BONUS RETURN
Reducing Emissions by Turning Nutrients and Carbon into Benefits
https://www.bonusprojects.org/bonusprojects/the_projects/blue_baltic_projects/return
www.bonusreturn.com

Deliverable No: D.2.3 – Systematic map report, database and interactive GIS

Ref: WP 2 Task 2.1.
Lead participant: SEI
Date: 31 Oct 2018

BONUS RETURN has received funding from BONUS (Art 185), funded jointly by the EU and Swedish Foundation for Strategic Environmental Research FORMAS, Innovation Fund Denmark, Academy of Finland and National Centre for Research and Development in Poland.

Deliverable Title	**D.2.3 – Systematic map report, database and interactive GIS**
Filename	BONUSRETURN_D.2.3_SYSTEMATIC MAP REPORT, DATABASE AND INTERACTIVE GIS
Authors	Biljana, Macura (SEI); Mikolaj, Piniewski (WULS); Solveig, Johannesdottir (RISE); Jennifer, Mcconville (RISE)
Contributors	Marta, Księżniak (WULS); Paweł, Osuch (WULS); Agnieszka Karczmarczyk (WULS); Neal, Haddaway (SEI); Filippa, Ek (SEI); Karolin, Andersson (SEI), Karina, Barquet (SEI), Sirkka, Tattari (SYKE); Jari, Koskiaho (SYKE)
Date	31/10/2018

Start of the project: 01/05/2017
End of the project: 01/05/2020
Project coordinator: Stockholm Environment Institute (SEI)

Dissemination level

x	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.

Table of Contents

EXECUTIVE SUMMARY

This deliverable contains two systematic map reports (documents describing the state of the evidence identified on a given subject, including the identification of knowledge gaps) accompanied by two searchable databases of research conducted on ecotechnologies for carbon and nutrient recovery and reuse in two sectors: 1) wastewater and 2) agriculture. Additionally, this report includes links to two evidence atlases i.e. interactive cartographic representations of the mapped evidence. This deliverable will allow stakeholders to visualise catalogued research on ecotechnologies for carbon and nutrient recovery and reuse from wastewater and in agriculture, extract meta-data describing the research and the eco-technologies investigated.

The evidence base for wastewater ecotechnologies included 481 relevant articles, each describing one ecotechnology, or a combination of ecotechnologies, for recovering/reusing carbon, nitrogen or phosphorus from wastewater. The evidence base for ecotechnologies used in agriculture included 338 relevant studies describing one ecotechnology for recovering/reusing carbon, nitrogen or phosphorus from various sources in agriculture.

For the wastewater sector, the body of evidence on ecotechnologies for energy recovery is larger than that of nutrient recovery, indicating that ecotechnologies for recovering energy are potentially more mature. The most common way of reusing nutrients is through biosolids or treated wastewater, both of which include organic carbon, nitrogen and phosphorus. Recovery of phosphorus is more common than nitrogen, especially when done through chemical processes. The higher representation of energy recovery over nutrient recovery, and of phosphorus recovery over nitrogen recovery, is in line with current paradigms within the wastewater sector.

In the agricultural sector, ecotechnologies for recovery of nitrogen and phosphorus were more prevalent than for carbon recovery. The most common way of reusing carbon and nutrients was through manure-based ecotechnologies. Animal manure on its own is the principal source of recovery of nutrients or carbon, with such publications constituting the majority of the evidence base. Among manure-based ecotechnologies, anaerobic digestion was the most frequent, followed by combinations/systems of technologies and struvite crystallization. The second largest group of studies was classified as ‘mixed’ which refers to manure mixed with plant biomass (e.g. crop residues). The most common ecotechnologies in this category were: composting/vermicomposting, pyrolysis/biochar production as well as anaerobic digestion / co-digestion. Two least frequent types of ecotechnologies were those relying only on plant biomass (e.g. crop residues) and those associated with water as the recovery source. Nitrogen recovery was overall slightly more common than phosphorus recovery, which in turn was significantly more common than carbon recovery.

The identified evidence on the ecotechnologies in the agricultural sector was less abundant than the one for the wastewater map (338 vs. 481 ecotechnologies). This can be explained by the differences in methodological approaches in the two maps (e.g. geographical limitations embedded in search for literature on ecotechnologies in agriculture, and no such limitations applied to search for literature in the wastewater ecotechnologies), as well as potentially easier access to recovery sources through centralised infrastructure dominating in the wastewater sector vs. small-scale and scattered infrastructure prevailing in agricultural sector. It is noteworthy to mention that most current environmental and water policies focus on reduction of pollution from different waste streams rather than on recovery and reuse of nutrients. Such ‘conventional’ measures do not, however, belong to this study. Instead, this report provides an unbiased and comprehensive evidence base on nutrient recovery and reuse that can be expected to gain much importance in the Baltic Sea Region in coming years.

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[1]. 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 2.3) is part of WP 2. The main objective of WP 2 is to use systematic mapping and systematic review methodology to summarize the evidence pertaining to reuse of carbon and nutrients using ecotechnologies.

This deliverable summarizes existing evidence on ecotechnologies in two sectors: 1) wastewater, and 2) agriculture in both the BSR region and globally. The deliverable describes knowledge gaps and clusters in both sectors. Additionally, the evidence base is visualised in an evidence atlas, an interactive geographical information system map (details below).

1.4 Outline of the report

This report is structured around seven subsections as follows:

2.1 Background
2.2 Methods
2.3 Results for systematic map of ecotechnologies for recovery and reuse of carbon and nutrients in the wastewater sector
2.4 Results for systematic map of ecotechnologies for recovery and reuse of carbon and nutrients in agriculture
2.5 Limitations
2.6 Discussion
2.7 Conclusions

All the source documents for this report, including two systematic map reports and all additional files are available on Figshare data repository via the following link: https://figshare.com/projects/Bonus_Return_Ecotechnologies_on_carbon_phosphorus_and_nitrogen_reuse_and_recovery_in_agriculture_and_wastewater/56240.

