**BONUS RETURN**
**Reducing Emissions by Turning Nutrients and Carbon into Benefits**
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# Deliverable No: D3.6 Scientific publication on sustainability of eco-technologies

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| ☒ | PU | Public. |
| ☐ | PP | Restricted to other project partners. |
| ☐ | RE | Restricted to a group specified by the consortium. |
| ☐ | CO | Confidential, only for members of the consortium. |

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## EXECUTIVE SUMMARY

This del. 3.6 provides a sustainability analysis of ecotechnologies selected from three empirical case areas (Slupia in Poland, Vantaanjoki in Finland, and Fyrisån in Sweden). With a CBA based bottom-up approach this study shows how involvement of stakeholders can serve as instrument for exploring the implementation of new solutions. The advantage from this approach is that the criteria included have gone through a robust participatory process, which provides more legitimacy to the decisions reached, as key stakeholders have had the opportunity to influence the elements considered in the assessment.

Findings from this study indicate that only one of the explored eco-technologies - anaerobic digestion of agricultural wastes in the Finish case - provide a positive NPV under the current conditions. Here, costs for investment are moderate compared to the baseline alternative (to build a composting plant) and the benefits from producing biogas are considerable. In contrast, ecotechnologies for the wastewater sector are costly and require large investments that do not seem to provide enough benefits compared to the baseline alternatives within the explored timeframe of 30 years. However, we only consider some extent of the impacts ecotechnologies may result in. To allow generating an even more complete picture with all the benefits and costs society may experience due to the implementation of ecotechnologies, further research is necessary to quantify and consider monetary values of additional impacts, possible risks, and co-benefits. Research is also needed to explore possibilities to obtain better balance between costs and benefits of sustainable and circular solutions. This is fundamental, as ecotechnologies for nutrient reuse are fundamental for rolling out the EU's circular economy approach and efforts to reduce and reuse "waste" safely and sustainably.

# 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 (3.6) is part of WP (3).

The objectives of WP3 are:
“to evaluate sustainability aspects of eco-technologies selected in 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 WP 2; 4) comparing the different options using the criteria from step 2.

The comparison will be done by using substance flow-, cost- effectiveness and cost benefit analysis, energy analysis and also qualitative assessments. Results of environmental impacts will be imported from WP4. In step 4, a multi-criteria analysis will be used for an integrated assessment of all dimensions to reach a complete decision support system for municipalities or regions. A second objective of WP3 will be to identify upcoming innovations for reuse (TRL 5 or higher), using the same sustainability criteria as above. The final results of WP3 will be a selection of interesting eco-technologies for further development in WP5” (DoW 2019).

The overall aim of this study is to assess sustainability aspects of selected ecotechnologies in three catchment areas in Finland, Sweden and Poland. To determine whether their implementation is worthwhile from a society’s point of view, they are assessed through applying cost-benefit analysis (CBA) informed by a participatory multi-criteria analysis. We demonstrate how a ‘bottom-up’ approach to CBA can serve as an instrument for exploring circular ecotechnologies and informing decision-making. Besides from revenues gained through the recovered products, benefits also reflect the provision of public goods through CO2 mitigation and eutrophication reduction. Interestingly, our assessment suggests that the benefits of the considered carbon and nutrient recovery ecotechnologies are still often outweighed by their costs.

### 1.2 Outline of the report

This report is structured as follows section 2 introduce the paper, section 3 describes the methodology, section 4 present the results and section 5 outline the conclusions and perspectives.

## 2 SCIENTIFIC PUBLICATION ON SUSTAINABILITY OF ECO-TECHNOLOGIES

This del. 3.6 provides a sustainability analysis of ecotechnologies selected from three empirical case areas (Slupia in Poland, Vantaanjoki in Finland, and Fyrisån in Sweden). With a CBA based bottom-up approach this study shows how involvement of stakeholders can serve as instrument for exploring the implementation of new solutions. The advantage from this approach is that the criteria included have gone through a robust participatory process, which provides more legitimacy to the decisions reached, as key stakeholders have had the opportunity to influence the elements considered in the assessment.

Findings from this study indicate that only one of the explored eco-technologies - anaerobic digestion of agricultural wastes in the Finish case - provide a positive NPV under the current conditions. Here, costs for investment are moderate compared to the baseline alternative (to build a composting plant) and the benefits from producing biogas are considerable. In contrast, ecotechnologies for the wastewater sector are costly and require large investments that do not seem to provide enough benefits compared to the baseline alternatives within the explored timeframe of 30 years. However, we only consider some extent of the impacts ecotechnologies may result in. To allow generating an even more complete picture with all the benefits and costs society may experience due to the implementation of ecotechnologies, further research is necessary to quantify and consider monetary values of additional impacts, possible risks, and co-benefits. Research is also needed to explore possibilities to obtain better balance between costs and benefits of sustainable and circular solutions. This is fundamental, as ecotechnologies for nutrient reuse are fundamental for rolling out the EU's circular economy approach and efforts to reduce and reuse "waste" safely and sustainably.

A full version of this study given in Appendix 1 is submitted to: Resources, Conservation & Recycling, Elsevier.

## 3 APPENDIX 1

# Sustainability of ecotechnologies to recover nutrients and carbon: Outcomes from three case studies in the Baltic Sea Region using cost-benefit analysis

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**Keywords:** Cost–benefit analysis, Circular Economy, Multi-Criteria Analysis, Ecotechnologies, Nutrient recovery, Phosphorus, Baltic Sea Region.

**Abstract**

Nutrients and carbon in wastewater, manure and other organic waste cause environmental problems like eutrophication and carbon emissions, yet they are underutilized and could be valorized in circular flows. Economic reasoning is among the most important barriers and decision criteria determining whether or not nutrient and carbon recovery ecotechnologies are adopted. In this paper, we investigate the sustainability of ecotechnologies for recovering carbon and nutrients based on three case-studies. We analyse technologies associated with domestic wastewater in Sweden and in Poland, and manure, grass and blackwater substrates in Finland. To determine whether their implementation is worthwhile from a society's point of view, they are assessed through applying cost-benefit analysis (CBA) informed by a participatory multi-criteria analysis. We demonstrate how a 'bottom-up' approach to CBA can serve as an instrument for exploring circular ecotechnologies and informing decision-making. Considering both social and private components provides a more complete appraisal of the impacts that the implementation of ecotechnologies have upon society and could ultimately trigger their adoption. The considered costs include investment, operation and maintenance costs. Besides from revenues gained through the recovered products, benefits also reflect the provision of public goods through $CO_2$ mitigation and eutrophication reduction. Interestingly, our assessment suggests that the benefits of the considered carbon and nutrient recovery ecotechnologies are still often outweighed by their costs.

# 1 INTRODUCTION

Eutrophication from nutrient input into waters and the ocean is a pervasive and serious environmental problem in the Baltic Sea, which is home to the world's largest hypoxic zones, i.e. areas with insufficient oxygen to support aquatic animal life (McCrackin et al., 2018). The causes and consequences of eutrophication are well documented, and a number of policies have been implemented to reduce external nutrient inputs (Andersen et al., 2017; HELCOM, 2017). Additionally, a number of European Union (EU) policies legally require member states — eight of the nine coastal counties of the Baltic Sea — to reduce nutrient inputs to surface waters in order to meet environmental goals (EEA, 2018; Schumacher, 2012). These policies are for instance the Water framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD).

Environmental problems associated with nitrogen (N) and phosphorus (P) use are particularly pressing in the Baltic Sea Region (BSR). Excessive inputs of nutrients from the surrounding land are among the primary causes of Baltic Sea eutrophication (HELCOM, 2017). According to HELCOM (2017), the application of mineral fertilizers and farmyard manure are *non-point sources of pollution* and contribute with 46.5% and 35.7% of total N and P riverine loads to the Baltic Sea, respectively. Only about half of the nutrients in mineral and organic fertilisers are converted to harvested crops, thus nutrient use efficiency must improve (Svanbäck and McCrackin, 2016). Consequently, nutrient recovery and reuse practices and technologies are increasingly used in the agricultural and wastewater treatment sectors (Cieślik & Konieczka, 2017).

