POLICY ROADMAP

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AUTHORS: KARI YLIVAINIO, SYLVIA KRATZ, ANDREA BAUERLE, ELSE BÜNEMANN, LARS STOUMANN JENSEN, CHRIS SLOOTWEG, LUDWIG HERMANN, MARZENA SMOL, JAKOB SANTNER, JEROEN BUYSSE, GERGELY TÓTH, ANTONIO DELGADO

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OPTIMISING BIO-BASED FERTILISERS IN AGRICULTURE – PROVIDING A KNOWLEDGE BASIS FOR NEW POLICIES

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LEX4BIO aims to reduce the dependence upon mineral/fossil fertilisers, benefiting the environment and the EU's economy. The project will focus on collecting and processing regional nutrient stock, flow, surplus and deficiency data, and reviewing and assessing the required technological solutions. Furthermore, socioeconomic benefits and limitations to increase substitution of mineral fertiliser for BBFs will be analysed. A key result of LEX4BIO will be a universal, science-based toolkit for optimising the use of BBFs in agriculture and to assess their environmental impact in terms of non-renewable energy use, greenhouse gas emissions and other LCA impact categories. LEX4BIO provides for the first-time connection between production technologies of BBFs and regional requirements for the safe use of BBFs.

The project runs from June 2019 to May 2024. It involves 20 partners and is coordinated by Luke (Luonnonvarakeskus - Natural Resources Institute Finland).

More information on the project can be found at: http://www.lex4bio.eu

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D8.5: POLICY ROADMAP

1. INTRODUCTION

Agriculture productivity is dependent on the availability of essential plant nutrients and phosphorus (P) and nitrogen (N) are the most limiting nutrients in plant production. Since the mineral P fertilisers were introduced in 1840s, food production has been increasingly dependent on the availability of fertilisers. Use of mineral fertilisers increased markedly in 1950s, but in certain areas over fertilisation has led to nutrient losses, causing eutrophication of surface waters. Excess use of P fertilisers has increased P concentration in agricultural soils that we nowadays are referring to “legacy P”, whereas excess use of N fertilisers is mainly lost, either in gaseous form or via leaching.

Mineral N fertilisers originates from atmospheric N_2, being a limitless source for N fertilisers, but production is a high energy consuming process (Haber-Bosch process). The current consumption of N-fertilisers in the EU (11.36 million tons) emits about 40.9 million tons of CO_2 annually and agricultural activities account for 10% of the total European GHG emissions (https://ec.europa.eu/eurostat/statistics-explained/pdfscache/16817.pdf). Unlike N fertilisers, P fertilisers originate from apatite minerals and main sources are locating in potentially politically unstable regions in Morocco, followed by China and USA. Having only one P mine in Europe, covering about 10% of the European demand (van Dijk et al. 2016), Europe is heavily dependent on imported P minerals. Crop and animal production are the main sectors for utilizing imported P in the EU, representing 92% share of the imported primary P and 77% of the total P import (van Dijk et al. 2016). Most of this imported P is used as P fertilisers in agriculture directly, whereas rest of the imported P is in the form of feed for the livestock.

Use of mineral P fertilisers has decreased in the EU since the 1970s and amounts applied as mineral fertilizer are less than that applied as manure, but still P balances are positive, especially in the Western Europe with high animal density and has led to a high soil P stock (van Dijk et al. 2016). Input of N from mineral fertilisers is higher than from livestock manure, although there was a drastic decrease in the use of mineral N fertilisers from 1980s to 1990s (http://www.fao.org/3/I8153EN/i8153en.pdf). Manure based nutrients are utilized in a close vicinity of the production sites and has caused nutrient hot spots. Intensive livestock production, especially in the Western Europe has caused surplus balances of N and P (Fig. 1). Balanced N application as manure may lead to excessive P supply since the N:P ratio in manures is usually lower than that required by crops. Environmental deterioration due to the high nutrient balances is further amplified by the segregation of crop and animal production.

In addition to manure, other main nutrient-rich side-streams (NRSS) are sewage sludges and bio-waste. However, these nutrient sources are poorly utilized in crop production, but rather considered as waste. Poor utilization is mainly due to the concern of organic contaminants and their effect on food and feed safety, human health, and agronomic efficiency as fertilisers. Optimising the use of NRSS as fertilisers in agriculture provides tools for reaching the targets sets in the European Green Deal for making Europe climate neutral by 2050. Improved utilisation of NRSS also supports Farm-to-Fork Strategy, for reducing both nutrient losses and ultimately use of fertilisers.

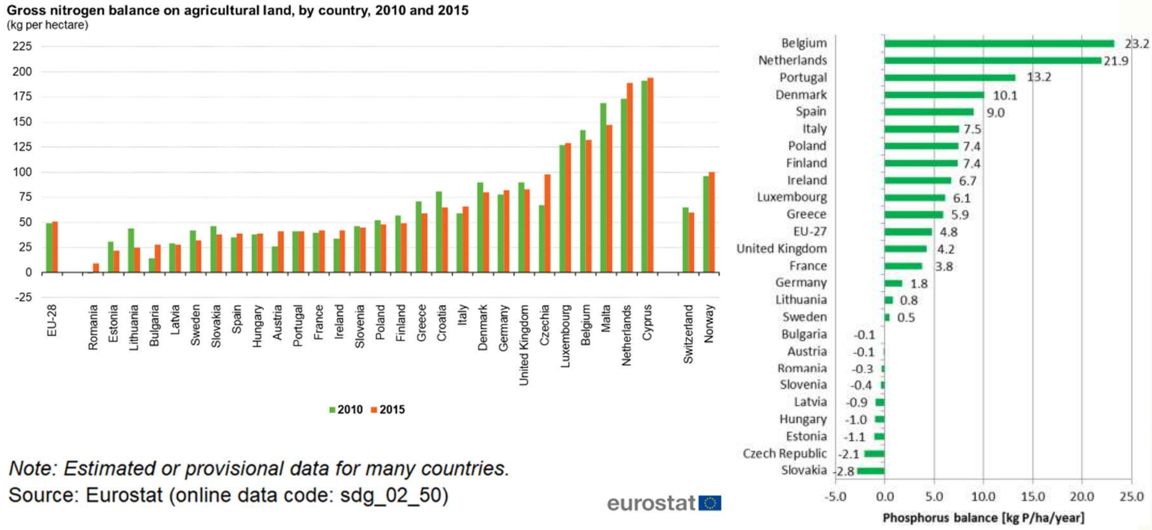

Figure 1. Nitrogen (left) and phosphorus (right: van Dijk et al. 2016) balances in the EU.

The aim of the LEX4BIO is to decrease European dependency on imported, finite P fertilisers and energy intensive N fertilisers by realising the full potential of NRSS as bio-based fertilisers (BBF) without compromising the food and feed safety and supply, human health and environmental protection, as presented in Figure 2. This will be achieved by developing a profound knowledge basis and new coherent methods to take full advantage of BBFs.

