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Understanding the future of bio-based fertilisers: The EU's policy and implementation

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ABSTRACT

Bio-based fertilisers (BBFs) aim to reduce the European Union's (EU) dependence on imported mineral fertilisers by recycling and reusing nutrient-rich by-streams. However, implementation can be very complex, and the right policies must be delivered to optimize BBFs' production-consumption flows. This study seeks a new perspective for policymakers by understanding current policies and reviewing previous studies on BBFs' implementation. Data collection from the researchers' database plus additional information from the "EU-Lex" platform and Member States' Government websites were obtained to fulfil the critical analysis. Our reviews indicate that policies related to BBFs are still under development to comply with some appropriate laws and regulations for their implementation. The current policies, implemented among others by the new EU Fertilising Products Regulation (FPR), are structured by component material categories (CMC) and product function categories (PFC) that govern the specific function of the product and the raw material utilization. For farmers and Small and Medium Enterprises (SMEs), compliance with the FPR may be challenging. Yet, for regional use, farmers and producers can still rely on BBFs in compliance with national regulations. In addition, attention from policymakers is needed to increase the level of public acceptance, farmer's adoption, and availability of BBF with acceptable prices. Finally, this study provides prospective research opportunities to help the development of BBFs.

Introduction

Chemical fertilizers are frequently imported by European agriculture [51], yet the exclusive and excessive use of fertilisers is causing some issues. Accumulation of cadmium carried by some rock phosphate can be dangerous to water sources and human health [21]. Moreover, unequal distribution and gradual depletion of non-renewable chemical fertilizer sources may lead to shocks in supply chains, especially during the energy crisis. Meanwhile, bio-based fertilisers (BBFs) are becoming popular among scientists and the agricultural industries. Therefore, shifting from chemical fertilisers to BBFs is very much expected, especially for European agriculture [2].

Bio-based products are emerging due to the global pressure to convert wastes to nutrient-rich products that can be valorised in the agricultural sector [52]. Potential nutrient-rich sources can be agricultural waste, food waste, wastewater, and sewage sludge, which are processed by specific technology for mineralization and are currently unused. This concept also supports the circular economy (CE), proposed by the European Commission (EC) as the official EU strategy in 2014 (COM/2014/398 final). In the meantime, a European zero-waste

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program, as an integral part of the CE implementation, underlines the importance of sustainable waste management, including nutrient-rich waste streams [29].

The first Circular Economy Action Plan was proposed in 2015 to follow the zero-waste program, with 54 measures supporting the CE model transition. The legislative proposals placed a special emphasis on waste management and long-run goals to restrict waste landfilling, including nutrient recovery from waste streams. Enhanced preparation for recycling different waste streams, such as municipal waste, is one of the goals of the 2015 action plan (COM/2015/614 final) [30]. The next following year, there was an implementation of the first CE Action Plan by proposing rules on making CE-marked fertilising products, including waste-based fertilisers (BBFs) availability in the market. The proposal was offered to help access the internal market due to the various local regulations and standards on fertilisers and fertilisation among EU countries [26]. The next Circular Economy Action Plan was published in 2020 (COM/2020/98 final) which the main agenda is to prepare Integrated Nutrient Management Action Plan (INMAP) and revises directives on wastewater treatment and sewage sludge [33].

The EU target is to replace up to 30% of chemical fertilisers using BBFs [31]. The government generates the strategy, policy, and law to support the implementation of BBFs, such as regulation (EU) 2019/1009 of the European Parliament and of the Council about EU fertilising products [46]. European countries, e.g., France, uses anaerobic digestion (AD) to produce fertilisers from renewable sources as their quality standard that can be a valuable instrument for developing management of waste and policy making [8]. Other than government policies, BBFs' production is also supported by non-governmental initiatives such as "waste-to-product" [14,22,24], which is not only suggested by the EC but also by European Industrial Organization of Fertilisers [2] and European Sustainable Phosphorus Platform (ESPP) [26].

Nowadays, BBFs' implementation is yet to reach the level of productivity of chemical fertilisers. Some of the challenges are the cost of transportation, technology process, regulation and certification, field validation trial, and social acceptance. Regarding farmers' responses, they are concerned about the mineralization process and hygienization of the products, and they expect a reasonable price than chemical fertilisers [51]. Meanwhile, to use the BBFs at the industrial level may lead to another issue.

Despite many challenges, BBFs can support energy and materials recovery as a response to environmental and social problems [2]. To reach the objective, laws and policies that regulate BBFs' implementation should be developed precisely based on an assessment of impacts since BBFs are eco-friendly fertilisers to complement the existence of chemical fertilisers in terms of preserving the environment and productivity. Therefore, this paper utilizes the literature review method to produce overviews of current policies and regulations and other initiatives for implementing BBFs in European agriculture.

