitivity analysis

Given uncertainties in assumptions that have been made during the analysis and uncertainties in the collected data used for evaluating indicator performance for the different alternatives, some additional evaluation of the effect of error margins on the computed sustainability score should be conducted. The purpose of the sensitivity analysis should be to find out how sensitive the sustainability analysis, and ultimately the ranking of the alternative deemed the most sustainable, is to the parameters used in the analysis (see Figure 4).

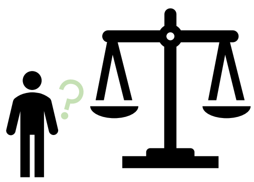

Figure 4: What changes in the analysis inputs would be necessary to tip the scales in the alternative ranking? Can introduced uncertainties affect which alternative is deemed the most sustainable?

3.8.1 Conduct a sensitivity analysis.

The sustainability score for each alternative will include uncertainties that have been introduced throughout the analysis, particularly through the criteria evaluation and the weighting procedures. In the evaluation step, uncertainties have likely been introduced during data collection and when making assumptions to assess criteria. In the weighting step, the applied method of collecting and aggregating stakeholder weightings to produce the final set of weights will also have added further uncertainties.

Uncertainties in total costs for the different alternatives can be used to illustrate the type of questions that should be asked in relation to data quality. It is likely relevant for all sustainability analyses to examine the effects of increases or decreases in the total costs for the assessed alternatives and how these changes in turn affects the final results. Are the costs used in the comparative analysis based on accurate information or is there a margin of error? And if so, what margin is likely, and can it be estimated? If there for instance is a ± 10% error in the assumed costs, does this influence the final outcome of the sustainability analysis? The accuracy of the data that the analysis is based on, and the effects these uncertainties in turn have on the result are the sorts of questions that should be addressed in a sensitivity analysis.

As a first step to analyze the sensitivity of the weighting step it can be of interest to look into the representation of different stakeholder groups in the weighting procedures. Were all groups of stakeholders represented equally or was the sample of stakeholder somehow skewed? If there was a potential skew did this affect the results of weightings? These questions can for instance be examined by looking into the weight distributions based on stakeholder affiliation, assuming that stakeholders that share the same affiliation (e.g. representatives for water utilities, agriculture, recreational values etc.) share similar goals and would apply similar weighting strategies.

This section should serve as an introduction to the general idea of sensitive analysis and to the very basics of uncertainty analysis, and there are far more sophisticated methods available than what is briefly presented here. Assumptions and uncertainties should be explicitly stated once the final analysis is completed

4 EXAMPLE FROM BONUS RETURN FOLLOWING THE PROPOSED PROCEDURE VANTAANJOKI

4.1 Example: Management of agricultural waste and blackwater in Vantaanjoki, Finland

In order to make the manual more understandable we have included parts of the Vantaanjoki case study from Del. No 3.3 by Johannesdottir et al. (2019) as an example to walk through the steps of the manual. This case study was carried out during the years 2018-2019 in parallel with two other case studies; Fyris in Sweden and Słupia in Poland. For the Vantaanjoki case study, the focus was the agricultural sector with an addition of source separated blackwater from scattered settlements (on-site sewage systems). Residual flows from agriculture studied as input biomass for alternative systems was horse manure and non-utilized grass such as set-aside grass and buffer zones grass. The substrates (horse manure, grass and source separated blackwater) were all discussed by local stakeholders as potentially interesting for resource recovery. For further reading on the Vantaanjoki case and the other case studies see Johannesdottir et al. (2019).

4.2 Step 1: Goal and scope definition

4.2.1 Define the purpose and aim of the project

Stakeholders in the Vantaanjoki case decided to focus on waste substrates that occur in the catchment area, while treatment of urban waste and sewage were left out. The substrates that require better management therefore were included in the study were horse manure, grass from set-aside fields and blackwater from onsite sewage facilities in the catchment area. Other substrates such as manure from cattle is already circulated and was therefore left out.