Figure 2. Overall goal of LEX4BIO for reaching circular economy through better utilisation of nutrient-rich side-streams as bio-based fertilisers (BBF) in agriculture, considering food and feed safety, human health and environmental protection in the EU.

Increasing the acceptance and thus utilisation of BBFs requires an affirmative reply at large, including farmers, consumers and both fertiliser and food industry and stakeholders from various fields involved in a circular economy. As one of the main targets of LEX4BIO is to increase the utilization of BBFs by replacing the use of mineral ones in European agriculture, relevant stakeholders involved in the field of BBFs were engaged to work in National Dissemination Fora (NDF) for evaluating the obstacles restricting the use of BBFs and ways for increasing their utilization. Their views for developing the utilization of BBFs were evaluated against the objectives of LEX4BIO.

2. METHODOLOGY

LEX4BIO consortium (www.lex4bio.eu) consists of 20 partners from 14 European countries, including two non-EU countries (Norway and Switzerland). One of the most effective dissemination and communication channels are National Dissemination Fora (NDF), established in Finland, Denmark, Germany, Poland, Austria, Hungary, Spain, Netherland, Belgium, and Switzerland. Participants in the NDF are ministries of Agriculture and Environment, representatives from agricultural advisory services, farmers unions, farmers, professional associations, fertiliser industries, food industries research institutes/universities, nutrient platforms and non-governmental organizations (NGO). Meetings with NDF will be arranged annually for securing the dissemination and communication of LEX4BIO activities at large.

Total of ten NDF-meetings were arranged during the period of June 2019 – October 2020 as some meeting were forced to postpone due to COVID-19. During these first meetings LEX4BIO was presented for the NDF, followed by the discussions related to obstacles and requirements for improving the utilization of BBFs. Meetings lasted up to few hours and minutes from these meetings were prepared. Outcomes of these meetings were arranged according to the topics (Section 3) and evaluated against the objectives of LEX4BIO (Section 4).

3. NDF POINT OF VIEW ON BBFs

NDF have proven to be a viable method for spreading the results of European Research Projects to national stakeholders. Particularly representatives of the Austrian Ministry of Agriculture have emphasised that typically national authorities are not informed about the results of those initiatives and consequently take policy decisions solely on the basis of national research activities. The LEX4BIO initiative of regular NDF, unfortunately hindered by the COVID-19 pandemic, was highly appreciated. Since trickling down knowledge from science to farmers and local actors in general is a challenge for all European research projects, NDF can contribute to closing the gap due to including competent authorities and national advisory bodies such as agricultural chambers. Conversely, NDF are providing important information to researchers in terms of explaining different national approaches, frequently in response to historic developments and regional frameworks and practices.

3.1. Legislation regarding the use of BBFs

Fertiliser Product Regulation (FPR; EU 2019/1009) sets criteria for CE-marked fertilisers and these can be utilized without restrictions on the internal market of the EU from 16th of July 2022 onwards. Currently national legislations are being adapted to meet the FPR. It was acknowledged that FPR will improve the utilization of NRSS (CMCs) as raw material for production of CE-marked BBFs and hence to reduce the dependency on imported fertilisers. It was pointed out that as the CMCs are accepted, it will automatically lead to an accepted BBF. Independent of the NRSS, FPR sets the same quality criteria for the BBFs and therefore it is good that FPR provides a possibility to take into consideration new research findings and risk assessments as processing of NRSS affects the quality of the BBFs and during the production process, harmful substances may be produced or antibiotic resistance may increase.

Although sewage sludge as such (digested/composted) is not an acceptable CMC for the BBFs, currently about 40% of the sewage sludge in Finland and 50% in Europe is utilized in agriculture. Therefore, it was suggested for national End-of-Waste criteria for BBFs produced out of sewage sludge. Also, in Germany End-of-Waste criteria for various NRSS and finally to BBFs differs to those in FPR. Because there are large variations in the quality of sewage sludge among the member states, common quality criteria were thought to be important in order to increase acceptance of sewage sludge based BBFs. This was considered to be one of the bottlenecks for accepting sewage sludge based BBFs between member states. Currently all BBFs are processed, except manure, either through mechanical or chemical processing, digestion, composting, or combination of these methods. Lowering the limits for harmful substances requires more efficient processing technologies as compared to conventional ones, leading to a higher price for the BBFs.

For improving the use of BBFs across the EU, there is a need for synchronizing the EU legislation regarding the use of BBFs even beyond the new FPR. As an example, was mentioned inconsistency of regulation on organic production and fertiliser regulation. Furthermore, on a national level lack of legal guidance towards enhanced use of BBFs is missing.

Obligation to blend BBFs with mineral fertilisers was not considered as an option for increasing the use of BBFs, whereas for high quality BBFs this could be a way to introduce them on the market, prerequisite for production and utilization of BBFs. On the other hand, convincing of farmers about the beneficial properties of BBFs needs to be performed before introducing legislation requiring farmers to use BBFs.

Subsidy policies for compensation of possible yield reduction after using BBFs was considered a possible way for increasing the acceptance of BBFs. However, in a long run, subsidies should be avoided, but used only when introducing BBFs to the market. As an example, was presented investment aid for biogas combined with the use of nutrients. As a reference were also mentioned subsidies for the wind energy.

Application of mineral and BBFs is considered differently in the legislation, both regarding timing and rates. Restrictions in the regulations poses a risk for the larger utilization of BBFs. Nitrate directive sets a minimum of 30% dry matter requirement for biomasses stored in heaps in the fields and it was noted that it might be difficult to reach this requirement. One of the ways for enhancing the use of BBFs was seen the possibility for adapting national manure policy in a way that farmers are allowed to apply additional N and P for improving soil fertility. New FPR was seen as a way for enhancing the use of sewage sludge-based P as precipitated P salts (CMC 12). It was pointed out that a wide variety of CMCs, including different production technologies and additives (e.g. micro-organisms), for enhancing nutrient utilization in NRSS, provides new means for circular economy and enhancing soil fertility and opens new business opportunities.

Legislation has an implication on recycling and use of BBFs. The EU Water Framework Directive (2000/60/EC) aims for "good status" for all ground and surface waters in the EU. This was considered as a milestone and soil conservation should also be considered and BBFs could be an important part of it. Also, renewable energy production normative should be integrated as part of nutrient recycling.