Material and method

The literature review collated relevant studies from literature databases and concluded with the desk research analysis. By using this method of reviewing articles, the paper consists of (1) an introduction, (2) the material and method used, (3) results discussing a) current legal and b) regulation of BBFs' utilization in the EU, c) the challenges of its implementation, d) the analysis and evaluation of the development of BBFs' implementation. Subsequently, we discuss (4) future research opportunities before presenting (5) the conclusion of this review.

This study requires several steps of desk research analysis to reach the objective. The framework is presented in Fig. 1.

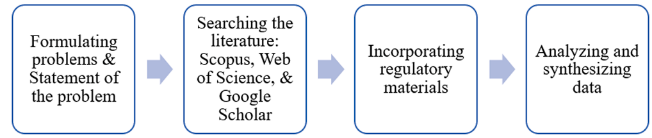

Fig. 1. The workflow of the analysis.

1 Formulating and identifying the statement of the problem.
2 Searching the literature with the following workflow:
   a Determining which scientific databases will be utilized. This review collects literature from well-known publishers and journal indexers, such as Scopus and Web of Science and a broadly accessed grey literature of Google Scholar.
   b Applying several eligibility criteria ensures that the article collected from the literature database can be relevant to the study topic.
   c Determining which types of articles need to be included. This review includes original articles, scientific conference presentations, book chapters, technical reports, and web pages as additional literature.
   d Determining keywords based on the intended topic of this study. This review uses the following keywords: "bio-based fertilisers," "policy," "regulation," "European Union," and "fertiliser products" to extract papers from databases.
3 Incorporating regulatory and jurisprudence materials. This review collects materials from the "EU-Lex" platform and Member States' Governments.
4 Analyzing and synthesizing all the materials. The authors then assessed and selected relevant materials regarding the topic discussed.

Results and discussion

Legal areas affecting fertiliser use in the EU

The EU intends to set an example for the rest of the world by leading climate action and promoting sustainable agriculture in a low-carbon economy through the European Green Deal (EGD) to minimize the use of fertilisers [39]. The EGD offers a singular opportunity to minimize the use of synthetic chemicals and fertilisers. For instance, the Farm to Fork Strategy seeks to look up the fairness, health, and food system sustainability [34]. Several restrictions that limit the use of chemical pesticides and require the use of biologic and sustainable goods support the EGD. Furthermore, soil nutrients, which are mostly dependent on external input, have been addressed in the Zero Pollution Action Plan [35]. The strategy calls attention to soil contamination brought on by heavy pesticide usage in agriculture [12] and suggests a 50% cut in the use of chemical pesticides by 2030, along with a 50% cut in the use of more dangerous pesticides. Additionally, the fertilisation governance of the Birds Directive [42] and the Habitats Directive [37] under the minimal requirement of Common Agricultural Policy (CAP) also manage preserving biodiversity and listing endangered species [7].

On the farmer's side, they must follow a set of Cross-Compliance (CC) to receive government subsidies [38]. The CC guidelines for the fertiliser regulation, which concentrate on minimizing of land management and considering condition of local site, aim to prevent soil erosion, maintain soil organic matter, and potentially lower phosphorus (P) losses. The legal basis of P management at the EU level is the Waste Framework Directive, which was amended in the summer of 2018 by Directive 2018/85 [7]. For example, Directive 86/278/EC known as the Sewage Sludge Directive (SSD) about the use of sewage sludge was the first of the specific directives on the use of waste in agroecosystems [36]. Then, sewage sludge is also used for fertilisation and set limit for the concentration of heavy metals. However, the SSD is not ambitious enough, and some European countries have set more stringent national standards [6]. In line with the prevention principle, the SSD's primary goal was to avoid any negative consequences sewage sludge use in agriculture would have on the soil, plants, animals, and public health. The SSD is now considered outdated and is under review considering new scientific knowledge on the risks of organic pollutants and pathogens and the available sludge treatment technologies [36]. According to the EU Fertilising Productions Regulation (FPR) [46], compost and digestion are included in substance lists allowed in the composition of fertilisers, provided they comply with the requirements of the EU FPR.

Another policy that affects fertiliser industries is Climate Change Policy. There is a draft of regulation of the European Parliament and of the Council establishing the framework to achieve climate neutrality and to amend Regulation (EU) 2018/1999 [41] and to develop a climate-resilient region. The long-term goal of the new EU Strategy on Adaptation to Climate Change [40] is for the EU to transform a climate-resilient civilization by the year 2050 that has fully adapted to the unavoidable effects of climate change. Nitrogen fertiliser manufacturers are among the sectors most at risk of carbon leakage due to the industry's emissions intensity and exposure to international trade [11].