In this paper, we focus on "ecotechnologies" understood as "*human interventions in social-ecological systems in the form of practices and/or biological, physical, and chemical processes designed to minimise harm to the environment and provide services of value to society*" (Haddaway et al., 2018, p. 266). Ecotechnologies have the potential to reduce nutrient use in the food chain, including treatment of pollution, waste management and depletion of finite resources, such as P while providing a number of co-benefits (Macura, et al., 2019a).

We explore the costs and benefits of ecotechnologies in the wastewater and agricultural sectors. We build on the work by Carolus (2018a and 2018b) (2018) to explore how the economic benefits contra costs has been approached for reuse or recovery technologies across Europe. The review shows that studies often apply cost benefit analysis (CBA), though they mostly consider only the private costs and benefits of ecotechnologies. Understanding benefits more broadly, is important in the context of circular ecotechnologies, because although economic validity is recognized as an important criterion for upscaling ecotechnologies, the lack of market competitiveness leads to ecotechnologies being mostly unprofitable and, thus, seldom implemented (Barquet et al., 2020; Roy, 2017).

CBA is a widely accepted method for evaluating policies and projects (OECD, 2018). CBA collects all costs and benefits of an intervention (e.g. a project, policy or measure) into a single monetary unit, the Net Present Value (NPV). From an economic point of view, interventions or technologies with a positive NPV should then be implemented. While CBAs originally only considered purely monetary values, the inclusion of social and/or environmental values into CBA was introduced in the 1980s (Molinos-Senante et al., 2010). In line with this approach, the present paper will quantify the economic impacts for both market and non-market benefits in the cost benefit analysis including both social and environmental impacts.

The overall aim of this study is to assess sustainability aspects of selected ecotechnologies in three catchment areas in Finland, Sweden and Poland. Based on activities in the BONUS RETURN project, we selected the nutrient and carbon recovery ecotechnologies and their potential benefits by using a bottom-up approach and drawing on site-specific model assumptions. In this paper, we estimate the cost and benefits of these ecotechnology scenarios in the three case areas. The assessment provides detailed insights on the monetary and non-monetary impacts that such ecotechnologies have on social welfare. The considered ecotechnologies include recovery and reuse of N and P from wastewater, struvite recovery and reuse from digested sludge, anaerobic digestion, biogas and fertiliser production from manure.

## 1.1 Methods

In this paper, we develop and apply an approach that combines CBA and multi-criteria analysis (MCA) within the topic of circular management of nutrients and carbon with the aim of supporting the effective implementation of ecotechnologies. By incorporating MCA results into a CBA, the approach captures the strengths of each appraisal method and provides a procedure for decision makers to create an initial ranking of ecotechnologies, which is consistent between all candidate investments for the ecotechnologies and has a clear link to policy goals in the management of the Baltic Sea. The methodology is applied to explore constellations or scenarios of ecotechnologies in three case studies.

### 1.1.1 Case Studies

The three catchment areas studied are Fyrisån River basin in Sweden, the Słupia River basin in Poland and the Vantaanjoki River basin in Finland. The Fyrisån River basin (1,982 km$^2$) located in the south-eastern part of Sweden is a tributary of Lake Mälaren, which has its outlet through Stockholm into the Baltic Sea. The Fyrisån catchment area is distributed among forests (60%), agriculture (32%), wetlands (4%), lakes (2%) and urban areas (2%). For the Fyrisån case study, wastewater was chosen as studied substrate. Three ecotechnologies were evaluated: i) incineration, ii) nutrient extraction and iii) source-separation.

The Słupia River basin (1,623 km$^2$) is a diverse coastal catchment with an expansive area of dunes stretching along the coast. In the Słupia catchment area agricultural land and forest represent 54% and 42% of the basin, respectively. Urban areas constitute around 3%, of which the largest portion is taken by the city of Słupsk with 95,000 inhabitants, and two smaller towns (Bytów and Ustka) (Johannesdottir et al., 2019). In this case, wastewater was studied and the three ecotechnologies were: i) nitrogen recovery from reject water ii) nutrient extraction and iii) source-separation.

In Finland, the Vantaanjoki river basin (1,680 km$^2$) which flows through the Helsinki metropolitan area before discharging into the Baltic Sea consists of 23% agriculture, 56% forestry and 17% urban area. Over 90% of the population is connected to a sewage network (Johannesdottir et al., 2019). In Vantaanjoki, the substrates studied for recovery was horse manure, set-aside grass and source-separated blackwater (toilet wastewater) from scattered settlements. The three ecotechnologies studied were: i) composting, ii) anaerobic digestion and iii) thermal treatment. A full-detailed description of the selected ecotechnologies included in this study, are well described as system alternatives for each of the catchment areas in the BONUS RETURN project multi-criteria analysis (Johannesdottir et al., 2019), therefore no detail will be discussed on this paper in that regard.

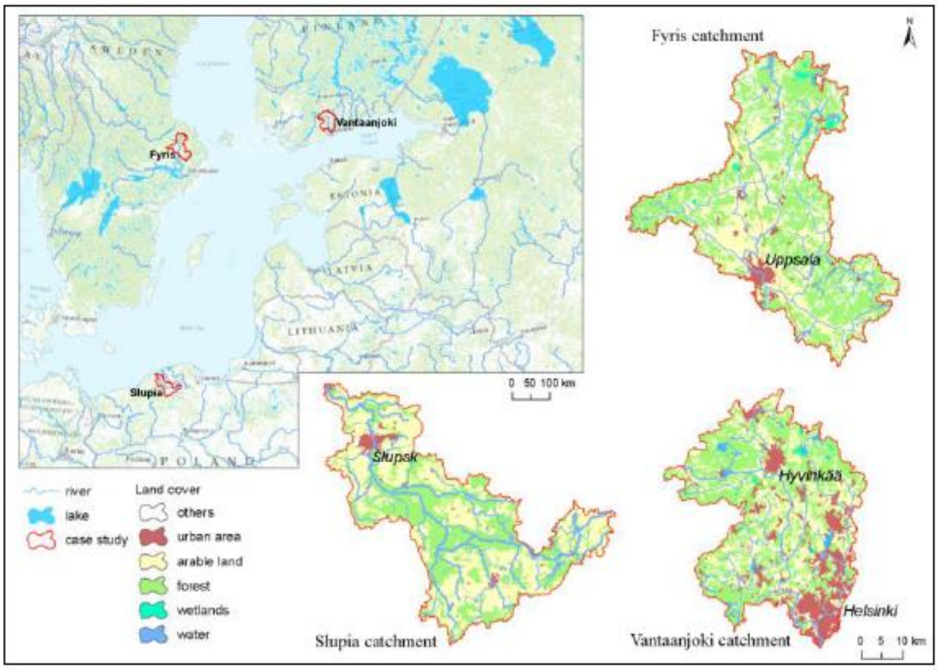


Figure 1 River basins Vantaanjoki in Finland, Slupia in Poland, Fyrisån in Sweden. Source:

### 1.1.2 A bottom-up approach to Cost-Benefit Analysis

A CBA is a comparative analysis approach that aggregates the costs and benefits of a project or policy. CBA is an often applied tool to inform decision-making and provides the means to determine how interventions affect social welfare, i.e. whether or not the implementation of some particular change is desirable from a societal point of view. The two underlying principles of environmental CBA are the Kaldor-Hicks compensation test and the monetisation of non-market goods. Roughly speaking, the Kaldor-Hicks compensation test states that some change should be implemented if it results in an increase in social welfare (Adlert & Posner, 1999; Hanley & Barbier, 2009). The test is represented by the NPV and is conducted by contrasting the present values of all social benefits (B) and all social cost (C) which occur throughout a set time period (T) as a consequence of the analysed change (eq. [1]).

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \qquad [1]$$

To convert all cost and benefit flows accruing throughout the time period into the present value, the CBA draws on the social discount rate (r) to account for society’s time preferences. Alhough according to the Ramsey equation (cf. OECD, 2018), the social discount rate is considered as a political decision (Arrow et al., 2014; Hanley & Barbier, 2009), there has been consensus in EU guidelines addressing CBA to use a higher discount rate for countries within the EU with a significantly lower gross national income (GNI) than the average (European Commission, 1997, 2008, 2014). In the latest issue of the guidelines (European Commission, 2014), the recommended rate is 5% for Cohesion countries (which includes Poland) and 3% for all others. The Cohesion countries have 90% or less of the average GNI in the EU and they therefore have a higher marginal utility of income and, thus, a higher time preference (OECD, 2018). Within the EU, it is common to use the Social Time Preference Rate (STPR) approach, which determines the social discount rate based on growth rate, elasticity and time preference.