2 SYSTEMATIC MAP REPORT, DATABASE AND INTERACTIVE GIS

2.1 Background

To date, investments in measures to reduce external inputs of pollutants and nutrients from both diffuse and point sources have not prevented degradation of the Baltic Sea. The Baltic is particularly vulnerable to waterborne nutrient loadings because of its large catchment in relation to the sea area, a long renewal time and limited water exchange with the North Sea. Excessive input of nutrients coming from terrestrial areas is among the primary causes of eutrophication of the Baltic Sea [1]. A recent indicator-based assessment revealed an increase in the spatial extent of eutrophication [2]. Although the organic matter (predominantly organic carbon) load into the Baltic Sea has been identified as the second greatest environmental pressure after increase of primary production induced by inorganic nutrients [3], both the magnitude of organic carbon (OC) loads from terrestrial sources and processes driving the aquatic carbon cycle are still poorly understood [1]. The most up-to-date knowledge regarding nitrogen (N) and phosphorus (P) pollution sources into the Baltic Sea suggests that, as of 2014, the key diffuse sources were two dominant riverine pollution pathways constituting 46.5% and 35.7% for total nitrogen (TN) and total phosphorus (TP), respectively [4]. Most of these diffuse sources originate from agricultural activities. Hence, much responsibility for addressing eutrophication is currently placed on the agricultural sector. Cost-efficient methods to reduce N and P loads from agriculture are being sought and investments in specific measures are being made to reduce external inputs of pollutants and nutrients [5].

Recently, attention has shifted from the reduction of carbon and nutrient flows towards their reuse, recycling or recovery. There is a number of possible sources for nutrient or carbon recovery in agriculture, i.e.: (1) animal manure, (2) plant biomass (e.g. crop residues), (3) derivatives of animal manure and plant biomass sometimes combined with sewage sludge and/or food waste (i.e. anaerobic digestate) and (4) (polluted) agricultural runoff (e.g. surface runoff from fields, tile flow, subsurface or groundwater flow, streamflow in small catchments). Animal manure is the principal source of potentially reuseable carbon and nutrients in agriculture. More effective manure recycling could be achieved, e.g. by 'recoupling' of livestock from intensive farms with cropping systems producing animal feed [6]. Agricultural (and food) waste could be more effectively reused through application of emerging technologies for treatment of digestion effluent [7]. However, to our knowledge, no comprehensive and systematic assessment of modern technologies or practices concerning reuse of carbon and nutrients in the agricultural sector is available.

When it comes to the wastewater sector, recovery of resources offers several benefits beyond protecting the Baltic from eutrophication. Cornejo et al. [8] found that nutrient recovery from wastewater can, by substituting mineral fertilizers, reduce the eutrophication potential by up to 8 % and total carbon footprint by up to 4 %, depending on the size of the treatment plant. The study also showed that by integrating recovery of water, nutrients and energy eutrophication could decrease by 18 % and carbon footprint by 34 % when treating wastewater from 100,000 people [9]. Recycled nutrients from waste and wastewater could substitute mineral nitrogen and phosphorus fertilizers in agriculture. There are also other uses for nutrients in industry and other resources in waste that could be utilized. For example, Mihelcic et al. [9] estimated, based on data for the year 2009, that the phosphorus in the excreta of the whole human population could satisfy 22 % of global phosphorus demand. The wastewater treatment of today could provide multiple benefits to society if integrated with resource recovery [10].

In this work, we comprehensively catalogued and described the research on ecotechnologies for reuse and recovery of carbon, phosphorus and nitrogen in agricultural and wastewater sectors. The term 'ecotechnology' in this report is defined in line with the project's approach as stated in Haddaway et al. [11] 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". This definition encompasses both hard technologies and practices and is hence very broad to remain conservative and broadly relevant.

2.2 Methods

Systematic maps are methods for collating, describing and summarizing evidence on a broad subject [4]. They aim to maximise transparency, objectivity, and repeatability at every stage of the review process. Systematic mapping process consists of the following key stages: 1) planning with stakeholder engagement to set the scope and define key terms; 2) searching for evidence in academic journals and other grey literature sources. Grey literature is defined as any documents that exist (online or in print) in any form and published by any organization whose sole purpose is not commercial publication (including documents such as government papers and organizational reports, along with theses, conference proceedings and commercial publications); 3) screening at title level, abstract level and full text level to include relevant research studies according to a set of predefined eligibility criteria; 4) coding of relevant studies and 5) production of the systematic map database and report that describes all relevant research undertaken on the topic. Below we will summarise mapping process for both systematic maps described in this report. The protocols for both systematic maps, setting out the detailed plans to conduct the mapping, can be found elsewhere [12,13].

The systematic mapping process followed the Collaboration for Environmental Evidence guidelines and standards for evidence synthesis in environmental management [2] and it conforms to Reporting Standards for Environmental Evidence Syntheses (ROSES) [3] (See *Additional file 1_Wastewater_ROSES for form systematic map reports.xlsx* and *Additional file 1_Agri_ROSES for form systematic map reports.xlsx)*.

2.2.1 Methods for systematic map of ecotechnologies for recovery and reuse of carbon and nutrients in wastewater sector

The primary review question for this map was as follows:
What evidence exists relating to ecotechnologies in agriculture for the recovery and/or reuse of carbon and nutrients in the Baltic Sea Region (or similar boreo-temperate systems)?

