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Closing the nutrient-food loop: technology innovation and (de) politicization in European nutrient policy

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This contribution examines the development of the European Union's nutrient policy from 2000 to 2022. It focuses on the policy's shift orienting toward expert knowledge and technological innovations in nutrient recovery and recycling, and explores the resulting (de)politicization of the policy area. Drawing on evolutionary policy change, agri-food (de)politicization, and agri-food technology innovation research, a three-phase development is identified through qualitative document and public feedback data analysis. The policy development started with a focus on environmental issues and nutrient scarcity in the 2000s (phase 1), expanded to nutrient recycling as a means to close the nutrient-food loop in the mid-2010s (phase 2), and began utilizing secondary nutrient sources for agri-food production and to ensure a stable supply of fertilizers in the 2020s (phase 3). The study shows that while expert knowledge and technological advancements have steered sectoral policies toward a circular agri-food system, they have also led to the EU's nutrient policy adopting a technocratic approach, privileging specific expert insights and depoliticizing the policy area. The findings highlight the intricate relationship between technological innovation, policy evolution, and public engagement in shaping the European agri-food system.

KEYWORDS

European Union, depoliticization, nutrient policy, policy change, technology innovation, expert knowledge

1 Introduction

For a considerable time, agri-food policy has been recognized as an exceptional sector, notable for its policy stability and depoliticization (Skogstad, 1998). Corporatist structures facilitated privileged access for producer groups in the intermediation of interests (Grant, 1995), while policy institutions, programs, and instruments were largely focused on addressing the interests and needs of farmers (Alons, 2017). In recent years, agri-food policy has undergone a transformation (Daugbjerg and Feindt, 2017), encompassing the opening to outsider ideas and the participation of new policy actors, such as social and environmental movement actors. These groups have emerged as policy entrepreneurs, advocating for alternative normative frames like food sovereignty or organic agriculture (Schwindenhammer, 2017; Schwindenhammer and Partzsch, 2023), thereby contributing to an increase in the contestation and politicization of agri-food policy issues (Feindt et al., 2021). All of this unfolds in an environment of various stressors and shocks, including climate change, geopolitical conflicts, and disruptions in global agri-food supply chains. These dynamics intensify political and analytical debates in the European Union (EU) on the best approach to ensure a food system that is equitable, healthy, environmentally-friendly, and guarantees uninterrupted access to affordable food for EU citizens, while functioning effectively in all circumstances (European Commission, 2020a).

In recent EU agri-food policy debates, a crucial topic is nutrient valorization, focusing on recovering and recycling nutrients to enhance the sustainability and resilience of the agri-food system. The EU emphasizes the critical role of nitrogen, potassium, and phosphorus as key components of fertilizers in agri-food production (European Commission, 2022a) and acknowledges the adverse effects of nutrient losses on public health, the environment, and various economic sectors (European Commission, 2022b). Under the European Green Deal, which targets making Europe climate-neutral by 2050, the Farm to Fork strategy aims for more sustainable nutrient use and reduced losses by at least 50% by 2030 (European Commission, 2020a). The New Circular Economy Action Plan promotes the use of recycled nutrients in fertilizer production and supports markets for recycled nutrients (European Commission, 2020b). The recent increase in fertilizer prices, further intensified by the Russian invasion of Ukraine, has spurred policy attention in the EU toward nutrient recycling. This aligns with the EU's strategic goals of safeguarding food security and reinforcing the resilience of food systems, especially by reducing agri-food system reliance on imported commodities, including fossil fuels, fertilizers, and other essential raw materials (European Commission, 2022c).

A key feature of recent agri-food policy is the orientation toward the potential of science and technological innovations to facilitate more efficient use and reuse of natural resources and to enhance agri-food system resilience (e.g., Schwindenhammer, 2020; Schwindenhammer and Gonglach, 2021; Vogeler et al., 2021; Finger, 2023; Schwindenhammer, 2023; von Braun et al., 2023). This study analyses the evolution of the EU's nutrient policy in the context of scientific knowledge and technological innovations in nutrient recovery and recycling that offer novel opportunities for reducing nutrient losses and optimizing fertilizer supply (Keuter et al., 2021; Saliu and Oladoja, 2021). Our analysis is grounded in the assumption that the EU's nutrient policy orientation toward technological innovations might promote both the politicization and depoliticization of the policy area. Such a policy could intensify levels of politicization by introducing new policy issues and debates (Daugbjerg and Swinbank, 2012). For example, it could foster new issue interconnections between the food, water, and energy sectors, or involve a wider array of policy actors with divergent concerns (Schwindenhammer and Gonglach, 2021). Conversely, it might relegate policy matters away from public scrutiny, transforming EU nutrient policy into a domain mainly influenced by experts and insiders with specialized communication and practices (Feindt et al., 2021). This study seeks to answer the question: *How has the EU's nutrient policy evolved orienting toward technological innovation, and what has been the impact of this orientation on the (de)politicization of the policy area?*

The paper begins with an analytical framework in Section 2, linking research on evolutionary policy change, agri-food technology innovation, and the (de)politicization of agri-food policy. Section 3 details the methods and materials for the historical analysis. The empirical results in Section 4 outline three phases of policy change. Initially, EU policy in the 2000s focused on environmental issues from nutrients, like eutrophication, and resource scarcity. Informed by nutrient removal technology opportunities, changes occurred in EU policies concerning water and critical raw materials (phase 1). By the mid-2010s, nutrient recycling became part of the EU's circular economy policy, with pioneering nutrient recycling technologies and associated expertise catalyzing a shift in the EU fertilizer policy, emphasizing the closure of the nutrient-food loop (phase 2). Post-2020, the focus shifted to defining and marketing secondary nutrient sources, particularly wastewater (phase 3). In Section 5, we discuss how these findings demonstrate the EU's nutrient policy integrating scientific and technological advancements, shaping sectoral policies over time. Although nutrient recycling promotes innovative agri-food systems, it has also led to a more technical, expert-driven policy discourse, reflecting a depoliticization of the policy area.