4.2.2 Define the goals and objectives of the project

The expected benefit was formulated as circular management of nutrients and carbon from horse manure, grass from set-aside fields and blackwater from onsite sewage facilities in the catchment area. The reasons for selecting these substrates is due to their significant volumes and because there is no general collection and recycling system available today.

4.2.3 Define the scope and boundaries of the project

The functional unit was set as the sum of selected activities in the catchment area: the management of horse manure, set-aside grass and blackwater from households in rural areas. The functional unit is the same thing as the results of the whole system. General geographical system boundaries in Vantaanjoki are the borders of the catchment area. The time horizon is that the alternatives are expected to be implemented by 2025. As an example, the technical system boundaries of the calculations of *global warming potential* in Vantaanjoki are presented in Figure 5. The climate impact calculations start with the treatment of biomass. The cultivation, harvesting and collection of the biomass are not included, as we focus here mainly on comparing different treatment options and we have the same amount of input biomass in each scenario.

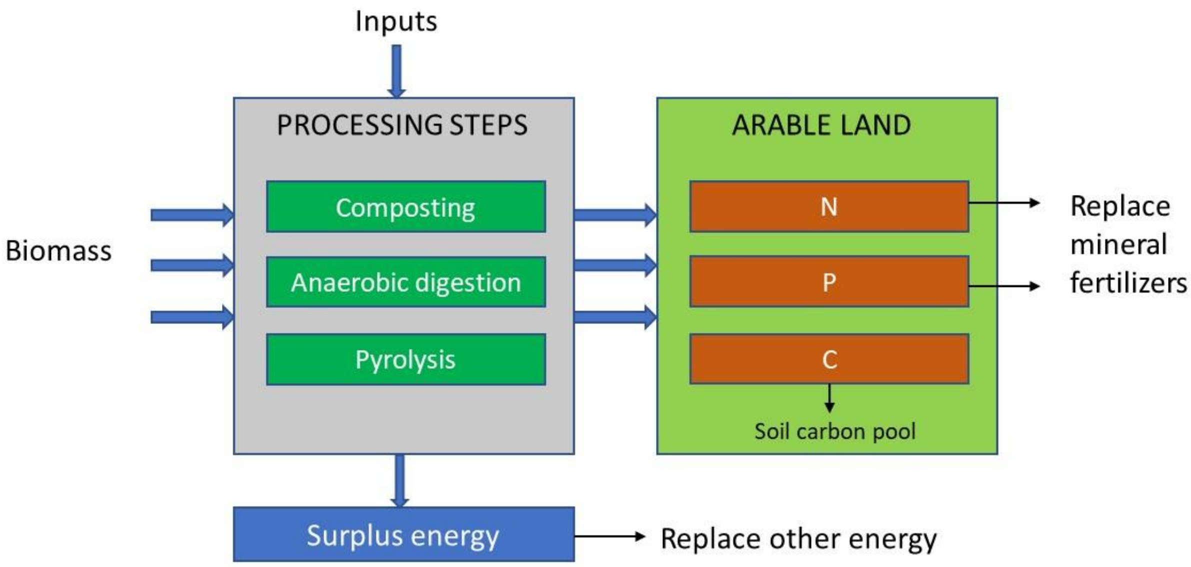

Figure 5. System boundaries for calculation of global warming potential in the Vantaanjoki case study.

The products that come out of the treatment are used as fertilizers and soil amendments on arable land. For products containing nitrogen and phosphorus, we assume that they can replace mineral fertilizer alternatives, giving the systems a climate credit by reducing the emissions from mineral fertilizer production. In the pyrolysis case, most nitrogen will be lost. However, in the pyrolysis scenario, the blackwater is treated with urea and the urea together with the blackwater is spread on the fields. The urea is however not seen as a credit to the system as it is an external input and does not mean a reduced use of mineral fertilizers.