Searches for the systematic map on the ecotechnologies for recovering and/or reusing carbon and nutrients (nitrogen and phosphorus) from wastewater (including e.g. sewage sludge and wastewater fractions) were performed in 4 bibliographic databases, Google Scholar and 35 specialist websites.

Searches were performed in English, but the search for literature in specialist websites also included Finnish, Polish and Swedish. All searches were restricted to the period 2013 to 2017. A list of benchmark studies used to test the comprehensiveness of the search is provided in *Additional file 2_Wastewater_List of benchmark studies.xlsx*. The following search string was used in bibliographic databases:

(recycl* OR reus* OR circul* OR conver* OR recover* OR return*) AND (agr* OR farm* OR crop* OR livestock OR "live stock" OR manure OR animal OR cultivat*) AND ("organic carbon" OR DOC OR "organic C" OR "organic matter" OR nutrient* OR nitrogen OR nitrate OR nitrite OR ammoni* OR phosphorus OR phosphate) [shown as formatted for Web of Science search]

Eligibility screening was conducted at two levels: title and abstract (screened concurrently for efficiency) and full text. Coding and meta-data extraction included information on ecotechnology name and short description, reuse outcome (i.e. recovery/reuse of organic carbon, energy, nitrogen and/or phosphorus), type of recovery/reuse (i.e. whether it is explicit or implicit), study country and location, latitude and longitude. Screening and coding was done after initial consistency checking. Evidence is summarised in a narrative form.

2.2.2 Methods for systematic map of ecotechnologies for recovery and reuse of carbon and nutrients in agriculture

The primary review question for this map was as follows: What evidence exists relating to potential ecotechnologies in municipal and domestic wastewater systems for the reuse of carbon, phosphorus and nitrogen?

Searches for the systematic map on the ecotechnologies for recovery and/or reuse of carbon and/or nutrients (nitrogen and phosphorus) from agriculture were performed in English in 5 bibliographic databases and Google Scholar. Additionally, searches in 36 specialist websites were performed in English, Finnish, Polish and Swedish. All searches were restricted to the period 2013 to 2017. A list of benchmark studies used to test the comprehensiveness of the search is provided in *Additional file 2_Agri_Benchmark studies.xlsx*. The following search string will bewas used in bibliographic databases:

("organic carbon" OR DOC OR "organic C" OR "organic matter" OR nutrient* OR nitrogen OR nitrate OR nitrite OR ammoni* OR phosphorus OR phosphate) AND (wastewater OR "waste water" OR "storm water" OR stormwater OR blackwater OR "black water" OR greywater OR "grey water" OR graywater OR "gray water" OR sludge OR septage OR sewage OR "organic waste*" OR "septic sludge" OR sewerage* OR digestate* OR "toilet waste") AND (return* OR recover* OR conver* OR circul* OR reus* OR recycl*)

Eligibility screening was conducted at two levels: title and abstract (screened concurrently for efficiency) and full text. Coding and meta-data extraction included information on ecotechnology name and short description, recovery/reuse outcome (i.e. carbon, nitrogen and/or phosphorus), type of ecotechnology depending on recovery source (manure-based, crop-based, mixed and other), study country and location, latitude and longitude. Screening and coding was done after initial consistency checking. Evidence is summarised in a narrative form.

It should be noted that in the case of the wastewater map no restrictions were made to study locations. The focus for agricultural mapping, however, was on studies conducted in boreo-temperate climate zones in order to exclude articles for significantly different climate zones than the ones occurring in the Baltic Sea Region.

The main findings of both systematic maps are summarised below.

2.3 Results for systematic map of ecotechnologies for recovery and reuse of carbon and nutrients in wastewater sector

2.3.1 Search results

The searches in Web of Science Core Collections, Scopus and Google Scholar resulted in a total of 4472 records. After duplicate removal, 3613 records remained. Records from the Directory Of Open Access Journals and Electronic Theses Online Service were pre-screened for relevance before being added to the software. From DOAJ, 6 records were added and from EThOS 12. A total of 3631 records were then screened for relevance on title and abstract level.

There were 1326 items included after title and abstract screening. 957 items were retrieved as full text. 369 items, out of the 1326 items included after title and abstract screening, were unobtainable a full text, 90 of these were not found online and the other 279 were found online but could not be accessed. A list of unretrievable articles is provided in *Additional file 3_Wastewater_List of unretrievable articles.xlsx*. The 957 items that were retrieved were screened as full text. There were 428 articles included after full text screening. A list of all articles excluded at full text screening and reasons for exclusions are provided in *Additional file 4_Wastewater_List of articles excluded at full text.xlsx*. The literature from specialist websites was screened separately. The final number of included studies at full text from the Finnish specialist websites search was 24, from the Polish 18, from the Swedish 7 and from the English 4. In total, 53 articles were added to the evidence base from the specialist websites. In total, this systematic map included 481 relevant articles each describing one ecotechnology for recovering/reusing carbon or nutrients from wastewater, or possibly a combination of ecotechnologies. A list of all included articles including meta-data and coding is provided in *Additional file 5_Wastewater_Evidence base.xlsx*.

2.3.2 Evidence atlas

An evidence atlas, a cartographic map, was created from the evidence base (see https://drive.google.com/open?id=1_S1B21E5opoX5LCZU3VPxvTmdRV1Ark0&usp=sharing). The evidence atlas shows the study location of each ecotechnology. Depending on the information available in the articles, we have extracted and mapped coordinates of: 1) sampling locations, 2) locations where an eco-technology was developed, or 3) locations where an eco-technology was implemented. The evidence atlas is interactive. The evidence atlas can be searched for specific cases and descriptive information about each study is available using a visual interface and accompanying data table. Articles that did not include any study location are not displayed in the evidence atlas (a total of 132 articles).

