BONUS RETURN
Reducing Emissions by Turning Nutrients and Carbon into Benefits
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EXECUTIVE SUMMARY

The following report serves as "Deliverable 2.4" and contains a comprehensive review on economic models and instruments related to the ecotechnologies which were selected in the three BONUS RETURN empirical case areas (Slupsk in Poland, Vantaanjoki in Finland, and Fyris in Sweden) . The review aims to increase the understanding on which and how particular economic models assess ecotechnologies, and to shed light on both the benefits and costs of adoption of selected eco-technologies, the social and private components of those costs and benefits, and which incentives may trigger or hinder their adoption.

Apart from introducing the theoretical background of typical economic models and analyses, the report contains a comprehensive review on ecotechnologies for carbon and nutrient recovery and reuse in the wastewater and agricultural sectors. Generally, the review reveals an increasing quantity of economic literature on ecotechnologies within the last six years, whereas the major share of studies focuses on the private costs related to implementing and maintaining a specific technology. While Cost-Benefit Analysis (CBA) is the foremost applied model, there is no consensus on how CBAs are conducted (e.g. in terms of which impacts to include or neglect). In addition to context- or case-specific variables which strongly determine the economic efficiency of ecotechnologies, the results of the reviewed economic analyses are therefore not generalisable and must be interpreted with caution.

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.

1.3 Deliverable context and objective

The current deliverable (Del. No. 2.4) is part of WP 2. The objectives of WP 2 are to systematically collate scientific research of existing and emerging eco-technologies, as well as of the economic models and policy instruments that support the implementation and development of these technologies in the BSR countries.

This deliverable summarises available literature on economic models and instruments related to the ecotechnologies which were selected in the three BONUS RETURN empirical case areas. The review describes which and how particular economic models assess ecotechnologies, and sheds light on both the benefits and costs of adoption of selected eco-technologies, the social and private components of those costs and benefits, and which incentives may trigger or hinder their adoption.

1.4 Outline of the report

This report is structured into the following sub-sections:

2.1 Background
2.2 Success factors, drivers and barriers of implementing eco-technologies
2.3 Economic models and analyses
2.4 Review on economic models of selected ecotechnologies
2.5 Limitations and concluding remarks

2 STATE OF THE ART REPORT ON ECONOMIC MODELS IN BSR

2.1 Background

In light of the megatrends in agriculture, namely increase productivity, advanced technologies, integrated food supply chain, multifunctionality of agriculture, food & health, and a bio-based economy (Rabbinge & Bindraban, 2012), P and N are not only critical and limiting factors for crop production and global food security (Nziguheba et al., 2016; Roy et al., 2016), but also major causes of eutrophication of aquatic ecosystems, as well as greenhouse gas (GHG) emissions (Bolzonella et al., 2018; EEA, 2018). Given that there are no substitutes for P in agricultural production, a trend towards a circular economy by recovering and reusing P and N is not surprising (Elser, 2012; Nesme & Withers, 2016).

A variety of literature addresses different technologies, for instance P recovery methods at various steps of wastewater treatment and sewage sludge management (Cieślik & Konieczka, 2017), or technical options for phosphorus and energy recovery (Pearce, 2015 and the references therein; Roy, 2017). However, while economic validity is recognised as the most important criterion for successfully implementing ecotechnologies, the lack of market competitiveness leads to recovery and reuse technologies being mostly not profitable and thus seldomly implemented. While the European Commission (EC) states a clear need for context specific cost analyses of recovery technologies (cf. Science Communication Unit, 2013), there is no consensus, clear guidelines or political requirements in terms of the approach and content of economic models dealing with recovery and reuse technologies. The objective of this study is therefore to shed light onto the available economic models, literature and procedures in context of the ecotechnologies which were and are selected in the course of the RETURN project.

2.2 Success factors, drivers and barriers of implementing eco-technologies

Different drivers and barriers determine a successful and beneficial management shift towards nutrient and carbon recovery and reuse technologies. In line with the definition of Haddaway et al. (2018), such technologies are from now on referred to as ecotechnologies describing "*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*". From an economic perspective, recovery and reuse technologies may be identical yet the outputs are handled differently: Recovery implies to remove, for instance, P from wastewater, whereas reuse refers to feeding the recovered product back into a market (e.g. selling recovered P as fertiliser). While a recovered product may therefore result in indirect and/or social benefits such as avoided costs due to reduced pollution (e.g. eutrophication), a reuse product additionally generates direct or indirect cash flows, e.g. when sold at a market.

Pearce (2015) categorises the drivers and barriers of implementing reuse-oriented technologies into (a) economic, (b) environmental, (c) technical, (d) regulatory, (e) organisational, and (f) individual drivers and barriers. Although the focus in this report is on the economic aspects of eco-technologies, the consideration of the other categories is worthwhile due to their potential impact upon the economic feasibility of eco-technologies and social well-being. For instance, economic aspects may not only consist of monetary but also of non-monetary goods, such as improved environmental quality due to a reduction in eutrophication (see also Pearce, 2015).

2.2.1 Economic drivers and barriers

While different drivers and barriers exist, the most important decision criterion leading to the implementation of some eco-technology is its economic feasibility (Pearce, 2015, p. 214; Roy, 2017; Schipper, 2019). However, if some project is considered economically feasible depends upon the perspectives, intentions and assessment frameworks. In particular, economic feasibility may be understood differently by operating actors and investors ("*should I invest in/implement the eco-technology?*"), or from the viewpoint of a decision-maker considering society as a whole ("*is overall social welfare increasing when spending tax money on stimulating eco-technologies?*"). The environmental and welfare economic disciplines therefore distinguishes between private and social costs and benefits. Although private and social costs and benefits are sometimes identical, i.e. the market price accounts for all associated costs, they are often not. For instance, externalities like pollution (leading to e.g. eutrophication) has an impact on social well-being yet such costs are typically not covered by the causing agents (see e.g. Coase, 1960; Hanley & Barbier, 2009):

$$\textit{Private Costs} + \textit{External Costs} = \textit{Social Costs}$$
$$\textit{If External Costs} > 0 \rightarrow \textit{Private Costs} < \textit{Social Costs}$$

For a privately operating actor or investor, economic feasibility is therefore usually understood as private benefits exceeding private costs, whereas the relevant criterion for the viewpoint of society is that social benefits outweigh social costs. The central elements of the *BONUS RETURN* project are typical and relevant examples leading to negative externalities (i.e. the social and private costs are dissimilar), namely the emissions of carbon (OECD, 2018; Pearce, 2003), nitrogen (Keeler et al., 2016), or phosphorus (Mayer et al., 2016). A special case for decision-making with respect to implementing eco-technologies is if regulations are in place, as P recovery in Switzerland and Germany, cf. Schipper (2019). The question would then move to how a set target or regulation can be achieved or fulfilled in the best (e.g. cheapest) manner.

These aspects are further elaborated in the next section, which touches upon the economic drivers and barriers of adopting eco-technologies described from the three different perspectives, i.e. in terms of (a) the private cost and benefits, (b) social cost and benefits, and (c) the case of active regulations.

The perspective of operating actors and investors: Private costs and benefits

The economic decision criterion for operating actors or investors to implement or finance eco-technologies is that the expected private benefits outweigh the expected private costs. Due to a permanent inherent risk when dealing with unpredictable future variables (such as expected income), **low or moderate investment and operation costs** are identified as one success criteria of implementing (eco-)technologies (Schipper, 2019). In turn, high cost (e.g. due to a costly use of chemicals and energy, or when generating additional waste streams which need to be disposed) may pose barriers, in particular "*if combined with an uncertain potential for market revenues*" (Schipper, 2019, p. 108). Such uncertain potential may occur if some recovered product is not a perfect substitute for a product already traded on the markets.

In the context of reuse technologies (i.e. with the intention to reuse the recovered outputs), an **existing market**, i.e. a source for expected income and profit, is another central economic element determining the adoption eco-technologies of some operating actor or investor (Mayer et al., 2016; Pronk & Koné, 2009). In other words, the "*ability to generate a product with a clearly defined market potential*" is essential (Schipper, 2019, p. 110). However, not only the existence of a suitable market, but also the expected **market prices** (for both the new and comparable products) matters. If the market prices are volatile or uncertain, the expected revenues decrease. Without prospects of profits, actors or investors may consequently abstain from too high cost and invest in other markets (Schipper, 2019). Even if some technology is tested for many years, the limited scale of production may result in (too) high costs per recovered unit (Fam & Mitchell, 2013). For instance, little recovery of P as the single product is currently undertaken, mainly due to unfavourable economic incentives: "*The market value of the recovered P products alone is generally not high enough to justify the cost of recovery*" (Mayer et al., 2016, p. 6616). Furthermore, the difficulties in integrating recovery products into markets is best evidenced by the most straightforward re-use product of wastewater treatment plants (WWTP), namely water. Amongst other barriers, Sanz & Gawlik (2014) identify a lack of financial incentives and poor business models as obstacles for a more extensive application of water reuse strategies in Europe.

Furthermore, while not implying a positive cash flow, **indirect benefits** may increase the economic feasibility of some systems or technology, even if the resulting outputs would not be feasible at markets. For instance, struvite recovery is typically too costly to compete with the mined alternative, yet its recovery may reduce the damage in valves and pipes (Mayer et al., 2016, p. 6614; Rao et al., 2015). Moreover, additional technologies may increase the investment costs but decrease the overall costs, for instance when covering the heat and electricity requirements of the process (Murashko et al., 2018).

Other economic barriers may as well be the **unwillingness to invest in new technologies**, or due to **risk averse** actors (Caniëls & Romijn, 2008; Fam & Mitchell, 2013, p. 776; Kemp et al., 1998).

From the viewpoint of society: Social costs and benefits

As previously introduced, considering merely the private costs and benefits may neglect the impact certain interventions have on third parties, particularly the overall society. In other words, some changes may be economic feasible for one or few individuals yet not necessarily for others.