Systems that generate surplus energy such as heat and biogas fuel will be credited the replacement of other energy, e.g. biogas can replace natural gas. For biochar, there is no replacement product; we assume that biochar will increase soil carbon content giving a climate benefit of carbon sequestration. Of the carbon that is applied to fields, only a share is transferred to the long-term soil carbon pool. In this study we assumed 15 % of the carbon in compost and digestate becomes stable soil carbon and is given climate credit. For blackwater we assume 5 %, and for biochar 30 %. A higher soil carbon content could lead to higher yields, especially in degraded soils. However, the effects in northern Europe are uncertain and therefore we did not include potential yield improvements in this study.

Transport distances were estimated based on maps of the Vantaanjoki region in combination with occurrences of activities in different areas of the region.

4.3 Step 2: Selection of criteria

4.3.1 Reviewing sustainability criteria

For all case studies, the same general method was used to conduct the sustainability assessment. Two workshops were held in each case study. The aim of the first workshop was to gain insights into the local contexts, challenges, opportunities and stakeholder interests. This was done during a one-day workshop with local stakeholders which included presentations of the BONUS RETURN project and group exercises to identify and discuss relevant sustainability criteria and eco-technologies for the area. The progress of the systematic mapping of eco-technologies from Del. No 2.2 (see Haddaway (2018)) was presented, as well as a list of example sustainability criteria from a literature review. Criteria were divided into five categories: environmental, economic, socio-cultural, health and hygiene, and technical function as outlined in Table 4.

Table 4. Sustainability criteria presented as examples to stakeholders at the first workshops.

Environmental	**Economic**	**Socio-cultural**	**Technical function**	**Health & hygiene**
Climate effect	Life cycle cost	Acceptance	Flexibility	Work environment
Reuse of resources	Capital costs	Laws and policy	Reliability	Health risks
Emission of pollutants	Work force demands	Encourage sustainability	Technical complexity	Pathogens
Biodiversity	Economic vulnerability	Cultural and aesthetic values	Lifetime	Toxic substances
Land use	Quality of products	Functioning organization	Compatibility with existing infrastructure	
Use of resources (energy, water etc.)	Support local economy	Equity	Maintenance requirement	

Together with stakeholders, a list of criteria to apply in the sustainability assessment was produced (Table 5).

Table 5. Finalized list of the nine criteria that were deemed relevant by local stakeholders to be included in the Vantaanjoki case study.

Environmental	**Economic**	**Socio-cultural**	**Technical function**	**Health & hygiene**
Global warming potential	Total costs	Acceptance	Compatibility with existing infrastructure	Risk of exposure to pollutants
Eutrophication potential	Impacts on local economy			
Nutrient recovery				
Effects on soil structure				

A generic set of criteria is of great use for selection of sustainability criteria in an MCA. Based on the experiences of the example described above a balanced set of criteria was compiled given in Table 1.

4.4 Step 3: Selection of alternatives

Based on discussions about preliminary results from Del. No 2.2 during the first workshop several eco-technologies that the stakeholders found interesting where combined into three different system alternatives.

System alternative 1: *Composting*
System alternative 2: *Anaerobic digestion*
System alternative 3: *Pyrolysis and urea-hygienization of source-separated blackwater*

For all system alternatives horse manure and grass are collected and transported to a centrally located plant co-located with the waste incineration plant in Vantaa. In system alternative 1. *Composting* and 2. *Anaerobic digestion*, also source-separated blackwater is treated in a central facility in Vantaa. For system alternative 3. *Pyrolysis and urea hygienization of source-separated blackwater*, the source-separated blackwater is treated locally in 32 basins for urea hygienization placed on farms with very short or no distance to the fields. *Composting* was the baseline system, against which the other two systems were compared.