2.3.3 Description of the evidence base

Among the 481 articles included in the systematic map database, the number of relevant articles published per year during 2013-2016 increased by 63 % (**Figure 1**). The number of included articles published in 2017 was 71. Note that the searches were performed in the fall of 2017, meaning that there are certainly articles published in late 2017 that were not captured in the searches.

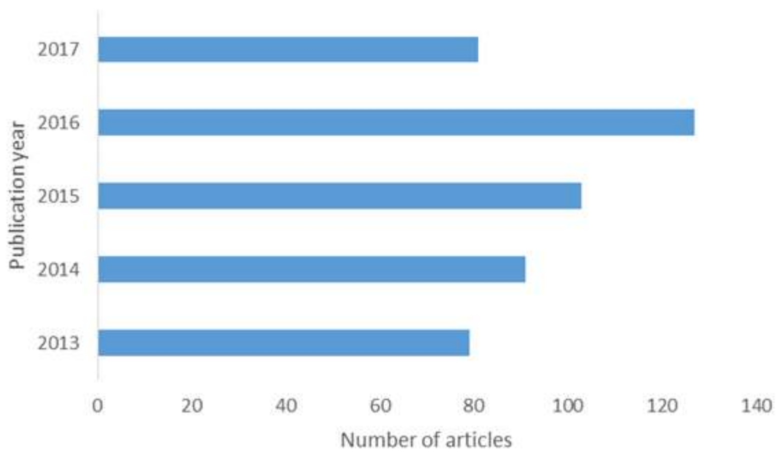

***Figure 1** Number of articles among all 481 included at full text published during the years 2013-2017 in the evidence base of ecotechnologies in the wastewater sector.*

The major part of the evidence base are journal articles, whilst grey literature comprises 11 % of the evidence base (**Table 1**).

***Table 1** Number of articles in the evidence base per publication type and publication year in the evidence base of ecotechnologies in the wastewater sector.*

Publication year	***Journal article***	***Books or book chapters***	***Conference Proceedings***	***Literature from specialist websites***
2017	*69*	*1*	*0*	*11*
2016	*105*	*7*	*2*	*13*
2015	*89*	*7*	*1*	*6*
2014	*73*	*1*	*3*	*14*
2013	*68*	*2*	*0*	*9*
Total	*404*	*18*	*6*	*53*

The evidence base has a wide geographic spread, including ecotechnologies from 56 different countries. The number of relevant articles per continent is presented in **Table 2**. A number of the articles (27%) did not contain indication of a study location. For information on articles in each country of the continent, see evidence atlas.

***Table 2** Number of relevant articles included in the systematic map database per continent in the evidence base of ecotechnologies in the wastewater sector.*

Continent	**# articles**
Europe	150
Asia	139
North America	31
South America	12
Africa	11
Australasia	9
No location stated	129

2.3.4 Narrative synthesis

Out of the 481 articles that were included in the systematic map database, 293 were coded as “Explicit reuse” (of carbon and/or nutrients) (61% of the evidence) and the remaining 188 articles (39% of the evidence) were coded as “Potential/implicit reuse” (see **Figure 3**). The type of recovery/reuse is explicit, is the process of recovery is described, or if it is stated in the article how the nutrients or carbon are used, e.g. as a fertilizer. It is implicit or potential recovery/reuse if recovery of nutrients or carbon is not stated, or if the reuse of the carbon or nutrients is not described, but it seems implicit.

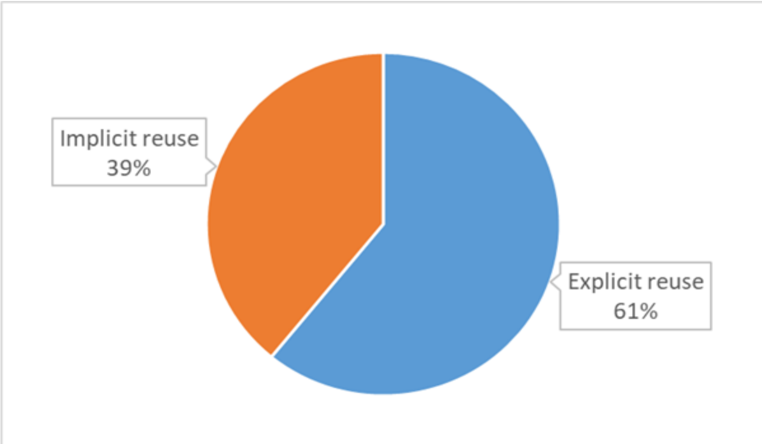

Figure 3*: The percentage of all included articles at full text that were coded with "Explicit reuse" and "Potential/implicit reuse" in the evidence base of ecotechnologies in the wastewater sector.*

The articles coded as “Explicit reuse” were grouped into categories based on the type of ecotechnology that was described. These are the articles that explicitly stated how carbon and/or nutrients were recovered and/or reused. The articles were grouped into categories depending on whether the focus of the article was on a treatment process or the use of a recovered product. Treatment processes constitute the different ways that carbon and/or nutrients can be recovered, whilst product reuse describes the use of the recovered products and focuses on their quality and usability.

The “Treatment process” category includes:

- Biological treatment: Ecotechnologies based on biological processes for example cultivation of microalgae, anaerobic digestion, composting and productive wetlands.
- Biochemical treatment: Ecotechnologies based on the microbial conversion of chemical energy to energy, such as microbial fuel cells (producing electricity) or microbial electrolysis cells (producing hydrogen).
- Physicochemical treatment: Ecotechnologies based on, for example, the selective separation of particles from the wastewater using membranes or sorption of selected substances into another substance such as adsorption or ammonia stripping.
- Chemical treatment: Ecotechnologies based on the chemical precipitation of a substance from the wastewater for example through acidification, alkalinisation or addition of chemicals to precipitate nutrients in solid form, such as struvite.
- Thermo-chemical treatment: Ecotechnologies based on various heat transformation processes such as pyrolysis, gasification, combustion and hydrothermal processes.