Assessing if some technology is economic feasible from an overall society's perspective relates to both monetary and non-monetary impacts (Pearce, 2015). Economic theory therefore draws on the concept of utility, which is synonymous with all *"factors that make people happy, or that explains people's choices"* (Hanley & Barbier, 2009, p. 15). This may, in fact, be money or goods with monetary values, but also non-market goods, such as environmental quality, recreational opportunities, or aesthetic values. In economic terms, and given that an individual's utility (U) is determined by income, as well as purchasing and consuming market and public goods (e.g. environmental quality), utility can thus be described as follows

$$U^h = U^h(p, w, z) \qquad [1]$$

where *h* is the individual (or, often, a household), *p* a vector for market goods, *w* the wage rate, and z the public goods vector (Johansson, 1993). Recalling the example of a single implementing actor or investor from the previous section, his or her utility would consequently increase if implementing some technology would increase the wage rate, whereas the market and public goods vector stays constant. However, given the aim to consider the welfare of the overall society, the utilities of all individuals need to be aggregated. Generally, there are three major aggregation approaches (see e.g. Johansson, 1993 for a more in-depth and mathematical explanation), namely the

a) Utilitarian perspective: the equally weighted sum of all utilities of every member or household of society gives the level of social welfare,
b) Weighted utilitarian perspective: the weighted sum of all utilities of every member or household of society gives the level of social welfare, or
c) Rawlsian social welfare function: the utility of the poorest individual or household determines social welfare.

Given now the different concepts of determining social welfare, it can be concluded that some change is economic feasible if it results in an increase in social welfare. However, from the most common utilitarian perspective, this would also imply that social welfare increases if the utilities of all individuals but one decrease, provided that the increased utility of the "winner" is higher than the aggregated utility of the "losers". In other words, if an individual (the "winner) gains $10 Million yet the aggregated utility of the rest of society (the "losers") drops by $9.9 Million, social welfare would nevertheless increase (by $0.1 Million). Again, economic theory introduced concepts to deal with such distributional issues.

The *Pareto criterion* states that a change should take place (e.g. the implementation or introduction of some technology or policy) if it makes at least one individual better off and no one worse off (Hanley et al., 2002; Nyborg, 2012). If the "winner" would gain $10 Million, yet each individual utility of all (formerly) "losers" remains constant, a *Pareto* improvement would be achieved. However, such improvement is hardly possible in practice. For instance, if just one individual is unhappy about only the "winner" receiving a utility increase, no *Pareto* improvement is reached. Consequently, a more practical version is the so-called *potential Pareto criterion* in which "*some change should happen if redistributions would hypothetically lead to Pareto improvements, i.e. the winners could compensate the losers, and still remain with some net gains*" (Carolus, 2018, p. 5; Hanley & Barbier, 2009; Nyborg, 2012). In other words, our "winner" could hypothetically compensate the rest of society for their welfare loss of $9.9 Million, and still remains with a net gain in utility of $0.1 Million.

Finally, changes in utility are not directly measurable. For instance, the degree to which a reduction in eutrophication makes a population better off cannot be measured in monetary values in a straightforward manner. Economists therefore draw on monetary proxies, namely the populations' willingness-to-pay (WTP) for some change to take place, or the willingness-to-accept (WTA) some change (Hanley & Barbier, 2009; Hanley et al., 2002).

2.2.2 Other drivers and barriers

While economic feasibility is identified as *sine qua non* to implementing recover and reuse technologies (Pearce, 2015), other drivers and barriers therefore also affect the adoption or implementation of eco-technologies (and may also have an indirect economic effect, e.g. when internalised):

- environmental drivers and barriers: reduced greenhouse gas emissions and eutrophication, defined as environmental drivers by Pearce (2015).
- technical drivers and barriers: some recovery processes may lead to lower maintenance costs, e.g. due to reduced damages in valves and pipes because of struvite precipitation (Mayer et al., 2016; Pearce, 2015; Rao et al., 2015). However, the general applicability of technologies may be constrained by the existing systems and infrastructure (Schipper, 2019).
- Individual behavioural drivers and barriers: personal commitment to sustainability; economic incentives (Roy, 2017); familiarity of the developer or seller with the market and market entry; absence of legal barriers; social and political acceptance of the product or technology (Schipper, 2019).

2.3 Economic models and analyses

Given the various success criteria (and barriers) including the rationale that the "*economic feasibility of the projects ultimately determined its fate",* whereas the feasibility relates to both monetary and non-monetary impacts (Pearce, 2015, p. 214), a number of economic analyses and models are applied to assess recovery or reuse technologies. Generally, such approaches aim to inform decision-making bodies on which approaches are (a) economic feasible, and/or (b) should be preferred provided one needs to select some, e.g., technology from a set of alternatives. However, the most suitable approach or model depends on the purpose of the analyses. Possible scenarios are, for instance, (1) if a private person should invest in or implement eco-technologies, (2) if implementing certain eco-technologies and/or the transition towards a circular economy is worthwhile from a society's point of view, or (3) which technologies should be selected given that one must select at least one, for instance if ruse or recovery technologies are mandatory or regulated.

Commonly, economic assessments or models are diverse. In the context of technology development and implementation, as well as environmental management, common approaches are Techno-Economic Assessments (TEA), Cost-Effectiveness Analysis (CEA) and Cost-Benefit Analysis (CBA). However, the boundaries between different models are not clearly pre-determined (cf. Nyborg, 2012). It is, for instance, the choice of the analyst to decide which impacts are included in such assessment, and to which degree those impacts are qualified, quantified or valued in monetary terms. While the importance of considering and accounting for environmental and social consequences is widely recognised (e.g. Mayer et al., 2016; OECD, 2018; Pearce, 2015), the quantification and monetarisation of such wider cost and benefits is complex and shaped by a high degree of uncertainty, making most economic analyses focusing on "*easily quantifiable/monetized costs and revenues*" (Mayer et al., 2016, p. 6615).

2.3.1 Techno-economic assessment (TEA)

Generally, TEA refers to the (typically ex-ante) assessment of some technology with the key purpose of setting a specific technology design in the context of its cost and performance, for instance in order to compare it to potential alternatives. While not explicitly restricted, TEAs commonly focus on the expected investment and ongoing cost of a technology in contest of the quantified yet not monetarised outputs, such as the relative cost of CO_2 capture (Frey & Zhu, 2012), wastewater treatment (Singh Nitin & Kazmi Absar, 2018) and/or digestate treatment (Bolzonella et al., 2018). A TEA can therefore be considered as technology-oriented, and rather refers to a recovery process, as the recovered process is usually not defined as having a market value.

2.3.2 Cost-Effectiveness Analysis (CEA)

Similar as TEA, CEA is conducted to provide a ranking of the relative performance of different technologies or measures. While this entails that CEA and TEA may consist of, de facto, the same content, CEA is usually rather output-oriented[1]. The approach thereby sets the cost of the technology in context of the associated physical effectiveness (Balana et al., 2011). Given that there are $i = 1 \ldots n$ technologies available, and for each technology C_i represents the costs and E_i some effectiveness unit, e.g. tons of recovered P, the cost-effectiveness ratio CER_i of the technology is computed as follows:

$$CER_i = \frac{C_i}{E_i} \qquad [1.1]$$

The CER thus expresses in the cost per physical unit, e.g. € per ton of recovered P, enabling a direct economic ranking of different technologies. However, while being a straightforward approach with relatively low data demands, neither a TEA nor a CEA can conclude if any of the analysed technologies would be worthwhile from both a private or a social perspective: An entire list of technologies, “*ranked by their cost-effectiveness, could be adopted without any assurance that any one of them is actually worth doing*” (OECD, 2018, p. 444).

2.3.3 Cost-Benefit Analysis (CBA)

Cost-Benefit Analysis (CBA) is a widely accepted method for evaluating policies and projects (Hanley & Barbier, 2009; Molinos-Senante et al., 2010). Essentially, CBA collects all costs and benefits of some intervention (like a project, policy or measure) into a bottom-line, the net present value (NPV). A positive NPV entails that the benefits outweigh the associated costs, and vice versa. From an economic point of view, interventions with positive NPVs should consequently be implemented. While originally only considering purely monetary values, the inclusion of social and/or environmental values into CBA was introduced in the 1980s (cf. Johansson, 1993; Molinos-Senante et al., 2010; Pearce & Nash, 1981). A CBA may therefore assess if some change is leading to a *potential Pareto improvement*, i.e. if the overall social welfare is increasing or decreasing. A CBA can be broken down to six consecutive analysis stages (Hanley & Barbier, 2009; OECD, 2018; Pearce, 2006):

[1] in other words, the focus of a TEA may rather be understood as the comparison of multiple technologies, whereas a CEA assesses how, for instance, some specific output may be recovered with the lowest cost.

1. Project or policy definition: Description of the change to be analysed; definition of the population and the spatial and temporal system.
2. Identification of physical impacts of the policy or project: Appraisal and quantification of the relevant physical impacts within the defined system boundaries.
3. Valuing the physical impacts: Allocating monetary values to the physical impacts, e.g. based on primary WTP/WTA-studies or benefit transfer.
4. Discounting of both cost and benefits: Conversion of all monetary flows into present value terms, based on a relevant (social) discount rate.
5. Applying the Net Present Value (NPV) test: Assessment whether the sum of discounted gains (benefits) exceeds the sum of discounted losses (costs).
6. Sensitivity analyses: Calculation of the NPV with changing key parameters.

Despite its limited use as the only criterion, CBA is increasingly applied as one component in environmental decision-making (Atkinson et al., 2018; OECD, 2018). For instance, the EU Water Framework Directive (WFD), the EU Marine Strategy Framework Directive (MSFD) suggest and/or request CBAs. The WFD (adopted in 2000) aims to achieve good ecological status in European surface and groundwater bodies and thereby suggests CBA as a method to identify disproportionate costs, i.e. substantially lower benefits than costs associated with improving the ecological status of some water body. The MSFD (adopted in 2008) explicitly suggests CBA as one ex ante method to assess the impact of introducing measures to achieve good environmental status in the EU's marine waters by 2020 (Bertram et al., 2014; European Commission, 2008).

However, just like TEA and CEA, CBA is not a fixed methodology with pre-set rules. It is thus a matter of defining which and how impacts are quantified and monetarised, where the temporal and spatial system boundaries are set, the baseline to which a change is measured, or the selected social discount rate. Often, studies refer to CBA when addressing some tangible costs and benefits (referred to as "operating cost and benefits" by Geerts et al. (2014)), without covering all of the analysis steps as outlined above. In the following, we therefore separate between "private" and "social" CBAs, depending upon which cost and benefit perspective the analyst considers.