Aspects of sustainability not only apply to the part where nutrients or carbon are extracted, but also before and after those steps. For example, collection and transport of manure is a source of both emissions and costs and should therefore be accounted for in the system. The same goes for transport of the product to the site where nutrients will be reused; different technologies could produce products of different densities leading to differences in emissions from transport. The system therefore consists of both collection, treatment and reuse of substrates and products. In order to make a comparison between the different systems, they all need to perform the same net function. If a certain amount of substrate is managed in one system, the same amount needs to be managed in some way in all the compared systems, otherwise they are not comparable. Furthermore, in order for the system to provide adequate functions, additional system components such as conventional management practices may need to be included. This could, for example, be additional, conventional treatment of wastewater after nutrients have been extracted in order to limit eutrophication.

There can be many different external inputs to the systems that have emissions, costs or other sustainability aspects accompanying them. Such external inputs can be electricity and chemicals. These resources need to be accounted for when comparing the systems, since they consume different amounts. This is done by adding e.g. the emissions from production of the amount of electricity needed in the system, even though electricity production is not included as an internal function of the system.

4.5 Step 4: Analysis and evaluation

The constructed system alternatives were evaluated against nine criteria: global warming potential, eutrophication potential, nutrient recovery, effects on soil structure, total costs, local economy, risk of exposure to pollutants, acceptance and compatibility with existing infrastructure. They were evaluated using the following indicators and methods:

Quantitative criteria:
Global warming potential was calculated as the system alternatives net emissions of CO_2 equivalents. There were several inputs to the systems in the form of electricity, heat and chemicals. In the systems, several sources of greenhouse gas emissions can occur such as from transport or from the treatment processes. Emissions from spreading and use of fertilizers were not included in the greenhouse gas calculations. The reasoning behind this was that it was assumed that the new fertilizer products replaced mineral fertilizers, so that in total no more fertilizers were used in agriculture compared to previously. Most greenhouse gas emissions from use of fertilizers (nitrous oxide) are connected to nitrogen load and as the nitrogen load will be the same it was assumed that the greenhouse gas emissions would be similar. This is a simplification, as emissions of indirect nitrous oxide emissions also occur, however we think this simplification will not matter greatly for the interpretation of the results. The systems can provide benefits and products which replace other resources, thereby “saving” emissions. An example is replacing mineral fertilizer with recovered nutrients. This constitutes a negative emission for the system, and so the net emissions are reduced accordingly. More detail on which processes and emissions that are included in the global warming potential calculation for each case study is found in Johannesdottir et. al (2019).

Eutrophication potential was assessed using PO_4^{3-}-equivalents calculated with the CML method from Heijungs et al., (1992). The calculated eutrophication potential was a “worst case” scenario where all emissions of nitrogen and phosphorus contributed to eutrophication. The sources of PO_4^{3-} eq. in this case was nitrogen and phosphorus released directly to water, air emissions of ammonia and NO_x emissions from transports. For the Vantaanjoki case study the assessment of this criterion was done qualitatively based on nutrient leakage using early modelling results from BONUS RETURN WP4.

The nutrient recovery criterion was based on substance flow calculations of nitrogen and phosphorus recovered and returned to agriculture in each system. The criteria effects on soil structure were based on substance flow calculations of the amount of carbon returned to agriculture in each system.

The total costs calculated included costs for investments, maintenance and operation. The investment costs included among other things the costs of reactors and construction of facilities. Annual capital cost was calculated with the annuity method, using 3% interest. The maintenance cost was calculated as 3% of the total investment cost. The operations costs included costs for energy, chemicals, staff, etc. Revenues for fertilizer products and surplus energy produces were subtracted, resulting in a net cost for the system studied. In Vantaanjoki, the criteria Impacts on local economy was applied assessing the pros and cons of the different alternatives for the people who lives or have their businesses within the catchment area.