The NPV captures the present value of costs and benefits occurring within a certain time period. In this study, we compare a baseline with the selected alternatives. We use a partial budgeting approach that considers changes from the baseline to a new situation, meaning that we only include additional costs and benefits that are related to that particular new scenario. The NPV and all other costs and benefits reported are therefore relative to the baseline (see eq. [2]).

$$NPV(Alternative) - NPV(Baseline) = NPV \qquad [2]$$

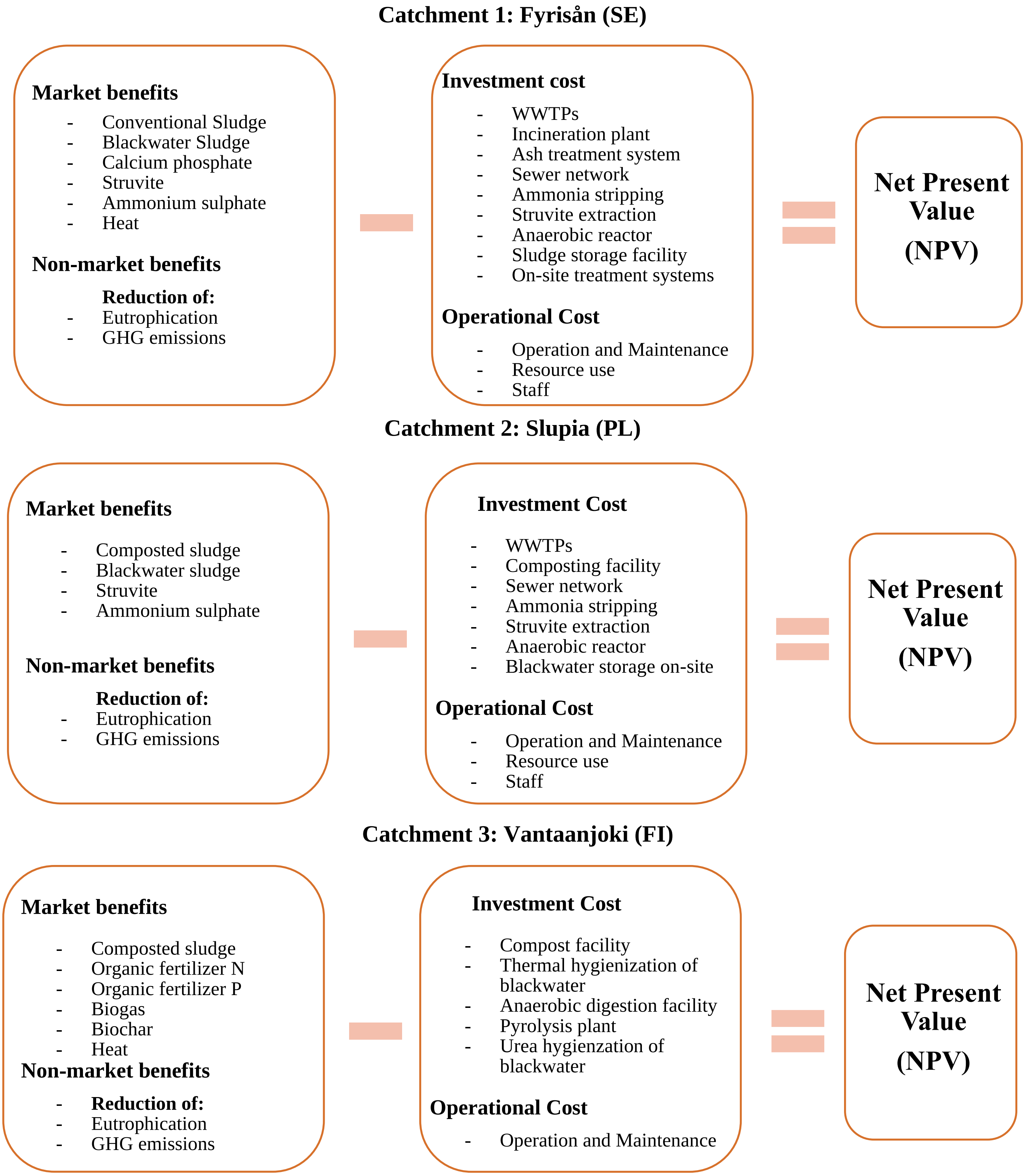
We apply CBA based on an MCA. MCA is a method that provides a systematic methodology that combines technical knowledge on benefits and trade-offs of particular choices with locally relevant criteria (Barquet & Cumiskey 2017). They are most often used to quantify decision-makers' and stakeholders' considerations about (mostly) non-monetary factors in order to balance reasons of different courses of action (Huang et al., 2011).

The selection of ecotechnologies for the MCA and further used in this study is based on a series of workshops executed in the context of the BONUS RETURN project (Johannesdottir et al., 2019). The MCA is carried out on a selection of ecotechnologies and sustainability criteria which are based on systematic mapping of ecotechnologies in the wastewater sector (Haddaway et al., 2019) and agricultural sector (Macura et al., 2019b), as well as stakeholder input (Johannesdottir et al 2019). Around 30 stakeholders took part in the workshops in each case area. These included representatives from water utilities, agriculture, forestry, universities and companies. They provided information through workshops in each case study on the following topics: 1) Goal and scope definition, 2) selection of sustainability criteria, 3) selection of ecotechnology constellations. The selected criteria are thereby divided into five categories: environmental, economic, socio-cultural, health and hygiene, and technical function. Further details of conducting the MCA, including the workshops and subsequent steps, are described in Johannesdottir et al. (2019).

Out of the sustainability criteria defined for the MCA, the following are included in the CBA: global warming potential, eutrophication potential, nutrient recovery and total costs. The global warming potential is calculated as the systems net emissions of $CO_2$ equivalents. The eutrophication potential is calculated as a "worst case" scenario where all emissions of N and P contribute to eutrophication. The nutrient recovery is based on substance flow calculations of N and P recovered and returned to agriculture in each catchment area The total costs calculated included costs for investments, revenues, maintenance and operation. The data considered in the MCA and, thus, in this paper's CBA is outlined in Table 1 and Figure 2.

**Table 1 Selected ecotechnologies for the CBA, based on data from MCA (Johannesdottir et al., 2019).**

| Catchment area | Baseline | Ecotechnology 1 | Ecotechnology 2 | Ecotechnology 3 |
|---|---|---|---|---|
| **Fyrisån (SE)** | Present treatment (conventional). Sludge is digested, stabilised and part of it returned to fields | Incineration:<br>Conventional treatment as in baseline. Digested sludge incinerated and P extracted from the ash | Nutrient extraction:<br>Wastewater treated anaerobically. Ammonia stripping and struvite precipitation from effluent. Sludge is stabilized and returned to field | Source-separation:<br>Greywater treated with mixed wastewater as in baseline. Blackwater treated by ecotechnology 2 |
| **Slupia (PL)** | Present treatment (conventional). Sludge is digested, composted and returned to field | Reject water:<br>Conventional treatment with ammonia stripping of reject water from anaerobic digestion. Sludge managed as in baseline | Nutrient extraction:<br>Wastewater treated anaerobically. Ammonia stripping and struvite precipitation from effluent. Sludge composted and returned to field | Source separation:<br>Greywater treated with mixed wastewater as in alt. 0. Blackwater treated by ecotechnology 2 |
| **Vantaanjoki (FI)** | Composting:<br>There are no central composting plants in the Vantaanjoki catchment and therefore ecotechnology 1 is used as a baseline. | Composting:<br>Composting of agricultural residues and horse manure at central plant. Blackwater from scattered settlements thermally hygienized at same plant | Anaerobic digestion:<br>Anaerobic co-digestion of agricultural residues, horse manure, and blackwater from scattered settlements at central plant | Thermal treatment:<br>Co-treatment of agricultural residues and horse manure by pyrolysis at central plant and local urea-treatment of blackwaters from scattered settlements |



**Catchment 1: Fyrisån (SE)**

**Market benefits**

- Conventional Sludge
- Blackwater Sludge
- Calcium phosphate
- Struvite
- Ammonium sulphate
- Heat