3.2. Obstacles for increasing the utilization of BBFs

3.2.1. Fertiliser efficiency of BBFs and their acceptance among farmers

It was recognized that fertilising efficiency of BBFs needs to be as effective as with mineral fertilisers and timing of nutrient release needs to meet crop demand during the growing season. This concerns especially N-BBFs, where part of N is often in organic form and mineralization needs to take place prior to crop uptake. For many N-BBFs, mineralization pattern is unknown, prerequisite for optimizing use efficiency of BBFs and minimizing N losses. Knowing mineralization pattern would also help manufacturers to provide application guidelines of BBFs for farmers. It was pointed out that many of the current BBFs have low efficiency as compared to mineral ones and efficiency of BBFs needs to be demonstrated for gaining acceptance among farmers. It was recognized that overall positive experiences from the use of BBFs will increase their acceptance and farmers are likely to use them again. Due to the large variation of different types of BBFs, guidance for their proper use is needed and BBFs should fit to the farming practices. Spreading of BBFs, especially bulky ones, requires special equipment and this may reduce willingness of farmers to use these materials. In addition to NPK fertilisers, BBFs contain also sulphur and micronutrients that will bring benefits for the farmers.

Use of sewage sludge based BBFs is forbidden in some European countries, mainly due to the potential contamination with organic pollutants. Furthermore, reluctance of farmers to accept sewage sludge based BBFs (digested/composted) is partly related to low P fertilising efficiency due to the added P precipitation chemicals. In Finland bioavailable P fraction of the total P is set to 60%, whereas actual P fertilisation value can be as low as 6%. Although organic contaminants and heavy metals can be removed with thermochemical treatments, concern of the fertilising efficiency was expressed. However, it was also noted that BBFs have produced high yields in Finnish conditions. Production of struvite out of the waste-water streams is based on biological P removal, and colder climate restricts utilization of this method in Northern Europe.

One of the main obstacles for using BBFs is the different equipment needed for spreading BBFs and mineral fertilisers. Application rates of the BBFs, e.g. compost, are several tons per hectare due to low nutrient concentrations and equipment used for spreading mineral fertilisers cannot be utilized for spreading BBFs. High application rates of bulky BBFs, with low nutrient contents, increases the transportation cost and thus economic feasibility for utilizing these BBFs at large, as was pointed out in the Hungarian (Fig. 3) and Spanish NDF meetings. This will often lead to a situation where BBFs are utilized in fields close to the production sites due to high transportation costs of voluminous BBFs and leads to hot-spot regions with high nutrient contents in soils and increases potential for nutrient losses. Providing application recommendations for BBFs with bulky properties (e.g. manures and compost) is complicated by both variable nutrient concentrations and solubility. Therefore, production of homogenous BBFs requires continuous monitoring and raw material for the BBFs should remain the same. Also, larger production scales provide more homogenous BBFs.

The main criteria for farmers to accept BBFs are price of the products and its quality, e.g. fertilising value. These criteria were considered to be fulfilled by BBFs in the NDF meeting arranged in Hungary

(Fig. 3), whereas others considered that currently only low quality BBFs are available and there are no incentives for farmers to use BBFs.

Raw materials, NRSS, used for producing BBFs are commonly scattered to large areas and needs to be transported to centralized processing site, increasing the cost of the products. Therefore, it is also vital to utilize unprocessed NRSS, which may be economically feasible in regions with low animal density. Furthermore, guidance for using BBFs is needed to increase their acceptance among farmers.

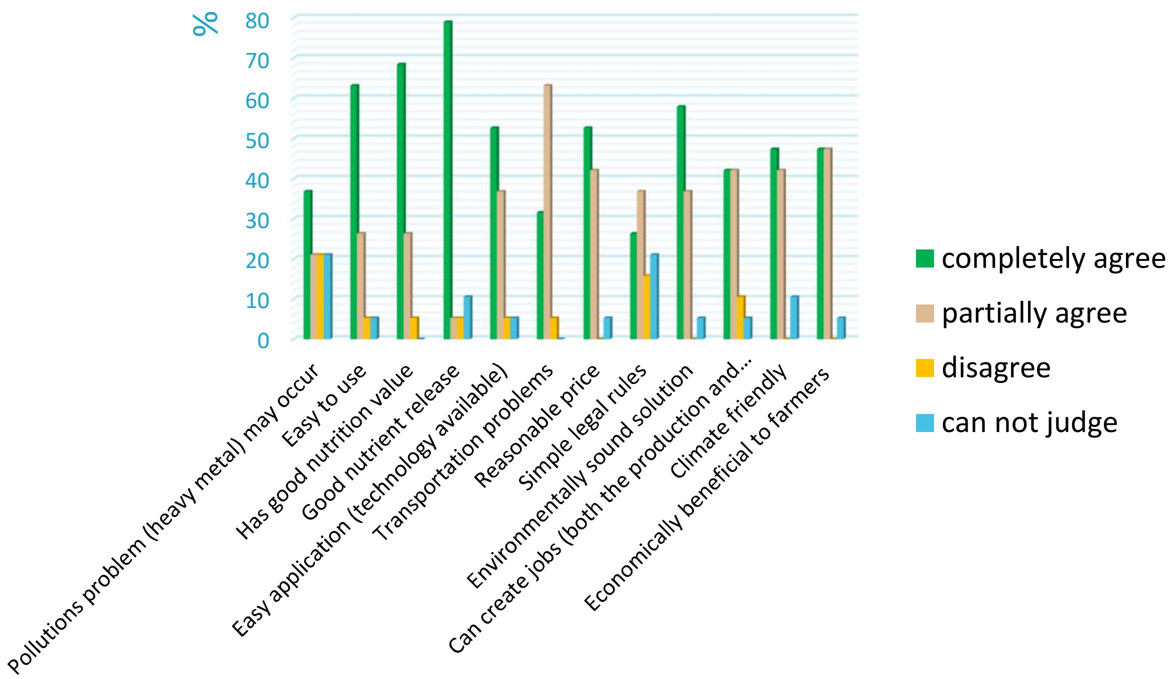

Figure 3. Results of the opinion survey about BBFs during the NDF meeting in Hungary.

Compliance methods for mineral fertilisers are based on chemical extraction and in the FPR these methods are also extended for BBFs. There were concerns whether these methods can predict agronomic efficiency as many BBFs have, e.g. very low P solubility in water as compared to mineral P fertilisers. Therefore, it was stated that it is important to verify the correlation between compliance methods with the actual agronomic efficiency. Also, the correspondence of the BBFs based N to that of mineral N fertiliser, timing of the N availability for the crop needs and transportability are the key questions for their acceptance for replacing mineral fertilisers.

Fertiliser industry is a global business and availability of raw materials needs to be secured for the fertiliser production. Also, the quality of the raw material needs to meet the criteria for production of mineral fertilisers. Currently all BBFs, except manures, are processed either with chemical treatment, anaerobic digestion, composting or with combination of these methods. It was pointed out that if limits for harmful substances will decrease in the future, traditional technologies will not meet these limits and more advanced as well as more expensive treatments needs to be utilized. It was pointed out that in Spain companies producing composts already have difficulties in registration of final products due to the limits set for the heavy metals.

