Project description

Strategisk instituttsatsing (SIS): Sustainable recycling of organic waste resources in the future bioeconomy

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Abstract

The intended future bioeconomy requires increased utilisation of available bioresources. As part of this, optimal utilisation of nutrients in waste resources as fertiliser in agriculture will be indispensable. However, waste resources are complex materials that are strongly varying in terms of composition, quantity and quality. Therefore, several barriers will have to be overcome to realise efficient nutrient cycling. For example, large amounts of water in many waste resources can result in difficulties related to handling and application as fertiliser, and that transport is costly over large distances. Further, unknown quality of waste resources as fertiliser is often hindering efficient and environmentally friendly use. Waste resources can contain environmental pollutants and pathogenic microorganisms. Especially microplastics have lately received gained focus. Also, acceptance of waste resources as fertiliser by farmers is unknown, and nutrient recycling can lead to environmental problem shifting.

In this SIS project, we aim at contributing to the future bioeconomy by providing new knowledge on sustainable use of organic waste resources as fertiliser. We will use microalgae for removing nutrients from liquid waste streams, and assess the effect of sorbents in biogas processes during digestate post-treatment and utilization. We also intend to identify a set of analytical parameters to predict fertilisation effects of waste resources compared with mineral fertiliser, and develop guideline models for balanced nutrition application in fertilisation plans. We aim at developing an unbiased analytical method for quantification of different plastic polymers in organic waste. This will permit a range of studies on sustainable waste treatment and quality assessment, as well as studies on fate and risks of microplastics and associated pollutants in terrestrial environments. Also, we will explore socioeconomic barriers for demand for and supply of waste resources as fertiliser. We will propose a framework to describe and compare waste resources in terms of their quality as fertiliser and impacts on the environment as a decision support for users and authorities.

Contents

1. Knowledge needs

Norway aims at replacing the current oil-based economy with a bioeconomy. Also in Europe political interest in achieving a circular economy is increasing. The intended future bioeconomy requires increased utilisation of available bioresources. As part of this, optimal utilisation of nutrients in waste resources within the food system e.g. as fertiliser in agriculture will be indispensable. Application of waste resources to agricultural land can provide both organic matter, which can improve soil quality, and essential plant nutrients. Particularly phosphorus (P) and nitrogen (N) are of concern. Mineable rock phosphate is a limited and non-renewable resource. The greatest P import reductions could be obtained by replacing mineral fertiliser with recycled P from waste resources (Schoumans et al. 2015). Nitrogen has great impact on yield and quality, but incorrect use can have serious adverse consequences on climate and the environment.

It is of strategic importance for NIBIO to ensure that the institute will continue to be nationally leading and an international actor in the development of that part of the circular economy that comprises recycling of waste resources. The demand for NIBIO’s competence on nutrient recycling has in the past years increased in line with increasing requirements on land-filling and separation of waste, as well as the need for improving treatment processes. NIBIO’s activities have mainly focused on optimising anaerobic digestion processes, recycling of P in plant production, and increasing understanding on the pathways of environmental pollutants in waste resources. The waste resources that have mainly been focused on include sewage sludge, manure, food waste and compost and meat bone meal. In the recent years, NIBIO has also obtained knowledge on the handling and use of fish sludge. Fish sludge is faeces and feed residues of aquaculture, and a waste resource of high and increasing importance. Fish sludge produced in Norway contains equally much P as the amount applied to agricultural land as mineral fertiliser (Hamilton et al. 2016). Treatment technologies for fish sludge handling are under development but so far there has been little focus on efficient recycling of containing nutrients, e.g. as fertiliser to agricultural land.

Waste resources are complex materials that are strongly varying in terms of composition, quantity and quality. To realise efficient nutrient cycling in the future bioeconomy, several barriers will have to be overcome:

- **Diluted nutrients in liquid waste resources:** Waste resources often contain large amounts of water. This results in difficulties related to handling and application of waste resources as fertiliser, and that transport is costly over large distances.
- **Unknown fertilisation effects and suitability:** The quality of waste resources as fertiliser is often unknown. This is hindering efficient and environmentally friendly use.
- **Undesirable components:** Waste resources can contain environmental pollutants and pathogenic microorganisms. Especially microplastics have lately gained focus. Using waste resources as fertiliser has to be safe.
- **Uncertain demand and environmental impacts:** Waste-based fertilisers may not automatically be in demand by farmers or accepted by other key stakeholders. There is also a risk that recycling of organic waste resources leads to environmental problem shifting.

2. Objectives

Main objective: Providing new knowledge to promote sustainable use of organic waste resources as fertiliser.

Secondary objectives:

1) Producing high-quality fertiliser products based on liquid waste resource (e.g. fish sludge, manure and anaerobic digestates) by separating and/or concentrating nutrients.
2) Exploring the suitability of organic waste resources as fertilisers.
3) Identifying a set of analytical parameters and tools to predict N and P fertilisation effects of organic waste resources compared with mineral fertiliser.
4) Developing guideline models for balanced nutrition application with organic waste resources in fertilisation plans.
5) Developing methods for quantification and identification of microplastics, and tracing microplastics in different waste streams where organic waste ends up in soils.
6) Evaluating risks associated with microplastics entering arable soil, focussing on fate and exposure to soil organisms of different types of plastic polymers and associated organic pollutants (e.g. PAH, brominated flame retardants and bisphenol A).
7) Exploring the factors determining farmers' demand for recycled fertilisers, institutional barriers and barriers for supply, in order to help design and usage of waste-based fertiliser products.
8) Assessing the environmental impacts of waste-based fertiliser products and to propose a labelling framework for new products to guide users and authorities.

3. Frontiers of knowledge and technology

Sustainable concentration/separation of nutrients

Many waste streams (e.g. digestate, manure, fish sludge, sewage sludge) are diluted, and nutrients need to be concentrated and separated in order to gain the most efficient form for application and transportation. This can be performed by several biological-, physical- and chemical processes or in a combination of those. Since efficient recycling of nutrients from such waste streams is a new era, increased knowledge regarding relevant processes to apply is huge and highly needed.