**Non-market benefits**

**Reduction of:**

- Eutrophication
- GHG emissions

−

**Investment cost**

- WWTPs
- Incineration plant
- Ash treatment system
- Sewer network
- Ammonia stripping
- Struvite extraction
- Anaerobic reactor
- Sludge storage facility
- On-site treatment systems

**Operational Cost**

- Operation and Maintenance
- Resource use
- Staff

=

**Net Present Value (NPV)**

**Catchment 2: Slupia (PL)**

**Market benefits**

- Composted sludge
- Blackwater sludge
- Struvite
- Ammonium sulphate

**Non-market benefits**

**Reduction of:**

- Eutrophication
- GHG emissions

−

**Investment Cost**

- WWTPs
- Composting facility
- Sewer network
- Ammonia stripping
- Struvite extraction
- Anaerobic reactor
- Blackwater storage on-site

**Operational Cost**

- Operation and Maintenance
- Resource use
- Staff

=

**Net Present Value (NPV)**

**Catchment 3: Vantaanjoki (FI)**

**Market benefits**

- Composted sludge
- Organic fertilizer N
- Organic fertilizer P
- Biogas
- Biochar
- Heat

**Non-market benefits**

- **Reduction of:**
- Eutrophication
- GHG emissions

−

**Investment Cost**

- Compost facility
- Thermal hygienization of blackwater
- Anaerobic digestion facility
- Pyrolysis plant
- Urea hygienzation of blackwater

**Operational Cost**

- Operation and Maintenance

=

**Net Present Value (NPV)**

**Figure 2. The costs and benefits considered when calculating the Net Present Value (NPV) of ecotechnologies in the Fyrisån, Slupia and Vantaajoki catchment areas.**

#### 1.1.2.1 *Valuation of Costs and Benefits*

The assess the NPV of the ecotechnology scenarios, we follow eq. 1 and use a time period of 30 years and a social discount rate of 3% for Finland and Sweden, and 5% for Poland. Furthermore, we test for the sensitivity of the results by doubling the rates and also using 0%. The lifetime of each scenario is assumed to be 30 years since the major investment activities for the ecotechnologies often have this lifetime. However, some of the investment costs have either shorter or longer lifespans. In order to apply eq. [1], the lifespan of all benefits and costs must be the same (e.g. 30 years). Thus, the costs have been re-calculated to fit the 30-year project scope. The present value (PV) of a cost stretching outside the project scope is fitted to the scope by subtracting the present value of the cost outside the project scope (e.g. the sewers are projected to last 50 years, meaning that 20 years are outside the lifetime scope) with the PV of the cost inside the scope (30 years).

The CBA model relies on different datasets gathered in order to identify costs and benefits for all scenarios considered for each of the catchment areas. Figure 2 displays the costs and benefits considered in this CBA in the three catchment areas. Estimation of costs include initial investments, operational costs and opportunity costs (farm income foregone). The PV of all costs are outlined in Table 3, whereas the details and groundwork of the calculations are provided in Appendix A and B.

The benefits considered in this study include both market and non-market benefits (Figure 2). The parameter values used for the market benefits are outlined in Table 2.

**Table 2. The market benefits for the three catchment areas.**

| | | **Values (€)** | | **Unit** | **Corrected for inflation** | **Corrected to market value*** |
|---|---|---|---|---|---|---|
| | **Fyrisån (SE)** | **Slupia (PL)** | **Vantaanjoki (FI)** | | | |
| Conventional sludge | 0 | 8 | - | ton | PL inflation index | 0 |
| Blackwater sludge | 0 | 8 | - | ton | PL inflation index | 0 |
| Biogas | | - | 88 | MWh | EMU inflation index | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Calcium phosphate | 1,135 | - | - | ton | DEU inflation index | x |
| Struvite | 820 | 820 | - | ton | DEU inflation index | x |
| Ammonium sulphate | 561 | 561 | - | ton | SE inflation index | x |
| Biochar | - | - | 1,363 | ton | EMU inflation index | x |
| Heat production | 84 | - | 48 | MWh | SE inflation index | 0 |
| Organic fertiliser N | - | - | 1,321 | ton | EMU inflation index | x |
| Organic fertiliser P | - | - | 2,179 | ton | EMU inflation index | x |

*Note: EMU is the euro area. * "x" indicate that the original value has been transformed into a market value, "0" that it has not been transformed and "-"that the value is not relevant for the catchment.*
*POL (Poland), SE (Sweden), FI (Finland), DEU(Germany; relevant for German values)*
Note: (Johannesdottir et al., 2019).

The considered non-market benefits are related to Greenhouse Gas (GHG) mitigation and eutrophication reduction (Figure 2). These benefits are characterized by the lack of a marked-based value even though they produce value to society and even though they are so-called public non-use goods (OECD, 2018). To cope with this, it is needed to rely on indirect ways to valuation such as benefit transfer.

Eutrophication has been valued in multiple issues of the Environmental Prices Handbook (Bruyn et al., 2010, 2017, 2018), primarily based on damage costs done to ecosystems as a willingness-to-pay value (Kuik et al., 2007). The shadow price of eutrophication is based on a linkage between the value of not losing species and the extinction of species due to eutrophication. Nutrient leakages are quantified for P into the water, N into the water, NOx to air and ammonia to air. The reductions in nutrients are valued based on environmental prices from Bruyn et al., (2017) as listed below (all for year 2020):

- Total P: 1.95 €/kg
- Total N: 4.66 €/kg
- NOx: 1.21 €/kg

The ammonia has been converted into total N by using the molar weight of N in ammonia (approx. 82%).

The GHG emission valuation is based on projections from Bryun et al. (2018) corrected for inflation as shown in Figure 3. below. The abatement cost of emitting one ton of $CO_2$ is discounted to the year of emission in nominal prices, based on a reduction target of -40% in 2030 and -65% in 2050.

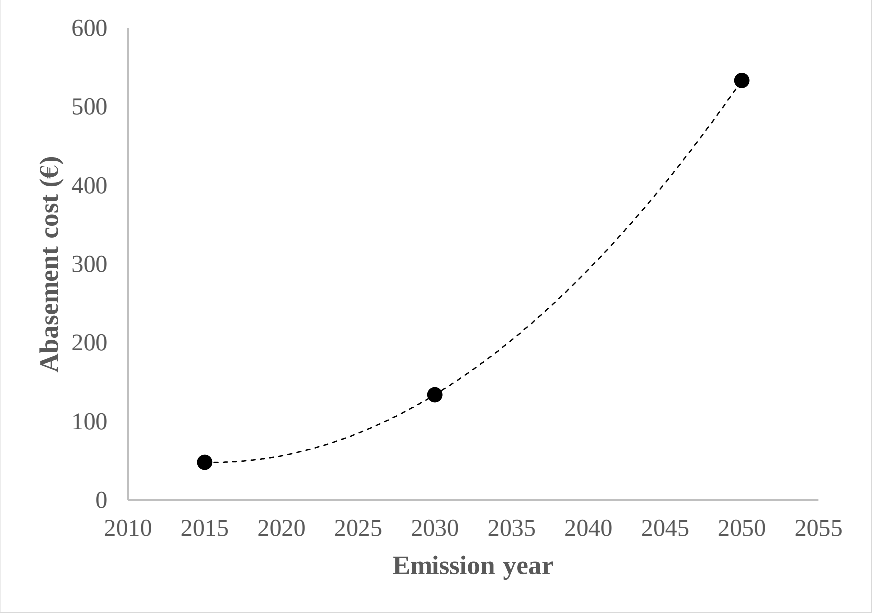


**Figure 3 NPV of GHG emissions in € $CO_2$ eq. $ton^{-1}$ in nominal 2020 prices excl. VAT**

Note: Based on (Bruyn et al., 2018).

Currently, the carbon reduction targets are changing, which means that the used valuation of climate change must be considered an underestimate because it is set on abatement and not damage costs.

#### 1.1.2.2 Factors of comparison

When comparing the costs and benefits of projects, the boundaries and basic assumptions must be the same. In other words, all aspects should be valued by considering the same purchasing power (e.g. the same year), all values should include taxes (market prices) and be considered to what extend prices will cause a deadweight loss of taxation. This analysis projected all obtained costs and benefits into 2020 values using the World Bank inflation database (World Bank, 2020).