The “Product reuse” category includes:

- Articles describing ways in which the recovered products can be reused, such as soil amendment/organic fertilizer, filter material, as solid fertilizer (extracted nutrients) or as irrigation-water.

Finally, the “Combinations” category includes:

- Articles describing different types of coupled ecotechnologies that fall into several of the categories above were categorized as Combinations. This category included, for example, anaerobic membrane bioreactors (biological and physiochemical treatment).

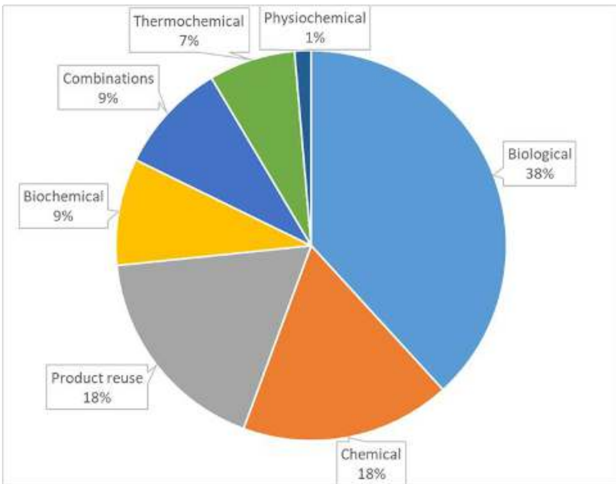

Figure 4 *Distribution of articles coded with explicit reuse in the categories: 'biological', 'chemical', 'physiochemical', 'thermochemical', 'product reuse', 'biochemical' or a combination of either of them ('combinations') in the evidence base of ecotechnologies in the wastewater sector.*

The distribution of the articles that were coded with explicit reuse between the groups above is shown in **Figure 4**. In order to identify knowledge gaps, a heat map was generated to identify over- or underrepresented subjects in the evidence base. The heat map is a function of the ecotechnology type (i.e. category) and the reuse outcome (i.e. what substance is recovered and/or reused) (**Table 3**).

As seen in **Figure 4,** most ecotechnologies in the evidence base are classified as biological processes (38%). An equal number of ecotechnologies were classified as chemical treatment or refer to product reuse, with 18% each. The majority of the articles in the Product reuse group document the efficiency and effect of using biosolids or treated wastewater as fertilizer. Both of these reuse products are most frequently the result of biological treatment processes. It is worth noting that biological processes most frequently recover or reuse of C, N and P. In addition, the most frequent biological process, anaerobic digestion, also has potential for energy recovery in the form of biogas. Combinations of treatment processes represent 10% of the evidence base. The most common combination was biological and physiochemical, mainly anaerobic membrane bioreactors. The most common type of product reuse was as application of biosolids (e.g. treated wastewater sludge) and treated wastewater as a fertilizer.

The heat map shows that among all articles (bottom row in **Table 3**) energy is the most frequently recovered resource, followed by phosphorus. The number of ecotechnologies recovering organic carbon is approximately the same as the ones recovering nitrogen. By far the most common treatment used for resource recovery are biological processes (**Table 3**). Chemical treatment processes in the evidence base are most often aimed at nutrient recovery, in particular phosphorus (**Table 3**). Biochemical and thermochemical processes are represented by similar evidence levels and both recover primarily carbon as an energy source. Application of these processes for nutrient recovery is limited. The greatest knowledge gap appears to be in the application of physiochemical processes in the context of resource recovery.

Table 3 *Heat map with number of articles per group that explicitly state reuse of organic carbon (OC), Energy, Nitrogen (N) or Phosphorus (P) in the evidence base of ecotechnologies in the wastewater sector. Note that an article may belong to more than one category.*

Main groups	OC	Energy	N	P
Biochemical	0	26	2	1
Biological	60	85	35	34
Chemical	2	1	19	49
Physiochemical	1	0	2	2
Thermochemical	10	20	2	6
Product reuse	41	4	45	43
Combinations	9	20	9	13
TOTAL	123	156	114	148

2.4 Results for systematic map of ecotechnologies for recovery and reuse of carbon and nutrients in agricultural sector

2.4.1 Search results

The initial search yielded 33314 articles, which, after the deduplication process resulted in 291352 unique records that were screened at title and abstract level concurrently. We have included 1774 records for retrieval and full text screening. Of these, 412 articles could not be found or accessed (see *Additional file 4_Agri_List of unretrievable articles.xlxs*), leaving a total of 1362 articles that were screened at full text. Of these, 234 were included and 1128 articles were excluded (see *Additional file 3_Agri_List of excluded articles at fulltext with reasons for exclusion.xlxs*). A total of 27 articles were added from searches of specialist websites in relevant languages (Finnish, Polish and Swedish). No relevant articles were added from searches of specialist websites in English. A final set of 261 articles with relevant data was included in the systematic map database (see *Additional file 5_Agri_Systematic map database.xlxs*). A total of 77 articles reported more than one eco-technology and in total, the evidence base includes records of 338 eco-technologies. If more than one ecotechnology was described in a single article, each ecotechnology was assigned a unique study ID and it is referred to as a 'study' in this map. A list of all included articles including meta-data and coding is provided in *Additional file 5_Agri_Systematic map database.xlxs.*

2.4.2 Evidence atlas

As in the case of the wastewater map, we have created an evidence atlas to visualise research on *ecotechnologies in agriculture and the atlas* available here: https://drive.google.com/open?id=1jBq6NOHophcfojzqxJIL90MfsX2GdzmL&usp=sharing. The evidence atlas shows locations from the studies included in the systematic map database on an interactive cartographic map. Based on the information available in the articles, we have extracted and mapped coordinates of 1) sampling locations; 2) locations where an eco-technology was developed or 3) implemented. The evidence atlas can be searched for specific ecotechnologies, and descriptive information about each study is available using a visual interface and accompanying data table. Studies that did not include any location (175) are not displayed in the evidence atlas.