In nature, plants on land and macro- and microalgae in the sea take up inorganic nutrients (CO_2, nitrate, phosphate) and build the basis for food webs in almost all ecosystems. Microalgae have higher growth rates and can grow to higher photosynthetic active biomass densities than plants, and can therefore utilise nutrients faster and with less areal land use (Xia and Murphy 2015). In addition, microalgae can live in a wide spectrum of environmental conditions (e.g. temperature, pH, salinity and nutrient concentrations) and are also known to efficiently remove heavy metals (Alam et al. 2015). For this reason, microalgae are suitable for removing nutrients (e.g. C, N, P) from wastewater streams or liquid digestate. Main limiting factors are light attenuation by particles, a high ammonium and especially free ammonia concentration, suboptimal N/P and C/N mass ratios, and bacterial contamination

(Xia and Murphy 2015). More research is necessary to determine if and how wastewater or liquid digestate should be pretreated (e.g. precipitation, filtration, ion-exchange), diluted or supplemented (e.g. C, P or trace elements) for optimal microalgae growth. Also, more research is needed on how to deal with bacterial contamination. So far, it is unknown if the microalgal biomass before and after extraction of secondary products can be used as a fertiliser for crops, and if the microalgal biomass sorbs contaminants that can reduce its value as fertiliser. We hypothesize that microalgae can be an eco-friendly and efficient method for concentrating nutrients in different kinds of nutrient-rich liquid waste streams.

Sorbents are materials that dissolved substances or gases will attach to, and thereby take them out of solution or air. Sorbents can bind and concentrate nutrients or gases, e.g. NH_3 which are formed when N-rich substrate like fish sludge is used for substrate in biogas. Ammonia will inhibit the biogas processes at high levels. Sorbents include charred organic material (e.g. activated carbon, biochar), clay minerals (e.g. zeolite, bentonite, alginite), commercial sorbents as well as upcoming innovative reactive sorbents. Related to biogas processes, zeolites are used to take out H_2S (Ozekmekci et al. 2015), and there have also been some attempts to use zeolite in digestate before de-watering to get more nutrients in the solid phase or before drying to reduce losses of ammonia (Ziganshina et al. 2015). Also adding sorbents before the digestion process rather than just to the digestate could have added advantages because reduction in the amount of dissolved ammonia and sulphide could also be beneficial during the digestion process (Mumme et al. 2014). More knowledge regarding different sorbents efficiency for concentrating nutrient in N-rich substrates and toxic gases for the biogas process is needed. In addition, little is known about how sorption affects the fertiliser value of the digestate. Our ongoing experiments suggest that N gets somewhat less available to plants, but also somewhat less prone to losses by leaching. Previous studies have found that sorbed ammonia gas is plant available (Taghizadeh-Toosi et al. 2012). The biogas facilities, and expertise on biogas processes at NIBIO is a strength for this research.

Use of organic waste resources as fertiliser

New products based on organic waste from households, the service industry, the food processing industry, fisheries and aquaculture are continuously entering the fertiliser market. The products have a large potential to replace mineral fertiliser in Norwegian agriculture (Hamilton et al. 2017) but the products' quality as fertiliser is largely varying also between batches, and fertilisation effects are often unknown. The total content of nutrients in waste products says usually little about their fertilisation effects. Therefore, each new product has to be tested to ensure its efficient and environmentally friendly use. Growth experiments (field- and pot experiments) are the most reliable method to determine fertilisation effects. However, they are time-consuming and costly. Standardizing growth experiments will make results comparable and increase the outcome of single experiments. Also, legal requirements for the declaration of quality are inadequate. For example, currently Norwegian regulations recommend predicting the P fertilisation effect of waste resources by the P-AL fraction, even though it has been shown to have poor prediction ability (Brod et al. 2015). It is therefore necessary to identify a set of parameters that can be used for reliable evaluation of a product's quality. The parameters can then be used for developing a calculation tool for predicting new waste products' fertilisation effects.

Especially fish sludge is a waste product of increasing importance in Norway. There is concern that increasingly common use of seawater in smolt and post-smolt production will result in a sludge with less commercial interest as fertiliser due to higher salt concentration. High concentrations of both sodium (Na) and chloride (Cl) in fish sludge might have negative effects on the growth of agricultural crops (Aasen 1997), if N levels at the same time are low. It is therefore necessary to study the effect of salt in marine fish sludge on plant growth.

Microplastics and other undesirable components

Microplastics are synthetic polymers measuring less than 5 mm in diameter and are derived from a wide range of sources including synthetic fibres from textiles, packaging debris, and personal care products (Browne et al. 2011). They have the potential to adsorb persistent organic contaminants and priority metals from the surrounding environment. These may be released upon digestion by biota or through environmental degradation, leading to possible impacts to human health and ecosystems (Teuten et al. 2007). Over the last 10 years, many studies have investigated the distribution and effects of microplastics within the marine environment, but few studies have sought to determine land-based sources of microplastics, not to speak of microplastics entering solid waste and soil. A major constraint for research on fate, effects and mitigation of microplastics pollution in terrestrial environments and solid waste is the lack of sensitive and precise methods for their quantification. Current methods for quantification of microplastics are based on flotation or elutriation (separates lighter particles from heavier ones through an upward flow of liquid and/or gas) combined with microscopy and manual counting based on criteria including form, colour and sheen under polarized light (e.g. Mahon et al. 2017). Current concerns for risks associated with microplastics entering arable soil and possibly the food chain are thus based on somewhat subjective and imperfect quantification, or on modelling of quantities and fate, which result in highly uncertain estimates (e.g. Nizzetto et al. 2016).