3.2.2. Safety of BBFs

Prerequisite for the use of BBFs is their safety for food and feed production and for the human health. Acceptance of BBFs can be increased by developing technologies for producing high quality BBFs. Especially organic contaminants, e.g. antibiotic residues, is the issue that needs to be solved. From the crop production point of view, it was stated that in Finland there is no evidence that harmful substances would be taken up by the crops from the applied BBFs. However, this is probably affected by the crop species, type of contaminants, concentration of the contaminants as well as growing conditions. Because uncertainty about the safety of BBFs restricts their wider use, risk assessment of using BBFs should be studied more. Also, critical concentrations related to food and feed safety as well as on human health should be determined.

Composition of BBFs may originate from various sources and this may pose a threat for the quality of BBFs. New FPR sets limits for both organic contaminants and heavy metal contents for the BBFs, independently of the CMCs. These limits are intended to secure food and feed safety and human health. In addition to heavy metal limit set by the FPR, some member states (Finland, Slovak Republic, Hungary, Sweden) have derogation for cadmium content (20 mg/kg P_2O_5), whereas in FPR cadmium limit is set to 60 mg/kg P_2O_5 for CE-marked fertilisers. This may limit the use of some CE-marked BBFs in those countries with lower Cd limits for the P fertilisers.

During the discussions it was pointed out that quality of the BBFs could be improved by decreasing contaminants existing in NRSS. Measures for this was suggested for having filters for microplastics in the washing machines, better separation of biowaste, and separation of industry and municipal waste streams where possible and increasing the citizens' awareness of harmful substances.

3.3. Expected benefits provided by the BBFs

Main source of NRSS for production of BBFs are manures, sewage sludges, biowaste and animal by-products. Especially manures are bulky, with low nutrient contents, and utilization in agriculture commonly takes place close to the production sites. This has caused increased N and P balances (nutrient input – nutrient output) in regions with high animal density (Fig. 1) and increases potential for nutrient losses, either directly to atmosphere (N) or leaching (N and P) to surface waters.

Surplus application of N is commonly lost either through volatilization or leaching, whereas surplus application of P as NRSS is mainly accumulated in soil and increases soil P content (Fig. 4). Excessive P enrichment of agricultural soil will lead to non-point P losses to water which may increase eutrophication of waterbodies. As the majority of mineral P fertilisers are imported to the EU, processing of NRSS into BBFs was considered to reduce EU´s dependency on imported mineral fertilisers. It was also considered as an opportunity to reduce overall use of raw materials; production of waste and energy use due to lower production of mineral fertilisers. Also, targets of circular economy can be reached when nutrients trapped into the NRSS are utilized as BBFs. Increased utilization of BBFs drives industry for developing new and improving current technologies for recovering N and P from the NRSS into a raw material for fertilisers.

Circular economy provides a framework for reducing nutrient loads in areas with high animal density and provides BBFs for regions relying on mineral fertilisers. However, for reaching environmental benefits with the BBFs, nutrients need to be in a plant available form, especially N being available when required by the crop. Higher utilization efficiency also reduces N leaching potential. This is the case especially with organic N-BBFs when mineralization occurs throughout the growing season.

Primary target for anaerobic digestion is to produce biogas, but it will also increase the share of inorganic N and thus fertilisation value of manures. This was considered to be advantageous especially for cattle manure. Low N/P- ratio in BBFs, especially in manures, is often not optimal for crop growth and leads to surplus application of P when fertilisation is conducted according to crop N demand. Therefore, processing of cattle manure provides a way for increasing the share of inorganic N and to better meet the timing of the N requirement by the crops and also reduce surplus of P. Incorporating the nutrient fluxes between animal and crop production farms, together with fertilisation according to crop demand, would benefit both farms and would bring the benefits of circular economy to bear.

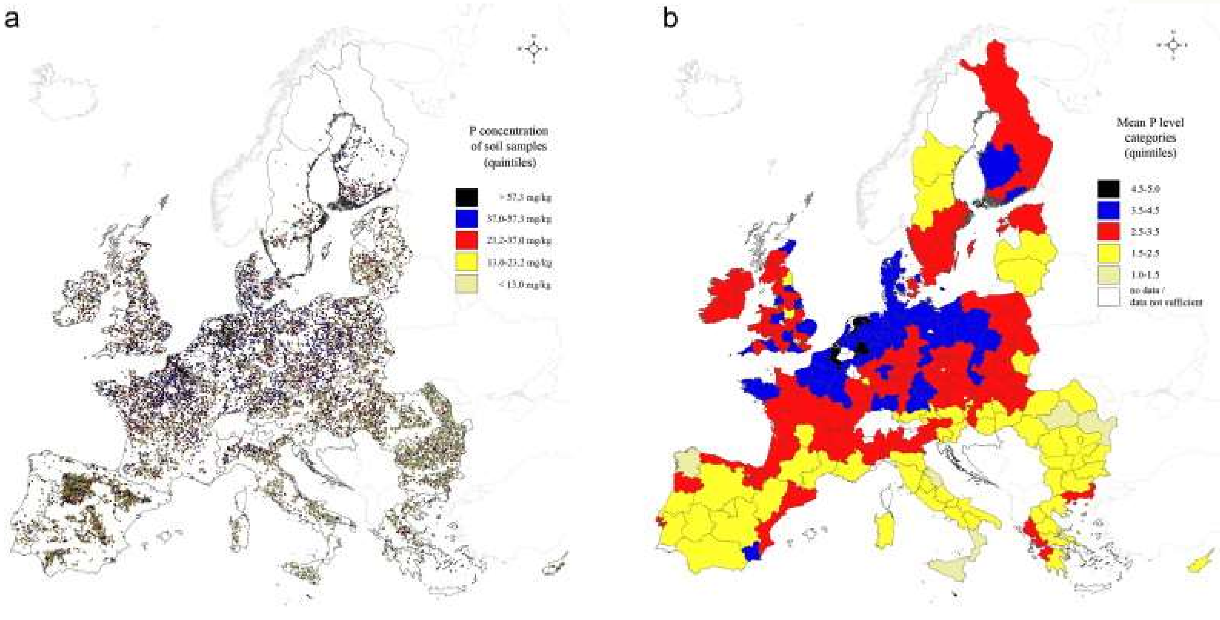

Figure 4. Soil P status in the EU´s cropland (Tóth et al. 2014).

Gaining environmental (and economical) benefits from the use of BBFs is affected by the BBF production technology. Reducing ammonia losses during the storage of NRSS or processing NRSS into BBFs and subsequent spreading of BBFs is crucial for reaching the sustainability goals. As an example, composting without capturing ammonia losses during the composting process was mentioned. Denmark has agreed to cut ammonia emissions by 25% as compared to year 2005, amongst the highest reduction goals in the EU. Recovery of ammonia and recycling back into BBFs, at a competitive price, will therefore be crucial to claim sustainability.