While consumers perceive value at one level, producers see another and the difference between the two is taxes. We use a standard conversion factor (SCF) to approximate the national proportion of value added tax (VAT) and other ad valorem taxes. This parameter is then used to account for the discrepancy between producer and consumer prices (Møller & Jensen, 2004). But since an officially SCF for Sweden, Poland and Finland could not be identified, this analysis uses a partial approach in line with EU's guide to CBA (European Commission, 2014). This partial approach consists of the standard VAT rate to known producer prices and acknowledging that this may lead to a minor underestimation. The following VAT factors are used (European Commission, 2019):

- Sweden: 1.25
- Poland: 1.23
- Finland: 1.24

Some uncertainties arise from the data used, assumptions made and the system boundaries. These are presented in more detail in Johannesdottir et al. (2019). On system boundaries for example, $CO_2$ emissions from infrastructure or nutrient emissions from soil (after fertilizer application) are not included. As far as was possible, local data was used. However, since it was not always possible, some data used was based on national standards or other case-studies. One example of assumption is that it was assumed technical performance data would remain constant, even though it might be reasonable to assume some technical development during the time period studied.

# 2 RESULTS

The results of the CBA reports on the social net benefits of a certain project compared to the baseline. The comprehensive analysis of alternative ecotechnologies has shown that only one of the proposed ecotechnologies would lead to an increase in social welfare. For Vantaanjoki, we find a positive NPV for anaerobic digestion. However, it should be stressed that this outcome is compared to our assumed baseline *composting* which is a best approximation for the real baseline for Vantannjoki. Hereby,the analysis of Vantaanjoki shows that anaerobic digestion has the highest NPV among the ecotechnologies studied – independently from the unknown baseline. Overall, costs and benefits and NPV of the different ecotechnologies are provided in Figure 4. Specific numbers of costs and benefits related to the alternative technologies in the three catchment areas are given in Appendix B, Table 6.

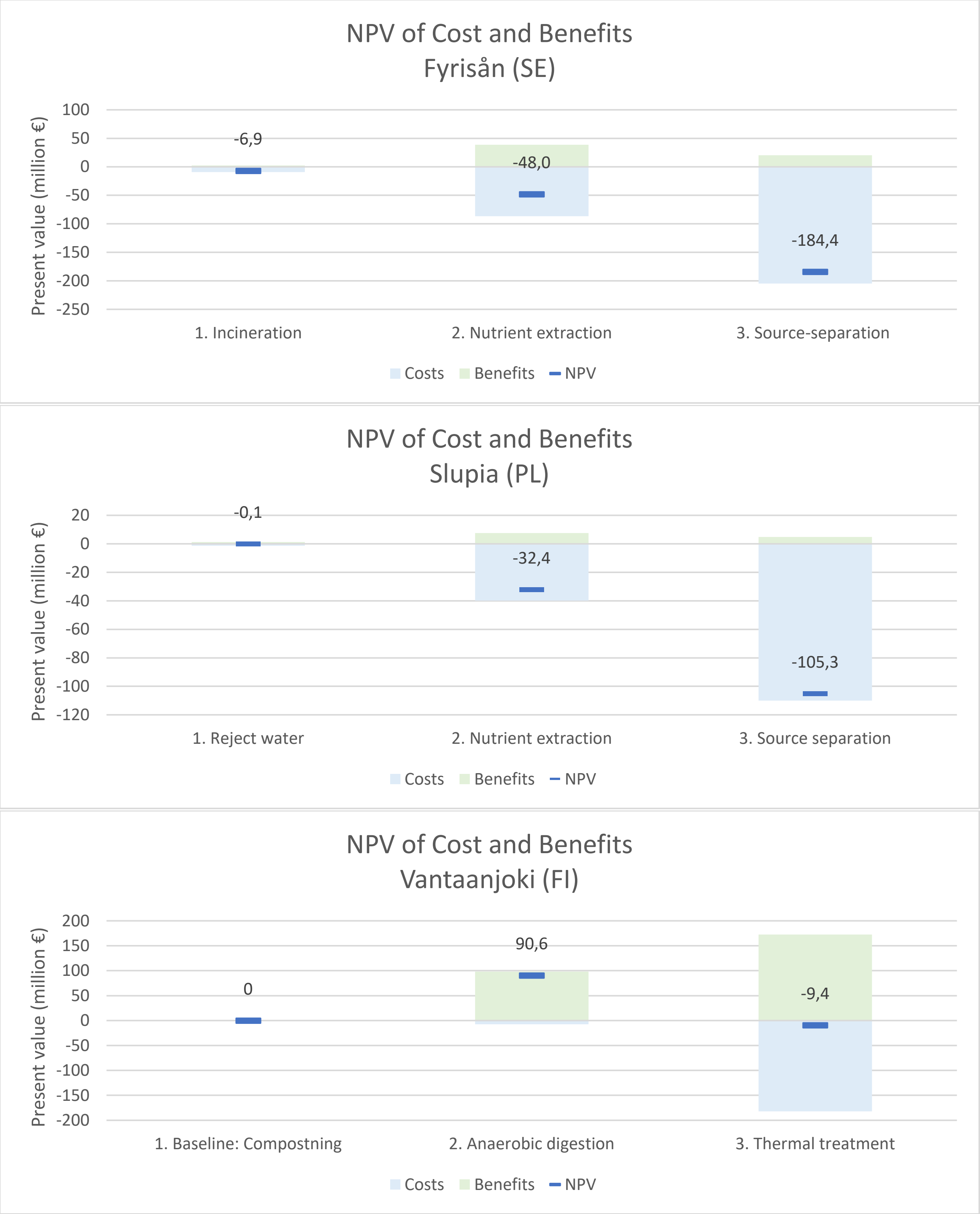


**Figure 4. The Present value of costs and benefits for Fyrisån, Slupia and Vantaanjoiki catchment in million euro. The numbers presented in the columns represent the NPVs of the alternatives.**

Table 3 shows the Present Value for the three catchment areas, Fyrisån, Slupia and Vantaanjoki, with their respective ecotechnologies alternatives. The core determinant for most ecotechnologies showing negative NPVs are the early and substantial investments into the facilities (i.e. the fixed costs), as shown in Table 3. The cost and benefit categories in Table 3 summarise the different parameters as outlined in Figure 2. The specific calculation details are provided in Appendix B.

**Table 3. PV of the fixed and variable costs. In € (year 2020) Project lifetime: 30 years.**

| | Costs | | Benefits | |
|---|---|---|---|---|
| **Fyrisån (SE)** | **Fixed** | **Variable** | **Market** | **Non-market** |
| 1. Incineration | 7,794,000 | 1,325,000 | 2,786,000 | -561,000 |
| 2. Nutrient extraction | 38,250,000 | 48,469,000 | 12,085,000 | 26,668,000 |
| 3. Source-separation | 134,795,000 | 69,874,000 | 7,197,000 | 13,092,000 |
| **Slupia (PL)** | | | | |
| 1. Reject water | 198,000 | 1,181,000 | 496,000 | 785,000 |
| 2. Nutrient extraction | 19,494,000 | 20,372,000 | 4,699,000 | 2,802,000 |
| 3. Source separation | 73,027,000 | 37,084,000 | 1,444,000 | 3,361,000 |
| **Vantaanjoki (FI)** | | | | |
| 1. Anaerobic digestion | 6,476,000 | 876,000 | 75,844,000 | 22,142,000 |
| 2. Thermal treatment | 47,927,000 | 134,006,000 | 152,194,000 | 20,297,000 |

All alternative scenarios provide additional market and non-market benefits, either in terms of reduced eutrophication or reduced GHG emissions. However, for most of the scenarios the benefits remain below the additional investments as well as operational and maintenance costs.