3 REVIEW ON ECONOMIC MODELS OF SELECTED ECOTECHNOLOGIES

Using the systematic map report approach as outlined in Macura et al. (2018), this deliverable aims to shed light upon utilised economic models in the context of the implementation or adoption of ecotechnologies. The review provides an overview of different approaches, whereas the focus is on recovery and reuse technologies integrated into wastewater treatment systems, or from agricultural waste. Although the process of defining and specifying the system alternatives is ongoing, the review focuses on the ecotechnologies selected in the course of the RETURN WP3 activities (Johannesdottir et al., 2018), namely

- anaerobic digestion (SE[2], PL, FI),
- sludge stabilisation and hygienisation (SE, PL, FI),
- incineration (SE),
- anaerobic membrane bioreactors (SE, PL),

[2] selected in the respective case area (SE = Sweden, PL = Poland, FI = Finland)

- ammonia stripping (SE, PL),
- struvite precipitation (SE, PL),
- up-flow anaerobic sludge blanket reactor (SE, PL),
- biochar filter (SE, PL),
- source-separation (SE, PL),
- septic tank and infiltration (SE),
- composting (PL, FI),
- thermal treatment (FI),
- Urea hygienization (FI).

The following review aims to reflect recent experiences and applied economic approaches. In light of the selected system alternatives, mechanisms and technologies, different studies apply analyses to estimate their economic efficiency.

3.1.1 Review methodology

To be in line with Macura et al. (2018), the review focuses on studies conducted since 2013. The search (cf. search string in Table 1) was conducted in *Web of Science* and led to 103 results of which 17 studies were selected. 67 studies were excluded due to being conducted outside of Europe, four studies were not accessible, and 15 were irrelevant (for instance due to covering a topic in public health or using "economic" merely as buzzword without conducting any form of analysis). Furthermore, the review was supported by a less systematic search on google scholar (key words: economic, drivers, barriers, recovery, reuse, cost, benefit, cost-effectiveness). The selected studies are summarised in Table 2, the overview of all studies including the reasons for exclusion are provided in appendix A.

Table 1 Search results

Database	Web of Science
Date	30.11.2018
Results	103
Search String	((("CBA" OR "CEA" OR "cost-benefit analy*" OR "cost-effectiveness analy*" OR "economic model*") AND (nutrient* OR phosphorus OR phosphate OR urine OR excret* OR feces OR fecal OR sludge OR struvite OR "phosphoric acid" OR manure OR faecal OR faeces OR slurry OR effluent OR wastewater OR runoff OR wetland* OR riparian OR ash* OR compost OR "slaughterhouse waste" OR fertilizer*) AND ("anaerobic diges*" OR "sludge stabilis*" OR hygienisation OR hygienization OR incineration OR membrane* OR Struvite* OR biochar* OR compost)))
Timespan	01/2013 – 11/2018)
Indexes	SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.

Figure 1 reveals and increasing trend of scientific publications (before the selection, blue bars in Figure 1), reaching its highest number in 2018. When considering only the 17 selected studies (orange bars in Figure 1), the trend is similar until 2017, yet with a slight decrease of published articles in 2018[3].

[3] the search was conducted on the 30.11.2018, the number for 2018 may therefore be underestimated.

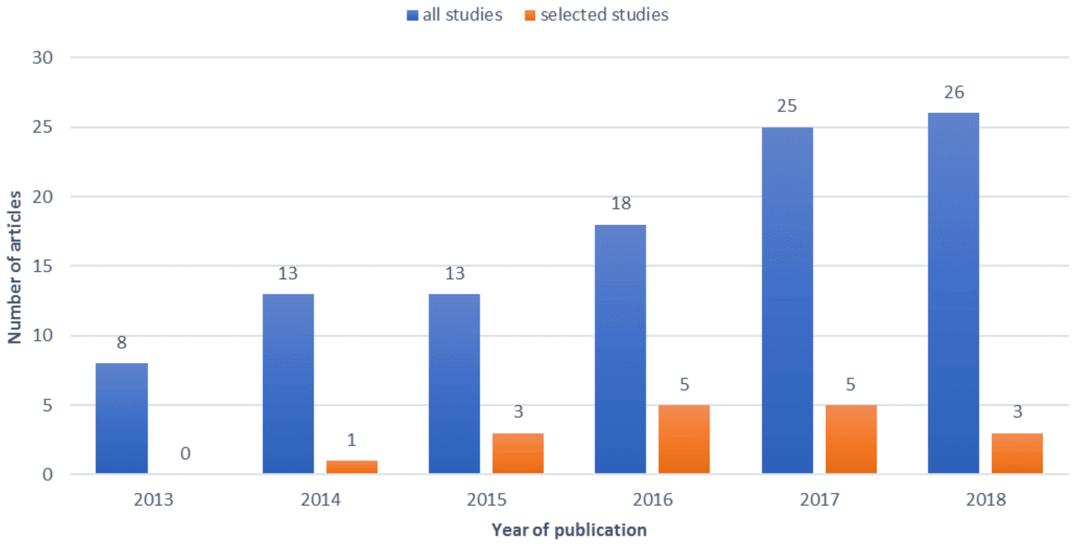

Figure 1 Number of articles per year (01/2013-11/2018)

All considered studies (cf. Table 2) addresses the private economic perspective of reuse or recovery technologies. In contrast, only 5 out of 17 studies selected in the more systematic review considered the social perspective to some extent, mostly in a partial way without monetarisation or even quantification.

Table 2 Overview of selected studies

Review [4]	Study	Economic analyses			Key contents and results	RETURN-relevant key words	Study country
		Private	Social	Model			
1	Atanasova et al. (2017)	x		Generic	Greywater reuse systems in hotel facilities; applied reuse system reveals economic feasibility for sizes from 60 PE and back periods of 3 years.	greywater reuse	Spain
1	Berber et al. (2017)	x		CBA	Economic assessment of environmental management options for municipal solid waste (MSW) incineration fly ash (FA); suggested alternatives result in considerable reductions in CO2 emissions	solid waste incineration fly ash	Estonia
2	Bolzonella et al. (2018)	x		Techno-economic analysis	Recovery rate over 50% possible for both N and P; Operating costs are between 5.40 and 6.97 Euro per treated m³ of digestate; while "*membrane systems can recover water of good quality while reducing the digestate volume*", drying systems can only treat some share of the digestate yet with a high effectiveness[5].	Anaerobic digestion; agro-waste; fertiliser; membrane; drying	Italy
1	Cucchiella et al. (2018)	x		CBA	Economic evaluation of small plants for biomethane injection into gas grid; Proposal of mathematical and economic model useful to evaluate the profitability of these plants; both positive and negative NPVs as result	Biomethane	Italy

[4] 1 = systematic review on Web of Science; 2 = review on google scholar
[5] note: if not explicitly referred to the economic effectiveness or cost-effectiveness, "effectiveness" is unrelated to economic efficiency, profitability, revenue, etc.

2	Egle et al. (2016)	x		CEA	Comparative assessment of 19 P recovery technologies; sewage sludge ash processes are the most cost-effective options to recover P, despite being more expensive than aqueous phase processes and less expensive than sewage sludge processes. However, the cost-effectiveness of most sewage sludge ash processes is only close to the market price of raw phosphate rock.	P recovery; struvite; sludge ash	Austria
1	Frank et al. (2016)	x		CBA	CBA reveals economic efficiency of leachate bioaugmentation using cellulase, with a net benefit of approximately €12.1 million on a 5 Mt mixed waste landfill.	Leachate circulation, Enzyme augmentation, Waste biostabilisation, Landfill bioreactor	UK
1	Garrido-Baserba et al. (2015)	x	(x)	CBA	Economic assessment of sewage sludge treatment alternatives in modern wastewater treatment systems; case study for a 1 million PE WWTP proved SCWO as the most adequate option when considering economic and environmental (in the study GWP) criteria as equally important.	anaerobic digestion plus composting, incineration, gasification, and supercritical water oxidation (SCWO)	n.a.
1	Geerts et al. (2014)	x		CBA	Struvite recovery from sludge waters reflect a low profitability; Required value (whether or not subsidized) per ton of struvite should be between €590 and €440 per ton at incoming PO_4^{3-} concentrations between 150 and 450 mg/L.	anaerobic digestion, phosphorous recovery, struvite,	Belgium
1	González-Viar et al. (2016)	x		CEA	Comparision of the cost-effectiveness of centralized and decentralized wastewater treatment strategies aimed to improve the ecological status of a Spanish river; sewer mining as the most cost-effective alternative.	hybrid membrane bioreactor	Spain
1	Keeley et al. (2016)	x		Generic	Assessment of the treatment performance and whole life cost (WLC) of the various recovered coagulant (RC) configurations have been considered in relation to fresh ferric sulphate (FFS)	P removal, coagulant	UK
1	Maaß et al. (2014)	x		CBA	Economic asssessment of struvite precipitation from WWTP; added-value gains result mainly from reduced costs in wastewater treatment, and are therefore higher than in crop production; survey reveal a basic willingness of farmers to substitute struvite for conventional mineral P-fertilizer (nevertheless, not wide farmer-demand of struvite as fertilizez); precipitation of struvite and its use as fertilizer generates added-value gains for wastewater treatment facilities (416,000 €) and for crop producers (35,000 €).	Struvite precipitation	Germany
1	Massaro et al. (2015)	x	x	CBA	Sustainability of biomass to energy (electrical, thermal) projects is investigated; the current production-	anaerobic digestion of	EU

					based incentive rates reveal an inadequate balance between private and public interest.	organic waste; cattle manure	
2	Mayer et al. (2016)	x	(x)	Generic	Assessment of the cost (in cost/capita year), the recovery potential (kg P recovered/capita year) and the energy requirements (kWh/capita year) of selected P recovery technologies; technologies are thereby spilt into three groups, namely crystallisation processes applied to liquids from sludge dewatering and precipitation from sludge free wastewater (lowest cost and energy requirements), P recovery from incinerated sewage sludge ash (highest recovery potential), and P recovery from sludge (highest energy requirements); Incineration products show a low weight (i.e. less costly transport potential) and contain little N (i.e. high application potential in areas which are prone to nitrate contamination); Price of recovered struvite is too low to be competitive, but indirect benefits (avoids costs) due to less valves and pipes damages.	P recovery; incineration; sludge ash; Sludge; struvite	n.a.
2	Molinos-Senante et al. (2010)	x	x	CBA	Assessment of the economic feasibility of wastewater treatment; environmental benefits (shadow prices) included; The maximum environmental benefits of wastewater treatment occurs due to the removal of nutrients, and the lowest environmental benefit due to the removal of suspended solids.	Conventional wastewater treatment	Spain
2	Murashko et al. (2018)	x		Techno-economic analysis	Techno-economic analysis of a decentralized wastewater treatment plant operating in closed-loop; Chemical requirement as cost driver, the use of heat and: integrating [a CHP plant to cover heat and electricity demands] into the wastewater treatment process may, despite considerable additional capital investments, reduce the operational costs between 21% and 30%.	Incineration of sludge; MSW; CHP; cost driver	Finland
1	Nagler et al. (2018)	x		CBA	Assessment of thermo-chemical PT-strategies in terms of net energy output and cost-efficiency; results suggest savings of ca. 28% of the yearly WAS-related expenditures of a wastewater treatment plant; most important costs generated by the PT are chemicals (NaOH; 5600 € a−1), personnel costs (4400 € a−1) and the increased polymer demand (1358 € a−1 increase compared to native sludge); increased savings in electrical power due to increased biogas production (4714 € a−1 more savings for treated WAS, −22%) and reduced disposal costs (22,791 € a−1 less for treated WAS; −27%) lead to positive effect of the PT.	Biogas; pre-treatment (PT) for anaerobic digestion	Austria