One of the main environmental benefits associated to BBFs was related to their positive effect on soil organic carbon content, although BBFs may first increase CO_2 emissions due to the mineralization of organic matter. Farmers also considers BBFs as a soil amendment that may improve soil properties, especially in Mediterranean regions with low soil organic matter content. It is also important to stop the current development of declining soil carbon content. Especially young farmers are interested in utilizing organic carbon in BBFs for improving soil productivity and structure.

When evaluating environmental benefits of BBFs, the whole life cycle of BBFs needs to be considered, starting from the raw material, production of BBFs up to the use of BBFs. Some of the BBFs are slow release fertilisers due to low P solubility. However, this may bring environmental benefits by reducing P losses through leaching.

3.4. Policy requirement for enhancing the use of BBFs

It was recognized that it is important to consider ways for establishing markets for the BBFs. Obligation to blend BBFs with mineral fertilisers was not considered as an option in case quality cannot be secured. However, blending of BBFs and mineral fertilisers may provide a way for introducing high quality BBFs to the market and thus enhance their production and utilization.

When considering only manufacturing costs, mineral fertilisers are cheaper than BBFs. For increasing the acceptance of BBFs, subsidy policy for covering possible yield reduction after using BBFs was suggested. However, in a long run subsidies should be avoided and used only when introducing BBFs to the market. As an example, was mentioned investment aid for biogas combined with the use of nutrients as well as subsidies for wind energy.

4. OBJECTIVES OF LEX4BIO FOR ENHANCING THE USE OF BBFs

Bio-based fertilisers have the potential to transform the agricultural industry by minimising the environmental impact of existing fertilisers and improving sustainability through recycling of nutrient-rich side-streams (NRSS). The overall objective of the project "*Optimising bio-based fertilisers in agriculture – Providing a knowledge basis for new policies* (LEX4BIO)" is to realise this potential by decreasing European dependency on finite and imported, apatite-based phosphorus (P) fertilisers and energy-intensive mineral nitrogen (N) fertiliser.

This will be achieved by developing a profound knowledge basis and new coherent methods to take full advantage of BBFs. For this purpose, LEX4BIO will focus on the most promising technologies for BBF production and evaluate their fertilisation potential and other properties against national and EU fertilisation requirements. This will provide essential tools for closing European nutrient cycles and contribute to ameliorating the impact of fertilisation on the environment. The most important impact of the project will be to provide technologies for developing safe BBFs, together with a policy framework for the EU's transition to maximising fertiliser self-sufficiency by using BBFs, while minimising risks to the environment, ensuring food and feed safety and supply, and protecting human health.

Specific objectives of LEX4BIO are implemented through a logical set of work packages (WPs) and presented in Figure 5:

- Mapping regional distribution of NRSS available for producing BBFs and assess their potential and legal restrictions for replacing mineral N and P fertilisers (WP1).
- Identifying novel BBFs for crop production and determining their effect on soil quality (chemical, physical and biological) and crop growth (WP2).
- Determining P fertiliser requirements across the EU according to crop uptake, regional agronomic P efficiency and quality requirement for BBFs, and develop and evaluate compliance methods for optimising BBF use (WP3).
- Determining the agronomic N efficiency of BBFs and develop compliance and on-site (remote sensing) methods for optimising BBF use (WP4).

- Determining the risks related to food safety, human health and environmental losses after application of BBFs and producing guiding principles for the safe use of BBFs (WP5).
- Assessing the integrated ecological impacts over the entire lifecycle of the production and use of BBFs (WP6)
- Determining the logistic costs, public perceptions and political actions required for optimal use of BBFs (WP7)

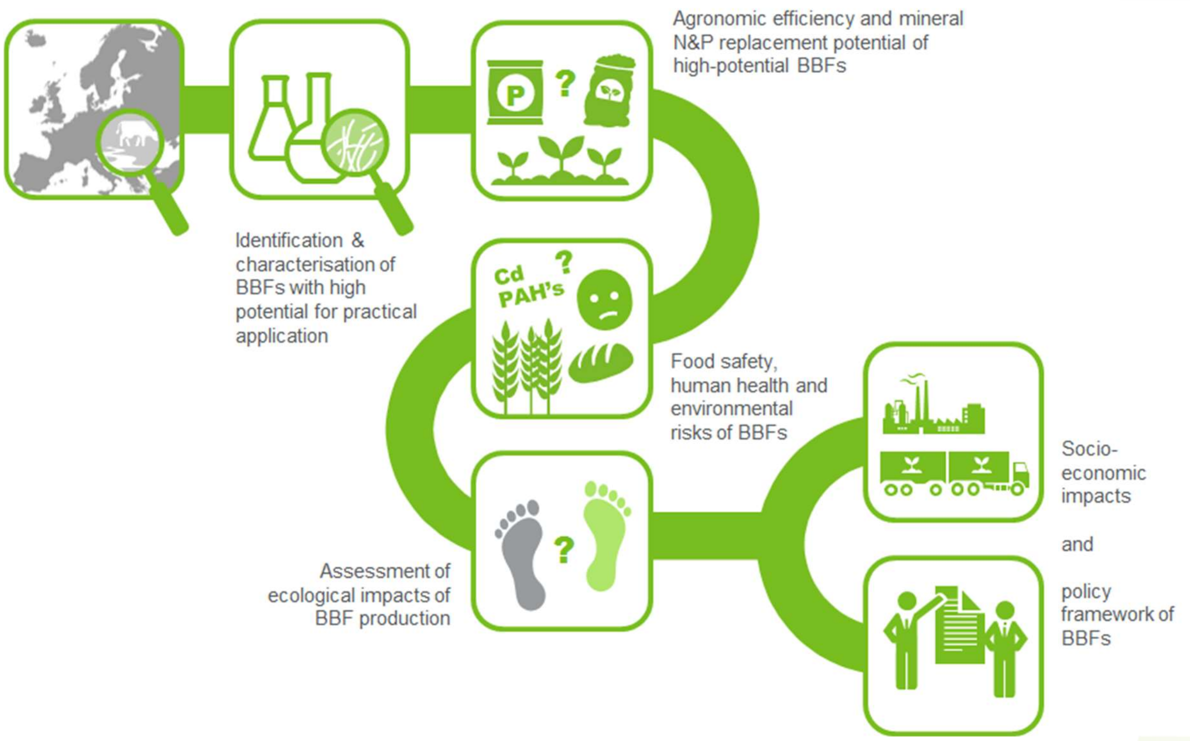

Figure 5. Logical steps in LEX4BIO for reaching the specific objectives.

4.1. Regional distribution of NRSS (WP1)

Availability of the main NRSS is mapped from each EU country and their fresh mass and average composition (especially nutrients) quantified and their geographical distribution determined. Available national statistical data is collected and literature data on national balances and flow analyses assessed. Also, the input data from the EUROSTAT/OECD national gross N and P budgets will be evaluated. Furthermore, clustering with other H2020 projects will be facilitated to ensure effective use of data collected.