2 Analytical framework

2.1 Conceptualizing evolutionary policy change

Classical studies of policy change assume policies follow the dominant paradigm in a given area (Skogstad and Schmidt, 2011). Hall's (1993) influential work, distinguishing three orders of change – in policy instruments, policy goals, and policy paradigms – has laid the foundation for numerous empirical studies and theoretical developments regarding different manifestations and processes of policy change (e.g., Baumgartner and Jones, 2009; Howlett and Cashore, 2009; Weible and Sabatier, 2017). According to Hall (1993), major third-order change is rare, occurring in times of crisis and profound policy failure, while first- and second-order changes evolve as policymakers rely on a set of ideas about politically feasible, practical, and desirable policies that become dominant, institutionalized, taken for granted, and reproduced (Skogstad and Schmidt, 2011; Cairney, 2013). The literature on evolutionary policy change suggests that change happens not only during crises when old policy paradigms fail (Carstensen, 2011) but also as an ongoing process where elements and structures are continuously constructed and reconstructed (Mahoney and Thelen, 2010). Policymaking is seen as ongoing co-evolution, reproduction, and discourse (Cairney, 2013), involving new ideas, issues, institutions, and interacting actors (Beunen and Van Assche, 2021). Some changes occur quickly, like annual budget regulations (Jones et al., 2009), while others take years or decades, as Hall (1993) shows with shifts in economic policymaking in the UK. Evolutionary change has been observed in various areas of EU policymaking, including the climate policy mix and integration (Oberthür and von Homeyer, 2023) and foreign policy on human rights for LGBTQ+ people (Malmedie, 2016). Agri-food policy literature identifies shifts toward what Daugbjerg and Feindt (2017) term *post-exceptionalism*, indicating today's agri-food policies are situated in more flexible, cross-sectoral, international, and debated contexts. Evolutionary models suggest that change occurs through feedback loops from sequenced policy adjustments over time (Daugbjerg, 2009) or from the overlay or coexistence of new policy ideas and institutions alongside existing ones (Daugbjerg and Swinbank, 2016). Agri-food policy has broadened the ideational debate to include input from new policy actors, particularly environmental and transnational non-governmental organizations, that have taken on central entrepreneurial roles, advocating for new normative frames such as food sovereignty and organic agriculture (Schwindenhammer, 2017; Schwindenhammer and Partzsch, 2023), and discursively re-framing established ideas (Breitmeier et al., 2021). Consequently, agri-food policy issues are now more closely tied to the overarching discourse on economic, ecological, and social sustainability (Daugbjerg and Feindt, 2017).

Our study assesses evolutionary change in EU nutrient policy over two decades, contributing to research on long-term policy change and expanding the thematic spectrum of evolutionary perspectives in EU policy analysis. We draw on models highlighting the interplay and complex connections among sectoral policies, goals, and instruments, resulting in policy packages (Givoni et al., 2013) or policy portfolios (Fitch-Roy et al., 2020). These configurations point to the congruence and interaction between different policy instruments, and the relevance of policy designs to traditional goals while adapting to new ones in response to regulatory challenges (Feindt and Flynn, 2009; Howlett and del Rio, 2015). Fitch-Roy et al. (2020, p. 987) distinguish four dimensions of change within policy portfolios: packaging, conversion, patching, and layering. These dimensions can be classified based on their degree of policy instrument innovation and the extent of change in policy objectives. *Packaging* involves high instrument innovation and a reorientation of policy objectives resulting in the creation of a novel portfolio of policy instruments. *Conversion* denotes low instrument innovation but significant changes to existing policy objectives in response to fundamentally changed policy imperatives. *Patching* includes the incremental adjustment of existing instruments, with low instrument innovation and objective change. *Layering* involves the introduction of new policy instruments, but low substantive change in the underlying policy objectives.

2.2 (De)politicization and technology innovation

Scholars of agri-food policy discuss evolutionary policy change in the context of politicization and depoliticization dynamics (Feindt et al., 2021). Politicization means making an issue the subject of public policymaking and/or public discussion (De Wilde and Zürn, 2012) and political conflict (Broekema, 2016), while depoliticization implies the opposite. According to De Wilde (2011, pp. 566-567), politicization means that policy issues become controversial over time, involving rising awareness (greater interest and engagement of more people in politics), increased resources spend in conflict on policy issues, and polarization (co-occurrence of conflicting demands for collective goods).

Agri-food policy research distinguishes (de)politicization as process, strategy, or outcome (see Feindt et al., 2021, pp. 512–513).

- As process, (de)politicization denotes the mechanisms through which an issue area is constituted as a more or less public and political affair, in particular that it is subject to an intensified public and/or political debate (De Wilde, 2011; De Wilde and Zürn, 2012).
- As strategy, politicization denotes the deliberate efforts by political actors over an extended period to constitute an issue area as a public affair governed by political modes of decision-making, intervention and accountability. In contrast, depoliticization strategies aim at removing an issue area from processes of political decision-making or even from the realm of public policy (Buller et al., 2019).
- As outcome, (de)politicization denotes the different degrees to which an issue area has been established as a domain of public policy and the closeness of its links to political mechanisms of governance, intervention and accountability (Wood and Flinders, 2014; Wood, 2016).

In an environment where various actors increasingly politicize agri-food policy issues (Breitmeier et al., 2021; Schwindenhammer and Partzsch, 2023), policymakers must defend their preferred policies against conflicting alternatives and political adversaries (Vogeler et al., 2021). The complexity of policy issues necessitates decisions made with limited ability to anticipate all consequences (Beunen and Van Assche, 2021), requiring advice from new experts and likely leading to the institutionalization of new ideas over time. Agri-food policies are increasingly oriented toward science and technological innovation (e.g., Schwindenhammer, 2020; Finger, 2023), driven by the EU's better regulation agenda (European Commission, 2002), which emphasizes scientific and technological knowledge for evidence-based policymaking. Specialized agencies such as the European Commission's Joint Research Centre (JRC), the Group of Chief Scientific Advisors, and the Panel for the Future of Science and Technology, contribute their scientific expertise (European Commission, 2022d). This focus on technology innovation reinforces beliefs in the feasibility and manageability of agri-food challenges (Schwindenhammer, 2020). Recent frameworks, such as the Farm to Fork strategy (European Commission, 2020a), highlight the potential of these technologies for efficient resource use, sustainable and resilient agri-food systems (Finger, 2023), and dynamic, forward-looking policies (European Commission, 2020c).