The most promising alternative is anaerobic digestion in Vantaanjoki which results in an NPV of 91 Mill. €. The need for investments is relatively low and the revenue from biogas production is large which means that this alternative is beneficial, reflected in a positive NPV (even under different discount rates, see Appendix C). In the same catchment, thermal treatment also appears to be an alternative that could potentially be interesting, although under the current conditions with a negative NPV of -4,570,000 €. Both alternatives in the Finnish case study, anaerobic digestion and thermal treatment are considered as not providing non-market benefits through reduced eutrophication. Assumed that the use of recycled nutrients would replace mineral fertilizer, the amount of nutrients used in agriculture will not be reduced. However, recycled nutrients could increase the soil carbon content, which in turn, leads to a decrease in nutrient leaching. Still, the amounts of organic carbon that could be incremented into the agricultural soil by the implementation ecotechnology could be so low that the effects to the nutrient load reductions remain minor at the level of an entire river basin. However, the reductions could be higher when considering smaller sub-basins (Koskiaho et al., 2020). In addition, the benefits due to eutrophication reduction could be more substantial in areas with intensive animal husbandry and excessive amounts of manure, like Southwestern Finland. Agriculture in Vantaanjoki mainly consists of crop production and some horse stables.

In Fyrisån and Slupia, the negative NPVs are mainly related to high investment costs, especially in relation to source separation, which has high costs but results in relatively small benefits. It is assumed that source-separating sewers would be built in new residential areas (assumed a population increase with new buildings with source-separation) as well as during renovation of existing sewers. Part of the reason why investment costs are high for the source-separation scenarios is that we relate the costs to installing sewage pipes, including one extra pipe for blackwater and additional pumps. Even though only part of the population is provided with source-separating sewage (37% in Fyriså and 14% in Slupia), the costs are therefore substantial. The results suggest that rejecting water in Slupia (NPV of -100,000 €) and incineration in Fyris (NPV of -6,900,000 €) are not desirable from the CBA point of view. Yet, they could potentially be promising and imply lower investment costs, at least for the 30-year timeline considered in this analysis.

The sensitivity analysis shows that changing the discount rate from 3% to 0%, 6% and 10% resulted in a relative and substantial change in NPV of some of the alternatives compared to the baseline. (see Appendix C)

## 3 DISCUSSION

This study applies a bottom-up approach to support the effective implementation of ecotechnologies when prioritizing between projects. In this case projects that circulate and reuse available nutrient resources.  The approach consists on incorporating results from a participatory MCA into a CBA, whereby data on ecotechnologies is collected through stakeholder workshops with inputs from experts and analysed in the face of a range of social, environmental and technical criteria. The assessment shows how CBAs based on a bottom-up approach can serve as instrument for exploring the implementation of new solutions, such as circular ecotechnologies, and informing decision-making. The advantage from the bottom-up approach to CBA piloted in this study is that the criteria included in the assessment of costs and benefits have gone through a robust participatory process to select relevant eco-technologies. In the context of decision-making, such a process provides more legitimacy to the decisions reached, as key stakeholders have had the opportunity to influence the elements considered in the assessment. The approach allows therefore to retain the strengths of each appraisal method while providing a procedure for decision makers to create an initial ranking of ecotechnologies.

Findings from this study indicate that only one ecotechnology - anaerobic digestion of agricultural wastes in the Finish case - provides a positive NPV. Generally, an outcome from comparing the three catchment areas is that ecotechnologies for circulating nutrients from agricultural wastes can have a positive NPV while ecotechnologies in wastewater management show negative NPVs. This is largely due to the need for expensive infrastructure for wastewater management, but also partly due to significant market benefits from agricultural wastes in relation to thermal treatment and Anaerobic digestion in Finland. However, the efficiency on reducing eutrophication as an isolated aspect is higher when applying wastewater related ecotechnologies in Fyris and Slupia compared to agricultural waste-related ecotechnologies in Vantaanjoki (Koskiaho et al., 2020). In Fyrisån and Slupia, the NPVs decrease with increasing complexity and deviation from the baseline scenarios. This emphasizes the large investments needed in the wastewater sector, which is one of the barriers to new technologies and treatment systems (Barquet et al. 2020). However, some additional benefits, which are not included in this CBA could make the implementation of these scenarios worthwhile. For example, source-separation can reduce the risk of environmental pollution due to overflow in the sewer systems during heavy rains. Moreover, Lennartsson et al. (2019) showed that, on one hand, the costs for source separation systems are considerably higher than for conventional system. However, on the other hand, the benefits are also much higher. The dominating factor was a decrease in release of pathogens, viruses and parasites to water as well as potential reduction of pharmaceuticals to water. These are non-market benefits, which were not considered in the study but should be taken into account in future studies. Other examples of additional benefits include incinerating sludge instead of spreading it on arable land can reduce the input of certain pollutants to the soil.

In terms of climate change potential, in Vantaanjoki, both explored scenarios had negative $CO_2e$ emissions, i.e. emissions omitted were larger than the emissions within the system boundaries. For anaerobic digestion, the main source of negative $CO_2e$ was replacing natural gas with biogas and in thermal treatment it was carbon sequestration by biochar application on soil. In Fyrisån, the system with the lowest $CO_2e$ was nutrient extraction, mainly due to replacing mineral fertilizers with recovered nutrients and the highest $CO_2e$ was from incineration, which was higher than the baseline. In Slupia, the system with lowest $CO_2e$ emissions was reject water, mainly through carbon sequestration. Both nutrient extraction and source-separation had higher $CO_2e$ than the baseline.

There are multiple layers of uncertainty in the transformation of GHG emissions into monetized benefits. In this study, it is likely that our estimation is an underestimate primarily due to two effects. First, we apply an abatement cost method to monetize the emission data. This is known to generate lower values than a damage cost method, but it is, however considered to be more precise (Bruyn et al. (2010). The abatement cost method assumes that the policy targets considered are economically efficient, which is seldom the case (Bruyn et al. (2010). The other source of uncertainty stems from an ethical discussion revolving around whether we should consider a decreasing marginal utility of time – also known as the pure time rate preference (Beckerman & Hepburn (2007)). We choose to follow the EU guidelines for CBA which include a time preference as it is the official approach.

The benefit of reducing eutrophication is in this study monetized through the marginal willingness to pay for improvement to water quality. Applying the value to this study is benefit transfer and as it stand uncorrected and is merely a mean unit value transfer as oppose to transferring actual benefit functions (OECD, 2018) it is subject to spatial and also temporal inaccuracy. But there is no empirical evidence that this so-called naive approach is subject to higher uncertainty (OECD, 2018). The approach is however still inducing subjectivity and uncertainty into the analysis. Future research should focus on more sensitivity analysis on the size of these non-market benefits. It is however, the assessment of the authors that the degree of uncertainty is not significant enough to alter the sign of the NPV in this study. The main conclusion therefore stands; none of the proposed ecotechnologies in Fyrisån and Slupia is more advantageous than the baseline. For Vantaanjoki the primary finding is that anaerobic digestion is the best alternative, but due to the missing baseline, its substitutional value is undetermined.

From a societal point of view, the value of the ecotechnologies should be outlined by their contribution to public budgets but also in terms of co-benefits to multiple policy goals. For example, increasing resource recovery is in line with policies on EU's circular economy, which aims for both better recycling of materials and energy savings in the society and can be a main driver for investments and implementation of circular ecotechnologies. Another example is that addressing eutrophication according to the Water Framework Directive requires closing loops and limiting the total input of nutrients. Sweden, Finland and Poland are EU-member states and as such they are tasked with reducing eutrophication and contributing to reducing acidification, but this analysis doesn't include this benefit even though it affects it.

Co-benefits are relevant not only for policy alignment, but also in economic terms, where co-benefits are said to diminish the costs of environmental impacts, like climate change, for society (Mayrhofer and Gupta, 2016). For instance, an ecotechnology might be planned for recovering nutrients but will have other co-benefits such as reducing eutrophication, which in turn could enhance recreational opportunities in inland waters, and potentially increase revenues from tourism. In countries where clear policy measures towards more circular systems have been put in place, private companies have become interested in investing in circular technologies (Barquet et al., 2020). Thus, a circular economy could boost productivity, improve performance and reduce costs (Ellen MacArthur Foundation, 2015). A circular economy could also help governments meet their climate targets; industries and food production systems could reduce their emissions; and at the same time, countries could improve their resilience to the effects of climate change (Ellen MacArthur Foundation, 2019).

Future studies should thus explore how the costs of sustainable ecotechnologies could be reduced through multiple policy alignment. This would require better quantification of a broader range of co-benefits than those included in this study. Longer time frames than 30 years, as well as adopting a systemic view that quantifies not only investment costs but also risks stemming from different technologies is necessary. Moreover, to accelerate progress and fully benefit from the benefits and co-benefits from circular eco-technologies, economic and policy incentives need to be set very differently than they do today so that market mechanisms can help balance out the costs from transitioning to more sustainable infrastructures (Barquet et al., 2020).