Socioeconomic barriers and decision support

The necessary increase in the use of waste-based fertiliser products relies on their acceptance by farmers, removal of institutional barriers, and their supply. New waste-based fertiliser products should at the same time not come in conflict with national ambitions and international obligations related to environmental impacts and resource use. Removal of institutional and economic barriers is identified as crucial for the fostering of a circular economy (Rizos et al. 2015). Studies on the acceptance and demand for waste-based fertiliser products among farmers in Norway are few as we only know of one study on farmers' acceptance of sewage sludge for field application (Refsgaard et al. 2004). Sharpley et al. (2016) emphasize that understanding of farming realities is needed to identify possible improvements of the fragmented P cycle, and Brod (2016) and Ekardt et al. (2010) emphasize that political incentives are needed to efficiently close P cycles. Further, innovative fertiliser products often face formal institutional barriers as existing regulations are made for existing products. Hence, we observe a need for knowledge on socioeconomic barriers for demand for and supply of waste-based fertiliser products, including mental, economic and formal institutional barriers.

In production and use of new waste-based fertiliser products there is a risk of environmental problem shifting, i.e. reducing one environmental impact while increasing another. The Norwegian government has both ambitions and obligations to reduce greenhouse gas emissions as well as emissions of ammonia from the agricultural sector (Norwegian Ministry of Agriculture and Food 2016). It is therefore of interest to assess whether value chains that improve resource use efficiency in the food system at the same time do not come in conflict with pollution reduction goals or increase the use of energy. Some studies are previously carried out to look at the impacts of handling organic waste resources, like the processing of food waste and animal manure for biogas production (Arnøy et al. 2014; Lyng et al. 2015), but the fertiliser aspect of waste fractions is often simplified. Refsgaard et al. (2011) point out that inventories for life cycle assessments (LCA) should be made more detailed than using Norwegian average emission factors, to be able to estimate the effect of different management practices, in this case for animal manure management. The use of LCA is meant to inform decision makers and users about the environmental impacts associated with a product from cradle to store/farm gate/field. A high level of geographical specification is needed for comparisons of agri-food systems since impacts of food production, including the use of fertilisers, are highly variable in different geographical settings (Notarnicola et al. 2017). The environmental impacts related to the production and especially use of waste-based fertilisers is therefore less straight forward to be assumed similar between countries and even between different regions within a country.

4. Research tasks and scientific methods

The project is divided into 5 work packages (WP).

WP 1: Sustainable concentration/separation of nutrients

(Work package leader: Roald Aasen)

Aim: Separation and concentration of nutrients for recycling of sustainable waste-based fertiliser products by enhanced knowledge and understanding of processes. The two main aims are 1) to develop and optimize biotic and abiotic processes to concentrate nutrients from liquid waste streams, and 2) to assess the effect of sorbents in biogas processes during digestate post-treatment and utilization.

Hypotheses:

- Microalgae can efficiently remove nutrients from waste streams.
- Microalgae can serve as a sustainable fertiliser.
- Nutrients in microalgae are more plant available than nutrients in most waste products.
- Sorbents can be part of a solution for concentrating nutrients in anaerobic digestion processes.
- Substances that sorb NH_3 and H_2S will avoid inhibition of the anaerobic digestion process when N-rich substrates are used.
- Sorbents can be found that make it possible to digest fish sludge as sole substrate or with small additions of other substrates.
- Effective sorbents will reduce N loss during composting of digestate but reduce plant availability.

Methods:

NIBIO has extensive experience in and facilities for studies on microalgae cultivation, anaerobic digestion and for investigating recycling of bioresources. The biogas laboratory at Vollebekk has several biogas- and microalgae reactors and possibilities to perform experiments to gain new knowledge in sustainable recycling of nutrients. In collaboration with producers of bioresources, different industries, consumers of nutrients or other relevant actors in the society and in discussion with WP 2, 3, 4 different types of organic waste resources (e.g. wastewater or liquid digestate) as substrates for biogas reactors and/or continuous photobioreactor cultures of selected microalgae strains will be investigated. We will perform experiments that combine applied and basic understanding of processes. The final goal is to separate and recycle nutrients from different sources as high-value nutrient products.

Initially a general knowledge will be built up on different available concentration processes by literature review. One of the activities will be the use of microalgae for nutrient concentration (e.g. C, N, P) from flue gas, wastewater streams and liquid digestate. The produced biomass can be utilised by extraction of certain products (e.g. bioplast) or as fertiliser for plants. Another activity will be the application of sorbents in biogas processes, including pre- and post-treatment. Sorbents can be used for the concentration of nutrients and for preventing the inhibition of a biogas process by N-rich substrates. The use of sorbents in every step from biogas production to digestate post-treatment (de-watering, composting) and the fertiliser value (WP 2) will be investigated. Possible need for pre-treatments and adjustment for optimal microalgae application in wastewater streams will also be studied.

WP 2: Use of organic waste resources as fertiliser

(Work package leader: Eva Brod)

Aim: The aim of this work package is three-fold: 1) We will explore the suitability of organic waste resources as fertilisers, 2) identify a set of analytical parameters and tools to predict N and P fertilisation effects compared with mineral fertiliser and 3) develop guideline models for balanced nutrition application with organic waste resources in fertilisation plans.

Hypotheses:

- The elemental composition in organic waste resources is unbalanced compared to the plants' needs.
- Nitrogen fertilisation effects of organic waste resources can be estimated by a combination of simple laboratory methods and standardized growth experiments.
- The laboratory methods that have earlier been suggested to estimate P fertilisation effects of organic waste resources can be verified on other waste products.
- The availability of sulphur (S) in organic waste resources is lower than total contents.
- Salt in marine fish sludge can decrease its value as fertiliser.