This study assumes that policy orientation toward scientific knowledge and technological innovation may lead to either politicization or depoliticization of a policy area (as an outcome). On the one hand, when policymakers address new challenges and demands by introducing new policy objectives and instruments to policy portfolios, reacting to new technological advancements, this can add to politicization. For example, it can create new cross-sectoral issue interlinkages (e.g., food-water-energy nexus), mobilize and connect new actors, and fuel new policy debates (Schwindenhammer, 2020; Schwindenhammer and Gonglach, 2021; Schwindenhammer, 2023). Civil society actors may politicize issues related to technology innovation, such as potential negative environmental impacts or the unequal distribution of intellectual property rights or bio-patents (Daugbjerg and Swinbank, 2012; Constance and Moseley, 2018). On the other hand, when changes in policy portfolios heavily rely on technological innovation and scientific knowledge, this might perpetuate the "very technical character" of agri-food policy (Feindt et al., 2021, p. 519). This approach privileges policymaking through specialized institutional arrangements that extend from parliamentary committees to specialized bureaucracies, agencies and knowledge institutions (Tosun et al., 2019). In this case, changes in policy portfolios involve highly specialized communication and practices based on expert knowledge and skills, keeping policymaking in a routine mode and removing policies from public scrutiny and debate

(Feindt et al., 2021). This renders policies into affairs reserved for experts and insiders, potentially leading to depoliticization by insulating a policy from public debate as a political issue open to judgment by the entire citizenry and liable to political decision-making through mechanisms of political representation or direct vote (Feindt et al., 2021). This risks sidelining political issues such as equal access, distributive justice, or societal skepticism toward new technological solutions.

This analysis focuses on one aspect of (de)politicization, namely whether policy issues have become part of EU policy debates, without delving deeply into the strategies of (de)politicization used by policy actors. This does not undermine the importance of (de)politicization strategies. Following Feindt et al. (2021), such strategies are crucial for initiating policy processes that may lead to policy change, and (de) politicization can be dampened through successful strategies. Although examining actors' motives, interests, coalition choices, and interdependencies in (de)politicization strategies is crucial for future research, it is beyond the scope of this study.

3 Materials and methods

The assessment of evolutionary change in the EU's nutrient policy spans from the early 2000s, when the issue emerged on the EU policy agenda, to 2022. It utilizes qualitative document and public feedback data analysis to address two dimensions: Firstly, a historical assessment of policy changes and focus related to nutrients in different sectoral policies, and their relation to scientific knowledge and technological innovations in nutrient recovery and recycling. Secondly, an assessment of the extent to which such policies have become a matter of public affair and policy debate. This approach provides a broad perspective, differing from methods like policy and discourse network approaches (Schaub and Metz, 2020), which allow for detailed assessment of interdependencies, coalition structures, policy preferences, and collective decision-making.

The document analysis searched for relevant documents in the EU's legal documents database, EUR-Lex, literature search databases, and via website research. Selected policy documents and scientific literature focus on sectoral policies and technology developments related to nutrients, covering various EU policy fields, especially environmental and sustainability policy, critical raw materials policy, circular economy policy, and fertilizer policy. The sample includes 51 documents comprising official EU reports and legislative texts, technical and scientific reports from the JRC, reports from European Commission's Working Groups, minutes from the Fertilizers Working Group, and scientific literature. The document analysis employed qualitative content analysis (Mayring, 2008), using both deductive and inductive approaches to structure the content. A category system was developed to code the material based on theoretical aspects – the four types of evolutionary change in policy portfolios (packaging, conversion, patching, and layering) as conceptualized by Fitch-Roy et al. (2020) – and seven categories based on patterns found in the documents. These categories structured the data according to policy focus and the ascribed role of scientific knowledge and technological innovation. The coding involved repeated close readings and discussions among the authors. Initially conducted independently, the results were compared and refined to develop a common understanding, balancing deductive insights and inductive analysis, and allowing empirical data to guide our interpretations.

To assess how far the EU's policy on nutrients has become a matter of public policy debate, the analysis draws on secondary literature and EU reports for the period from the 2000s to 2015, and for 2015 onwards on data derived from the EU's Better Regulation online portal *Have Your Say*[1] and public feedback consultations related to the policies dealing with the nutrient topic. The Have Your Say online portal, open to every EU citizen and organization, has been used by the European Commission since 2015 to gather evidence and public feedback from citizens, businesses, and other stakeholder groups on legislative proposals, existing EU laws, and policy processes across various domains. The assessment of this empirical data facilitated the identification of the engagement of diverse stakeholder groups in the public feedback consultations on nutrient policies at the EU level.

4 Results

The empirical results are presented using a three-phase heuristic approach, highlighting different dimensions of policy change across these phases. The findings emphasize varied policy focuses and an orientation toward scientific and technological advancements in different sectoral EU policies related to nutrients, alongside a depoliticization of the policy area.

4.1 Phase 1: Emerging environmental and resource scarcity concerns regarding nutrients in the 2000s

Evolutionary change in the EU policy on nutrients can be traced back to the 2000s. At that time, nutrients received growing attention in the context of debates on the state of the environment in the EU and the challenge of resource scarcity, leading to changes in the EU policies on water and critical raw materials. Since the mid-1990s, assessment reports of the European Environment Agency prominently pointed out that in excess amounts, nutrients cause serious water quality problems and negatively affect aquatic and eco-systems (eutrophication) (Stanners and Bourdeau, 1995; Crouzet et al., 1999). The area of eutrophication-affected ecosystems peaked in 1990 at 84% in the EU member states (European Environment Agency, 2015). Excessive fertilizer application and discharge of treated wastewater into nutrient-poor waters led to nutrient accumulation, causing excessive algae and aquatic plant growth and depriving other plant species and animals of their livelihood (Crouzet et al., 1999). The poor condition of European surface waters emerged as an environmental security problem, exerting pressure for change on European water policy. In 2000, the EU Water Framework Directive (WFD) was introduced with the main goals of ensuring good quality of surface and ground waters in the member states and meeting the environmental quality standards for priority substances set in the

1 Have Your Say online portal: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives_en.

WFD (EU, 2000). To achieve these goals, technological innovations in nutrient removal from large domestic wastewater treatment plants received attention (Bunce et al., 2018). The elimination of phosphate was realized through various technological treatment approaches (Cordell et al., 2009; Zheng et al., 2022), particularly by chemical–physical processes using iron, aluminum and calcium salts to convert phosphate into an insoluble, separable form (Stanners and Bourdeau, 1995). In this way, it can be separated from the liquid phase in various ways (Liese et al., 2021). The introduction of the WFD can be classified as *packaging* (Fitch-Roy et al., 2020) because it changed policy objectives, emphasizing the improvement of water quality and environmental conditions, and introduced new policy instruments like emission limit values and environmental quality standards based on new technological opportunities.