The CBA itself also entails some degree of limitation. For instance, social costs and benefits are defined as anything that affects individuals' utility, positively and negatively (cf. Hanley & Barbier, 2009). However, given the utilitarian approach of defining social welfare as the sum of all individual utilities, we do not consider equity or distributional issues. In other words, this means

that the CBA might report a positive NPV but does not consider who benefits and who pays. However, these are policy issues beyond this study.
Moreover, the CBA has a baseline scenario based on business as usual compared against a number of alternatives. Assuming that increased costs in these alternatives would increase the tax or tariffs on using the services that these investments may provide, one should also consider distortions to the consumption/production ratio – also known as the marginal cost of public funds (MCPF) or the deadweight loss of taxation. If the price increases, a deadweight loss would mean an additional loss in income to the state, therefore, one would expect an increased general marginal cost of public funded services (Møller & Jensen, 2004).

We have applied the European Commission's guide to CBA in investment projects that recommend MCPF=1 if no national guidelines can be identified which means that we assume no deadweight loss associated with increasing the costs of the investment (European Commission, 2014). Secondly, the applied valued for eutrophication is based on a comprehensive meta-analysis done by Kuik et al. (2007) but by applying it here it is assumed that the preferences uncovered in the study are static. This is statistically unlikely (Brouwer & Bateman, 2005) and it is therefore a source of a unknown level of uncertainty (Lo & Mueller, 2010). The interpretation of results should therefore consider these limitations.

# 4 CONCLUSIONS

This paper provides an assessment of costs and benefits of ecotechnologies selected from three empirical case areas (Slupia in Poland, Vantaanjoki in Finland, and Fyrisån in Sweden). By applying a CBA based bottom-up approach this study shows how involvement of stakeholders can serve as instrument for exploring the implementation of new solutions. The advantage from this approach is that the criteria included have gone through a robust participatory process, which provides more legitimacy to the decisions reached, as key stakeholders have had the opportunity to influence the elements considered in the assessment.

Findings from this study indicate that only one of the explored eco-technologies - anaerobic digestion of agricultural wastes in the Finish case - provide a positive NPV under the current conditions. Here, costs for investment are moderate compared to the baseline alternative (to build a composting plant) and the benefits from producing biogas are considerable. In contrast, ecotechnologies for the wastewater sector are costly and require large investments that do not seem to provide enough benefits compared to the baseline alternatives within the explored timeframe of 30 years. However, we only consider some extent of the impacts ecotechnologies may result in. To allow generating an even more complete picture with all the benefits and costs society may experience due to the implementation of ecotechnologies, further research is necessary to quantify and consider monetary values of additional impacts, possible risks, and co-benefits. Research is also needed to explore possibilities to obtain better balance between costs and benefits of sustainable and circular solutions. This is fundamental, as ecotechnologies for nutrient reuse are fundamental for rolling out the EU's circular economy approach and efforts to reduce and reuse "waste" safely and sustainably.

## 5 ACKNOWLEDGMENTS

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# 7 APPENDIX A

Table 4 Investments, operational costs and maintenance costs (O&M) for Fyrisån and Slupia catchment. In market values incl. VAT.

**Fyrisån (SE) Catcment**

| Investment | Value | Unit (€ in year 2020) per | Corrected for inflation with | Corrected to market value* |
|---|---|---|---|---|
| WWTP > 50,000 cap | 324 | cap per year | SE inflation index | x |
| WWTP > 2,000 cap | 1,493 | cap per year | SE inflation index | x |
| WWTP < 2,000 cap | 706 | cap per year | SE inflation index | x |
| Incineration plant | 405 | ton incinerated per year | SE inflation index | x |
| Ash treatment system | 2,057 | ton ash per year | SE inflation index | x |
| Conventional sewers | 753 | m | SE inflation index | x |
| Sewer pipe for blackwater | 506 | m/, material and installation)/cap | SE inflation index | x |
| Pumps in sewers | 59,411 | 2500 cap | SE inflation index | x |
| Ammonia stripping | 84 | cap | SE inflation index | x |
| Struvite extraction | 42 | cap | SE inflation index | x |
| Anaerobic reactor | 301 | cap | SE inflation index | x |
| Sludge storage | 33 | $m^2$ | uncorrected | x |
| Conventional on-site systems | 14,682 | household | SE inflation index | x |
| Source-separated on-site systems | 10,402 | household | SE inflation index | x |
| **O&M** | | | | |
| Transports | 0.2 | ton*km | SE inflation index | x |
| Electricity | 28 | MWh | SE inflation index | 0 |
| Heat | 84 | MWh | SE inflation index | 0 |
| Iron chloride | 213 | ton | SE inflation index | x |
| Polymer | 5,045 | ton | DEU inflation index | x |
| Sodium hydroxide | 114 | ton | DEU inflation index | x |
| Citric acid | 757 | ton | DEU inflation index | x |
| Sulphuric acid | 114 | ton | DEU inflation index | x |

| | | | | |
|---|---|---|---|---|
| Magnesium chloride | 95 | ton | DEU inflation index | x |
| Calcium hydroxide | 114 | ton | DEU inflation index | x |
| Staff | 51,519 | employee per year | SE inflation index | x |
| | | **Slupia (PL) catchment** | | |
| **Investments** | **Value** | **Unit (€ in year 2020) per** | **Corrected for inflation with** | **Corrected to market value*** |
| WWTP > 50.000 cap | 1.59 | cap | EUR inflation index | x |
| Conventional sewers | 1.59 | /cap | EUR inflation index | x |
| Sewer pipe for blackwater | 602 | m/material and installation)/cap | SE inflation index | x |
| Pumps in sewers | 58,460 | 2500 cap | SE inflation index | x |
| Ammonia stripping | 82 | cap | SE inflation index | x |
| Struvite extraction | 41 | cap | SE inflation index | x |
| Anaerobic reactor | 296 | cap | SE inflation index | x |
| Closed tanks for blackwater storage on-site | 10,235 | household | SE inflation index | x |
| **O&M** | | | | |
| Electricity | 146 | MWh | POL inflation index | x |
| Heat | 17 | GJ | POL inflation index | x |
| Iron chloride | 210 | ton | SE inflation index | x |
| Polymer | 4 | kg | POL inflation index | x |
| Sodium hydroxide | 112 | ton | DEU inflation index | x |
| Sulphuric acid | 112 | ton | DEU inflation index | x |
| Magnesium chloride | 0,5 | kg | POL inflation index | x |
| Maintenance | 3,0 | % of investment | % of investment | x |
| Staff | 19,012 | yr | POL inflation index | x |

** "x" signifies that the original value have been transformed into a market valuation and "0" that it have not been transformed.* Note: cap is short for *capita.*

Based on (Johannesdottir et al., 2019).

**Table 5. Correction factors for the Finnish cost catchment data. In market values incl. VAT.**

| | **Year of ref.** | **Inflation index correction*** | **VAT (FI)** | **Correction factor** |
|---|---|---|---|---|
| Composting | 2013 | 1.06 | 1.24 | 1.32 |
| Digestion | 2017 | 1.05 | 1.24 | 1.30 |
| Thermal threatment | 2018 | 1.03 | 1.24 | 1.28 |

*Euro area inflation index used.