Qualitative criteria

The criterion *acceptance* was qualitatively assessed on the general acceptance of using the recovered nutrient products as fertilizers in agriculture. This criterion was assessed by stakeholders at the second workshop for the Fyris and Słupia case studies. For the Vantaanjoki case study, acceptance was based on a local study of acceptance in the region. *Risk of exposure to* pollutants was assessed based on the content of heavy metals, pharmaceuticals, microplastics and visible contaminants in the fertilizer products and possible other outputs produced in the different system alternatives. The *compatibility with infrastructure* criterion was assessed by local stakeholders at the second workshop in the Vantaanjoki catchment area. *Technical robustness* was assessed based on expert judgements of the system alternatives risk for operational stops, sensitivity for overflows and severity of consequences if either were to occur. *Technical flexibility* was likewise based on expert assessments of system alternatives flexibility to changes in load, due to increase or decrease in population, and ability to adapt to new technologies or new treatment requirements.

4.6 Step 5: Scoring

In the scoring, the composting alternative was set as the baseline alternative and is thus scored 0 for all the evaluated criteria and indicators. The resulting final calculated scores are presented in Table 6.

Table 6. Scores for each criterion for each system alternative for the Vantaanjoki case study.

Criteria	Composting	Anaerobic digestion	Pyrolysis + urea hyg.
Global Warming potential	0	2	2
Eutrophication potential	0	-1	0
Nutrient recovery	0	0	-2
Effects on soil structure	0	-2	0
Local economy	0	0	1
Total costs	0	2	-2
Acceptance of using recycled fertilizer products	0	0	1
Risk of exposure to pollutants	0	0	1
Compatibility with infrastructure	0	0	1

4.7 Steps 6 and 7: Weighting and interpretation of results

4.7.1 Gather weightings for the relative importance of the sustainability criteria

In Vantaanjoki, workshop participants were divided into three groups. To start with, they individually gave weights to the previously mentioned nine criteria so that the sum of weights had to be 100. The three group averages were then discussed within the whole group and adjusted through consensus if necessary. The results of the groups varied. The results by criterion categories are shown in Table 7.

Table 7. Weights assigned by the three groups and the average weights for the Vantaanjoki case study.

Criteria	Group 1	Group 2	Group 3	Average weight
Global warming potential	21	10	18	16
Eutrophication potential	5	5	4	5
Effects on soil structure	8	10	20	13
Nutrient recovery	5	5	6	5
Local economy	8	5	7	7
Total costs	16	25	9	17
Acceptance	13	15	12	13
Risk of exposure to pollutants	10	15	13	13
Compatibility with existing infrastructure	14	10	11	11

Based on the average of weights from Table 7, the weighted sum of the three alternatives was calculated in Figure 6. The results show that alternative 2, Anaerobic digestion got the highest weighted score followed by alternative 3, Pyrolysis. Alternatives 2 and 3 reach almost the same sum but considerably higher than alternative 1, Composting. Both alternatives 2 and 3 have a large advantage compared to alternative 1 because of a lower impact on climate change. Alternative 3, Pyrolysis, also has other strengths in terms of *local economy*, *acceptance*, *risk of exposure to pollutants* and *compatibility with infrastructure*. Alternative 3 has, however, one disadvantage which is the considerable annual costs.