Methods:

WP 2.1 Nitrogen

A wide range of organic waste resources will be collected and the elemental composition will be analysed. A selected range of relevant laboratory methods identified by a literature review will be applied to characterise the N quality in organic waste resources. Laboratory methods will contain e.g. chemical extraction methods and spectrometric methods applied to the waste products, as well as incubation experiments. Results of the laboratory methods on the quality of organic waste resources will be related to their fertilisation effects studied by growth experiments (pot- and field experiment). Based on these results, models are suggested for predicting fertilisation effects compared to mineral fertiliser as a basis for a net-based prediction tool. To begin with, we will use relevant organic waste resources that are already produced in society (e.g. food waste, fish sludge, meat bone meal, manure) for identifying laboratory methods that best predict fertilisation effects. Later during the project, we aim at verifying the suggested prediction models by fertiliser products produced in WP 1.

WP 2.2 Phosphorus

In comparison to N, there has already been conducted research on how to predict P fertilisation effects of waste resources both in Norway (Brod et al. 2015) and abroad e.g. in Denmark, Finland and Switzerland. We will collect produced results, standardise them and identify the methods that best predict P fertilisation effects when all data are compiled. Further, we will conduct growth experiments (pot- and/or field experiment) with various soil types and laboratory methods with new, unknown waste products to verify and calibrate the prediction models that have earlier been suggested. Experiments will be conducted in cooperation with the BIONÆR project MIND-P that will start up in September 2017. So far, suggested models fail at predicting long-term fertilisation effects. Therefore, we also aim at conducting a long-time incubation experiment to monitor P release over time, and a field experiment over several years where changes in available P in soil after application of waste products will be monitored.

WP 2.3 Sulphur and other nutrients

There are indications that total S contents in manure are not equivalent to the amount of S that is available to plants. Therefore, it is likely that the same will be the case for organic waste resources. We will therefore conduct a literature research on extraction methods on S and their ability to predict available S. Plant samples from pot- and field experiments will be analysed for S and potentially other nutrients, to give indications of the waste product's ability to deliver S to plants.

WP 2.4 Salt

We will conduct a literature research to determine upper limits for electrical conductivity for plant growth and/or chlorine. Also we will conduct an incubation experiment with different soils and with marine fish sludge with increasing rates of salt and measure electrical conductivity.

WP 2.5 Guideline and net-based prediction calculator

At last, we will compile the results of the work package in a guideline for declaring the quality of new organic waste resources as fertiliser. The guideline will include a set of analytical parameters and a suggestion of standards for how to conduct growth experiments. Also we will suggest a net-based calculation tool that can be used by farmers to estimate fertilisation effects of unknown organic waste resources.

WP 3: Microplastics and other undesirable components

(Work package leader: Erik Joner)

Aim: The aim of this work package is to develop an unbiased analytical method for quantification of different plastic polymers that can be used for analyses of organic waste and soil. This will permit a range of studies on sustainable waste treatment and quality assessment, as well as studies on fate and risks of plastics/microplastics and associated pollutants in terrestrial environments.

Hypotheses:

- Plastics and microplastics can be identified and quantified using differential scanning calorimetry (DSC) coupled with Fourier-transform infrared spectroscopy (FT-IR) and gas chromatography due to specific melting points of different polymers, and the appearance of volatiles coinciding with such melting.

- Plastics and microplastics can be measured quantitatively using DSC/FT-IR/GC even when constituting a small fraction of organic wastes where they have been partially transformed and occluded during processing. The ageing process can be mimicked and included in controlled experiments to assess the extent of quenching.
- A good quantitative method for measuring microplastics in solid waste and soil will permit descriptions of transport and fate of plastics from a wide range of sources and in a wide range of waste types. This can be used to improve waste treatment processes and to ensure proper classification of such waste in order to protect the environment, arable soils and the human food chain.
- Knowledge on fate and behaviour of microplastics in organic waste will permit a better assessment of risks to the environment and the human food chain.

Methods:

NIBIO already possesses a DSC/FT-IR/GC analytical line and staff with experience on operation of this equipment. Plastic analyses using DSC/FT-IR/GC relies on sensitive thermocouples and tuning of temperature gradients, sample size, crucible type/size, sample preparation, etc. Tuning these aspects using defined types of plastics spiked into various organic matrices will constitute tasks of an early phase of the project. When these basic aspects are set, the method will be tested on real samples and compared to analyses made using traditional density-based separation and microscopy. Bioavailability of organic pollutants associated with and affected by microplastics in waste will be assessed using passive samplers (SPME) and earthworms, analysing targeted pollutants using GC-MS/MS.

WP 4: Socioeconomic barriers and decision support

(Work package leader: Ola Stedje Hanserud)

Aim: The aim of this work package is twofold: 1) Explore socioeconomic barriers for demand for and supply of waste-based fertiliser products; 2) Propose a framework to describe and compare waste-based fertiliser products in terms of their quality and impacts on the environment as a decision support for users and authorities.

Research questions:

- Which factors are important when the farmers are deciding what product they are going to use as fertiliser?
- How do the farmers judge products made from different organic waste?
- What demands do the farmers have concerning the end-product? What price can they accept; and how user-friendly do the products need to be; what quality is needed; how important are the environmental questions concerning such use?
- Are there any regulatory gaps and institutional mismatches concerning use of waste-based fertiliser?
- What are the formal institutional barriers for use of waste-based fertiliser? And how are these barriers perceived from the end users, the authority and the producers and the potential producers?

- What economic and eventually mental barriers exist among the producers and potential producers of waste-based fertiliser products?
- What is relevant information to inform authorities about potential environmental impact of waste-based fertiliser products?
- How can knowledge about content and fate of plastics and microplastics in organic waste be integrated in the evaluation of waste-based fertiliser products?
- Do waste-based fertiliser products evaluated in other WPs of this project represent an improvement in terms of environmental impacts compared to conventional/traditional alternatives?