Legal restrictions hindering the production of BBFs, both at the national and EU level is evaluated as there is a need for coherent EU policies for using BBFs and reaching the EU strategy for Circular Economy. Potential of BBFs, without considering the actual bioavailability, to replace mineral fertilisers is evaluated against sold mineral fertilisers. As a starting point for the fertiliser requirement across the EU, national fertiliser recommendations are evaluated to consider possible reasons behind the variable fertiliser rate, even among neighbouring countries in the EU. Furthermore, detailed case studies on existing inter-regional and trans-boundary exchange of NRSS/BBFs will be studied. For these studies regions with extreme nutrient balances, i.e. regions of highly intensive animal husbandry with excess manure and regions with intensive crop production dependent on nutrient imports (e.g. NL-DE; NL-FR; BE-FR; NL-BE), are included.

4.2. Selection of BBFs for laboratory and growth trials (WP2)

Screening of available BBFs to be evaluated in the LEX4BIO was conducted through online questionnaire send to BBF producers across the EU by asking them to provide information about the properties of the BBFs, including type of the product, i.e. whether it is organic, organo-mineral or mineral type BBFs, as stated in the FPR, raw material used for the production of BBF, production method and nutrient contents. Furthermore, partners of LEX4BIO contacted BBF producers for completing the list of available BBFs. Final decision for selection of BBFs for testing was based on criteria set by the FPR (Table 1). In LEX4BIO main interest is towards N and P (macronutrients). Total of about 40, both N- and P-based BBFs were selected, covering PFC and CMC categories as thoroughly as possible.

Table 1. Description of BBFs according to the FPR. OF = organic fertiliser, OMF = organo-mineral fertiliser, IF = inorganic fertiliser, IMAF = inorganic macronutrient fertiliser, IMIF = inorganic micronutrient fertiliser, S = solid, L = liquid. Green boxes represent BBFs (macronutrients) categories that will be studied in LEX4BIO.

PFC 1 (Fertilisers)	**PFC 1(A), OF**	**PFC 1(A)(I), S, OF**		
		PFC 1(A)(II), L, OF		
	PFC 1(B), OMF	**PFC 1(B)(I), S, OMF**		
		PFC 1(B)(II), L, OMF		
	PFC 1(C), IF	**PFC 1(C)(I), IMAF**	PFC 1(C)(I)(a), S, IMAF	PFC 1 (C)(I)(a)(i-ii)(A), straight or compound inorganic macronutrient NH_4NO_3 fertiliser of high N content
			PFC 1(C)(I)(b), L, IMAF	PFC 1 (C)(I)(b)(i-ii), straight or compound liquid IMAF
		PFC 1(C)(II), IMIF	PFC 1 (C)(II)(a), straight IMIF	
			PFC 1 (C)(II)(b), compound IMIF	

FPR determines Component Material Categories (CMC), the starting materials for organic, organo-mineral or mineral type BBFs (PFC). The main CMC refer to manures, sewage sludges, biowaste and animal by-products. For fertiliser production, also the STRUBIAS group, including nutrient precipitates (struvite), ashes and biochars, were included in the selection process.

According to the FPR, the only CE-marked fertilising products derived from sewage sludges are precipitated phosphate salts (e.g. struvite) or nutrients extracted from the ash. Anaerobically digested or composted sewage sludge as such will not be CE-marked fertilisers but can be used as a fertiliser under national legislation. Therefore, digested/composted sewage sludge based BBFs were also included for testing.

4.3. General effect of BBFs on soil quality, functioning and plant growth (WP2)

Effect of BBFs on soil quality, e.g. soil organic carbon, pH and water holding capacity is evaluated through literature review as well as utilising the medium to long-term field experiments. Especially the capacity of BBFs to enhance carbon sequestration will be evaluated, either due to the direct (improved biomass production) or indirect (priming) effects. Also, sensitive molecular biology methods are used to assess the effects of BBFs on soil microbial communities, including symbionts (mycorrhizal fungi and rhizobia). Enzymatic activities, related to nutrient circulating in soils are investigated as well, as BBFs based organic materials often greatly enhances phosphatase activities, which may affect P availability for crops.

Potential effect of BBFs on crop growth and on soil chemical, physical and biological properties is evaluated in a large container trial (Figure 6). Several harvests (wheat, ryegrass) allow to exhaust both N and P supplied by BBFs and determine their bioavailability during the experimental years. Also, the effect of BBFs on soil carbon content dynamics and the fate of N and P is determined.

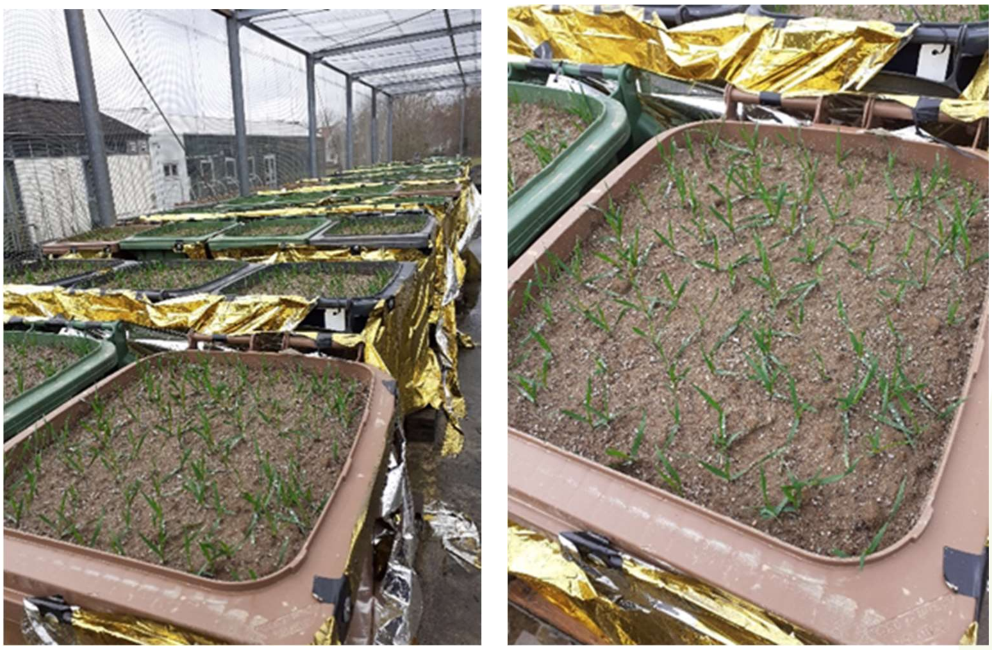

Figure 6. Large containers sown with winter wheat.