1	Ruffino & Zanetti (2017)	x		CBA	Economic assessment of waste and wastewater in a candied fruit–jam factory; new solutions could decrease CO2 emissions by 50%	waste and wastewater; composting; anaerobic digestion;	Italy
1	Saez de Bikuña et al. (2017)	x	(x)	General Equilibrium Model	Environmental performance of gasified willow; Focus on GHG emission reduction.	bioenergy; cogeneration of heat and power (CHP); ash–char output	Denmark
1	Schreck & Wagner (2017)	(x)	X	CBA	Theoretical economic model on sustainable waste management; allows to reveal how firm profit and social welfare optimizing objectives can be reconciled in a two-product market of waste management processes	Waste management (reuse)	n.a.
1	Suárez et al. (2015)	x		CBA	Evaluation of the profitability of a reverse osmosis application; a design flow of 20 m^3/h produced a payback period of 3.3 years, being a cost-effective facility for the amortization period studied.	membrane, reverse osmosis	Spain
1	Thomsen et al. (2018)	x	x	CBA	Economic and environmental effects of organic waste management scenarios; a separate collection and transport of biowaste to biogas plants as the most economically and environmentally sustainable solution.	anaerobic sludge digestion; biogas, incineration	Denmark
1	Torija et al. (2016)	x		CEA/partial CBA	Up to 5.5% of UK primary energy could be met by biogas, representing 14.4% of gas consumption; Fuel cells (FCs) are the most efficient and environmentally benign energy convertor of any device of equivalent scale and in addition are well suited for biogas utilization.	anaerobic digestion, biogas; livestock and food waste plants	UK
2	Yazan et al. (2018)	x	x	Economic assessment based on physical in- and outputs	Analysis of a circular economic business in which animal manure is used to produce biogas and alternative fertilizer in a regional network of manure suppliers and biogas producers; Conditions under which the regional cooperation of manure suppliers and biogas producers can be economically beneficial depends upon the manure quantity, transportation distance, dry content and price of manure, and the manure discharge price.	anaerobic digestion; biogas	Netherlands

3.1.2 Literature on the perspective of operating actors: Private costs and benefits

In the systematic review, all 17 studies covered at least some economic components of the private perspective. Most commonly, studies apply CBAs (13 out of 17 studies), followed by CEAs with 2 applications. However, as previously introduced, the definition and steps of CBAs, CEAs or other economic assessment (like TEA) are not standardised.

While most selected studies considering the private perspective focus on directly observable cash flows (e.g. the economic value of all physical in- and outputs, cf. Yazan et al., 2018), indirect (private) benefits are recognised as potentially increasing the economic feasibility of some ecotechnology (e.g. Mayer et al., 2016), even if the outputs are not competitive at the market level. The quantification or monetarisation of such indirect benefits is, however, scarce. For instance, struvite recovery is typically too costly to compete with rock P-derived fertiliser, yet additional paybacks are "*driven by cost avoidance of removing P, which limits damage caused by struvite precipitation in valves and pipes*" (Mayer et al., 2016, p. 6614; Rao et al., 2015). The extent and value of the avoided cost remains, however, unclear. Murashko et al. (2018) go one step further. The authors describe the case of co-incinerating sludge and MSW in WWTPs. While highlighting the relation of solid waste management and the availability of fresh water resources, the detailed economic assessment focuses on the provision of sustainable reuse of water resources. The study demonstrates how additionally integrating a CHP plant to cover heat and electricity demands into the wastewater treatment system may, despite additional capital investments, reduce the overall operational costs considerably (in the case study, the ongoing costs are reduced between 21% and 30% which would likely increase the overall profitability, see also Schipper (2019)).

Selected eco-technologies

The **recovery and reuse of P from wastewater** is a central theme in context of the RETURN project. A variety of economic literature covers different aspects of the associated approaches and technologies. For instance, Mayer et al. (2016) calculate the cost (in cost/capita year), the recovery potential (kg P recovered/capita year) and the energy requirements (kWh/capita year) of selected P recovery technologies. The technologies are thereby spilt into three groups, namely (A) crystallisation processes applied to liquids from sludge dewatering (*Airprex*, *PRISA, Crystalactor*, and precipitation from sludge free wastewater), (B) P recovery from incinerated sewage sludge ash (*ASH-DEC* and *PASCH*), and (C) P recovery from sludge (*Seaborne* and *KREPRO*). The authors show that group (A) reflects the lowest cost and energy requirements, followed by (B) and (C). However, although the analysis can demonstrate that, on average, group (A) is the cheapest, group (C) requires most energy, and (C) recovers the largest quantity of P, the indicated units cannot reveal which technology is the most cost-effective one, or if any of them is economic feasible (cf. section 2.3). For instance, the recovered products from group (C) show a low weight (i.e. less costly transport potential) and contain little N (i.e. high application potential in areas which are prone to nitrate contamination). While this certainly determines the economic feasibility of such ecotechnologies, the additional factors are explained qualitatively and remain unconsidered in the economic assessment. Consequently, the authors conclude that "*on the basis of energy and economic costs, P extraction from the liquid*[6] *is most attractive, but considering the possible revenues from the fertilizer products and, in particular, the social and environmental benefits, several of these technologies may operate economically*" (Mayer et al., 2016, p. 6614). Consequently, in order to provide insights in whether the adoption of the assessed technologies is economic feasible (from either the private or the societal perspective), further input is required.

The results of Egle et al. (2016) generally confirm the outlined results of Mayer et al. (2016), yet the analysis also indicates the product specific costs in terms of cost (in Euro) per recovered kg of P, i.e. the cost-effectiveness ratio of P recovery. Most notably, the study demonstrates that sewage sludge

[6] i.e. Group (A)

ash processes, i.e. similar to group (B) in Mayer et al. (2016), are the most cost-effective options to recover P, although being more expensive than aqueous phase processes, i.e. group (A), and less expensive than sewage sludge processes. However, according to the authors the cost-effectiveness of most sewage sludge ash processes is still only close to the market price of raw phosphate rock.

With a focus on **struvite[7] recovery and reuse from digested sludge**, Geerts et al. (2014) assess both costs (negative cash flows) and benefits (positive cash flows) of a recovery installation. While struvite precipitation is identified as a relatively ineffective technology (only around 20% of the total P entering some WWTP can be retrieved), it is simultaneously a relatively cheap technique compared to alternative P recovery approaches (Egle et al., 2016; Geerts et al., 2014). By calculating that the "*required value (whether or not subsidized) per ton of struvite should be between €590 and €440/ton at incoming* PO_4^{3-} *concentrations between 150 and 450 mg/L*" to allow for an profitable recovery process, Geerts et al. (2014) highlight that different conditions or variables determine whether some technology is economical efficient or not, making economic assessments of ecotechnologies context- or case-specific. Furthermore, Geerts et al. (2014) identify lower investment costs (e.g. by achieving a higher amount of recovered units), a higher market price for P, or higher PO_4^{3-} concentrations (for instance due to pre-treatments like digestion) as factors increasing the economic feasibility of struvite recovering approaches. Finally, and in contrast to struvite recovery from digested sludge, the assessment demonstrates that **struvite recovery from sludge waters** reflect a low profitability.

Anaerobic digestion is another central element of the system alternatives in any of the three RETURN project case study areas, and describes the process eventually leading to producing, amongst others, biogas. A techno-economical assessment (cf. section 2.3.1) by Bolzonella et al. (2018) highlights that the performance of nutrient recovery approaches from anaerobic digestate of livestock manure differs depending upon the treatment system: For instance, while "*membrane systems can recover water of good quality while reducing the digestate volume*", drying systems can only treat some share of the digestate yet with a high effectiveness[8] (Bolzonella et al., 2018, p. 119). For all tested systems, the authors find the operating costs to be between 5.40 and 6.97 Euro per treated m³ of digestate. The economic analysis, however, does not consider the revenues from selling fertilisers and nutrients. Consequently, the assessment provides insights in terms of the expected cost components of anaerobic nutrient digestion, but not in terms of the economic feasibility of the overall process. Moreover, the feedstock of the monitored systems in the study consists of pig, cow and chicken manure, energy crops, slaughterhouse residues and food waste, but not of horse manure as foreseen in the Finnish case study in the RETURN project.

A study by Yazan et al. (2018) assess the economic efficiency of **biogas and fertiliser production from manure by drawing on anaerobic digestion based on the physical in- and outputs**. The focus of the study is thereby on the conditions under which the regional cooperation of manure suppliers and biogas producers can be economically beneficial. The study highlights that the economic efficiency highly depends upon variables such as manure quantity, the transportation distance, the dry content of the manure, the manure price, or the manure discharge price. While the variables are context-specific and thus do not allow for a generalisability of the results, and even though the assessment

[7] magnesium ammonium phosphate (to be used as, for instance, fertiliser)

[8] note: if not explicitly referred to the economic effectiveness or cost-effectiveness, "effectiveness" is unrelated to economic efficiency, profitability, revenue, etc.

considers the purely monetary flows without additional (e.g. non-market) benefits, the authors demonstrate that profitability may be possible. However, the complexity of making conclusions is best evidenced by the findings of the study which are conditional upon various "ifs" [9].

3.1.3 Studies on the viewpoint of society: Social costs and benefits

The major share of economic analyses concerning recovery technologies appears to focus on the direct monetary flow, i.e. the economic feasibility of technology implementation from the perspective of private costs and benefits. However, the economic feasibility for implementing actors or investors (cf. section 0) is mainly determined by such purely monetary values ("do I gain more than I spend?"). In contrast, the "social" economic feasibility relates to both monetary and non-monetary impacts of anything affecting social welfare (Pearce, 2015). The inclusion of social benefits (and costs) is recognised as making recovery technologies more beneficial (Mayer et al., 2016; Schipper, 2019), and as providing a more holistic picture of some technology's economic feasibility, for instance by revealing or internalising both positive and negative externalities.