Methods:

<u>WP 4.1 Farmer demand and acceptance</u>

This sub-WP will use an economic-sociological framework combined with an explorative methodological approach. The WP will identify what needs to be in place for farmers as end users to choose waste-based fertiliser products instead of or in addition to conventional fertiliser. We will look for economic as well as mental barriers and beliefs, which are hindering the farmers from using waste-based fertiliser products. Furthermore, we seek to identify which expectations farmers have to waste-based fertiliser products (e.g. price requirements, user-friendliness, quality, environment etc.). Methodologically we will use a grounded theory approach to develop an empirically based theoretical understanding of the on-farm decision making process. The work will start out with a qualitative in depth study of strategically selected users and potential users of sludge in the regions Akershus and Østfold. The study will consist of farm visits and interviews. The interviews will include questions around already exciting waste-based fertiliser products (e.g. pelleted fish sludge and chicken manure), but also questions around possible new products. Contributions from the other WPs will be needed to help describe these products. After the first round of interviews the research team will decide whether it is fruitful to conduct a representative quantitative survey among the farmers in the region or to extend the qualitative study to get a deeper understanding of the decision making process and possible barriers.

<u>WP 4.2 Institutions and policy on waste-based fertiliser products</u>

This sub-WP will employ a classic document analysis to identify the rationale behind regulations, laws and policy instruments, combined with informant interviews with central policymakers and enforcement authorities. Findings from this WP will be compared with findings from WP 4.1 and 4.3.

<u>WP 4.3 Producer barriers</u>

This sub-WP will conduct qualitative interviews with producers and potential producers of waste-based fertiliser products to identify economic and eventually mental barriers. Also institutional barriers which the producers experience will be investigated and findings from this WP will inform the empirical data for the WP 4.2.

<u>WP 4.4 Authority decision support and product labelling</u>

This WP aims at proposing a framework to characterise waste-based fertiliser products in terms of their potential environmental impact as well as other quality parameters in order to inform authorities and users through a product quality labelling. Qualitative methods will be employed to find what information is relevant for authorities, including environmental impacts from the waste-based fertiliser value chain. Selected representatives from relevant agencies like the Norwegian Environment Agency and the Norwegian Food Safety Authority will be consulted, amongst others through planned project meetings (see WP 5), to find what information is required and useful in their evaluation of existing and new fertiliser products. The results from the WPs 4.1-4.3 will feed into the development of guidelines for product labelling to support both authorities and users.

WP 4.5 Impact assessment of waste-based fertiliser products

In light of the relevant environmental impact categories identified through WP4.4 and literature review, an LCA will be performed in this sub-WP to estimate the environmental impacts of selected waste-based fertiliser products evaluated in WP2. The results on the environmental impacts will be of particular relevance for authorities and may inform the use of incentives as it allows a fair comparison of alternative products. The products to be evaluated will be selected later in the project depending on data availability and what products come to be viewed as strategic important. This sub-WP will also evaluate different LCA tools (e.g. SimaPro, OpenLCA, ORWARE, EASETECH) for estimating environmental impacts of waste-based fertiliser products also beyond this project. Cooperation will be sought with NTNU (Program of Industrial ecology), in particular to extend the selection of products to be evaluated with the LCA methodology and to draw from their competence on the development of environmental product declarations (EPDs), which also will be useful for WP 4.4.

WP 5: Project co-ordination and dissemination

(Work package leader: Eva Brod)

WP 5 will be devoted to co-ordination of activities in all WPs as well as dissemination from the project. The project management will involve regular project meetings (1-2 per year) in addition to the regular meetings within each WP. Relevant stakeholders (i.e. industry partners, Norwegian Environment Agency, Norwegian Food Safety Authority, Norwegian extension service) will be invited to selected project meetings to ensure regular contact and exchange throughout the period of the project. Each year in January, the work packages are internally reporting on-going and completed activities and planning the budget for the coming year. After 2 years, in January 2019, the project will be evaluated and the budget reconsidered. From each WP, results will be published in 3-4 scientific publications in international and peer-reviewed journals. Additionally, results will be presented on a regular basis as news on the NIBIO homepage. The current homepage about NIBIOs competence on organic waste as fertiliser (http://www.nibio.no/tema/organisk-avfall-som-gjdsel) will be updated and expanded within the project. Towards the end of the project relevant results will be summarised in fact sheets to communicate them to relevant stakeholders. Internal communication within NIBIO will be emphasized as the project aims at increasing NIBIOs competence within the field. The project will be introduced on the intranet and updates will be given regularly.

5. Organisation

Project group

The project involves researchers from 3 divisions and 8 departments in NIBIO:

- *Dr. Eva Brod* (NIBIO, Division for Environment and Natural Resources, Urban Greening and Environmental Engineering) will be the project manager and leading WP 2 and 5. She has recently defended her PhD thesis on P recycling.