Since the mid-2000s, new scientific knowledge on phosphorus scarcity emerged (Ulrich and Frossard, 2014). This substantiated a crisis narrative of *peak phosphorous*, estimated to occur around 2035 (e.g., Cordell et al., 2009), and gave impetus to calls for a more efficient and effective use of phosphorous. There were appeals to reduce waste and losses throughout the phosphorus lifecycle and to promote phosphorus recycling (EcoSanRes, 2005; Ulrich and Frossard, 2014). Early calls by scientists were voiced to begin recycling phosphorus and reintroducing it to the soil, pursuing the goal of reducing dependence on mined phosphorus for artificial fertilizers, accompanied by warnings that, "within a half century, the severity of this crisis will result in increasing food prices, food shortages, and geopolitical rifts" (EcoSanRes, 2005, p. 1). The increasing attention to nutrient problems was linked to economic issues emphasizing the impacts of global shifts in the supply and demand for raw materials (European Commission, 2011; Christmann, 2021), the fallout from the global economic crisis in 2008 (European Commission, 2011), and significant phosphorus price hikes (Cordell et al., 2009; Schoumans et al., 2015). Consequently, there was political consensus on the EU's critical economic dependence on imported raw materials and the necessity of addressing this dependency in future EU policy (Christmann, 2021).

In 2008, the EU launched the Raw Materials Initiative, drawing attention to the identification, regular evaluation, and production of critical raw materials (European Commission, 2008). Through this initiative, the EU prioritized needs and future actions, aiming to bolster the competitiveness of the European industry, "through actions in other policy areas" (European Commission, 2014a, p. 2), and promoted research projects focusing on resource-efficient products and production under the Seventh Framework Programme for Research and Development (European Commission, 2008; European Commission, 2011). The Raw Materials Initiative adopts a three-pillar approach to secure access to critical raw materials by ensuring equal access on world markets, fostering sustainable supply from European sources, and reducing primary raw material consumption through increased efficiency and recycling (European Commission, 2008). A central element of the initiative was the improvement of technology and knowledge related to critical raw materials (European Commission, 2011) and the institutional integration of technical and expert-driven policy advice. Since 2010, the *Ad-Hoc* Working Group on Defining Critical Raw Materials has operated as a subgroup of the European Commission's Raw Materials Supply Group to the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW). This group is comprised of member state representatives and experts from extractive industries, intermediate users (e.g., steel), downstream industries, the recycling industry, and academia (Ad-hoc Working Group on Defining Critical Raw Materials, 2014). Its main objective is to develop policy recommendations and to assist the Commission in defining the critical raw materials for the EU (Ad-hoc Working Group on Defining Critical Raw Materials, 2010), regularly assessing various non-interchangeable raw materials that are vitally important to the EU economy. The evaluation process, which considers factors like supply risks, economic importance, and environmental impacts, has led to the incremental development of the EU's *list of critical raw materials* (CRMs). The *Ad-hoc* Working Group initially published a list containing 14 CRMs in 2011 and has updated it every 3 years since then (European Commission, 2011). In terms of policy change, the introduction of this list signifies a new policy instrument, albeit with a low degree of change in the overall policy objectives, a change typified as *layering* (Fitch-Roy et al., 2020). However, the institutionalization of regular adjustments or revisions of the list, incorporating expert advice and addressing changing contextual conditions and challenges, suggests that the ongoing development of the list may be characterized as *patching* (Fitch-Roy et al., 2020).

Growing awareness of *peak phosphorus* (Ulrich and Frossard, 2014), the EU's dependence on phosphate rock imports, and the significant price fluctuations (Schoumans et al., 2015) facilitated policy debates on strategies for raw material recycling and, more specifically, sustainable phosphorus utilization and recycling. To address these concerns at the EU level for the first time, the Commission initiated the public "Consultative Communication on the Sustainable Use of Phosphorus" between July and December 2013, sparking a debate on the current situation and potential future actions to be taken (European Commission, 2013). The Commission received 125 (joint) responses from 150 policy actors, including nine member state administrations, other government agencies and local authorities, industry associations, research institutions, businesses, NGOs and private individuals (European Commission, 2014b). The respondents represented specific sectors, especially phosphorus recycling, water and waste management, agriculture, food, fertilizers, chemicals, energy and other manufacturers (European Commission, 2014b). The policy debate expanded beyond phosphorus sustainability and secure supply to embrace a cross-sectoral perspective, covering areas such as resource efficiency, waste management, circular economy, agricultural and food production, and the health of soil and water (European Commission, 2014b). Several phosphorus recovery technologies were acknowledged, but seen as "still at a laboratory/pilot stage," emphasizing the necessity for market uptake support and additional research funding under the Horizon 2020 Programme (European Commission, 2014b, pp. 6–7).

In 2014, phosphate rock was added to the list of critical raw materials (European Commission, 2014a) and phosphorus 3 years later (European Commission, 2017). Although the cross-sectoral issue dimension of governing nutrients was recognized, policy debates were predominantly oriented toward economic considerations. The expansion of the list of critical raw materials largely catered to the demands of industry stakeholders and policy actors like the European Sustainable Phosphorus Platform (ESPP), which highlighted phosphorus as vital for numerous chemical sectors, including fire safety, pharmaceuticals, catalysts, and agrochemicals (ESPP, 2022a), emphasizing economic value and different applications and technological processing routes for phosphate rock and phosphorus

(ESPP, 2020). However, the policy process faced criticism for insufficient inclusivity of civil society and lacking transparency (Sydow et al., 2011). Despite concerns about the potential adverse effects on global food security if global phosphorus production peaks and then diminishes (Ulrich and Frossard, 2014), neither the WFD nor the EU policy on critical raw materials took the step to conceptualize recycled nutrients as a component for agri-food production.

4.2 Phase 2: Nutrient recycling to ensure self-sufficiency, circular economy, and sustainable agri-food production since the mid-2010s

This changed in the mid-2010s, with EU nutrient policy expanding to include nutrient recycling to close the nutrient-food loop (using recovered nutrients in fertilizer production). In 2014, the Commission highlighted the vital role of phosphorus in food production and its significant security-of-supply risks, along with waste and losses throughout its lifecycle (European Commission, 2014c). The Commission considered "developing a policy framework on phosphorus to enhance its recycling, foster innovation, improve market conditions and mainstream its sustainable use in EU legislation on fertilisers, food, water and waste" (European Commission, 2014c, p. 13). This approach linked recycled nutrients in agri-food production to the EU's circular economy objectives, aiming to prevent resource depletion, close resource loops, and enable sustainable development. In 2015, the first EU Action Plan for the Circular Economy specifically mentioned nutrient recycling as a source for secondary raw materials for organic and waste-based fertilizers (European Commission, 2015a). In the same year, a workshop on circular approaches to phosphorus, jointly organized by the European Commission (DG Research & Innovation), the ESPP and the P-REX project, brought together research projects on phosphorus recycling from across Europe, most of these funded under the EU's Seventh Framework Programme for Research and Development. The workshop identified regulatory barriers to the use of secondary and recycled materials and, as outlined in the summary report, prioritized "a revision of the EU Fertiliser Regulation […] to extend its scope to nutrients from secondary sources (e.g., recycled phosphates) and organic sources" (European Commission, 2015b, p. 9). To promote nutrient recycling, facilitate recognition of organic and waste-based fertilizers in the single market, and support "the role of bio-nutrients in the circular economy," the Commission decided to revise the EU regulation on fertilizers (European Commission, 2015a, p. 13). Since the first EU Action Plan for the Circular Economy altered policy objectives (closing the nutrient-food loop) and declared the introduction of new policy instruments, it can be interpreted as *packaging* (Fitch-Roy et al., 2020).