The systematic review (cf. Table 2) reveals that only few studies deal with the social cost and benefits of a specific ecotechnology. In the few studies covering the social perspective, differently defined degrees of social impacts are considered; in a descriptive (Mayer et al., 2016), quantitative (Garrido-Baserba et al., 2015; Saez de Bikuña et al., 2017) or theoretical manner (Schreck & Wagner, 2017), yet only one study includes monetary values of social and non-market components (Massaro et al., 2015). In contrast to the social CBA introduced in section 2.3.3 (i.e. considering the change in social welfare rather than the change in cash flows), authors usually consider directly observable operating costs and benefits when referring to CBA and other "economic" components. This is best evidenced by Garrido-Baserba et al. (2015); the authors conclude that some alternative is most adequate when "*economic and environmental criteria are considered equally important*", whereas the environmental criteria refer to the GWP of the process and different outputs. A full and social CBA would, however, imply to picture and quantify all impacts on social welfare, including economic and environmental criteria.

However, this observed trend is not unexpected. Typically, social CBAs are conducted on the societal level rather than on individual technologies. For instance, the average external costs of **P pollution** in the US is estimated to be around $2.2 billion per year, which includes the loss in recreational values, price reductions in real estates, expenses in terms of rehabilitating threatened or endangered species, as well as the therefore required purification of drinking water[10] (Dodds et al., 2009; Shakhramanyan et al., 2012). Furthermore, applications include CBAs in the context of water quality and eutrophication (Åström et al., 2018; Bertram et al., 2014; Carolus et al., 2018; Czajkowski et al., 2015; Gren et al., 1997; Hyytiäinen et al., 2015; Hyytiäinen et al., 2013) or nitrogen emission control (Åström et al., 2018) in the Baltic Sea Region. Most notably, Hyytiäinen et al. (2013) estimate the total benefits of reaching the

[9] "*The cooperation is profitable for a large-scale farm (>20,000 t/year) if biogas producer (b) pays farmer (f) to receive its manure (5 €/t) or if f sells manure for free and manure disposal costs are >10 €/t. Cooperation is always profitable for b if f pays b to supply its manure (5€/t). If b receives manure for free, benefits are always positive if b is a medium-large-scale plant (>20,000 t/year). For a small-scale plant, benefits are positive if manure dry content (MDC) is ≥12 per cent and transportation distance is ≤10 km*" (Yazan et al., 2018, p. 605).

[10] Including further non-market (e.g. non-use) benefits or supporting services with an (indirect) impact on social welfare would further increase the costs.

BSAP[11] eutrophication targets between €3600 and €4000 million per year and the associated cost between €1400 and €2800 million, and thus project a net gain in social welfare. Furthermore, CBAs are examined in light of the provision of ecosystem services (Hockley, 2014; Wegner & Pascual, 2011), address the water-reuse of WWTPs (Godfrey et al., 2009; Haruvy, 1997; Molinos-Senante et al., 2011), also in the Finnish context (Punttila, 2014), or determine the social costs and benefits of waste incineration to produce energy (Jamasb & Nepal, 2010) or biogas (Gebrezgabher et al., 2010).

CBAs are extremely data intensive and especially dealing with non-market goods often requires the prediction of unpredictable future variables. Consequently, the outcomes in terms of the NPVs are often uncertain and therefore provide a rough estimate rather than precise numbers. This may be one reason for few social CBAs being conducted on the technology-level. For instance, the above introduced CBA of Hyytiäinen et al. (2013) assumes a load reduction of 10 555 tonnes of P per year, of which one or few of the introduced ecotechnologies would only contribute a very minor share.

3.1.4 Drivers and barriers: The example of P recovery and reuse technologies

As previously introduced, a variety of economic models and analyses considers recovery and reuse technologies, of which the majority restricts the assessment to operating costs and benefits associated with the in- and outputs relevant to running some technology or system. This trend is in line with the previously introduced economic drivers, namely investment and ongoing cost, as well as the availability of markets and sufficient market prices (Pearce, 2015; Roy, 2017), and underlines the observation that a major share of the literature focuses on the private perspective of ecotechnologies, i.e. elaborates on the requirements and obstacles to facilitate the implementation of ecotechnologies and thus the transition towards a circular economy.

The case of P recovery and reuse technologies

Different ecotechnologies recover various outputs, which implies that different costs, markets and other variables need to be considered when conducting economic analyses. This section aims to give an overview of relevant considerations when further investigating the economic components of P recovery and reuse technologies (Table 3), and may therefore serve as starting point for further BONUS RETURN activities, such as the subsequent CBA (upcoming in Work Package 3).

Table 3 Economic barriers and drivers

Systems	Economic drivers for implementing nutrient and energy recovery technologies			
	Cost of technology and production cost	**market demand for recovery products**	**market price**	**transportability**
P recovery/ reuse	Recovery cost likely to exceed market value of the outputs; indirect savings due to heat or electricity reuse; social benefits are likely to reveal externalities.	Market demand is given for most products (possibly only after further treatment); legislative framework often insufficient due to not classifying recovered products with similar characteristics as commercial alternatives.	Production cost likely to exceed market value of mined P.	Important but an often unconsidered condition. Results depend on the specific technology and product, for instance incineration products have a low weight.

[11] Baltic Sea Action Plan, http://www.helcom.fi/baltic-sea-action-plan

Despite some ecotechnologies resulting in output costs close to market prices of comparable goods (cf. previous and the upcoming sections), there is a general agreement that reuse or recovery business models are not profitable. According to Mayer et al. (2016, p. 6615), most "*business models are hybrids with revenue streams consisting of (1) sales of technology/patent or operational service charges and (2) subsidies based on social benefits including cost offsets such as sustainable feedstock, process cost savings, and improved environmental quality and food security*".

The implementation of technologies recovering and reusing phosphorus (e.g. struvite) is determined by the global market price of phosphate rock (cf. Figure 2), which ultimately affects the revenue and profitability of any technology. Figure 2 highlights the market price fluctuations. If strictly following the private costs and benefits, recovered P must therefore be supplied with the same or lower market price to be economic feasible. Recovered P therefore "*competes against an industry characterized by huge volumes and optimized technology. This gives advantages of scale and ripeness not available to new recycling technologies, posing a challenge for newcomers to become financially attractive and profitable*" (Schipper, 2019, p. 109). Despite price peaks in the 1970s and since 2008, phosphate is "*a relatively cheap raw material*" (Schipper, 2019, p. 108). Investments in ecotechnologies may therefore be inappropriately high. In combination with "*the need for a number of processing steps to obtain a readily marketable material*", this implies that the "*development of P recovery and recycling technologies is not often a naturally evident business case*" (Schipper, 2019, p. 108). This is further evidenced by several introduced competitions or prizes which aim at offering incentives to develop and introduce technologies targeting circular economy or phosphorus pollution, most notably the Baltic Sea Nutrient & Carbon Reuse Challenge in context of the *BONUS RETURN* project, or the George Barley Water Prize (https://barleyprize.org).

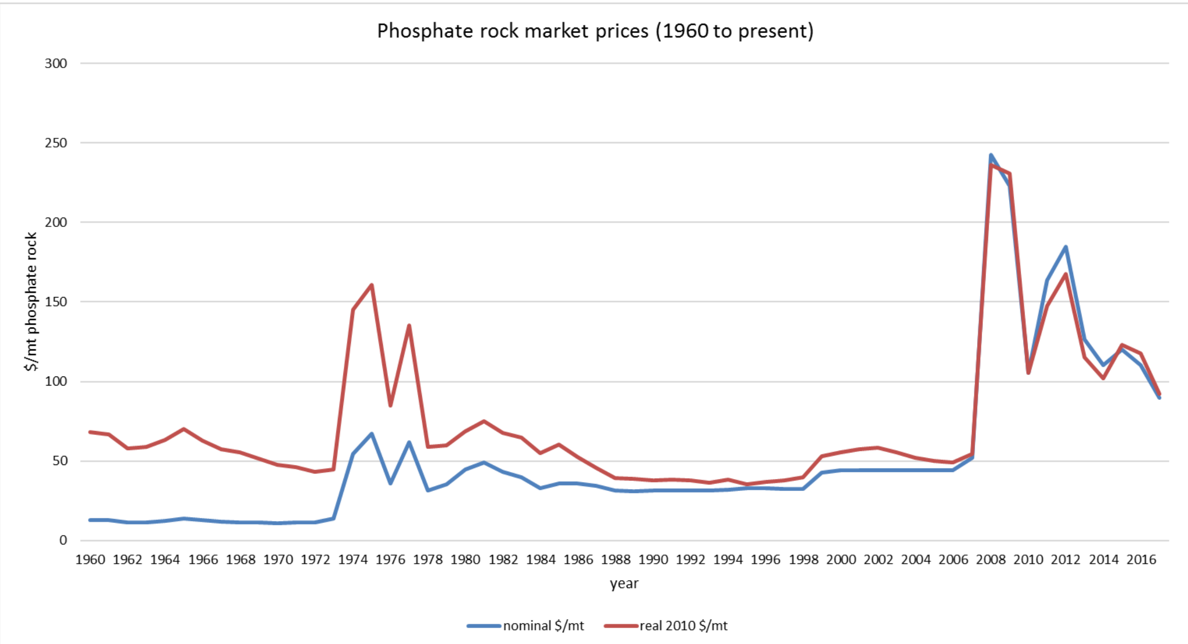

Figure 2 Phosphate rock market prices (1960 to present, nominal and real prices in US dollars). Source: World Bank (2018)

Despite a world mine production capacity which is projected to substantially increase in the upcoming years (from 147 million tons in 2017 to 168 million tons in 2021, excluding China), and despite no available substitutes for phosphorus in agriculture, an imminent shortage of phosphorus rock is not expected (cf. Mayer et al., 2016; U.S. Geological Survey, 2018). However, the predictions of available resources are divergent (Cordell et al., 2011). For instance, Cordell et al. (2009) expect phosphorus to be depleted within the next 50 to 100 years. Furthermore, "*its geographic concentration creates political and economic risks for the vast majority of countries, which must import all or almost all fertilizer P. The risk is especially severe for low-income countries, in which fertilizer is a large proportion of the total cost of food production*" (Mayer et al., 2016, p. 6606). Most notably, Morocco and Western Sahara possess of more than two thirds of the global rock reserves. Moreover, P is one major driver of insufficient ecological status and eutrophication in aquatic ecosystems (EEA, 2018; Mayer et al., 2016).