- *Roald Aasen* (NIBIO, Division for Environment and Natural Resources, Bioresources and Recycling Technologies) has special competence on biogas processes, composting and biowaste characterization and will be leading WP 1.
- *Dr. Erik Joner* (NIBIO, Division for Environment and Natural Resources, Soil Quality and Climate Change) has special competence on organic pollutants (fate, exposure, toxicity) and will be leading WP 3.
- *Ola Stedje Hanserud* (NIBIO, Division for Environment and Natural Resources, Urban Greening and Environmental Engineering) is currently doing his PhD on recycling P in an environmental systems perspective and will be leading WP 4.
- *Dr. Thorsten Heidorn* (NIBIO, Division for Environment and Natural Resources, Bioresources and Recycling Technologies) has special competence on microalgae cultivation and will be taking part in WP 1.
- *Dr. Roar Linjordet* (NIBIO, Division for Environment and Natural Resources, Bioresources and Recycling Technologies) has special competence on soil microbiology and anaerobic digestion, biomass pre-treatment, biogas processes and different types of analysis and will be taking part in WP 1.
- *Linn Solli* (NIBIO, Division for Environment and Natural Resources, Bioresources and Recycling Technologies) is currently doing her PhD on anaerobic digestion and biogas processes. She is investigating the use of fish sludge as substrate in anaerobic digestion, and will participate in WP 1.
- *Dr. Anne Falk Øgaard* (NIBIO, Division for Environment and Natural Resources, Soil and Land Use) has special competence on soil science and plant-availability of P and N and will be taking part in WP 2.
- *Dr. Annbjørg Øverli Kristoffersen* (NIBIO, Division for Food Production and Society, Grain and Forage Seed Agronomy) has special competence in plant nutrition and P utilization and will be taking part in WP 2.
- *Dr. Trond Henriksen* (NIBIO, Division for Food Production and Society Grain and Forage Seed Agronomy)
- *Dr. Claire Coutris* (NIBIO, Division for Environment and Natural Resources, Soil Quality and Climate Change) has competence on organic pollutants (fate, analysis) and GC analyses, and will be taking part in WP 3.
- *Dr. Andreas Treu* (NIBIO, Division for Forest and Forest Resources, Wood technology) has special competence on DSC analyses for material characterization, and will be taking part in WP 3.
- *Dr. Valborg Kvakkestad* (NIBIO, Division for Food Production and Society, Economics and Society) has special competence in farmers’ behaviour and agri-environmental policy instruments, and will be taking part in WP 4.
- *Dr. Bjørn Egil Flø* (NIBIO, Division for Food Production and Society, Economics and Society) is a rural sociologist with special competence on culture and informal institutions role in a process of innovation and institutional change, and will be taking part in WP 4.
- *Dr. Anne-Grete Roer Hjelkrem* (NIBIO, Division for Food Production and Society, Agricultural Technology and System Analysis) has special competence on LCA, and will be taking part in WP 4.

Cooperation between work packages

Figure 1 shows an overview of how activities in the different WPs are interrelated. WP 1 will provide fertiliser products to WP 2, where the fertilisation effects will be evaluated. Further, the products will be used to verify prediction models suggested for N fertilisation effects. WP 1 will also provide samples to WP 3 in order to quantify and identify potential contamination with microplastics and other undesirable components. WP 4 will receive data from WP 1 on gaseous losses during processing of different waste and data from WP 2 on fertiliser value for product labelling. All WPs will provide data to WP 4 for the evaluation of socioeconomic barriers and decision support.

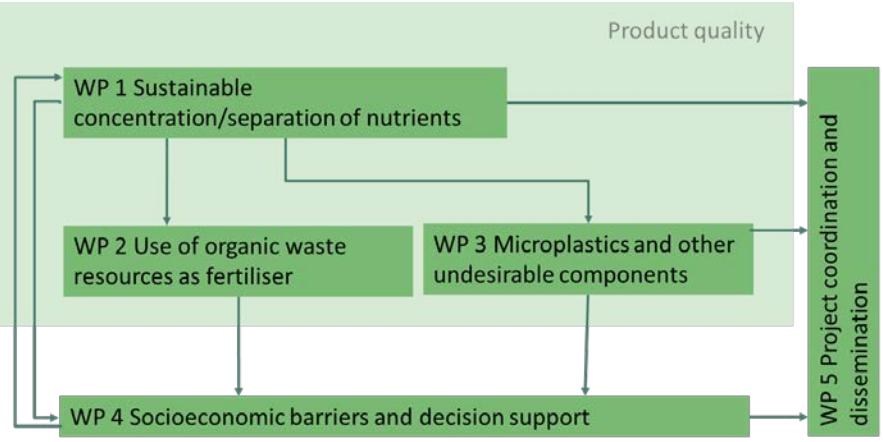

Figure 1. Overview of how the different work packages are interrelated

Cooperation with other partners

The project will actively seek to establish contact with other research groups as well as authorities and companies for network building and ensuring relevance of the project's outcome.

WP 1 will cooperate with established research partners within biogas- and microalgae, i.e. NMBU, NTNU, SINTEF, and industry partners, e.g. Statskraft, Yara and Goodtech. New industry and companies partners, national and international, within process technologies of relevance for concentration and separation of nutrients for reuse, or producers of bioresources for nutrient recycling, will be established. The aquaculture and sea food industry is especially important regarding concentrating nutrient from fish waste resources.

WP 2 will get in touch with research groups at Aarhus University in Denmark, ETHZ in Switzerland and others for compilation of existing data on the prediction of P fertilisation effects of waste products. Further, companies producing waste-based fertiliser products will be conducted. They will be offered the possibility to get their product characterised and the fertilisation effect tested in the experiments that are planned within WP 2. Especially companies providing treatment solutions of fish sludge as well as seafood companies will be contacted (e.g. Salsnes Filter, Goodtech, AquaGreen/Melbu, Marine Harvest, Salten havbrukspark…). Phosphorus experiments will be conducted in cooperation with the BIONÆR project MIND-P that will start up in September 2017. Further, the Norwegian Food Safety Authority (Mattilsynet) and Norsk Landbruksrådgiving will be contacted to ensure relevance of the work package's outcome.

WP 3 will collaborate with both national (NIVA, NGI) and international laboratories (Bundesamt für Materialforschung und -prüfung, Berlin, Germany; University of Vienna, Department of Environmental Geosciences and Environmental Science, Austria; EMGR, Université Grenoble, France) regarding comparisons of methods, use on different plastic containing media and establishment of common projects funded by NFR and EU.

WP 4 will approach the BIOSMART and MIND-P research projects to explore possible collaboration on the research work related to socioeconomic barriers and sustainability of organic resource recycling in the bioeconomy. We will also invite staff and students at the Program for Industrial ecology at NTNU to collaborate on impact assessment of waste-based fertiliserproducts through LCA, in particular. Greve Biogass and possibly other current producers of waste-based fertiliser products will be contacted for input on the producer perspective, while organisations such as the Norwegian Food Safety Authority, Norwegian Environment Agency, Norwegian Waste Management and Recycling Association (Avfall Norge) and Norwegian Agriculture Agency (Landbruksdirektoratet) and/or Norsk Landbruksrådgivning will be contacted for input on the development of labelling guidelines, including choice of environmental impact categories.