The P and nitrogen (N) management are also mentioned in Water Policy. In this context, the EU Nitrates Directive, which limits the permissible nitrate content of water bodies to 50 mg/l, is vital and aims to prevent eutrophication. Meanwhile, the Urban Waste Water Treatment Directive (UWWTD) is imperative for sustainable P management and mandates that P be removed from wastewater. A method for phosphorus recovery may be used and will be revised in the new UWWTD, but they are currently under discussion. So, soil and water legislation should effectively limit agricultural P inputs to water bodies, if not, then to what extent fertilisation legislation can comply these [7].

The EU Biodiversity Strategy is a part of the EGD and aims to stop the EU's ecological services and biodiversity from disappearing. The Biodiversity Strategy is expected to work with the farm-to-fork strategy and the revised Common Agricultural Policy (CAP), with the primary target of having at least 25% of EU agricultural land under organic farming by 2030. Agroecology should be promoted as it can incorporate natural processes and ecological principles into farming techniques [48]. Moreover, this program is connected to the EU Soil Strategy 2030 for healthy soil by 2050, which sets out a framework and actions to preserve soils and assure their sustainable use [27]. It also notifies a new Soil Health Act [49] by 2023 to ensure a level playing field and a high level of environmental and health protection. As regards the use of fertilisers, the framework states that they should be applied according to the needs of the crops grown, avoiding over-application, and aiming to reduce the amount of nitrogen and phosphorus leaching from soil by 50% by 2030 [47], in line with the objectives of the Farm to Fork strategy. Summary of the policies related to the fertiliser issues can be seen on Table 1 below.

Table 1
Fertiliser policy in the EU.

Policy Area	Legislation	Type	Effect on Fertiliser Use
European Green Deal (COM/2019/640 final)	Farm to Fork - COM/2020/381 final [32]	Strategy	20% less fertiliser uses and at least a 50% reduction in nitrogen losses without deteriorating soil fertility.
	Zero Pollution Action Plan - COM/2021/400 final [35]	Strategy	By 2030, usage of chemical pesticides will be reduced by 50%, while use of more dangerous pesticides will be reduced by 50%.
Circular Economy	Zero waste programme for Europe - COM/2014/398 final [29]	Strategy	The key area of the CE implementation is to increase sustainable waste management.
	First CE Action Plan - COM/2015/614 final [30]	Strategy	Set of legislative proposals on waste management and reduction of waste landfilling.
	Second CE Action Plan - COM/2020/98 final [33]	Strategy	Development of the Integrated Nutrient Management Action Plan (INMAP), reviewing directives on wastewater and sewage sludge management, and the assessment of natural means of nutrient removal, for example, by algae.
Common Agricultural Policy (CAP)	Cross-compliance (C/2022/3390)	Regulation	To maintain soil organic matter levels, reflect site-specific circumstances, and perhaps limit P losses, minimal land management is required.
	Habitats Directive (92/43/EEC)	Directive	To protect biodiversity, e.g., nutrient-poor grasslands which are sensitive to fertilization.
	Birds Directive (2009/147/EC)	Directive	Agricultural management to meet the goals of habitat and species protection.
Waste Policy	Sewage Sludge Directive (86/278/EEC)	Directive	Preventing sewage sludge has potentially negative effects on soil, plants, animals, and human health.
Climate Change Policy	European Climate Law (PE/27/2021/REV/1)	Regulation	By 2030, GHG emission levels must be reduced by at least 55% from 1990 levels.
Water Policy	The Nitrates Directive (91/676/EEC)	Directive	Demands that Member States develop action plans to lessen nitrogen eutrophication brought on by agricultural sources and to stop additional water contamination.

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Current regulation related to bio-based fertilisers in the EU

Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) is the EU's instrument for managing the risks presented by chemical substances for human health and the environment that is used to regulate the use of mineral fertilisers under the scope of the European Union Regulation 1907/2006 [43]. Furthermore, the current legislation regarding bio-based fertilisers the EU has adopted the 2019/1009 directive of the European Parliament and of the Council for marketing fertility enhancers on the EU market which entered into force in the summer of 2022 [46].

According to Garske et al. [7], as part of the CE Package, current legislation aims to reduce the dependence upon mineral/fossil fertilisers, benefit the environment and the EU's economy and promote a higher use of fertilisers from organic sources. The regulation adopted by the Council harmonizes the regulations for fertilisers produced from phosphate minerals and organic materials or secondary raw materials in the Union [17]. It thus creates new opportunities for their large-scale production and market sale. The regulation establishes harmonized limits for some of the pollutants found in mineral fertilisers, such as cadmium.