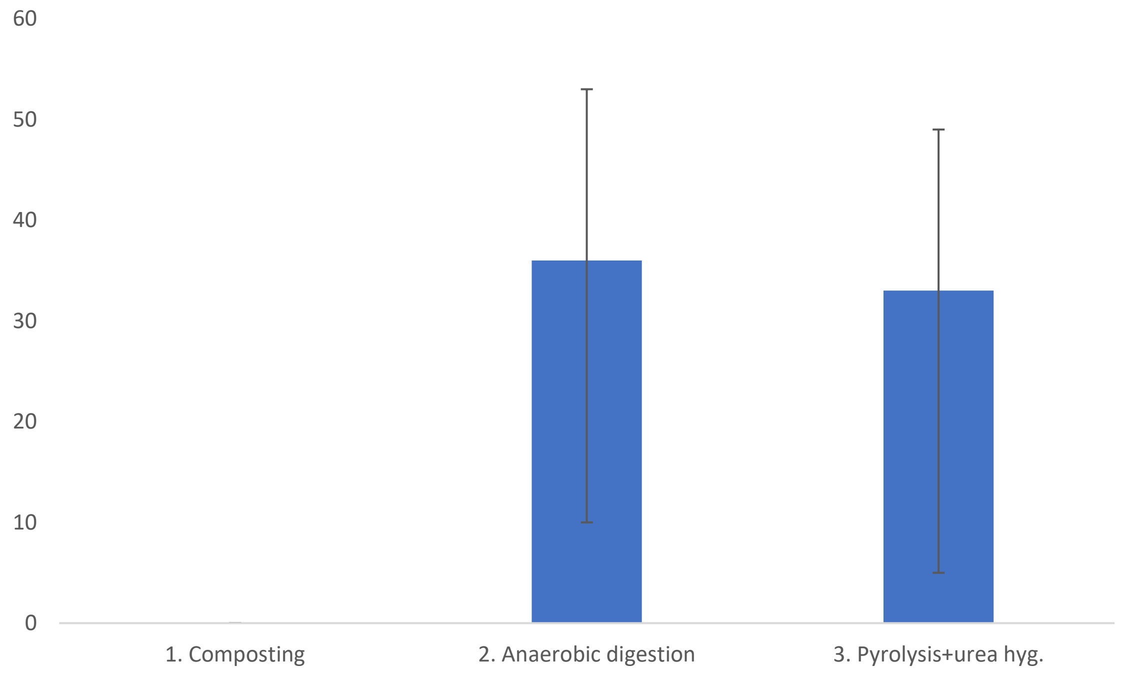

Figure 6. Total sustainability score for each system alternative in the Vantaanjoki case study. The error bars show the scores based on the different weighting of criteria from the three stakeholder groups at the second workshop.

4.8 Step 8: Sensitivity analysis

No formalised sensitivity analysis was performed in the Vantaanjoki case study due to a lack of time. General ideas of sensitivity analysis are given in chapter 3.8.

5 CONCLUDING REMARKS

The purpose of this manual was to lay out a basic step-by-step process for how to conduct a general sustainability analysis. This manual is not intended to be a complete resource for how to conduct a general MCA. The focus of this manual is on the use of MCA as a tool for sustainability analysis of ecotechnologies in the context of resource recovery (recovery of nitrogen, phosphorus and organic carbon) from waste and by-products from the wastewater and agricultural sectors.

In conjunction with this manual a simple Microsoft Excel-based tool for sustainability analysis based on MCA has been developed, see BONUSRETURN.EU for more information.

Transparency, simplicity and ease of use are important factors to increase the acceptance of the results that arise from applying any decision support method. This is particularly important when there is a risk of conflicting interests arising from involving a diverse group of stakeholders.

The method applied within BONUS RETURN is relatively simple to apply and intuitive to understand which adds to the methods transparency and usability. Implemented correctly, MCA can become an effective tool for communication not only within a group of decisionmakers but also when disseminating results to a greater group of stakeholders. It is important to keep in mind that a sustainability analysis is context specific and an alternative or solution that is found to be the most sustainable in one setting, area or region might be unsuitable to apply in another. This can be due to different local needs and variations in attitudes towards different aspects or trade-offs that come with specific solutions. As previously stated, sustainability is multi-dimensional and requires multi-disciplinary input for a fair assessment. There is rarely a “one-size fits all” solution to a specific challenge.

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7 APPENDIX

Table A1. Criteria used in the scientific literature to assess sustainability of wastewater systems and possible indicators that can be applied. The table is based on compilations done by Johannesdottir et al. (2019). Impact/effect probabilities are graded as follows: VH = Very high, H = High, M = Medium, L = Low and VL = Very low.