While low market prices for P products decrease the economic efficiency of most P recovery technologies, in particular when not providing or accounting for additional indirect benefits, the reuse of the products, or social benefits, a price increase of P rock may eventually result in more competitive recycling technologies (Schipper, 2019).

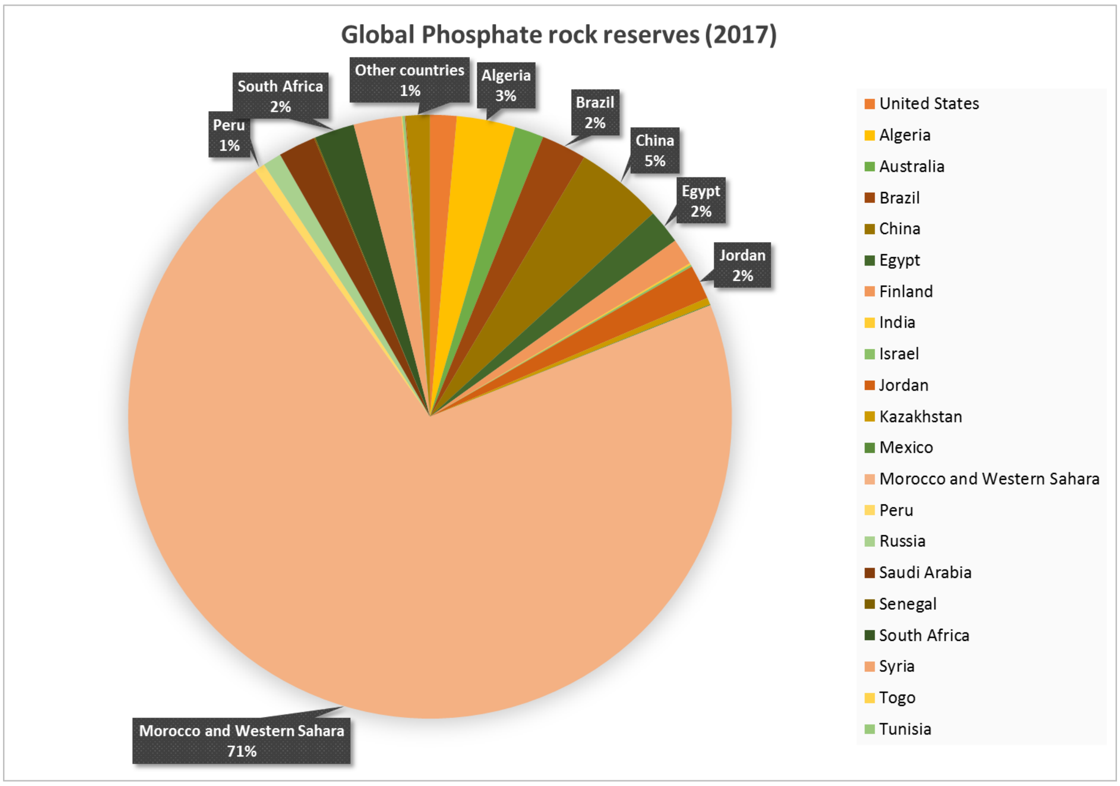

Figure 3 Global Phosphate rock reserves in 2017. Source: U.S. Geological Survey (2018)

4 LIMITATIONS AND CONCLUDING REMARKS

With the objective of shedding light on the importance, use and type of economic models in relation to ecotechnologies, this deliverable serves as a starting point for further economic analyses in the context of the RETURN project, in particular the subsequent CBA. Overall, the review reveals some trends:

1. Increasing amount of literature on the economics of ecotechnologies

Confirming the trend indicated in Macura et al. (2018), the review within this deliverable reveals that an increasing amount of literature deals with economic questions and models in context of ecotechnologies, both within and outside Europe. However, the systematic review may be incomprehensive, in particular due to (a) only considering studies published within the last 6 years, (b) restricting the review to studies in the European context, (c) searching in two databases, and (d) starting out with a quite extensive search string.

2. The ideal economic model depends upon the purpose, its results upon the context

The considered literature highlights that selecting the "ideal" economic model depends upon the purpose. Due to the rather novel theme of recovery and reuse technologies as well as circular economy, a considerable share of the economic literature and analyses mostly assess the private perspective, i.e. mainly the monetary operational costs and benefits which are essential for bringing such systems or technologies onto a market without requiring political regulations or subsidies. Interestingly, most studies refer to their economic assessment as CBA, without, however, considering non-operational costs and benefits. Various drivers thereby determine the success (and failure) of implementing such technologies, whereas different studies identified economic viability as the overarching and indispensable success criterion. However, generic conclusions are difficult due to that any analysis outcome (e.g. in terms of economic efficiency) depends highly on the context-specific variables. For instance, the profitability of manure-based supply chains to produce biogas, just one of various components in the selected system alternatives in context of the BONUS RETURN project, depends upon variables such as local land prices, manure quantity, the transportation distance, the dry content of the manure, the manure price, or the manure discharge price, which are likely to differ across systems or spatial and temporal scales (Bolzonella et al., 2018). For subsequent economic analyses, this underlines the requirement of determining the exact system specifications to obtain robust recommendations.

3. The social perspective makes ecotechnologies more economically efficient

The literature review reveals two essential trends, namely (a) that the production prices of products of most ecotechnologies are not competitive on the market level, and (b) that the minority of literature includes social benefits of recovery or reuse processes. However, with the ultimate aim of benefiting overall society, the social perspective may add valuable insights. Including indirect and/or social benefits (such as reduced eutrophication or GHG emissions) into economic assessments is not only improving the relative economic validity of recovery and reuse technologies, but, equally important, highlights the potential impacts that ecotechnologies have on social welfare, even when a particular technology may not be efficient at first sight.

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APPENDIX A: ALL STUDIES FOUND IN THE SYSTEMATIC REVIEW EXERCISE

Authors	Title	Journal	Reason for in/exclusion (yes = included; country = study conducted outside Europe; not relevant = different topic; not accesible = not accesible)
Beegle, JR; Borole, AP	Energy production from waste: Evaluation of anaerobic digestion and bioelectrochemical systems based on energy efficiency and economic factors	RENEWABLE & SUSTAINABLE ENERGY REVIEWS	country
Thomsen, M; Romeo, D; Caro, D; Seghetta, M; Cong, RG	Environmental-Economic Analysis of Integrated Organic Waste and Wastewater Management Systems: A Case Study from Aarhus City (Denmark)	SUSTAINABILITY	yes
Aller, DM; Archontoulis, SV; Zhang, WD; Sawadgo, W; Laird, DA; Moore, K	Long term biochar effects on corn yield, soil quality and profitability in the US Midwest	FIELD CROPS RESEARCH	country
Pandit, NR; Mulder, J; Hale, SE; Zimmerman, AR; Pandit, BH; Cornelissen, G	Multi-year double cropping biochar field trials in Nepal: Finding the optimal biochar dose through agronomic trials and cost-benefit analysis	SCIENCE OF THE TOTAL ENVIRONMENT	country
Shi, YL; Zhou, L; Xu, YY; Zhou, HJ; Shi, L	Life cycle cost and environmental assessment for resource-oriented toilet systems	JOURNAL OF CLEANER PRODUCTION	country
Padmi, T; Dewiandratika, M; Damanhuri, E	AN ENVIRONMENTAL AND ECONOMIC COMPARISON OF FRUIT AND VEGETABLE WASTE TREATMENT IN THE TRADITIONAL MARKETS	INTERNATIONAL JOURNAL OF GEOMATE	country
Ji, CY; Cheng, K; Nayak, D; Pan, GX	Environmental and economic assessment of crop residue competitive utilization for biochar, briquette fuel and combined heat and power generation	JOURNAL OF CLEANER PRODUCTION	country
Joshi, J; Wang, JJ	Manure management coupled with bioenergy production: An environmental and economic assessment of large dairies in New Mexico	ENERGY ECONOMICS	country
Yin, K; Ahamed, A; Lisak, G	Environmental perspectives of recycling various combustion ashes in cement production - A review	WASTE MANAGEMENT	not relevant
Allesina, G; Pedrazzi, S; Allegretti, F; Morselli, N; Puglia, M; Santunione, G; Tartarini, P	Gasification of cotton crop residues for combined power and biochar production in Mozambique	APPLIED THERMAL ENGINEERING	country
Ushani, U; Kavitha, S; Kannah, RY; Gunasekaran, M; Kumar, G; Nguyen, DD; Chang, SW; Banu, JR	Sodium thiosulphate induced immobilized bacterial disintegration of sludge: An energy efficient and cost effective platform for sludge management and biomethanation	BIORESOURCE TECHNOLOGY	country
Lam, CM; Yu, IKM; Medel, F; Tsang, DCW; Hsu, SC; Poon, CS	Life-cycle cost-benefit analysis on sustainable food waste management: The case of Hong Kong International Airport	JOURNAL OF CLEANER PRODUCTION	country
Zhang, YP; Zhang, L; Li, LH; Chen, GH; Jiang, F	A novel elemental sulfur reduction and sulfide oxidation integrated process for wastewater treatment and sulfur recycling	CHEMICAL ENGINEERING JOURNAL	country
Cucchiella, F; D'Adamo, I; Gastaldi, M; Miliacca, M	A profitability analysis of small-scale plants for biomethane injection into the gas grid	JOURNAL OF CLEANER PRODUCTION	yes