2.4.3 Description of the evidence base

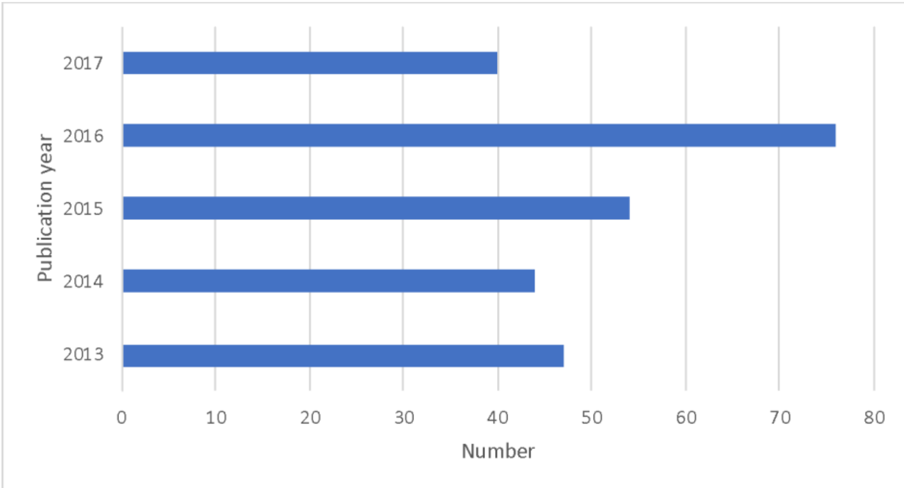

Figure 5 *Number of articles included in the systematic map database on ecotechnologies in agriculture published per year from 2013 to 2017.*

Figure 5 shows the number of relevant articles included in the map database published per year. There is an apparent increasing trend during the period 2014-2016. This trend may also have continued during 2017 and beyond, but this was not captured in our map since the database searches were done in the third quarter of 2017.

Journal articles were by far (more than 90%) the most abundant publication type, followed by reports and books or book chapters. Dissertations and conference proceedings constituted a minor part of the evidence base (**Table 4**).

Table 4 Number of articles (261 in total) per publication type and publication year in the evidence base of ecotechnologies in agriculture.

Publication year	*Journal article*	*Book or book chapter*	*Conference Proceedings*	*Dissertation*	*Report*
2013	38	4	0	0	5
2014	31	2	1	2	8
2015	47	4	1	0	2
2016	65	2	2	0	7
2017	34	1	0	2	3
Total (261)	215	13	4	4	25

Out of 338 studies included in the map database, the majority were from Europe (89 out of 338), followed by North America (50), and more specifically, the United States (34). Two most frequently occurring European countries were Finland (19 studies) and Belgium (14 studies). However about 51% of studies did not indicate their location.

Table 5 *Number of included studies (338 in total) in the evidence base of ecotechnologies in agriculture per continent.*

Continent	**# studies**
Europe	89
North America	50
Asia	16
South America	7
Australasia	1
No location stated	175

2.4.4 Narrative synthesis

We have classified all the included ecotechnologies (338 in total) into 4 different categories with respect to the source of recovered nutrients or carbon: a) manure-based (183 studies), b) crop-based (49), c) mixed (89) and d) other (20). Figure 6 shows the distribution of studies according to these 4 categories.

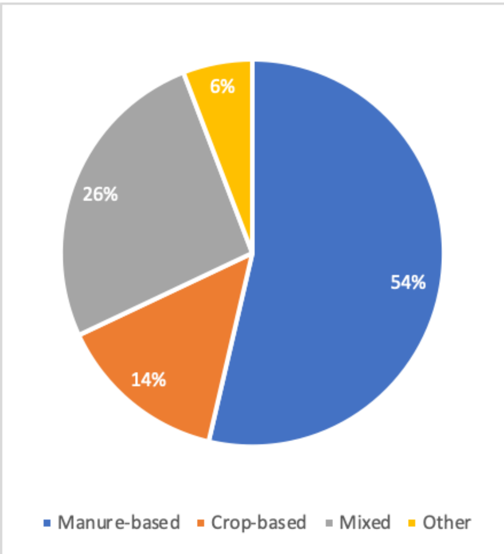

Figure 6 *The percentage of all types of ecotechnologies included in the evidence base of ecotechnologies in agriculture.*

The most prevalent ecotechnologies in the evidence base of agricultural ecotechnologies were manure-based (**Figure 6**). Manure is the principal source for recovery of nutrients or carbon, constituting 54% of the evidence base. Among manure-based ecotechnologies, anaerobic digestion/ co-digestion was the most frequent, followed by combinations/systems of technologies and struvite crystallization. Other typical ecotechnologies in this group were: solid-liquid manure separation, air stripping, composting and vermicomposting, manure drying. Various types of manures: swine, poultry, cattle, horse, etc. were reported as a recovery source, but some studies did not specify manure type. Another division of manure was into solid and liquid, without specification of the source animal species.