In 2016, the Commission published the official proposal of the revised fertilizer regulation to "incentivise large scale fertiliser production in the EU from domestic organic or secondary raw materials in line with the circular economy model" (European Commission, 2016a, p. 3). The policy debate focused on achieving economic effectiveness and sustainability by closing the nutrient-food loop. Meeting minutes of the EU Fertilisers Working Group from December 2014 show growing recognition that future fertilizer regulation had to include new legal requirements for compost and digestate, with the option to extend to other recovered fertilizing products such as ashes and struvite (Fertilisers Working Group, 2015a). Additionally, the meeting minutes from March 2015 show that DG GROW was committed to supporting the development of legal requirements for struvite, biochar, and ashes in the future (Fertilisers Working Group, 2015b). In 2017, the EIP-AGRI Focus Group stressed the need for market-ready recycling techniques and outlined several economic benefits from using recycled nutrients in EU agriculture, such as making farmers less dependent on imported and purchased fertilizers, reducing vulnerability to price fluctuations and supply shortages, and creating rural jobs in the processing, marketing, and distribution of recycled nutrient products (EIP-AGRI Focus Group on Nutrient Recycling, 2017). At that time, several research and development projects in the EU's Horizon 2020 funding program (2014–2020) were dedicated to developing and evaluating innovative technological approaches for nutrient recycling within the circular economy, including LEX4BIO, FERTIMANURE, Water2Return, and SMART-Plant. The emerging scientific and technical knowledge fostered circular agricultural systems, with wastewater being recognized as a valuable source for nutrient recycling (Saliu and Oladoja, 2021). The overall focus had shifted from phosphorus removal to prevent environmental pollution to phosphorus recovery and recycling (Jupp et al., 2021; Zheng et al., 2022).

The new Fertilizing Products Regulation (FPR) ((EU) 2019/1009), in force from 16 July 2019 and implemented from 16 July 2022 (EU, 2019), aims to enhance the role of recovered nutrients and level a playing field for organic and waste-based fertilizers (European Commission, 2016b). As a novel policy instrument, the FPR introduced *Component Material Categories* (CMCs) that specify the specific components a fertilizer must contain to receive a CE-labeling and gain access to the European fertilizer market (EU, 2019, Annex 2). Upon the FPR's entry into force, there were 11 CMCs established.[2] For each of these CMCs and their input materials, specific requirements and maximum values for certain substances have been defined (EU, 2019). While the previous EU fertilizer policy focused on regulating mineral-based fertilizers derived from primary resources, the FPR, for the first time, enables the utilization of secondary raw materials in fertilizer production and promotes organic and waste-based fertilizers in alignment with the goals of the European circular economy. This policy change can be classified as *packaging* (Fitch-Roy et al., 2020), involving significant shifts in policy instruments (introduction of CMCs) and policy objectives.

The FPR also involves a specific institutional feature – *delegated acts* – that institutionally delegates policymaking from the active involvement of EU policy institutions to a more technocratic process. The European Commission can adopt delegated acts, authorized by the Parliament and the Council, to modify certain non-essential parts

2 These 11 CMCs include CMC 1 Virgin material substances and mixtures; CMC 2 Plants, plant parts or plant extracts; CMC 3 Compost; CMC 4 Fresh crop digestate; CMC 5 Digestate other than fresh crop digestate; CMC 6 Food industry by-products; CMC 7 Micro-organisms; CMC 8 Nutrient polymers; CMC 9 Polymers other than nutrient polymers; CMC 10 Derived products within the meaning of Regulation (EC) No 1069/2009; and CMC 11 By-products within the meaning of Directive 2008/98/EC.

of a legislative act (EU, 2012, Art. 290), such as setting out detailed policy measures. After consulting national experts and stakeholders, delegated acts undergo ex-post scrutiny by the Parliament and Council, both of which can veto them. This procedure is mainly used to align legislative acts with the state of technology and scientific advances. Through Article 42 of the FPR, the Commission is empowered to adopt delegated acts to adapt the corresponding Annexes of the FPR "to technical progress" and facilitate internal market access and free movement for EU fertilizing products (EU, 2019, p. 30). As adaptation to technological innovation may have a direct or indirect impact on food and feed safety and the environment, e.g., when new limits for contaminants are introduced, the FPR stipulates that the Commission "shall take into account scientific opinions" of the JRC, the European Food Safety Authority, or the European Chemicals Agency before amending the regulation through delegated acts (EU, 2019, p. 30). The expansion of the CMCs through delegated acts had already been decided in 2019. Pursuant to Article 42(2) of the FPR, the Commission shall, immediately after the entry into force of the regulation and after extensive consideration, adopt delegated acts to include the additional categories CMC 12 *Struvite*, CMC 13 *Biochar*, and CMC 14 *Ash-based products* (the STRUBIAS criteria) in Annex 2 (EU, 2019). Since the FPR provides for the expansion of additional CMCs and other adjustments, it institutionally favors *layering* and *patching*, which leave policy objectives unchanged but change policy instruments.