Criteria	Type of criteria	Possible indicator
Environmental		
Water emissions	Quantitative	kg PO_4-eq./yr
Air emissions	Quantitative	kg CO_2-eq./yr
Impact on biodiversity and land fertility	Qualitative	VH-H-M-L-VL
Emissions to land	Quantitative	kg/yr
Resource recovery	Quantitative	% P, % N
Use of energy/natural resources	Quantitative	kWh/yr
Land requirement	Quantitative	ha/FU
Economic		
Total costs	Quantitative	€/yr
Annual costs	Quantitative	€/yr
Capital costs	Quantitative	€/yr
Work demand	Quantitative	€/yr
Social		
Acceptance	Quantitative /Qualitative	VH-H-M-L-VL
Awareness and participation	Quantitative /Qualitative	VH-H-M-L-VL
Institutional requirements/capacity	Quantitative /Qualitative	VH-H-M-L-VL
Promoting sustainable behaviour	Quantitative /Qualitative	VH-H-M-L-VL
Policy and legal issues	Quantitative /Qualitative	VH-H-M-L-VL
Health		
Work environment	Quantitative /Qualitative	VH-H-M-L-VL
Health risk	Quantitative /Qualitative	VH-H-M-L-VL
Technical		
Flexibility	Qualitative	VH-H-M-L-VL
Reliability	Qualitative	VH-H-M-L-VL
Robustness	Qualitative	VH-H-M-L-VL
Lifetime	Quantitative	yr
Compatibility with existing infrastructure	Qualitative	VH-H-M-L-VL

Table A2. Criteria used in the scientific literature to assess sustainability of agricultural systems and possible indicators that can be assessed. The table based on compilations done by Johannesdottir et al. (2019). Impact/effect probabilities are graded as follows: VH = Very high, H = High, M = Medium, L = Low and VL = Very low.

Criteria	Type of criteria	Possible indicator
Environmental		
Fertiliser use	Quantitative	kg N, P, K/ha
Land use	Quantitative	ha/FU
Biodiversity	Qualitative	VH-H-M-L-VL
Resource use	Quantitative	kWh/yr
Water use	Quantitative	m^3/yr
Air emissions	Quantitative	kg CO_2-eq./yr
Soil effects	Qualitative	VH-H-M-L-VL
Pesticides	Quantitative	kg/yr
Water emissions	Quantitative	kg PO_4-eq./yr
Animal welfare	Qualitative	VH-H-M-L-VL
Economic		
Productivity	Quantitative	ton biomass/ha
Subsidies	Quantitative	€/yr
Total costs	Quantitative	€/yr
Investment costs	Quantitative	€/yr
Employment	Quantitative	€/yr
Product quality	Quantitative	€/yr
Local economy	Quantitative	€/yr
Amortization time	Quantitative	yr
Stability	Quantitative	VH-H-M-L-VL
Multifunctionality	Quantitative	VH-H-M-L-VL
Quality of products	Quantitative	VH-H-M-L-VL
Social		
Livelihood	Quantitative	€/yr
Acceptance	Qualitative	VH-H-M-L-VL
Equity	Qualitative	VH-H-M-L-VL
Cultural and aesthetic values	Qualitative	VH-H-M-L-VL
Continuity	Qualitative	VH-H-M-L-VL
Applicability	Qualitative	VH-H-M-L-VL
Local economy	Quantitative	€/yr
Quality of products	Quantitative	VH-H-M-L-VL
Uncertainties in crop cultivation	Qualitative	VH-H-M-L-VL
Corporate ethics	Qualitative	VH-H-M-L-VL
Accountability	Qualitative	VH-H-M-L-VL
Participation	Qualitative	VH-H-M-L-VL
Rule of law	Qualitative	VH-H-M-L-VL
Holistic management	Qualitative	VH-H-M-L-VL
Health		
Health	Quantitative /Qualitative	VH-H-M-L-VL
Working conditions	Quantitative /Qualitative	VH-H-M-L-VL