6. Key milestones and deliverables

Table 1. Key milestones

	Key milestones	**From**	**To**
Work package 1			
M 1.1	Literature review on growing microalgae on wastewater, digestate and fish sludge, technologies for volume reduction/concentration of nutrient rich liquids and sorbents for use in biogas	2017	2017
M.1.2	Establishing photobioreactors for microalgae at Vollebekk/NMBU/Statskraft district heating plant	2017	2017
M 1.3	Test of pre-treatment of substrates and solutions of microalgae	2018	2018
M 1.4	Microalgae growth experiments with different substrates	2017	2019
M 1.5	Evaluating the effect of concentrating of nutrients with use of algae	2017	2019
M 1.6	Investigating the potential for sorbents to concentrate nutrients during biogas processes, and use of N-rich substrate as a sole substrate	2017	2021
Work package 2			
M 2.1	Literature review on methods to predict N fertilisation effects and selection of methods	2017	2017
M 2.2	Growth experiment to study N fertilisation effects and application of laboratory methods to predict N fertilisation effects and incubation experiment	2017	2019

M 2.3	Verification of suggested N prediction models with products produced in WP 1	2020	2020
M 2.4	Compilation of own and international data on predicting P fertilisation effects	2017	2018
M 2.5	Growth experiment to study P fertilisation effects, application of laboratory methods to predict P fertilisation effects	2018	2019
M 2.6	Incubation experiment to study long-term P fertilisation effects	2018	2020
M 2.7	Literature review on extraction methods for S	2017	2017
M 2.8	Literature review on the effect of salt on plant growth	2019	2019
M 2.9	Incubation experiment on the effect salt in fish sludge	2019	2021
Work package 3			
M 3.1	Literature review on methods to quantify microplastics in waste and soil	1.1.2017	31.4.2017
M 3.2	Development of a base-line analytical method for quantification of individual polymers	1.1.2017	31.12.2017
M 3.3	Establishment of an analytical method for quantification of microplastics in organic matrices	1.5.2017	31.12.2018
M 3.4	Describing fate and hazards from microplastics in organic waste, including associated key organic pollutants	1.9.2018	31.12.2019
Work package 4			
M 4.1	Literature review on the sociology of use of waste-based fertilisers in agriculture	2017	2017
M 4.2	Field work: observation and qualitative interviews on farm level	2017	2017
M 4.3	Analysis: economic and mental barrier, demands for the product, on-farm decision making processes	2017	2018
M 4.4	Document analysis formal institutional barriers for waste-based fertiliser products	2017	2019
M 4.5	Field work: qualitative interviews (existing suppliers and authorities) on formal institutional barriers for waste-based fertiliser products	2018	2018
M 4.6	Analysis formal institutional barriers	2018	2019
M 4.7	Field work: interviews with possible suppliers of waste-based fertiliser products	2018	2019
M 4.8	Analysis: economic and mental barriers for supply of waste-based fertiliser products	2018	2019
M 4.9	Clarify important environmental indicators for	2017	2019

	authorities		
M 4.10	Development of labelling guidelines	2019	2021
M 4.11	LCA of selected waste-based fertiliser products	2019	2021

Table 2. Deliverables

Deliverables		
Work package 1		
D.1.1	Summary of literature (internal document)	8/2017
D.1.2	Scientific publication on microalgae	12/2019
D.1.3.	Scientific publication on methods and sorbents possibilities to concentrate nutrients	12/2020
D.1.4	Scientific publication on methods for reducing NH_3 in biogas processes with use of N-rich substrate	12/2021
D.1.5	Scientific publication on sorbents and processes influence on nutrient purity and bioavailablility	12/2021
Work package 2		
D 2.1	Scientific publication on N results	12/2021
D 2.2	Scientific publication on compilation of international P data	12/2018
D 2.3	Scientific publication on P results	12/2018
D 2.4	Report on S results	12/2018
D 2.5	Report on salt results	12/2021
D 2.6	Guideline	12/2021
D 2.7	Net-based calculator	2020
Work package 3		
D 3.1	Literature review on methods to quantify microplastics in waste and soil (internal document and database)	4/2017
D 3.2	Developed of a base-line analytical method for quantification of individual polymers	12/2017
D 3.3	Established an analytical method for quantification of microplastics in organic matrices. Published in an international journal.	12/2018
D 3.4	Describing fate and hazards from microplastics in organic waste, including associated key organic pollutants. Experimental data published in an international journal.	12/2019
Work package 4		

D 4.1	Scientific publication on economic, institutional and mental barrier, demands and supply for the product, on-farm decision making processes	12/2020
D 4.2	Scientific publication on guidelines for labelling	12/2020
D 4.3	Scientific publication on LCA results	12/2021
D 4.4	Report on guidelines for labelling	12/2020
Work package 5		
D 5.1	Kick-off meeting	3.2017
D 5.2	Project meeting	9.2017
D 5.3	Project meeting	3.2018
D 5.4	Project meeting	9.2018
D 5.5	Evaluation and re-consideration of the budget	1.2019
D 5.6	Project meeting	3.2019
D 5.7	Project meeting	9.2019
D 5.8	Project meeting	3.2020
D 5.9	Project meeting	9.2020
D 5.10	Project meeting	3.2021
M 5.11	Final meeting	11.2021

7. Budget

Table 3 shows how the budget is divided between the different WPs for the entire project period. Table 4 shows how the budget is divided between the different WPs for 2017.