The policy process of the three delegated acts introducing the STRUBIAS criteria provided privileged access to experts. In 2016, the STRUBIAS expert group had been formed as a subgroup of the Commission expert group on Fertilising Products to work on the topic of nutrient recovery from STRUBIAS materials. The group, which existed until 2018, comprised 31 members and 2 observers. They were selected by the Commission and came from companies, academia, think tanks, trade and business associations, as well as member state authorities (Huygens et al., 2017). In August 2017, the JRC conducted a written consultation on the development of the STRUBIAS CMCs. This process was predominantly technical and, as the JRC "is not able to accept responses and opinions from organisations and individual persons other than official STRUBIAS member organisations and their selected representatives," it was aimed exclusively at the members of STRUBIAS expert group (Huygens et al., 2017, p. 115). The STRUBIAS expert group's draft technical proposals noted that specific STRUBIAS materials have a phosphorus pentoxide (P_2O_5) content similar to conventional synthetic phosphorus fertilizers, but with lower cadmium (Cd) levels than most primary phosphate rock sources. This offers environmental benefits, particularly in "reducing Cd accumulation in agricultural soils" (Huygens et al., 2017, p. 1). In 2019, the JCR published a report on the introduction of CMCs 12–14, highlighting that many STRUBIAS materials have great potential as a safe phosphorus source and that "market demand and trade is expected for all three STRUBIAS material groups in different segments of the EU agricultural sector" (Huygens et al., 2019, p. 6). However, the report also pointed out that the market for P-fertilizers derived from STRUBIAS materials "is dependent on the technological readiness and potential production limitations of the production processes" (Huygens et al., 2019, p. 217). The mechanism of delegated acts institutionally enabled the introduction of the CMCs 12, 13, and 14 in July 2021, valid since 16 July 2022. This policy development can be classified as *layering* (Fitch-Roy et al., 2020), since the three CMCs expand the FPR to adapt to technical progress. However, the policy process was largely influenced by scientific and technical experts and their knowledge.

4.3 Phase 3: Unlocking secondary resource sources and utilizing recovered nutrients from wastewater in the 2020s

In September 2020, the European Commission unveiled its new European Action Plan on Raw Materials, emphasizing the urgent need "to ensure a secure, sustainable supply of raw materials" (European Commission, 2020d, p. 6) and to "diversify supply from both primary and secondary sources, reduce dependencies and improve resource efficiency and circularity" (European Commission, 2020d, p. 1). In the same year, the EU Action Plan for the Circular Economy was revised (European Commission, 2020b). The New Circular Economy Action Plan reaffirmed the goals of promoting the more sustainable application of nutrients, stimulating markets for recovered nutrients, and explicitly encouraging circular approaches to water reuse in agriculture. Under the heading "Creating a well-functioning EU market for secondary raw materials," the plan explicitly emphasizes the economic valorization and reuse of secondary raw materials (European Commission, 2020b, p. 14). The Commission also announced to revise other directives, particularly those related to wastewater treatment and sewage sludge, and to develop an Integrated Nutrient Management Action Plan (European Commission, 2020b, p. 12). In 2022, the Commission sought related evidence for this plan (European Commission, 2022b) and held a public feedback consultation on "Nutrients – action plan for better management" (European Commission, 2022e) from March to April 2022. This consultation aimed to gather public input on enhancing nutrient cycle efficiencies, ensuring food security, and protecting ecosystems and human health. It received a total of 69 responses, predominantly from business associations (26.09%), followed by companies (21.74%), and academia and research institutes (14.49%). 9 out of the 69 responses (13.04%) were from EU citizens (European Commission, 2022e).

Regarding the New Circular Economy Action Plan, the European Parliament adopted an own-initiative resolution in February 2021 that includes more than 130 policy recommendations to promote the circular economy. This resolution calls on the Commission to take further measures to "close the agricultural nutrient loop" and enhance the use of recycled organic nutrients instead of synthetic fertilizers (European Parliament, 2021, recommendation 90). The EP resolution confirms the potential of nutrient recovery from wastewater and supports a circular approach to promote recycling of municipal and urban wastewater (European Parliament, 2021, recommendation 91). Policy change in the context of the EU circular economy can be classified as *conversion* (Fitch-Roy et al., 2020), as existing policies, especially wastewater treatment and sewage sludge directives, shall be re-purposed due to a change in policy objectives (transforming the EU economy from a fossil-based economy to a bio-based one).

The use of recovered nutrients from treated wastewater in EU agriculture has sparked policy debates about the future scope of EU fertilizer regulation and cross-sectoral policy issues. These debates are accompanied by the new European research and innovation program, Horizon Europe 2021–2027, which, under pillar 2 in cluster 6, provides research funding to evaluate "Food, Bioeconomy, Natural

Resources, Agriculture & Environment" (European Commission, 2021). Research findings on implementing the circular economy model in the EU emphasize the vital role of the water and wastewater sector, particularly the technical potential for nutrient recycling from wastewater (Smol et al., 2020). In EU fertilizer policy, the FPR already permits wastewater as an input material for CMC 12 (precipitated phosphate salts and derivatives) and allows the production of Struvite obtained from wastewater. Additionally, fertilizers produced with components under CMC 13 (thermal oxidation materials or derivates) can be derived from sewage sludge from municipal wastewater treatment plants. In 2022, the JRC released a report containing guidelines for a new CMC 15 for by-products and high purity materials (Huygens and Saveyn, 2022). These guidelines were developed through a techno-scientific analysis conducted by the Commission's Expert Group on Fertilising Products, as well as through consultations with stakeholders, including NGOs, industry, science and member state authorities (Huygens and Saveyn, 2022). Furthermore, a public feedback initiative on "Fertilisers – high purity materials in EU fertilising products" was conducted between December 2021 and January 2022 (European Commission, 2022f). This consultation received nine responses in total, including five from companies, two from trade unions, one from an NGO and one from a business association. This consultation again shows a low level of attention to the issue, both in general and among the European public. CMC 15, which came into effect on 16 July 2022, allows for the inclusion of wastewater as an input material, but only in specific manufacturing processes (European Commission, 2022g). Input materials like wastewater and sludge are exclusively permitted in gas purification or emission control processes designed to remove nutrients from off-gases (European Commission, 2022g, p. 6), so wastewater can currently only be considered as a source material for specific substances. Since CMC 15 qualifies as the introduction of a new policy instrument while maintaining the same policy objectives, this change can be categorized as *layering* (Fitch-Roy et al., 2020).