The essence of the new regulation is that any product that meets the

Table 1 (*continued*)

Policy Area	Legislation	Type	Effect on Fertiliser Use
Biodiversity Policy	EU Soil Strategy for 2030 (COM/2021/699 final)	Strategy	The reduction of nutrient losses from fertilisers to the environment by 50% and the use of nitrogen fertiliser is decreased by 20%.
Soil Policy	Soil Health Legislation (2022/C 290/21) (Currently under adoption by the European Commission)	Possibly a Framework Directive, based on TFEU 191 and 192	Foreseen requirements towards member states to adopt soil protection measures and restore soils to their healthy state.

Source: authors elaboration based on EUR-lex, 2023

requirements of the regulation can be placed on the market in all EU Member States if the conformity of the product is certified by an accredited conformity assessment organization. Moreover, establishing regulatory levels for hazardous contaminants in these products will reduce their adverse effects on the environment and open the single market to fertilisers made from organic waste. Additionally, it might lower Europe's reliance on foreign fertilisers [50].

According to the regulation, CE-marked EU plant fertilisers must meet specific requirements to enter the EU's internal market comfortably. The new regulation will have two categories, one of which is Product Function Category (PFC), which includes fertilisers, liming substances, soil improvers, growing media, inhibitors, plant bio stimulants, and mixtures. The other category is the Component Material Category (CMC), which includes the following: original raw materials and their mixtures; plants, plant parts, extracts; compost; fermented fresh vegetable products; other fermented products; food industry by-products; microorganisms; nutrient polymers; other polymers; substances produced from animal by-products [23]. The product that complies with the regulations for these categories is considered safe to use [46].

These requirements include, among other things, the maximum permissible level of pollutants, the use of specific categories of ingredients and labelling. The three-year transition period will provide organizations time to modify their manufacturing procedures and adhere to legal requirements. It establishes the safety and quality requirements for fertilising products sold across all EU countries. It replaces 27 differing sets of rules with one single, coherent set for the whole EU.

Organic-based fertilisers are one of the new fertilising products targeted by the new regulation because of their circular and resource-efficient nature. The EU has created new rules related to fertilising products to contribute to the European Green Deal and, in the face of the energy crisis, to facilitate the production of bio-based fertilisers. It keeps harmonization optional by allowing non-harmonized fertiliser products to be sold on the internal market in compliance with national legislation and the principles of free movement. Manufacturers of fertilisers without CE marking still can market their products on the national markets [45]. The license applicant can therefore choose a more favorable procedure. Through mutual recognition, EU Member States usually accept non-hazardous industrial products authorized in the other country [3]. This condition limits the development of standard protective requirements. At the same time, based on the principle of equivalence of protection derivable from the European treaty [44], every member state has the right to maintain the protection it previously maintained in its territory. In general, the rules and activities that occur in BBFs support can be seen in Fig. 2.

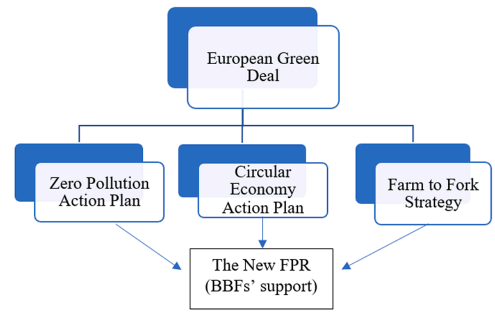

Fig. 2. From The European Green Deal to The New FPR.

The challenges of the new fertiliser product regulation (FPR) - point of view

Policy implementation

Significant regulatory efforts have been made in the EU towards waste recycling and recovery as alternative raw materials to reduce the dependency on mineral fertilisers in a circular economy, as seen in Fig. 2. The EU FPR shifted the paradigm of the 2003/2003 regulation, which only covered mineral fertilisers. Due to covering organic and secondary resources, the new regulation mandates to follow what the product is made of and under which category it would be put on the market. Thus, it regulates not only the products' characteristics but also the input materials contained in every fertilising product. Therefore, the goal is to produce safe and high-quality fertilisers, including those derived from wastes that can be labelled to be freely traded between Member States.

However, there are some challenges to implementing the new EU FPR. In the new draft of FPRs, contaminants are only sometimes expressed in the most appropriate forms. For instance, macroalgae – an essential component of some bio-based fertilisers and other fertilising products – contain high levels of organic arsenic, such as arse-no-sugars which is almost entirely harmless to humans and animals, and almost no inorganic arsenic [18]. However, in the proposed regulation, arsenic is only expressed as 'total arsenic' without differentiating its two forms. In this case, the regulation is not strict enough to distinguish and define the toxicity or maximum residue limit for food and feed.