# 8 APPENDIX B

**Table 6. PV of costs and benefits related to the alternatives to the baseline in the three catchment areas. In 2020 € prices. Project lifetime: 30 years.**

| **Fyrisån (SE)** | **PV(Costs)** | **PV(Benefits)** | **NPV** |
|---|---|---|---|
| 1. Incineration | 9,117.773 | 2,225.031 | -6,892,743 |
| 2. Nutrient extraction | 86,719.735 | 38,753.254 | -47,966,481 |
| 3. Source-separation | 204,668.363 | 20,288.347 | -184,380,016 |
| **Slupia (PL)** | | | |
| 1. Reject water | 1,378,465 | 1,281,060 | -97,405 |
| 2. Nutrient extraction | 39,866,667 | 7,500,923 | -32,365,744 |
| 3. Source separation | 110,111,015 | 4,805,148 | -105,305,867 |
| **Vantaanjoki (FI)** | | | |
| 2. Anaerobic digestion | 7,352.532 | 97,986,522 | 90,633,991 |
| 3. Thermal treatment | 181,932.557 | 172,491,181 | -9,441,377 |

Table 7. Investment costs, (year 2020) €

| **Fyrisån (SE)** | Treatment plants | Incineration plant | LeachPhos-system | Sewers | Pumps in sewers | Ammonia stripping | Struvite extraction | UASB | Storage of sludge | Septic tank +infiltration | Closed tanks +installation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Incineration | - | 5,600,768 | 2,556,650 | - | - | - | - | - | -364,319 | - | - |
| 2. Nutrient extraction | -59,646,109 | - | - | - | - | 19,230,450 | 9,600,809 | 69,137,360 | -72,236 | - | - |
| 3. Source-separation | -20,536,063 | 4,862,829 | 2,219,328 | 35,971,748 | 1,687,089 | 8,486,607 | 4,236,942 | 30,511,072 | -183,436 | - | 67,538,424 |
| **Slupia (PL)** | WW TPs | Composting | Sewage net | Sewage net, BW | Ammonia stripping | Struvite extraction | UASB | Closed tanks | | | |

|  |  |  |  | pump |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| 1. Reject water | - | - | - | - | 197,961 | - | - | - |
| 2. Nutrient extraction | -20,414,068 | -103,101 | - | - | 1,713,562 | 3,674,321 | 34,623,514 | - |
| 3. Source separation | -197,127 | -122,850 | 9,722,883 | 784,825 | 526,926 | 919,041 | 8,660,217 | 52,733,477 |

| **Vantaanjoki (FI)** | Compost facility | Black water hygienization | Biogas facility | Pyreg plant | Urea hygienization |
|---|---|---|---|---|---|
| 2. Anaerobic digestion | -22,092,044 | -5,445,769 | 34,013,884 | - | - |
| 3. Thermal treatment | -22,092,044 | -5,445,769 | - | 34,081,659 | 41,382,951 |

Note: The negative values indicate that the operational cost is higher in the alternative than it is in the baseline. “-“ indicate that the value is the same in the alternative as it is in the baseline.

Table 8 Operational costs (year 2020) €

***Operational costs (2020-€)***

| **Fyrisån (SE)** | Operation and maintenance | Resource use | Staff |
|---|---|---|---|
| 1. Incineration | 3,343,489 | -1,810,404 | -208,410 |
| 2. Nutrient extraction | 22,860,923 | 25,608,538 | - |
| 3. Source-separation | 84,352,407 | -14,417,006 | -61,579 |
| **Slupia (PL)** | Maintenance | Operation | Staff |
| 1. Reject water | 100,606 | 1,079,898 | - |
| 2. Nutrient extraction | 9,070,820 | 11,301,618 | - |
| 3. Source separation | 33,739,998 | 3,343,626 | - |
| **Vantaanjoki (FI)** | Operation and maintenance | | |
| 2. Anaerobic digestion | 876,461 | | |
| 3. Thermal treatment | 134,005,761 | | |

Note: The negative values indicate that the operational cost is higher in the alternative than it is in the baseline. "-" indicate that the value is the same in the alternative as it is in the baseline.

Table 9 Market and non-market benefits (in year 2020) €

| | *Market benefits (2020-€)* | | | | | | | *Non-market benefits (2020-€)* | |
|---|---|---|---|---|---|---|---|---|---|
| **Fyrisån (SE)** | Conventional sludge | Blackwater sludge | Calcium phosphate | Struvite | Ammonium sulphate | Biochar | Heat production | Eutrophication reduction | GHG emission mitigation |
| 1. Incineration | - | - | 2,785,756 | - | - | - | - | -296,652 | -264,074 |
| 2. Nutrient extraction | - | - | 0 | 2,130,851 | 9,953,945 | - | - | 17,570,144 | 9,098,314 |
| 3. Source-separation | - | - | 1,991,415 | 575,298 | 3,599,241 | - | 1,030,782 | 9,835,543 | 3,256,068 |
| **Slupia (PL)** | Conventional sludge | Blackwater sludge | Struvite | Ammonium sulphate | | | | Eutrophication reduction | GHG emission mitigation |
| 1. Reject water | - | - | - | 495,809 | | | | 517,371 | 267,880 |
| 2. Nutrient extraction | -4,862 | - | 825,521 | 3,878,406 | | | | 4,882,458 | -2,080,601 |
| 3. Source separation | -97,491 | 76,765 | 138,611 | 1,325,874 | | | | 3,464,174 | -102,784 |
| **Vantaanjoki (FI)** | Organic fertilizer N | Organic fertiliser P | Biogas | Biochar | Heat production | | | Eutrophication reduction | GHG emission mitigation |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| 2. Anaerobic digestion | -225,232 | 29,901 | 76,039,602 | 0 | 0 |  | - | 22,142,251 |
| 3. Thermal treatment | -5,208,808 | -4,720,158 | 0 | 160,530,521 | 1,592,562 |  | - | 20,297,063 |

Note: The negative values indicate that the operational cost is higher in the alternative than it is in the baseline. “-“ indicate that the value is the same in the alternative as it is in the baseline.

# 9 APPENDIX C

Table 10. Impact on NPV with change in discount rate. Here a discount rate of 6% and 10%. In € (2020 prices). Project lifetime: 30 years.

| **Fyrisån (SE)** | **PV(Costs) 6%** | **% change from baseline** | **PV(Benefits) 6%** | **% change from baseline** | **NPV 6%** | **% change from baseline** |
|---|---|---|---|---|---|---|
| 1. Incineration | 8,681,875 | -5% | 1,609,448 | -28% | -7,072,427 | 3% |
| 2. Nutrient extraction | 72,280,765 | -17% | 25,600,390 | -34% | -46,680,374 | -3% |
| 3. Source-separation | 188,134,314 | -8% | 13,669,988 | -33% | -174,464,326 | -5% |
| **Slupia (PL)** | **10%** | | **10%** | | **10%** | |
| 1. Reject water | 937,076 | -32% | 725,214 | -43% | -211,862 | 118% |
| 2. Nutrient extraction | 32,118,787 | -19% | 5,068,760 | -32% | -27,050,026 | -16% |
| 3. Source separation | 95,868,991 | -13% | 2,969,848 | -38% | -92,899,144 | -12% |
| **Vantaanjoki (FI)** | **6%** | | **6%** | | **6%** | |
| 2. Anaerobic digestion | 7,270,416 | -1% | 64.,882,978 | -34% | 57,612,562 | -36% |
| 3. Thermal treatment | 133,072,880 | -27% | 117,532,989 | -32% | -15,539,890 | 65% |

**Table 11. Sensitivity analysis, Impact on NPV with change in discount rate. Here a discount rate of 0 % is used In 2020-€ prices. Project lifetime: 30 years.**

| **Fyrisån (SE)** | **PV(Costs) 0%** | **% change from baseline** | **PV(Benefits) 0%** | **% change from baseline** | **NPV 0%** | **% change from baseline** |
|---|---|---|---|---|---|---|
| 1. Incineration | 9,923,214 | 9% | 3,265,594 | 47% | -6,657,620 | -3% |
| 2. Nutrient extraction | 112,456,896 | 30% | 64,138,006 | 66% | -48,318,890 | 1% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3. Source-separation | 231,188,272 | 13% | 32,778,978 | 62% | -198,409,294 | 8% |
| | 0 | | 0 | | 0 | |
| **Slupia (PL)** | **0%** | | **0%** | | **0%** | |
| 1. Reject water | 2,434,695 | 77% | 2,833,137 | 121% | 398,443 | -509% |
| 2. Nutrient extraction | 58,671,355 | 47% | 12,051,263 | 61% | -46,620,092 | 44% |
| 3. Source separation | 144,953,252 | 32% | 9,249,648 | 92% | -135,703,604 | 29% |
| **Vantaanjoki (FI)** | **0%** | | **0%** | | **0%** | |
| 2. Anaerobic digestion | 7,375,504 | 0% | 161,713,895 | 65% | 154,338,391 | 70% |
| 3. Thermal treatment | 275,187,277 | 51% | 274,770,911 | 59% | -416,366 | -96% |