Table 3. Overall budget in 1000 NOK

Work package	Payroll and indir. exp.	Experiments and analyses	Other op. expenses	Sum
1	3325	1175		4500
2	2700	1800		4500
3	3900	500	100	4500
4	2500			2500
5	1500			1500
SUM	13925	3475	100	17500

Table 4. Budget 2017 in 1000 NOK

Work package	Payroll and indir. exp.	Experiments and analyses	Other op. expenses	Sum

1	675	225		900
2	500	400		900
3	750	150		900
4	500			500
5	300			300
SUM	2725	775		3500

References

Aasen I 1997. Mangelsjukdomar og andre ernæringsforstyrringar hos kulturplanter: årsaker – symptom – rådgjerder. Oslo, Landbruksforlag. 95 p. + appendix

Alam MA, Wan C, Zhao X-Q, Chen L-J, Chang J-S, Bai F-W 2015. Enhanced removal of Zn2+ or Cd2+ by the flocculating Chlorella vulgaris JSC-7. Journal of Hazardous Materials 289: 38–45

Arnøy S, Lyng K-A, Modahl IS, Baxter J, Bakke R, Hovland J 2014. Utilisation of farm manure for biogas production. Environmental and economic analysis of local and central biogas plants, including pipeline transport of biogas. Or.06.14. Østfoldforskning, Norway.

Brod E 2016. The recycling potential of phosphorus in secondary resources. Philosophiae Doctor (PhD) Thesis, Department of Environmental Sciences, Faculty of Environmental Science and Technology, Norwegian University of Life Sciences, Ås, Thesis number 2016:35

Brod E, Øgaard AF, Haraldsen TK, Krogstad T 2015. Waste products as alternative phosphorus fertilisers part II: Predicting P fertilisation effects by chemical extraction. Nutrient Cycling in Agroecosystems 103: 187–199

Browne MA, Crump P, Niven SJ, Teuten E, Tonkin A, Galloway T, et al. 2011. Accumulation of microplastic on shorelines worldwide: Sources and sinks. Environ Sci Technol 45:9175−9179

Ekardt F, Holzapfel N, Ulrich AE 2010. Phosphorus, Land Use and Absolute Quantity Reductions as a Legal Problem. Journal for European Environmental and Planning Law 7: 267−287

Hamilton HA, Brod E, Hanserud OS, Gracey EO, Vestrum MI, Bøen A, Steinhoff FS, Müller DB, Brattebø H 2016. Investigating Cross-Sectoral Synergies through Integrated Aquaculture, Fisheries, and Agriculture Phosphorus Assessments. Journal of Industrial Ecology 20: 867–881

Hamilton HA, Brod E, Hanserud OS, Müller DB, Brattebø H, Haraldsen TK 2017. Recycling potential of secondary phosphorus resources as assessed by integrating substance flow analysis and plant-availability. Science of the Total Environment 575: 1546−1555

Norwegian Ministry of Agriculture and Food 2016. St.meld. nr. 11 (2016-2017) Endring og utvikling - En fremtidsrettet jordbruksproduksjon.

Lyng K-A, Modahl IS, Møller H, Morken J, Briseid T, Hanssen OJ. 2015. The biovaluechain model: A Norwegian model for calculating environmental impacts of biogas value chains. Int J Life Cycle Assess 20: 490−502

Mahon AM, O'Connell B, Healy MG, O'Connor I, Officer R, Nash R, Morrison L 2017. Microplastics in sewage sludge: Effects of treatment. Environmental Science & Technology 51: 810−818

Mumme J, Srocke F, Heeg K, Werner M 2014. Use of biochars in anaerobic digestion. Bioresource Technology 164: 189-197

Nizzetto L, Futter M, Langaas S. 2016. Are agricultural soils dumps for microplastics of urban origin? Environmental Science & Technology 50: 10777−10779

Notarnicola B, Sala S, Anton A, McLaren SJ, Saouter E, Sonesson U. 2017. The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. Journal of Cleaner Production 140, Part 2:399‒409.

Ozekmekci M, Salkic G, Fellah MF 2015. Use of zeolites for removal of H2S: a mini-review. Fuel Processing technology 139: 49-60

Refsgaard K, Asdal Aa, Magnussen K, Veidal A 2004. Organisk avfall og slam anvendt i jordbruket - egenskaper, kvalitet og potensiale – holdninger blant bønder.(Organic waste and sludge used in agriculture – properties, qualities and potential) NILF-report 2004:5. Norwegian Agricultural Economics Research Institute.

Refsgaard K, Bergsdal H, Pettersen J, Berglann H. 2011. Climate gas emissions from food systems - use of lca analyses. (Discussion paper No 2011-3). Oslo, Norway:Norwegian Agricultural Economics Research Institute.

Rizos et al. 2015. The Circular Economy: Barriers and Opportunities for SMEs. CEPS Working Document, No. 412 / September.

Schoumans OF, Bouraoui F, Kabbe C, Oenema O, van Dijk K 2015. Phosphorus management in Europe in a changing world. AMBIO 44: 180–192

Sharpley A, Kleinman P, Jarvie H, Flaten D 2016. Distant Views and Local Realities: The Limits of Global Assessments to Restore the Fragmented Phosphorus Cycle. Agricultural & Environmental Letters, Published October 6, 2016.

Taghizadeh-Toosi A, Clough TJ, Sherlock RR, Condron LM 2012. Biochar adsorbed ammonia is bioavailable. Plant and Soil, 350, 57-69.

Teuten EL, Rowland SJ, Galloway TS, Thompson RC. 2007. Potential for plastics to transport hydrophobic contaminants. Environmental Science & Technology 41:7759-7764.

Xia A, Murphy JD 2016. Microalgal Cultivation in Treating Liquid Digestate from Biogas Systems. Trends in Biotechnology 34: 264–275

Ziganshina EE, Belostotskiy DE, Ilinskaya ON, Boulygina EA, Grigoryeva TV, Ziganshin AM 2015. Effect of the Organic Loading Rate Increase and the Presence of Zeolite on Microbial Community Composition and Process Stability During Anaerobic Digestion of Chicken Wastes. Microb Ecol 70:948–960