Despite the new regulation, which is limited to covering all raw materials and defining the maximum residue values for fertilisers, fertiliser companies still need help producing BBFs based on policy standards. However, FPR compliance is not obligatory since fertilisers can be marketed as either "national fertilisers" (subject to national regulation) or "EC fertilisers", permitting distribution in the EU (FPR compliant) and receiving the CE mark. The new FPR (EU) 2019/1009 promotes a higher use of fertilisers from organic sources, ensuring soil health and food safety. However, there is a limit to the regulation on how to guarantee the highest agricultural land productivity while safeguarding human beings from contaminants [21]. The CMC and PFC are limited to covering all raw materials, so it would be a missed opportunity if such by-products were wasted instead of reused and innovative, effective, and safe products. Therefore, the new FPR can be challenging to apply within European countries.

BBFs application

The research on waste processing is still running to produce safe and sustainable biofertilisers. The reason behind the development is that the long-term use of bio-waste-based substrate leads to even more excellent soil chemical or microbial contamination, such as microplastics, nanoparticles, or active compounds of pharmaceuticals [13]. The Regulation (EU) 2019/1009 represents an important step of the EU circular economy action plan with its aim to promote the production of fertilisers with reduced cadmium content. However, soil cadmium reduction is questionable and needs to complement policy tools to protect and conserve agricultural soil health, such as EU Soil Framework Directive

(SFD) [21].

The problems can be a paradox since the situation could bring out business opportunities for producer companies due to the decentralization of biogas plants. Waste management can be done locally to reduce the transportation cost from waste collection to waste treatment. As a result, BBFs as source nutrients for plants is also a profitable business in the future.

Farmers already used manures in their farming as part of bio-based fertilisers. Across all regions, more than 90% of farmers admitted to using manure on their crops, with nearly half claiming to have encountered macronutrient or micronutrient deficiencies [51]. Therefore, BBFs' production should fulfil similar characteristics with mineral fertilisers to be accepted in society. Moreover, it will benefit not only concentrated products but also the price and the fast-release nutrients.

The analysis and evaluation of the current situation to support the implementation

EU Circular Economy Package introduces not only the new FPR regulation, but also the Farm-to-Fork Strategy which mitigates soil, air, and water pollution by increasing nutrient use efficiency (NUE) by reducing nutrient losses by 50% by 2030. Also, the new Common Agricultural Policies 2023-2027 which is assigning 25% of 1st pillar support payments to eco-schemes will be a key tool in reaching the ambitions of the Farm-to-Fork Strategy. These whole scenarios would be integrated to support the program linked and it can be used as a strong force in the development of BBFs and their application specifically.

However, the implementation model approach of bio-based fertilisers could vary depending on the situation and condition at the farm level (see Table 2) and each model could serve different perspectives to comply with the new FPR to be adopted sustainably. A bio-based fertilizer with the same volume as a chemical one, with assurance about its nitrogen content, and at a lower price is preferred by most farmers [51]. Therefore, we will discuss the implementation model based on several points of view to cover the problems and recommendations of BBFs usage as seen on the Table 2.

Technology and production aspects

Having 25% of EU agricultural land under organic farming is targeted by EU farm-to-fork strategy by 2030. However, the use of bio-based fertilisers for organic farming is still under evaluation, while circular, bio-based economy focusing on nutrient recovery and recycling. Several raw materials were not included in the new FPR, so public consultation is still ongoing to propose and review the legal act. For instance, through European Commission's Join Research Centre (JRC), a technical working group (STRUBIAS subgroup) proposed Struvites, Biochars, and Ashes as CMC 12 (Precipitated phosphate salts & derivates), CMC 13 (Thermal oxidation materials and derivates), and CMC 14 (Pyrolysis and gasification materials) that is already published as a scientific report [10]. In the case of biomass ashes, a maximum limit of organic carbon is still under discussion due to certain types of ashes containing high organic carbon but still delivering valuable macronutrients to the soil. Also, limits for contaminants such as chloride and organic pollutants are still unclear. The STRUBIAS report mentioned mere labelling "poor in chlorine" for PFC containing chloride concentrations lower than 3% wt (dry matter basis) [25].

Furthermore, the manufacturing chain of animal by-products (ABP) to be feed stock or fertiliser is still questionable to put on the market for human consumption since the use is under veterinary control or request from the European Food Safety Authority (EFSA). On the other hand, animal by-products including meat-and-bone meal (MBM) could have possibility to replace mineral fertiliser. The macronutrient concentration in the maize grains following the application of MBM was like the composition of the grains of maize fertilised with mineral N, P and K fertilisers [28]. Like mineral fertiliser, after considering the legal requirement in toxic content, the risk of contaminant in BBFs still exists

Table 2
Implementation model approach of bio-based fertilisers in EU.