Mirmasoumi, S; Saray, RK; Ebrahimi, S	Evaluation of thermal pretreatment and digestion temperature rise in a biogas fueled combined cooling, heat, and power system using exergo-economic analysis	ENERGY CONVERSION AND MANAGEMENT	country
Rehman, MZU; Rizwan, M; Khalid, H; Ali, S; Naeem, A; Yousaf, B; Liu, GJ; Sabir, M; Farooq, M	Farmyard manure alone and combined with immobilizing amendments reduced cadmium accumulation in wheat and rice grains grown in field irrigated with raw effluents	CHEMOSPHERE	country
Lu, WC; Yu, SA; Ma, YX; Huang, HR	Integrated economic and environmental analysis of agricultural straw reuse in edible fungi industry	PEERJ	country
Ditzler, L; Breland, TA; Francis, C; Chakraborty, M; Singh, DK; Srivastava, A; Eyhorn, F; Groot, JCJ; Six, J; Decock, C	Identifying viable nutrient management interventions at the farm level: The case of smallholder organic Basmati rice production in Uttarakhand, India	AGRICULTURAL SYSTEMS	country
Singh, NK; Kazmi, AA	Performance and Cost Analysis of Decentralized Wastewater Treatment Plants in Northern India: Case Study	JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT	country
Allen, VM; Yudin, MH	No. 276-Management of Group B Streptococcal Bacteriuria in Pregnancy	JOURNAL OF OBSTETRICS AND GYNAECOLOGY CANADA	not relevant
Robb, S; Dargusch, P	A financial analysis and life-cycle carbon emissions assessment of oil palm waste biochar exports from Indonesia for use in Australian broad-acre agriculture	CARBON MANAGEMENT	country
Garoma, T; Pappaterra, D	An investigation of ultrasound effect on digestate solubilization and methane yield	WASTE MANAGEMENT	not relevant
Nagler, M; Aichinger, P; Kuprian, M; Pumpel, T; Insam, H; Ebner, C	A case study for a cost-benefit-based, stepwise optimization of thermo-chemical WAS pre-treatment for anaerobic digestion	JOURNAL OF MATERIAL CYCLES AND WASTE MANAGEMENT	yes
Zhu, LD; Li, ZH; Hiltunen, E	Theoretical assessment of biomethane production from algal residues after biodiesel production	WILEY INTERDISCIPLINARY REVIEWS-ENERGY AND ENVIRONMENT	country
Yao, ZY; You, SM; Ge, TS; Wang, CH	Biomass gasification for syngas and biochar co-production: Energy application and economic evaluation	APPLIED ENERGY	country
Hashemi, SSG; Bin Mahmud, H; Djobo, JNY; Tan, CG; Ang, BC; Ranjbar, N	Microstructural characterization and mechanical properties of bottom ash mortar	JOURNAL OF CLEANER PRODUCTION	country
Ali, HM; Hafez, AI; Khedr, MMA; Gadallah, H; Sabry, R; Ali, SS; Gadallah, AG	Techno-economic evaluation of forward/reverse osmosis hybrid system for saline water desalination	DESALINATION AND WATER TREATMENT	country
Lee, KH; Oh, JI; Chu, KH; Kwon, SH; Yoo, SS	Comparison and Evaluation of Large-Scale and On-Site Recycling Systems for Food Waste via Life Cycle Cost Analysis	SUSTAINABILITY	country
Bong, CPC; Goh, RKY; Lim, JS; Ho, WS; Lee, CT; Hashim, H; Abu Mansor, NN; Ho, CS; Ramli, AR; Takeshi, F	Towards low carbon society in Iskandar Malaysia: Implementation and feasibility of community organic waste composting	JOURNAL OF ENVIRONMENTAL MANAGEMENT	country
Ma, YQ; Cai, WW; Liu, Y	An integrated engineering system for maximizing bioenergy production from food waste	APPLIED ENERGY	country

Ng, WC; You, SM; Ling, R; Gin, KYH; Dai, YJ; Wang, CH	Co-gasification of woody biomass and chicken manure: Syngas production, biochar reutilization, and cost-benefit analysis	ENERGY	country
Safferman, SI; Smith, JS; Dong, Y; Saffron, CM; Wallace, JM; Binkley, D; Thomas, MR; Miller, SA; Bissel, E; Booth, J; Lenz, J	Resources from Wastes: Benefits and Complexity	JOURNAL OF ENVIRONMENTAL ENGINEERING	country
Shen, Y; Tan, MTT; Chong, C; Xiao, WD; Wang, CH	An environmental friendly animal waste disposal process with ammonia recovery and energy production: Experimental study and economic analysis	WASTE MANAGEMENT	country
Grau, F; Drechsel, N; Haering, V; Trautz, D; Weerakkody, WJSK; Drechsel, P; Marschner, B; Dissanayake, DMPS; Sinnathamby, V	Impact of Fecal Sludge and Municipal Solid Waste Co-Compost on Crop Growth of Raphanus Sativus L. and Capsicum Anuum L. under Stress Conditions	RESOURCES-BASEL	country
Schreck, M; Wagner, J	Incentivizing secondary raw material markets for sustainable waste management	WASTE MANAGEMENT	yes
Berber, H; Frey, R; Voronova, V; Koroljova, A	A feasibility study of municipal solid waste incineration fly ash utilisation in Estonia	WASTE MANAGEMENT & RESEARCH	yes
Ruffino, B; Zanetti, M	Present and future solutions of waste management in a candied fruit - jam factory: Optimized anaerobic digestion for on site energy production	JOURNAL OF CLEANER PRODUCTION	yes
Vezina, F; Gerson, AR; Guglielmo, CG; Piersma, T	The performing animal: causes and consequences of body remodeling and metabolic adjustments in red knots facing contrasting thermal environments	AMERICAN JOURNAL OF PHYSIOLOGY-REGULATORY INTEGRATIVE AND COMPARATIVE PHYSIOLOGY	not relevant
Wang, YZ; Ren, GX; Zhang, T; Zou, SZ; Mao, CL; Wang, XJ	Effect of magnetite powder on anaerobic co-digestion of pig manure and wheat straw	WASTE MANAGEMENT	country
Huang, TY; Chiueh, PT; Lo, SL	Life-cycle environmental and cost impacts of reusing fly ash	RESOURCES CONSERVATION AND RECYCLING	country
Zavala-Reyna, A; Bautista-Olivas, AL; Alvarado-Ibarra, J; Velazquez-Contreras, LE; Pena-Leon, D	ENVIRONMENTAL EMERGY QUANTIFICATION FOR VERMICOMPOST PRODUCTION	AGROCIENCIA	country
Kishida, M; Harato, T; Tokoro, C; Owada, S	In situ remediation of bauxite residue by sulfuric acid leaching and bipolar-membrane electrodialysis	HYDROMETALLURGY	not relevant
Lee, S; Esfahani, IJ; Ifaei, P; Moya, W; Yoo, C	Thermo-environ-economic modeling and optimization of an integrated wastewater treatment plant with a combined heat and power generation system	ENERGY CONVERSION AND MANAGEMENT	country
Atanasova, N; Dalmau, M; Comas, J; Poch, M; Rodriguez-Roda, I; Buttiglieri, G	Optimized MBR for greywater reuse systems in hotel facilities	JOURNAL OF ENVIRONMENTAL MANAGEMENT	yes
Chung, HW; Banchik, LD; Swaminathan, J; Lienhard, VJH	On the present and future economic viability of stand-alone pressure-retarded osmosis	DESALINATION	country

Zheng, JF; Han, JM; Liu, ZW; Xia, WB; Zhang, XH; Li, LQ; Liu, XY; Bian, RJ; Cheng, K; Zheng, JW; Pan, GX	Biochar compound fertilizer increases nitrogen productivity and economic benefits but decreases carbon emission of maize production	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	country
De Bikuna, KS; Hauschild, MZ; Pilegaard, K; Ibrom, A	Environmental performance of gasified willow from different lands including land-use changes	GLOBAL CHANGE BIOLOGY BIOENERGY	yes
Hamawand, I; Pittaway, P; Lewis, L; Chakrabarty, S; Caldwell, J; Eberhard, J; Chakraborty, A	Waste management in the meat processing industry: Conversion of paunch and DAF sludge into solid fuel	WASTE MANAGEMENT	country
Kern, JD; Hise, AM; Characklis, GW; Gerlach, R; Viamajala, S; Gardner, RD	Using life cycle assessment and techno-economic analysis in a real options framework to inform the design of algal biofuel production facilities	BIORESOURCE TECHNOLOGY	country
Bustillo-Lecompte, CF; Mehrvar, M	Treatment of actual slaughterhouse wastewater by combined anaerobic-aerobic processes for biogas generation and removal of organics and nutrients: An optimization study towards a cleaner production in the meat processing industry	JOURNAL OF CLEANER PRODUCTION	country
Mu, DY; Horowitz, N; Casey, M; Jones, K	Environmental and economic analysis of an in-vessel food waste composting system at Kean University in the US	WASTE MANAGEMENT	country
Osei, I; Akowuah, JO; Kemausuor, F	Techno-Economic Models for Optimised Utilisation of Jatropha curcas Linnaeus under an Out-Grower Farming Scheme in Ghana	RESOURCES-BASEL	country
Money, D; Allen, VM	The Prevention of Early-Onset Neonatal Group B Streptococcal Disease	JOURNAL OF OBSTETRICS AND GYNAECOLOGY CANADA	not relevant
Launio, CC; Asis, CA; Manalili, RG; Javier, EF	Cost-effectiveness analysis of farmers' rice straw management practices considering CH4 and N2O emissions	JOURNAL OF ENVIRONMENTAL MANAGEMENT	not relevant
Chen, YT	A Cost Analysis of Food Waste Composting in Taiwan	SUSTAINABILITY	country
Bustillo-Lecompte, CF; Mehrvar, M	Treatment of an actual slaughterhouse wastewater by integration of biological and advanced oxidation processes: Modeling, optimization, and cost-effectiveness analysis	JOURNAL OF ENVIRONMENTAL MANAGEMENT	country
You, SM; Wang, W; Dai, YJ; Tong, YW; Wang, CH	Comparison of the co-gasification of sewage sludge and food wastes and cost-benefit analysis of gasification- and incineration-based waste treatment schemes	BIORESOURCE TECHNOLOGY	country
York, L; Heffernan, C; Rymer, C	The role of subsidy in ensuring the sustainability of small-scale anaerobic digesters in Odisha, India	RENEWABLE ENERGY	country
Geerts, S; Marchi, A; Saerens, B; Weemaes, M	Pilot size matters: the case of a full scale pilot for P-recovery from digestate in Belgium	WATER PRACTICE AND TECHNOLOGY	yes
Frank, RR; Davies, S; Wagland, ST; Villa, R; Trois, C; Coulon, F	Evaluating leachate recirculation with cellulase addition to enhance waste biostabilisation and landfill gas production	WASTE MANAGEMENT	yes
Gottumukkala, LD; Haigh, K; Collard, FX; Van Rensburg, E; Gorgens, J	Opportunities and prospects of biorefinery-based valorisation of pulp and paper sludge	BIORESOURCE TECHNOLOGY	country