As much as additional 26% of studies are classified as ‘mixed’ which refers to manure mixed with plant biomass (e.g. crop residues). The most common ecotechnologies in this category were: composting/vermicomposting, pyrolysis/biochar production as well as anaerobic digestion/co-digestion. The term 'mixed' characterizes the source of recovered nutrients or carbon: a mixture of animal and plant-based agricultural wastes. Some of the studies also characterized reuse of end products of recovery in agriculture as soil amendments (compost or biochar) or biogas residues as fertilizers.

Out of 338 studies in the evidence base of ecotechnologies in agriculture, only 14% refer to crop-based recovery of carbon, nitrogen or phosphorus. Crop-based ecotechnologies included both some of the same types of technologies as in two previous categories, i.e. composting/vermicomposting or pyrolysis, but also some other types related to crop cultivation or management, i.e. cover crops/catch crops, green manures application, bioenergy crops, etc.

Finally, the least frequent ecotechnologies classified as 'other' are all those that could not be easily categorized as 'manure-based', 'crop-based' or 'mixed' with respect to the source of recovered nutrients or carbon. Three noteworthy examples of ecotechnologies in this class were: aquaponics (recirculation systems typically with fish tanks and hydroponic plants, e.g. vegetables); bioreactors placed in drainage ditches for nutrient removal/recovery; constructed wetlands for nutrient removal and recovery from agricultural runoff.

Table 6 *Heat map with number of studies per type of carbon and nutrient (phosphorus and nitrogen) recovery and type of ecotechnology included in the evidence base of ecotechnologies in agriculture. Note: one ecotechnology can focus on reuse of multiple nutrients.*

Type of ecotechnology	Carbon	Nitrogen	Phosphorus
Manure-based	58	142	136
Crop-based	27	38	22
Mixed	53	76	60
Other	6	17	14
Total	144	273	232

The heat map (Table 6, bottom row) shows the most prevalent focus of ecotechnologies is a recovery of nitrogen (80%), followed by phosphorus (69%). Manure-based ecotechnologies were focused on recovery of nutrients, with almost equal numbers of included ecotechnologies on phosphorus and nitrogen recovery). Focus on nitrogen recovery was prevalent in the case of crop-based ecotechnologies. The percentage of studies dealing with carbon recovery was the highest for 'mixed' ecotechnologies and the lowest for those classified as 'other'.

2.5 Limitations

Although we have used a comprehensive set of both general and specific search terms and we have checked the comprehensiveness of our search using benchmark lists, there is a risk that we have missed some studies. Future maps could address this limitation by introducing additional synonyms for different eco-technologies. The main limitation in this respect is that our search terms were 'open' to any ecotechnologies for reuse/recovery/recycling of nutrients and carbon but did not contain any specific example names/types of existing ecotechnologies. There may be relevant articles on these ecotechnologies that do not contain any of our 'reuse' terms in their title, abstract or keywords, but however, do mention or describe the reuse aspect at full text level. On the other hand, although we implicitly searched for 'ecotechnologies', as defined in the Introduction, only one of the studies we found [14] actually mentioned this term at title/abstract/keyword level.

We have limited our search to the 5-year period 2013 and 2017 as we focused on the technological innovations, but future work could be easily expanded to cover publications in longer time range.

Even though the search in Web of Science, Scopus and Google Scholar had a larger scope in both maps, the grey literature searches were done for Sweden, Finland and Poland. This means that the evidence base is overrepresented with studies from the Baltic Sea region and Europe in relation to global studies. Future work should include more searches for grey literature in non-European specialist websites.

In the map of ecotechnologies in agriculture, studies from some large countries such as Russia, covering large part of the relevant climate zones, provide a minor contribution to the evidence base (n=2), which may also be partly explained by the scarcity of Russian studies published in English. Furthermore, a geographical bias towards more developed countries, especially the United States and Finland, can be observed in this evidence base. However, this is not surprising given the fact that the main focus of the map is on the technological innovations. Nevertheless, almost half of the studies reported no location even at the country level, which makes difficult to assess a full geographical spread of the evidence.

While we restricted the scope of the agricultural map to the boreo-temperate regions, this was not done for the wastewater map since ecotechnologies for wastewater management are not necessarily dependent on e.g. climatic factors and developers of technology can be inspired by work done in other parts of the world. When considering suitable ecotechnologies for agriculture as an example, the climate zone can have a great impact on the feasibility of the ecotechnology in another location than it is studied in. However, for wastewater management this might not be the case as it might be indoors, with external heat or artificial irradiation. These factors can of course affect the suitability or feasibility of an ecotechnology at a given location, e.g. it might be too energy-intensive, but this was not assessed within wastewater systematic map. Furthermore, no assessment of the efficiency of these ecotechnologies with regards to reusing carbon and nutrient was made. Also, not considered fully in the systematic maps are the additional benefits that some of the ecotechnologies may bring. Examples of additional benefits include: reducing emissions but not reusing them, reducing water use or reclaiming water and reducing emission of harmful substances such as pathogens or micropollutants, etc.

2.6 Discussion

The most common form of recovery and reuse from wastewater is energy, indicating that nutrients as a resource are not as well studied or implemented. The main knowledge gaps identified in this map include a relative lack of studies focusing on nutrient recovery, particularly nitrogen, in relation to energy recovery. There is room for further research that focuses on non-biological treatment processes for the recovery of nitrogen and phosphorus. In addition, the recovery of organic carbon through physiochemical processes could be further studied. This would be possible since membranes can be used to filter out organic matter which could potentially be reused, but this was not captured in the systematic map. When coupling membranes with anaerobic bioreactors, for example, there is potential for both energy and organic matter recovery through biogas and sludge. Articles describing this are captured in the group Combinations. The ecotechnologies that use chemical processes are mostly focused on the precipitation or sorption of phosphorus, even though different means of nitrogen sorption are also present in the evidence base. In general, the recovery of phosphorus is more common than recovery of nitrogen in the evidence base. Furthermore, the most commonly described use for the recovered products are organic fertilizers or soil amendments, and not nutrients that have been extracted through e.g. precipitation through struvite. This indicates a knowledge gap concerning the use of extracted nutrients, such as struvite, in agriculture, as opposed to the use of biosolids as fertilizer. It is symptomatic that the most frequent exclusion reason was the one related to reuse/recovery of carbon and/or nutrients. This indicates that wastewater management is still mostly focused on removal of these substances.