Contribution	Model implementation	Challenges	Recommendations
[2]	The use of biological waste to recover valuable fertiliser components	Logistic and production organization	Incentives for recovery of waste streams and fines for the use of non-renewable raw materials
[14]	Polish sewage treatment using anaerobic digestion	The treatment of post-fermentation eutrophic sludge liquors requires additional costs	Granulated soil fertiliser production
[8]	Digestate could be used as bio-based fertiliser	Digestate (without any post-treatment) did not fulfil French standards and the latest European Union regulation proposal on fertilisers	Post-treatments and/or product formulation can be applied to meet the needs for organic fertilisers and soil improvers for digestates from source-separated AD inputs.
[22]	Circular economy indicators for resource recovery focused on technological aspects in the wastewater sector	Policy incentives to increase the recovery of nutrient-rich waste streams in wastewater treatment plants were not fully implemented in many countries.	The adoption of circular and sustainable practices for using waste by-products from the wastewater sector should be encouraged through circular economy indicators related to resource recovery.
[25]	Biomass ash utilization in soil amelioration and nutrient recycling	The use of ash-based materials does not fully cover by the new FPR	Two EU legislative frameworks: the WFD and the new FPR can support recycling of ash-based materials as soil fertilisers.
[24]	Food waste recovery	Technological, economic, and cultural challenges	Adjustment on local condition is important to design and plan the recovery pathways.
[26]	Nutrient-rich waste fertilisers (from water and wastewater)	Low level of experience from the end-user and low level of acceptance from social and health aspects	Frequently conducting dissemination activity of the waste-based fertiliser to the end-user while building social trust
[1]	Processed and unprocessed organic waste-based fertilisers	Unpleasant odor produced by the fertiliser (social), uncertainty in nutrient content and difficult to use (technical)	Developing better manure processing for the bioenergy recovery, creating a model of producing fertiliser by the mixed involvement from government and industry to boost organic fertiliser availability and level of usage from farmers
[9]	There are four types of waste-based fertilisers tested in this study (straw incorporation, green manure or cover crops, compost, and farmyard manure)	Farmers found bacteria, parasites, or plant diseases after the application of organic fertilisers	Providing specific guidance on the best practice of using organic matters to prevent unwanted pests and diseases. Addressing more research on the financial consequences of using

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Table 2 (*continued*)

Contribution	Model implementation	Challenges	Recommendations
			organic inputs both in short and long terms
[15]	Organo-mineral fertilisers manufacturing	Potential presence of pollutants, lack of consumer confidence, lack of support incentives, and difficulties related to waste status of input materials (sewage sludge and poultry ash)	Developing the quality of input materials to obtain 'safe' fertilisers

Source: authors elaboration, 2023

due to exposure of heavy metal accumulation. Increased doses of organo-mineral fertiliser can lead to the accumulation of heavy metals especially cadmium (Cd) and Nikel (Ni) in plant biomass, so it is recommended for biofuel production or ornamental plants since the risk that they enter the food chain is not studied yet [16]. The idea is to use ABP as fertiliser applied only for forest plantation, but the question: is it profitable to develop it in a large scale? Future research should address this issue. On the ground and the surface of water bodies, Liu et al. [19] and Zhao et al. [53], found out that $NiFe_2O_4/g\text{-}C_3N_4$ and $CuO/g\text{-}C_3N_4$ composite can be used for photocatalytic degradation of tetracycline hydrochloride antibiotic and for inactivation of *E. coli* bacteria.

Although the new law does not mention producing certain forms other than liquid and solid, the form of BBFs is also essential to be considered because it is connected to the logistical issue. Hence, the producer company has the challenge of shaping the BBFs into materials that are easy to carry and store as well to use by the farmers. For instance, in Poland, the eco-innovative approaches obtained novel granulated fertilisers from urban wastewater treatment and management of sewage sludges. However, extra cost is needed to manage the hazardous waste after fermentation [14]. Differently, Kominko et al. [15] found that the developed method of organo-mineral fertiliser manufacturing does not include complicated technological operations, which would be associated with the increased cost of fertiliser manufacturing, but it is adapted to selected plants. Therefore, the situation and condition of BBF production vary from place to place. Santagata et al. [24] suggested that the production process of waste by-products must carefully acknowledge local characteristics.

Socio-economic aspects

The policy demands clarity of nutrient content which must be stated through detailed information on the fertiliser packaging. This regulation can address one of the farmers' issues, in which they are hoping for detailed information regarding nutrient content to escalate their farming analysis [9]. Moreover, the new FPR policy has also encouraged manufacturers to provide application methods for specific products. Labelling on the PFC level is stated under the new FPR policy, which may help farmers minimize the risk of application failures [10].