Root growth is essential for utilizing nutrients from BBFs, and phenotyping studies will be conducted for visualizing crop growth, especially of roots (Fig. 7) and potential phytotoxicity of organic contaminants or heavy metals on crop growth. Anticipated climate change may have drastic effect on crop growth in the future. Therefore, both water deficit and heat stress are induced and effect of BBFs on crop growth in these variable growing conditions is evaluated in a phenotyping platform (Fig. 7).

Figure 7. Phenotyping platform for visualizing crop growth, both shoot and root growth, caused by different BBFs.

4.4. Agronomic efficiency of P- and N-based BBFs (WP3 & WP4)

Agronomic efficiency of both P- and N-BBFs are determined in field trials conducted across Europe to cover different soil types and climatic conditions. For both P- and N-trials, a total of ten BBFs will be selected covering different types of BBFs. Phosphorus trials will be conducted in Spain, France, Hungary, Austria, and Finland, whereas N-trial will be conducted in Spain, France, Germany, Denmark, and Finland. In each of these trial sites common BBFs will be tested, providing information of agronomic efficiency of BBFs in different climatic conditions. Furthermore, local BBFs will be also tested, especially bulky BBFs (e.g. digestates, composts) that are not economically feasible to transport far from the production site. Selection of BBFs for the field trials is based on the availability of BBFs in quantities needed for the field trials as well as to cover the large variation of different types of BBFs. Field trials will last for two growing seasons and this allows to determine the residual fertilisation value of BBFs as well.

In field trials it is not possible to test all the selected BBFs, mainly because not enough BBFs are available for field trials, but also due to the availability of such large areas required for the field trials. Short-term agronomic efficiency (one growing season) of about 40 different P-BBFs will be evaluated in pot trials under different climatic and soil conditions. In these pot trials crops (barley, wheat, sunflower/maize) will be grown up to the maturity and crops will be selected to be representative for each region (Finland, Austria, Spain). Residual fertilisation effects will be further tested in a wheat/ryegrass crop rotation (Germany) and only with ryegrass (Switzerland) with several harvests during the growing season.

Potential N mineral fertiliser replacement potential of BBFs is evaluated in a laboratory trials covering following characteristics of the BBFs: 1) potential N availability of BBFs shortly after application, 2) potential ammonia loss, 3) potential organic N mineralisation profile. Ability of the methods presented will be validated in both field and greenhouse trials for providing a standardised set of protocols for determining the mineral fertiliser replacement potential of BBFs and can be further used for compliance methods for new BBFs.

Satellite-based remote sensing and spectral imaging of crops and soils is utilized for guiding variable rate application of BBFs for optimising N use efficiency. Satellite monitoring is set for the field trials and together with the information of mineral fertiliser replacement potential of BBFs, remote sensing will provide tools for optimising the use of BBFs that have different mineralisation profile during the growing season in variable growing conditions.

Current compliance methods for mineral P fertiliser poorly predicts P bioavailability from BBFs (Duboc et al. 2017; Ylivainio et al. 2021). Therefore, novel methods, including sink-based extraction procedures, are evaluated against agronomic efficiency determined in both field and greenhouse trials. Novel methods will be evaluated against compliance methods included in the FPR and suitable compliance methods for BBFs will be presented. Also, sensor technologies (NIR/XRD/XRF/FTIR) and ^{31}P-NMR method will be used for improving rapid testing of BBFs for N and P availability.

4.5. Regional P fertilisation for optimal yields in the EU (WP3)

Information of bioavailable P content in European agricultural soils is prerequisite for optimising P fertilisation and reducing environmental impact caused by excessive use of P. Currently several soil P testing methods exists across the EU (Jordan-Meille et al. 2012), complicating the evaluation of P requirement for fertilisation due to the different climatic and soil conditions across Europe. Out of the LUCAS soil archive collected by JRC (Orgiazzi 2018), representative amount of soil samples from agricultural soils (EU-28), collected in 2015, will be analysed with the novel methods, such as DGT, EUF and modified Olsen-P according to Recena et al. (2016).

Critical P content in soil and P fertilisation required for reaching optimal yield is determined from the soil samples taken from the field trials. Furthermore, other soil samples from the previous and on-going projects will be analysed as well. This data together with the bioavailable P content in the European agriculture soils (LUCAS soil samples) gives estimation for P fertilisation need in Europe.

4.6. Nutrient and heavy metal losses after application of BBFs (WP3 & WP4)

Environmental protection, thus minimising the nutrient losses after application of BBFs, needs to be ensured when utilizing BBFs in agriculture. Knowledge of N mineralization potential of BBFs provides means for securing the timely application of BBFs during the growing season and minimizes ammonia losses from BBFs in different climatic and soil conditions. This information is also needed for optimising the application technologies for reducing N losses. Remote sensing will further provide means for optimising the N utilization from BBFs and thus reducing both gaseous N losses as well as losses through leaching.

Phosphorus losses from BBFs is mimicked in a rainfall simulation, where BBFs are incubated with different types of soils originating from Spain, Germany, and Finland. After incubation period rainfall simulation (5 mm h^{-1}) is applied (Fig. 8) and nutrient and heavy metals will be analysed from the percolated water. These results will provide information of nutrient loss potential under different soil conditions.

Figure 8. Rainfall simulation for studying nutrient losses after application of BBFs in soils originating from Spain, Germany, and Finland.

4.7. Securing food and feed safety, and human health after using BBFs (WP5)

Food and feed safety and human health are prerequisite for using BBFs. The main pollutants in BBFs are organic contaminants and heavy metals. Increased concern of using BBFs relates to the effect of these contaminants and inducing antibiotic resistance in soils and possibility to enter to the food production cycle as well as on ecotoxicological effects.

Organic contaminants in BBFs (e.g. PAHs, PCBs, dioxin, pharmaceuticals, microplastics, glyphosate and perfluorinated compounds) will be screened from the studied BBFs and their biodegradation in different soil types will be studied and predictions for their potential uptake by crops is conducted. Samplers (POCIS) will be utilized for determining bioavailable contaminants in soils and uptake by crops of potentially problematic substances, e.g. pharmaceuticals, will be determined. These results will provide tools for predicting bioaccumulation of contaminants and full-scale application of BBFs.

Currently dietary exposure of many European consumers exceeds the safe limits of heavy metals (Cd, Pb, As and Ni). Estimating regional heavy metal concentrations in crops will be based on mass balance calculations by using total heavy metal concentrations extracted from the LUCAS soil dataset and bioavailable heavy metal concentration analysed with the EUF method. Heavy metal uptake by crops is determined from the harvested yields (WP3&WP4) for determining the effect of BBFs on heavy metal uptake and evaluated against the legislative maximum levels (EC 1881/2006).

Potential effect of BBFs on antibiotic resistance in agricultural soils after their application will be studied in Spain, France and Finland, having different climatic and soil conditions. Both BBFs and soil samples from the field trials will be analysed for the abundance and diversity of antibiotic resistance genes. With the epicPCR method it is possible to link genes to their host bacteria and finally conclude the antibiotic resistance dissemination potential of the used BBFs.