Hu, M; Fan, B; Wang, HL; Qu, B; Zhu, SK	Constructing the ecological sanitation: a review on technology and methods	JOURNAL OF CLEANER PRODUCTION	country
Anwar, SW; Tao, WD	Cost benefit assessment of a novel thermal stripping - acid absorption process for ammonia recovery from anaerobically digested dairy manure	WATER PRACTICE AND TECHNOLOGY	country
Gonzalez-Viar, M; Diez-Montero, R; Molinos-Senante, M; De-Florio, L; Esteban-Garcia, AL; Sala-Garrido, R; Hernandez-Sancho, F; Tejero, I	Cost-effectiveness analysis of sewer mining versus centralized wastewater treatment: Case study of the Arga river basin, Spain	URBAN WATER JOURNAL	yes
Mor, A; Tal, R; Irani, M; McCalla, S; Haberman, S; Garg, D; Wajntraub, B	Carcinoembryonic antigen as a biomarker for meconium-stained amniotic fluid	INTERNATIONAL JOURNAL OF GYNECOLOGY & OBSTETRICS	not relevant
Torija, S; Castillo-Castillo, A; Brandon, NP	The Prospects for Biogas Integration withFuel Cells in the United Kingdom	FUEL CELLS	yes
Khan, MMUH; Jain, S; Vaezi, M; Kumar, A	Development of a decision model for the techno-economic assessment of municipal solid waste utilization pathways	WASTE MANAGEMENT	country
Liu, GR; Zheng, MH; Jiang, XX; Jin, R; Zhao, YY; Zhan, JY	Insights into the emission reductions of multiple unintentional persistent organic pollutants from industrial activities	CHEMOSPHERE	country
Keeley, J; Smith, AD; Judd, SJ; Jarvis, P	Acidified and ultrafiltered recovered coagulants from water treatment works sludge for removal of phosphorus from wastewater	WATER RESEARCH	yes
Khan, S; Waqas, M; Ding, FH; Shamshad, I; Arp, HPH; Li, G	The influence of various biochars on the bioaccessibility and bioaccumulation of PAHs and potentially toxic elements to turnips (Brassica rapa L.)	JOURNAL OF HAZARDOUS MATERIALS	country
Garrido-Baserba, M; Molinos-Senante, M; Abelleira-Pereira, JM; Fdez-Guelfo, LA; Poch, M; Hernandez-Sancho, F	Selecting sewage sludge treatment alternatives in modern wastewater treatment plants using environmental decision support systems	JOURNAL OF CLEANER PRODUCTION	yes
Clare, A; Shackley, S; Joseph, S; Hammond, J; Pan, GX; Bloom, A	Competing uses for China's straw: the economic and carbon abatement potential of biochar	GLOBAL CHANGE BIOLOGY BIOENERGY	country
Suarez, A; Fernandez, P; Iglesias, JR; Iglesias, E; Riera, FA	Cost assessment of membrane processes: A practical example in the dairy wastewater reclamation by reverse osmosis	JOURNAL OF MEMBRANE SCIENCE	yes
Nawaratna, SSK; Gobert, GN; Willis, C; Mulvenna, J; Hofmann, A; McManus, DP; Jones, MK	Lysosome-associated membrane glycoprotein (LAMP) - preliminary study on a hidden antigen target for vaccination against schistosomiasis	SCIENTIFIC REPORTS	not relevant
Park, SH; Chung, SW; Lee, SK; Choi, HK; Lee, SH	Thermo-economic evaluation of 300 MW class integrated gasification combined cycle with ash free coal (AFC) process	APPLIED THERMAL ENGINEERING	country
Yang, ZF; Zhou, XC; Xu, LY	Eco-efficiency optimization for municipal solid waste management	JOURNAL OF CLEANER PRODUCTION	country
Massaro, V; Digiesi, S; Mossa, G; Ranieri, L	The sustainability of anaerobic digestion plants: a win win strategy for public and private bodies	JOURNAL OF CLEANER PRODUCTION	yes

Brooks, SJ; Harman, C; Hultman, MT; Berge, JA	Integrated biomarker assessment of the effects of tailing discharges from an iron ore mine using blue mussels (Mytilus spp.)	SCIENCE OF THE TOTAL ENVIRONMENT	not relevant
Chow, WL; Chan, YJ; Chong, MF	A new energy source from the anaerobic co-digestion (acd) treatment of oleo chemical effluent with glycerin pitch	ASIA-PACIFIC JOURNAL OF CHEMICAL ENGINEERING	country
Guan, YD; Zhang, Y; Zhao, DY; Huang, XF; Li, HN	Rural domestic waste management in Zhejiang Province, China: Characteristics, current practices, and an improved strategy	JOURNAL OF THE AIR & WASTE MANAGEMENT ASSOCIATION	country
Lansing, SA; Klavon, KH; Mulbry, WW; Moss, AR	DESIGN AND VALIDATION OF FIELD-SCALE ANAEROBIC DIGESTERS TREATING DAIRY MANURE FOR SMALL FARMS	TRANSACTIONS OF THE ASABE	country
Meir, IA	Constraints to assets, waste to resources: integrating green technologies in a novel pilot project for drylands	INTERNATIONAL JOURNAL OF SUSTAINABLE ENERGY	country
Abourached, C; Lesnik, KL; Liu, H	Enhanced power generation and energy conversion of sewage sludge by CEA-microbial fuel cells	BIORESOURCE TECHNOLOGY	country
Qu, LL; Zhang, TZ; Lu, W	Assessing the potential of crop residue recycling in China and technology options based on a bottom-up model	FRONTIERS OF ENVIRONMENTAL SCIENCE & ENGINEERING	country
Maass, O; Grundmann, P; Polach, CVU	Added-value from innovative value chains by establishing nutrient cycles via struvite	RESOURCES CONSERVATION AND RECYCLING	yes
Lam, CSC; Cheung, AHK; Wong, SKM; Wan, TMH; Ng, L; Chow, AKM; Cheng, NSM; Pak, RCH; Li, HS; Man, JHW; Yau, TCC; Lo, OSH; Poon, JTC; Pang, RWC; Law, WL	Prognostic Significance of CD26 in Patients with Colorectal Cancer	PLOS ONE	not relevant
Diaz, R; Otoma, S	Cost-benefit analysis of waste reduction in developing countries: a simulation	JOURNAL OF MATERIAL CYCLES AND WASTE MANAGEMENT	country
Kontokostas, G; Goulos, I; Stamatis, A	TECHNO-ECONOMIC EVALUATION OF RECUPERATED GAS TURBINE COGENERATION CYCLES UTILIZING ANIMAL MANURE AND ENERGY CROPS FOR BIOGAS FUEL	PROCEEDINGS OF THE ASME TURBO EXPO: TURBINE TECHNICAL CONFERENCE AND EXPOSITION, 2014, VOL 3A	not accesible
Blair, A; Hollands, G; McIntosh, K; MacDonald, A; Mehta, B; Umali, H; Pagsuyoin, S	Alternative Management of Organic Waste in Chatham-Kent, Ontario, Canada	2014 SYSTEMS AND INFORMATION ENGINEERING DESIGN SYMPOSIUM (SIEDS)	country
Lai, K; Li, LD; Mutti, S; Staring, R; Taylor, M; Umali, J; Pagsuyoin, S	Evaluation of Waste Reduction and Diversion as Alternatives to Landfill Disposal	2014 SYSTEMS AND INFORMATION ENGINEERING DESIGN SYMPOSIUM (SIEDS)	country
Kuppens, T; Van Dael, M; Maggen, J; Vanreppelen, K; Yperman, J; Carleer, R; Elen, H; Van Passel, S	TECHNO-ECONOMIC ASSESSMENT OF DIFFERENT CONVERSION PATHWAYS FOR PYROLYSIS CHAR FROM PIG MANURE	PAPERS OF THE 22ND EUROPEAN BIOMASS CONFERENCE: SETTING THE COURSE FOR A BIOBASED ECONOMY	not accesible
Ma, YX; Lu, WC; Bergmann, H	Economic and environmental effects of nutrient budgeting strategies in animal excreta treatment A case study from rural China	CHINA AGRICULTURAL ECONOMIC REVIEW	country

Lu, WC; Ma, YX; Bergmann, H	Technological Options to Ameliorate Waste Treatment of Intensive Pig Production in China: An Analysis Based on Bio-Economic Model	JOURNAL OF INTEGRATIVE AGRICULTURE	country
Bidart, C; Frohling, M; Schultmann, F	Electricity and substitute natural gas generation from the conversion of wastewater treatment plant sludge	APPLIED ENERGY	country
Rodriguez-Garcia, G; Molinos-Senante, M; Gabarron, S; Alfonsin, C; Hospido, A; Corominas, L; Hernandez-Sancho, F; Omil, F; Feijoo, G; Sala-Garrido, R; Rodriguez-Roda, I; Moreira, MT	Cost benefit and environmental Life Cycle Assessment	MEMBRANE BIOLOGICAL REACTORS: THEORY, MODELING, DESIGN, MANAGEMENT AND APPLICATIONS TO WASTEWATER REUSE	not accesible
Hammer, NL; Boateng, AA; Mullen, CA; Wheeler, MC	Aspen Plus (R) and economic modeling of equine waste utilization for localized hot water heating via fast pyrolysis	JOURNAL OF ENVIRONMENTAL MANAGEMENT	country
Ding, WG; Wu, Y; Li, Q	Cost Effectiveness Analysis of Household Biogas Plants in China	ENERGY SOURCES PART B-ECONOMICS PLANNING AND POLICY	country
Noel, F; Pierard, GE; Delvenne, P; Quatresooz, P; Humbert, P; Pierard-Franchimont, C	Immunohistochemical sweat gland profiles	JOURNAL OF COSMETIC DERMATOLOGY	not relevant
Sharp, R; Vadiveloo, E; Fergen, R; Moncholi, M; Pitt, P; Wankmuller, D; Latimer, R	A Theoretical and Practical Evaluation of Struvite Control and Recovery	WATER ENVIRONMENT RESEARCH	country
Iwa, N; Ito, S; Takegaki, Y; Ikura, Y; Kobayashi, TK; Yasukawa, S; Kobayashi, Y	Cytologic features of sarcomatoid carcinoma of the urinary bladder: A case report	DIAGNOSTIC CYTOPATHOLOGY	not relevant
Zeng, HT; Ren, Z; Guzman, L; Wang, XQ; Sutton-McDowall, ML; Ritter, LJ; De Vos, M; Smitz, J; Thompson, JG; Gilchrist, RB	Heparin and cAMP modulators interact during pre-in vitro maturation to affect mouse and human oocyte meiosis and developmental competence	HUMAN REPRODUCTION	not relevant
Petit, FM; Serres, C; Bourgeon, F; Pineau, C; Auer, J	Identification of sperm head proteins involved in zona pellucida binding	HUMAN REPRODUCTION	not relevant
Robert, B	SIGNIFICANCE AND RISKS OF USING ECONOMIC INSTRUMENTS IN WASTE MANAGEMENT ISSUES IN CONTEXT OF PUBLIC SAFETY	FINANCE AND THE PERFORMANCE OF FIRMS IN SCIENCE, EDUCATION, AND PRACTICE	not accesible