Even with this, the policy draft can be improved by considering other research findings related to BBF implementation in the EU. The BBF product can be further developed according to local characteristics. In this regard, several EU countries have different regulations and standards. For example, there is an obligatory policy for sewage sludge producers in France to be able to spread their waste on agricultural land [20]. Moreover, bio-based or waste-based fertilisers often need help in meeting regional standards. On the other hand, to meet health and environmental standards, the production process usually connects to a specific technology, which involves additional costs often ignored when considering the economic framework of complex waste-utilizing systems [14]. Again, prices are prominent for business activity.

Previous studies from Case et al. [1] and Tur-Cardona et al. [51] show that farmers expect BBF to have competitive prices, even less than conventional fertilisers. However, no BBF-related policies have addressed the price or cost of making BBF. In this case, recommendations from policymakers will help find the right price that can benefit both parties, i.e. manufacturers, and end-users (farmers). A comfortable relationship between manufacturers and farmers could boost bio-based product implementation in the agricultural field [1]. Furthermore, some farmers sometimes question the price instead of ensuring the result after applying BBF products [1,9].

BBF-related policy, including the new FPR, must also increase the BBF dissemination function to stakeholders, including farmers and the public. In addition to farmers needing more experience in using BBF, the general acceptance of this product could be higher. There are negative public perceptions towards waste-based fertilisers [15], such as bio-based fertilisers can cause unpleasant odors [1] and uncertainty health impact [26]. In this case, agricultural extension's participation in promoting BBF products can be paramount to reducing farmers' reluctance to use BBF. Moreover, government and manufacturer should boost their campaigns to increase BBF's social acceptance level while also securing any issue on the parameter of health. In the realization program, the European Commissions through their research and innovation has been doing the dissemination agenda (such as demonstration plots) and scientific publication as the results to show the effects of BBFs utilization for public [5].

The policy addressing BBF implementation is expected to support the EU's circular economy and sustainability movement. The new FPR policy has incorporated those objectives in several important points as you can see at Fig. 3. The future policy could be improved by tackling its blind spots. There are two key stakeholders to be considered: producers and end users (farmers).

Regarding the socio-economic aspect, complexities in formulating and implementing policies related to BBFs were frequently present. Farmers are ready to accept BBF albeit asking for some requests (i.e. low price guarantee, application guidelines, and detailed material contents). On the other hand, policymakers also need to pay attention to the public acceptance of fertilisers and food products from waste-based materials. Although there are several goals to be achieved, the community is the important goal of this scheme due to its significance of accepting newly

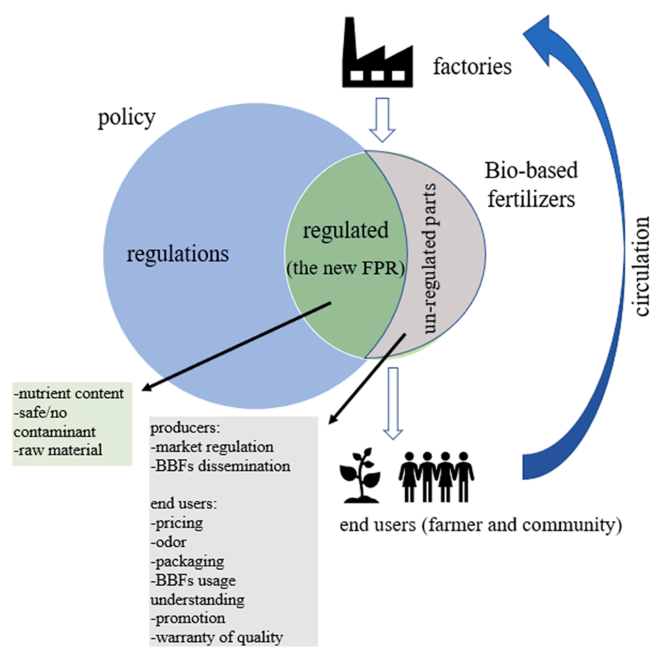

Fig. 3. The new FPR in relation to the domains related to BBFs.
Source: Authors, 2023

innovated products. In addition, if one of the EU's strategic agenda is circular economy, then the points related to pricing and product availability are highly recommended to be addressed in further policy discussion.