In the systematic map of ecotechnologies in agriculture, we have catalogued a total of 338 studies with different technological solutions for recovery of carbon, nitrogen and phosphorus from agricultural sources. The majority of studies focused on nutrient recovery (primarily nitrogen, followed by phosphorus) and the majority of studies described manure-based ecotechnologies, of which the most common were anaerobic digestion/co-digestion, struvite precipitation and composting/ vermicomposting. Indeed, it seems that animal manure of various types (primarily swine, cattle, poultry and horse) is the most straightforward source for nutrient recovery in agriculture. Therefore, these subject areas with sufficient evidence to allow for a full synthesis of study findings (knowledge clusters) could be suitable for understanding effectiveness of the ecotechnologies. Ecotechnologies for which crops (plant biomass) were the sole recovery source were not as much in focus of the identified research. Even less studied were ecotechnologies for which recovery is carried out in agricultural runoff (e.g. constructed wetlands or bioreactors placed in small ditches) or water in closed recirculation systems such as aquaponics. Future work could investigate these processes more thoroughly.

2.7 Conclusions

This work collated and catalogued ecotechnologies - the term defined strictly for the purpose of the BONUS RETURN project - for recovery and reuse of nutrients and carbon in agriculture and wastewater sectors. The identified evidence on the ecotechnologies in the agricultural sector was less abundant than the one for the wastewater map (338 vs. 481 ecotechnologies). This can be explained by the differences in methodological approaches used for maps, as well as by the potentially easier access to recovery sources through centralised infrastructure dominating in the wastewater sector vs. small-scale and scattered infrastructure prevailing in agricultural sector. It is noteworthy to mention that current environmental and water policies focus on reduction of pollution from different waste streams rather than on recovery and reuse of nutrients. Such ‘conventional’ measures are not, however, part of this study. Instead, this report provides an unbiased and comprehensive evidence base within the subject that is expected to gain much importance in the Baltic Sea Region in the coming years.

REFERENCES

1. Powell N, Osbeck M, Larsen RK, Andersson K, Schwartz G, Davis M: **The Common Agricultural Policy Post-2013: Could Reforms Make Baltic Sea Region Farms More Sustainable?** In: *SEI and Baltic COMPASS Policy Brief.* 2013.
2. Collaboration for Environmental Evidence: **Guidelines and Standards for Evidence synthesis in Environmental Management. Version 5.0.** In. Edited by Pullin A, Frampton G, Livoreil B, Petrokofsky G; 2018.
3. Haddaway NR, Macura B, Whaley P, Pullin AS: **ROSES RepOrting standards for Systematic Evidence Syntheses: pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps**. *Environmental Evidence* 2018, **7**(1):7.
4. James K, Randall N, Haddaway N: **A methodology for systematic mapping in environmental sciences**. *Environmental Evidence* 2016, **5**:7.
5. Balana BB, Vinten A, Slee B: **A review on cost-effectiveness analysis of agri-environmental measures related to the EU WFD: Key issues, methods, and applications.** *Ecological Economics* 2011, **70**(6): 1021-1031.
6. Naylor R, Steinfeld H, Falcon W, Galloway J, Smil V, Bradford E, Alder J, Mooney H: **Losing the Links Between Livestock and Land**. *Science* 2005, **310**(5754):1621.
7. Sheets JP, Yang L, Ge X, Wang Z, Li Y: **Beyond land application: Emerging technologies for the treatment and reuse of anaerobically digested agricultural and food waste**. *Waste Management* 2016, **44**:94-115.
8. Cornejo PK, Zhang Q, Mihelcic JR: **How Does Scale of Implementation Impact the Environmental Sustainability of Wastewater Treatment Integrated with Resource Recovery?** *Environmental Science and Technology*, 2016, **50**:6680-6689.
9. Mihelcic JR, Fry LM, Shaw R: **Global potential of phosphorus recovery from human urine and feces.** *Chemosphere*, 2011, **84**:832-839.
10. Trimmer JT, Cusick RD, Guest JS: **Amplifying Progress toward Multiple Development Goals through Resource Recovery from Sanitation.** *Environmental Science and Technology,* 2017, **51**:10765–10776.
11. Haddaway NR, Mcconville J, Piniewski M: **How is the term 'ecotechnology' used in the research literature? A systematic review with thematic synthesis.** *Ecohydrology and Hydrobiology*, 2018, **18**:247-261.
12. Haddaway NR, Johannesdottir S, Piniewski M, Macura B. **What evidence exists relating to potential ecotechnologies for the recycling of carbon and nutrients from wastewater?: A systematic map protocol.** *Environmental Evidence* 2018 (in review).
13. Haddaway NR, Piniewski M, Macura B. **What evidence exists relating to potential ecotechnologies in agriculture for the reuse of carbon and nutrients in the boreo-temporate regions? A systematic map protocol**. *Environmental Evidence* 2018 (in review).
14. Roy, D: **Phosphorus recovery and recycling with ecological engineering: A review**. *Ecological Engineering*; 2017, **98**:213-227.