Ecotoxicological assessment of BBFs on soil biota and crop growth will be studied for ensuring their safe use. Both acute toxicity (e.g. phytotoxicity, bacterial growth) and chronic toxicity (e.g. Daphnia magna – reproduction test, genetoxicity) will be evaluated. Also, BBFs effect on soil respiration, enzyme activities (e.g. dehydrogenase), soil micro-/macroorganisms and plant growth and development will be evaluated.

4.8. Ecological impact of BBF production (WP6)

Ecological impact of BBFs is evaluated with LCA. By performing LCAs in a transparent and meaningful way, BBFs with a higher environmental impact than synthetic fertilisers can be identified and excluded from supporting schemes. The risk of BBFs with a high environmental footprint exists for P-fertilisers due to manufacturing processes requiring high amounts of chemicals and energy and for N-fertilisers due to losses to air during processing, handling, storage, and application. Transparency is guaranteed by disclosing the information on data sources and data integrity, selected functional units, system boundaries, and methods of considering the benefits of replacing fossil resources.

LCA´s of BBFs and mineral fertilisers needs to be comparable for policymakers, regulatory bodies, and stakeholders at large to understand and compare the expected ecological impact of producing and using BBFs and mineral fertilisers. The LCA should be used to determine if a BBF merits supporting action – it makes no sense to replace synthetic fertilisers with products that have a higher environmental footprint in terms of greenhouse gas emissions or toxicity.

Critical evaluating of the current LCAs of BBFs is conducted and draft convention for making nutrient recycling LCAs comparable will be developed by considering other studies and stakeholders view as well. The surprising diversity of LCAs presented in peer reviewed journals underlines the benefit of developing such a draft convention: LCAs have been found that assign the full footprint of wastewater treatment to sewage sludge derived BBFs - the purpose of wastewater treatment is water purification including nutrient removal but not nutrient recycling. Assigning the water purification footprint to BBFs is therefore meaningless. A meaningful system boundary is sewage sludge which could be used as BBF, sometimes with a very low (6%) P use efficiency which poses another challenge if compared to fertilisers with, e.g. 60% P use efficiency. If only total P concentrations are compared, the LCA result will be misleading. LEX4BIO will provide policy guidance on how LCAs can be used for policy decisions.

4.9. Socioeconomic impacts for using BBFs (WP7)

Impact of current fertilisation practices on economic indicators (GDP, employment) and externalities (nitrate losses, ammonia emissions, resource depletion, biodiversity, soil health) will be quantified in different settings and regions. This information will be obtained from literature, through interviews with stakeholders and with concerned third parties (municipalities, NGOs, tourism offices, etc.) in selected hotspot regions covered by LEX4BIO. Nitrate leaching, ammonia emissions and yield responses will be obtained from bio-economic models. The contribution to GDP and employment of different fertiliser practices will be assessed using input-output models based on regional social accounting matrices. Accounting the true costs of current fertilising practices the budget for improvement policies and measures is unveiled.

Drivers and barriers for replacing mineral fertilisers with BBFs are evaluated, including farmers, fertiliser industry, food and beverage industry and consumers. A structured questionnaire will be targeted towards above mentioned groups for determining real drivers and barriers guiding the overall attitude of each group towards BBFs. This action provides information for necessary, convenient, and redundant properties of BBFs and provides guidance for BBFs producers towards designing BBFs for which demand can be expected. New products must avoid/minimise the negative impacts of current products and practices while being widely accepted by farmers, fertiliser industry (as far as products are designed for replacing virgin raw material), food and beverage industry and consumers.

4.10. Optimal combination of processing, transport and use of BBFs (WP7)

The indirect economic and environmental impact and the demand drivers and barriers of BBFs will be built into an existing partial equilibrium model of BBFs and manure. The model uses spatially explicit data on livestock numbers and types of crops. Data can be obtained from regional administrative databases and Eurostat data. It can be complemented with FADN and LUCAS soil-data. Different processing (separation, composting, drying, struvite precipitation, digestion, denitrification and their combination) and transport options are covered in the model and are based on results from the FP7 ManureEcomine project.

The model can simulate the spatially explicit market of BBFs, manure, transport, fertiliser application and processing under different scenarios. Based on the above mentioned information, the broader economic impact (GDP, employment and ecosystem services) will also be assessed. Recommendations for various treatment options and intensities from simple process steps (e.g. dewatering) to comprehensive processing (e.g. to high grade fertilisers) depending on regional framework conditions such as available manure, soil nutrients and heavy metal status, regional nutrient balances, transport distances to regions in need of nutrients, etc., will be provided. These results are valuable to investors to see where and which costs they can invest in new processing technologies.

The model will be applied for EU-28 at NUTS2 (NUTS = Nomenclature of territorial units for statistics) level and at NUTS3 or more detailed in the selected case study regions: Belgium and the Netherlands extended with manure transport in northwest EU, Finland and the Hohenlohe region in Germany.

4.11. Policy recommendations for enhancing the use of BBFs (WP7)

Stakeholder consultation will be utilised to evaluate the history and differences of the legal framework in place and discuss promising modifications including the potential hazards and trade-offs. These will result in a set of policy scenarios that will be tested using the models and integrated information obtained in LEX4BIO. Scenarios can include taxes on fertilisers, investment support to BBFs infrastructure, fertilisation standards, command and control measures.

Recommendations will include guidelines for comparative, normalised impact-based (LCA derived) prioritisation of more promising and sustainable pathways to others (e.g. the trade-off between energy consuming metal removal and metal accumulation in soils). There will be also specific attention on compliance behaviour and loopholes in the policies because the current experience has shown that farms are controlled more strictly on BBFs than on synthetic fertiliser. Benefits and drawbacks of the current and potential recommendations focusing on the risks of circular economy enabling policies will be compared. The policy analysis results will, based on the indicators input and output models also give an indication on the difference in contribution in terms of economic growth, jobs and quality of life (value of ecosystem services).

Socioeconomic and policy recommendations will be proposed by encouraging farmers, fertiliser industries, food and beverage industries and consumers to decouple materials' use from outcomes and replace conventional fertilisers by BBFs. Socioeconomic recommendations will cover all relevant activity areas from outlining missions and promotional activities, educational incentives, awareness raising activities to recommendations for regulatory initiatives. Regulatory interventions may include restrictive (e.g. nutrient application per land unit limitations) and incentivising (e.g. premiums for sustainable practices) measures, relevant in the Common Agricultural Policy and the Nutrient Management Plans currently under development. Recommendations will be pre-evaluated during iterative rounds of reviews and stakeholder meetings (in the form of seminars, workshops, round table panel discussions, etc.) with the national dissemination forums of each participating country.

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