Future research perspective

The EGD develops the feasibility of regulatory measures to improve the market for secondary raw materials with obligatory recycled content [10]. This situation is stated in some scenarios, such as Farm-To-Fork (F2F) Strategy, Biodiversity Strategy, Chemicals Strategy, Zero Pollution Action Plan, and Circular Economy Action Plan. EU F2F strategy directly impacts nutrients (fertiliser use), and it is required to use bio-based fertilisers to support EGD's implementation. Furthermore, the development of BBFs offers business opportunities for farmers and producer/supplier companies. For farmers, their land will be healthier in the long run due to organic input from fertilisers [9]. For companies, producing BBFs based on regulation standards is quite challenging. However, once it can be adopted, it can be developed around countries by slightly modifying the local plants and raw materials. Hence, the benefit of decentralization can be achieved step by step, plus its sustainability for all involved sectors.

Mostly, the challenges of BBFs implementation come from the technology process to produce fertilisers which are supposed to meet the rapid change in the global situation related to fertilisers, such as growing demand, energy issues, changing supply chains, and issues of logistics, limited sources, and environmental issues. In line with Davidson et al. [4] that it will take further technological advancements to generate more food with less pollution. However, it will also need regulations considering the social and economic aspects influencing farmers' choices. We need to develop partnerships among actors in the value chain, as described in Fig. 4. The conversion of waste into valuable items requires the fulfilment of several circumstances (quality of waste, condition of processing, law, and local conditions) [13].

The circularity of BBF usage could support the goals and outcomes of a circular economy. However, the core application is highly complex because each production process could vary depending on raw materials. Hence, it would be formidable to set monitoring tools generally. For instance, in the wastewater industry, the designed indicators for

Fig. 4. The role of Policies and Facilities to support stakeholders on BBFs implementation.
Source: Authors, 2023

resource recovery monitoring were the importance of the global or local circularity level, range of application, and appropriate units [22]. These indicators are needed to measure the circularity of BBFs usage and to propose a recommendation based on CE framework's development.

The existing regulation through the new FPR supports the partial replacement of mineral fertilisers by bio-based fertilisers while ensuring minimum nutrient losses. The nutrient use efficiency through increasing nutrient recycling and recovery of BBFs could be a way out of import dependency for fertilisers. To keep this mindset in farmers' minds, we need intense political and social pressure to adopt cutting-edge bio-based technology promoting waste management practices that are economically advantageous and environmentally safe [14]. Moreover, Silva et al. [25] also mentioned that adequate regulation for biomass ash as a raw material from the energy industry is acknowledged as the most important driving force for the adoption of proper ash management and valorisation.

The characteristics of raw materials, such as origin, composition, and complexity induce difficulties to achieve an industrial scale fertiliser even to meet the current regulation. Bio-based fertiliser tends to be a local solution, so it opens opportunities for many sectors to develop BBFs based on available situation and condition, while the government also works on the legal facilities. Through study and research, the finding of specific treatment for specific raw materials helps producers build the plant quickly. For instance, in the case of anaerobic digestion residues, there is a tool suggested by Guilayn et al. [8] that raising the quality of digestate management and policymaking can be accomplished by using a digestate typology developed based on fertilizing value. Finally, facilitated product conversion along the following path results in economic and environmental circularity: environment of soil or water → bioorganic waste → treatment (biotransformation, biodegradation, mineralization) → fertiliser → soil or water [14].

Conclusion

The study confirmed the importance of laws and policies regulating the implementation of nutrient use efficiency using organic fertilisers and nutrients from recycled waste-stream to support the EU circular economy. Several sectors, such as the chemical industry, technology providers, waste-management bodies, and society, especially farmers, should also be involved. At the same time, policy maker supports clear regulatory actions to help and control the use of BBFs. Furthermore, the study identified several challenges of the current policy, especially in the production and technology aspects, and later determined how BBFs can be gradually accepted. First, the new FPR does not cover some raw materials; thus, there is a necessity for action plans to comply criteria. Other critical points of BBFs that should be mentioned in the legal requirements compared to mineral fertilisers are logistic issues, the characteristic of nutrient content, and prices. Also, the source of the waste stream needs to be more stable to produce in different batches.

Regarding the first challenge, the new FPR policy only focuses on raw materials based on Component Material Category (CMC) and Product Function Category (PFC) that ensure safety and effectiveness. Adding new materials (CMC) also generates confusion between CMC and PFC since contaminants are put in the CMC criteria, not in the PFC criteria. Moreover, the undiscussed explanation relies on other tools, including REACH, which needs more clarity regarding the status of such materials.

To sum up, the recommendation is to design BBFs as future fertilisers to tackle the problem of dependency on importing mineral fertilisers in EU countries through support from all parties. For instance, policy incentives to optimize wastes valorisation and penalties to reduce the intensive use of non-renewable materials for fertiliser production could be alternative methods. However, the effectiveness of every action plan varies from country to country, depending on its socio-economic characteristic. In the end, regional initiatives could complement the new FPR to improve the success rate of its implementation.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

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