Using recovered nutrients from wastewater to produce waste-based fertilizers and enhance the EU's fertilizer supply has intensified cross-sectoral regulatory debates, especially about the end-of-waste status. Untreated wastewater is classified as waste under the Waste Framework Directive (2008/98/EC). Article 6 of this directive, updated by Directive (EU) 2018/851, entails monitoring national end-of-waste criteria and determining the need for Union-wide criteria (EU, 2018, p. 122). Policy actors like ESPP and the European Federation of National Associations of Water Services (EurEau) have advocated for Union-wide criteria to identify wastewater as potentially attaining the end-of-waste status (ESPP, 2021; ESPP and EurEau, 2021). However, regarding fertilizer production, the Waste Framework Directive suggests that achieving end-of-waste status in this context depends on product-specific legislative requirements (EU, 2018, p. 112). The FPR has established Union-wide end-of-waste criteria for fertilizing products with Article 19 outlining criteria under which a material classified as waste, as defined in Directive 2008/98/EC, can cease to be waste if it is included in a compliant EU fertilizing product (EU, 2019). However, there is still criticism, such as from ESPP, regarding several materials recovered from wastewater not yet covered by current CMCs but that should be considered for inclusion (ESPP, 2021). The end-of-waste debate signifies a shift in policy objectives regarding the extended use of secondary raw materials. However, it also underscores the need to reconsider when certain waste products no longer qualify as waste. Referring to Fitch-Roy et al. (2020), the change in policy objectives and the introduction of the end-of-waste criteria in the FPR can be classified as *packaging.*

In 2022, the ESPP called for proposals for additional CMCs or secondary raw materials to be considered by the Commission (ESPP, 2022b). The Commission introduced a draft delegated act with technical amendments to the FPR, specifically addressing the minimum content of calcium oxide in straight solid inorganic macronutrient fertilizers, decided in November 2022 (European Commission, 2023). A public consultation on this draft occurred between July and August 2022 (European Commission, 2022h), receiving only one response from an EU citizen. The FPR is not only expanded with new CMCs but also continuously adapted to other policy areas. This reveals *patching*, because policy instruments are adjusted to the current circumstances in response to changed contexts (Fitch-Roy et al., 2020). A recent adjustment involves agronomic efficiency and safety criteria for by-products in EU fertilizing products (European Commission, 2022i), with a related public feedback initiative from December 2021 to January 2022 that received 28 responses (European Commission, 2022j).

5 Discussion

The policy developments identified across the three phases demonstrate ongoing first- and second-order policy changes (Hall, 1993) and the formation of various policy portfolios (Fitch-Roy et al., 2020) within different sectoral policies addressing nutrients, in light of technological innovations in nutrient recovery and recycling (see Table 1). Over more than two decades, policy instruments and objectives in the EU's nutrient policy evolved with the emergence of new ideas, issues, institutions, and interacting actors (Beunen and Van Assche, 2021). This confirms the evolutionary policy change perspective that elements and structures are continuously constructed and reconstructed (Mahoney and Thelen, 2010) and that policymaking is characterized by ongoing co-evolution, reproduction, and discourse (Cairney, 2013). In terms of the different dimensions of evolutionary change in policy portfolios (Fitch-Roy et al., 2020), the findings show the presence of *packaging*, *layering*, and *patching* in all phases. *Conversion,* which implies low instrument innovation but significant changes to policy objectives in response to fundamentally changed policy imperatives, occurs less frequently.

In phase 1, policy change started in the 2000s when the issue of nutrients gained growing attention due to new scientific knowledge and public concerns about the state of the environment in the EU (Stanners and Bourdeau, 1995; Crouzet et al., 1999), and increasing awareness of resource scarcity (Christmann, 2021). The introduction of the WFD can be classified as *packaging* since policy objectives changed toward the improvement of water quality and environmental conditions and new policy instruments such as emission limit values and environmental quality standards were introduced. The particular attention to phosphorus can be interpreted as a response to the crisis narrative of peak phosphorus and economic pressure (Ulrich and Frossard, 2014). The introduction of the list of critical raw materials as a novel policy instrument of the EU Raw Materials Initiative qualifies as *layering.* The EU introduced a novel policy instrument while the degree of change in the general policy objectives remained low, because the topic of critical raw materials was already on the

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TABLE 1 Overview of results on evolutionary change in EU nutrient policy.

Phase	Type of change				Role of technology	Policy focus
	packaging	*conversion*	*patching*	*layering*		
Phase 1 since 2000s	X		X	X	Research and development in nutrient removal technology show the potential for solving environmental problems and inform policymaking	• Environmental issues: combating nutrient-caused environmental problems (eutrophication) • Resource resilience issues: addressing resource scarcity (peak phosphorus) • Economic issues: adapting to price fluctuations (phosphorus price hikes) and reducing dependency on critical raw material imports (list of CRMs)
Phase 2 since mid-2010s	X		X	X	Research and development in nutrient recycling technology for closing the nutrient-food loop are stimulated by and influence policymaking	• Circular economy issues: closing the nutrient-food loop (recognition of waste-based fertilizers) and adding value to EU agri-food systems through nutrient recycling • Self-sufficiency issues: achieving nutrient security and enhancing efficiency through localized valorization • Sustainability issues: ensuring economic, environmental, and social value through nutrient recycling
Phase 3 since 2020s	X	X	X	X	Policy orientation towards innovation in nutrient recycling technology has become an official part of policymaking (FPR, delegated acts)	• Fertilizer issues: ensuring a stable supply of fertilizers and adding value from new secondary raw materials as input for fertilizing products (nutrients recovered from wastewater) • Circular economy issues: closing the nutrient-food loop and adding value to EU agri-food systems through valorization and use of secondary raw materials • Sustainability issues: ensuring economic, environmental, and social value through nutrient recycling

political agenda. However, with the institutionalization of the new mechanism of adjusting or revising the list of critical raw materials regularly to respond to changing contextual conditions and challenges, it can be argued that the further development of the list qualifies as *patching*. By including phosphate rock and phosphorus in the list of critical raw materials, the EU prioritized nutrient recovery on its agenda, establishing a foundation for further policy action. However, the EU's consultative communication on the sustainable use of phosphorus from 2013 shows predominant input from industry representatives and their ideas on technological solutions for phosphorus recovery (European Commission, 2014b).

In phase 2, the EU policy discourse on nutrients broadened in the mid-2010s with technological advancements in nutrient recycling (Jupp et al., 2021; Zheng et al., 2022), linking it to the EU circular economy goals, ensuring self-sufficiency, and promoting sustainability in agri-food production. The first EU Action Plan for the Circular Economy introduced a portfolio of new policy instruments in line with *packaging*. In addition to the sustainable and efficient use of raw materials, nutrient recycling became a component of circular approaches to agri-food production, aimed at closing the nutrient-food loop. The introduction of the new FPR can be classified as *packaging*, involving substantial changes in policy instruments (introduction of CMCs) and significant change in policy objectives. While the previous fertilizer policy regulated mineral fertilizers from primary resources, the FPR allows for the first time the use of secondary raw materials and promotes waste-based fertilizers in line with the goals of the European circular economy. Since the FPR provides for a general openness to the expansion of additional CMCs and other adjustments through delegated acts, it institutionally favors *layering* and *patching*. The mechanism of delegated acts enabled the introduction of the CMCs 12–14, which can be classified as *layering*, because the new CMCs expand the FPR to adapt to technical progress. New nutrient recycling technologies and related expert knowledge informed and influenced policy change in the EU policy on fertilizers. However, the delegated acts not only allowed for incremental policy change but also provided institutionally privileged access and representation to scientific and technical experts, as revealed by the exclusivity of membership in the STRUBIAS working group (Huygens et al., 2017), thereby limiting broader public participation in the institutional discourse on nutrients.

In phase 3, since 2020, the policy discourse has continued to reference EU circular economy goals and promote sustainability in agri-food production. Additionally, it has directed specific attention to the exploration, definition, and marketing of secondary nutrient sources to ensure stable fertilizer supply. With the New Circular Economy Action Plan, the Commission considered revising other directives regarding nutrient recycling, classifiable as *conversion*, since existing policies like wastewater treatment and sewage sludge directives shall be re-purposed due to a change in policy objectives toward transforming the EU economy from a fossil-based economy to a bio-based one. The introduction of CMC 15 as a new instrument of the FPR served to supplement the existing ones and can be classified as *layering*. Additionally, the FPR is not only extended by new CMCs, but also continuously adapted to other policy areas. This mechanism can be classified as *patching*, because the existing policy instruments are adjusted to the current circumstances in response to changed contexts. The debate on the end-of-waste status shifted policy objectives regarding the extended use of secondary raw materials for fertilizer production, thereby raising the new and cross-sectoral policy issue of reconsidering when waste products no longer qualify as waste. The change in policy objectives and the introduction of the end-of-waste criteria in the FPR can be classified as *packaging*. Even though the Commission carried out regular public feedback consultations for the development of the new CMCs and any amendment in the form of delegated acts, these consultations revealed a low level of participation in general (1 to 69 feedbacks in total), the dominance of business and science perspectives, and a low level of citizen participation. The institutionalized public feedback procedures did not achieve broad public participation, resulting in EU nutrient policymaking being characterized by highly specialized communication and practices based on expert knowledge and skills. Hence, it seems appropriate to qualify the EU's nutrient policy as a depoliticized policy area, which is largely removed from public scrutiny and debate. Scientific and technological advances in nutrient recovery and recycling inform the introduction of new policy instruments, the adjustment of existing ones, as well as change in policy objectives. The EU simultaneously promoted the spread of research funding lines and projects to assess and develop new technological approaches of nutrient recovery for fertilizer production. Moreover, policy orientation toward technological innovation became an official component of policymaking (delegated acts) in the context of the FPR. One could argue that the complex issue area of nutrient policy particularly highlights policymakers' reliance on expert input and scientific knowledge in policy change, and their institutional responses to new challenges through specialized institutional arrangements (Tosun et al., 2019), thereby maintaining policymaking largely in a routine mode (Feindt et al., 2021).

6 Conclusion

This study has directed attention to the evolution and implications of the EU's policy on nutrients oriented toward technological innovations. The empirical findings reveal evolutionary policy change in EU nutrient policy which is marked by the establishment of several policy portfolios that address various sectoral policies: water, critical raw materials, circular economy, fertilizer, and waste. While in the 2000s policy attention was directed toward environmental challenges caused by nutrients (eutrophication), resource scarcity (peak phosphorus), and economic dependency on nutrient imports, the focus in the mid-2010s shifted to nutrient recycling to ensure the EU circular economy approach through enhanced nutrient efficiency, self-sufficiency and economic value and to close the nutrient-food loop. The ongoing renewal of the FPR and integration of secondary raw materials as input materials for fertilizing products broadens the perspective on stable fertilizer supply but also raises new cross-sectoral policy challenges, especially between the wastewater and agricultural sectors (Schwindenhammer and Gonglach, 2021). These include definitional challenges regarding the end-of-waste criteria and specific risk assessment challenges. With the processing of previous waste streams into fertilizer products, it must be clarified which directive applies in which area. In the case of fertilizing products for the European market, the FPR now regulates the end-of-waste criteria for specific waste products. This novel instrument in the FPR can be interpreted as a reaction to the changing policy objectives, as it now promotes the reuse of secondary raw materials. Furthermore, the amendment of the new four CMCs provides the opportunity to use wastewater-derived nutrients in the form of certain production processes for fertilizer production, but still leaves out other technological approaches to recovery.

The promotion of nutrient recycling in European nutrient policy is based on the premise that environmental and economic benefits can be achieved simultaneously through technical solutions, research, and development. New technological approaches to reusing recycled nutrients in agri-food production are viewed as an opportunity to reduce the EU's dependence on non-renewable, imported phosphorus and manufactured nitrogenous fertilizers. This topic has gained urgency, especially given the economic impacts of Russia's war on Ukraine, which has led to rising food and fertilizer prices (Laaninen, 2022). Even though nutrient recycling can contribute to a more resilient and sustainable European agri-food system, it will not be achieved by technological innovation alone. Interlinking the many actors and stakeholders along the agri-food value chain is necessary to reach broad societal consensus among farmers, the fertilizer industry, the food industry, consumers, and other actors involved in logistics, distribution, and retail (EIP-AGRI Focus Group on Nutrient Recycling, 2017). However, the EU nutrient policy process is predominantly shaped by expert knowledge and the privileged access of experts, resulting in a specialized discourse. This creates a challenge, as varying interests and perspectives on achieving a sustainable and resilient EU agri-food system may lead to societal conflicts. For instance, while some stakeholders might focus on the use of renewable nutrient resources, others could express concerns about the unknown environmental impacts or the perceived (real or imagined) risks associated with recycled products (EIP-AGRI Focus Group on Nutrient Recycling, 2017). It could be argued that the EU policy on nutrients has yet untapped potential to increase public awareness about resource efficiency, the current state of finite resources, such as phosphorus, and the benefits and constraints of new technologies that allow the recovery and reuse of nutrients. However, the current policy process and the resulting depoliticization of the policy area involve the risk of the topic losing sight from broader societal debates and the public interest. Increasing technical complexity of technological innovation adds to this tendency. Future research needs to focus on the potential and constraints of science-policy interactions, the conditions for success and specific manifestations of (de)politicization strategies of different policy actors, and the options for ensuring broader societal participation in debates on agri-food policy. This is not only to raise acceptance of novel technological approaches but also to legitimize wide-reaching changes.

Data availability statement

The raw data supporting the conclusions of this article will be made available upon request by the authors, without undue reservation. Requests to access these datasets should be directed to sandra.schwindenhammer@sowi.uni-giessen.de.

Author contributions

SS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. DG: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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