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ORIGINAL PAPER

Identifying and Overcoming Circular Economy Barriers in the Agriculture of Southwest Finland – a Gap Framework Approach

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Abstract
Growing environmental pressures and resource constraints highlight the need for agricultural systems to transition from linear resource use toward circularity. Despite global interest in circular economy (CE) solutions for food systems, practical implementation at farm level remains limited. This study examines barriers to adopting CE practices among farmers in Southwest Finland and considers what these barriers imply for advancing circular nutrient and material flows. Using qualitative responses from a survey ($N=389$), we applied an adapted PEST framework together with conventional content analysis to inductively classify reported barriers. We then organised these barriers within a gap framework, linking them to perceived gaps between farm-level practices and the policy, market, and infrastructural conditions required to implement circular economy solutions. Farmers most often highlighted inadequate financial steering and high upfront costs, bureaucracy and restrictive regulation, limited local partners and underdeveloped exchange systems for recycled inputs, and agronomic and practical concerns. Overall, the responses suggest that adoption is constrained not only by farm-level willingness or knowledge, but by system-level lock-ins such as weak markets and logistics for recycled inputs and incentives that favour linear solutions. The study contributes to the CE literature by showing how structural barriers are experienced at farm scale and by illustrating the value of integrated barrier analysis for agricultural CE transitions. Based on the reported constraints, the results point to the need for more coherent incentives, reduced administrative burden, and market- and service-system development to support CE adoption in Southwest Finland and comparable contexts.

Keywords Agriculture · Circular economy · Gap framework · PEST analysis · Sustainability transition

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Introduction: The Nutrient Cycle Gap

The agricultural sector faces increasing pressure to adopt sustainable practices that minimise environmental impact while maintaining productivity. This pressure stems from growing global awareness of climate change, environmental degradation, and resource scarcity. The pressure from governments, international organisations, and consumers to adopt more sustainable agricultural practices has increased with increasing awareness of climate change, biodiversity, and food security. Economic incentives and regulatory frameworks are increasingly being aligned with sustainability goals, further driving the need for a transition towards more sustainable and resource-efficient agricultural systems. [1, 2]. One of the most important sustainability problems in global agriculture is the disruption of biogeochemical flows [3]. These flows are among the key boundaries to the planet's carrying capacity, and their state is of exceptional concern [4, 5]. Owing to the artificial fertilisers used in cultivation, the cycles of nitrogen and phosphorus have accelerated many times faster than natural ones, contributing significantly to eutrophication in aquatic ecosystems.

The concept of a circular economy (CE) offers a framework for restoring balance. In contrast to the traditional linear "take-make-dispose" model, the CE emphasises resource circularity, waste minimisation, and ecosystem regeneration [6, 7]. This transition is particularly relevant in agriculture given its deep and inextricable dependence and impact on natural systems [8].

This study aims to identify the specific barriers faced by farmers in the context of Southwest Finland ahead of the transition to a CE. Figure 1 illustrates the analytical framework of the study. The underlying driver is the gap between the current situation, characterized by poor nutrient cycles and excessively high nutrient emissions, and the desired future situation, in which strong nutrient cycles enable the minimization of environmental harm. The transition to a CE was examined as a means of bridging this gap.

Using a gap framework and PEST analysis, we systematically analyse qualitative survey responses from local farmers to uncover the barriers preventing the widespread adoption of circular practices. The methodology not only highlights the discrepancies between current practices and the desired state of a CE but also provides a framework for understanding the underlying reasons for these barriers. To our knowledge, no prior study has as comprehensively addressed CE adoption barriers in agriculture within a vulnerable region like Southwest Finland, thereby providing a previously unaddressed lens for sustainable agricultural transition.

The approach of this study is normative: in addition to identifying the challenges, it offers practical solutions to support the CE transition in agriculture. By revealing the barriers between current practices and the CE model, we can propose policy reforms and practical tools tailored to farmers' diverse needs. The insights are intended to inform policymakers, agricultural stakeholders, and the farming community, contributing to a more sustainable and resilient agricultural system in Southwest Finland.

Related studies have been conducted internationally (e.g., [9–11]) and nationally (e.g., [12–14]), but none have focused comprehensively on CE barriers in agriculture specific to a vulnerable region like this. Kokkonen [15], for instance, studied the barriers to the introduction of gypsum treatment on farms located in the Archipelago Sea catchment area. Our study builds on this type of work by broadening the scope to include a wider range of

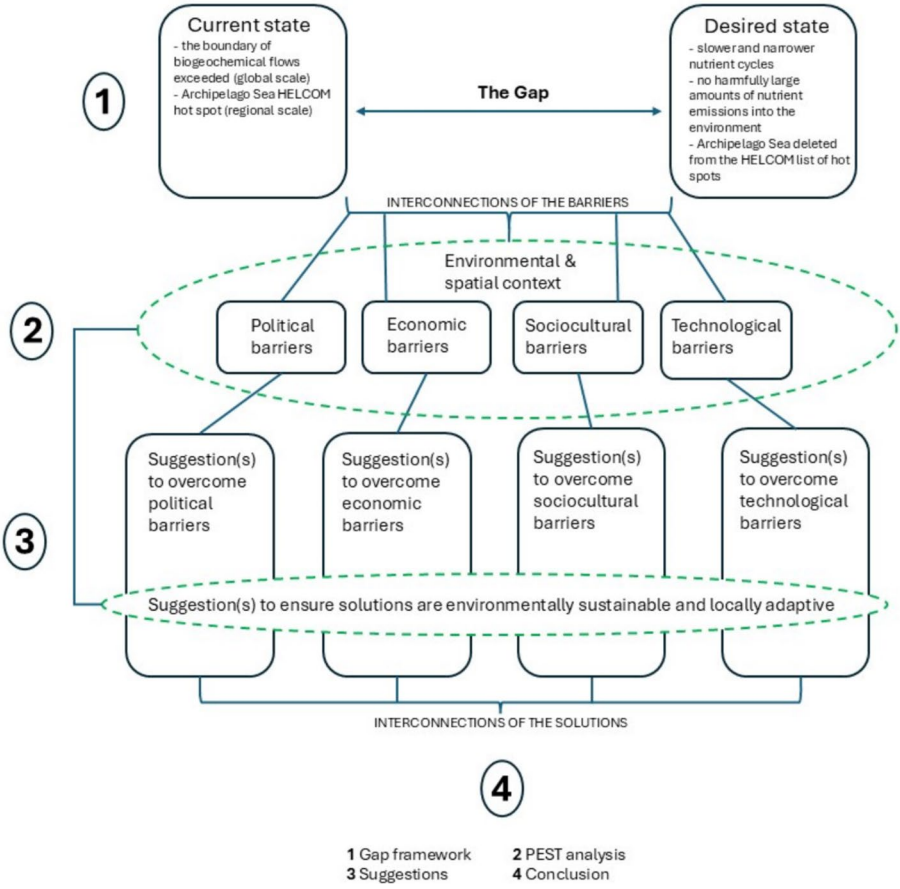

Fig. 1 Analytical framework illustrating the gap between the current and desired agricultural system in Southwest Finland and the PEST barriers that maintain this gap

circular practices and providing a more comprehensive analysis of the factors influencing CE adoption in agriculture.

Southwest Finland, a region with a diverse agricultural landscape and significant contribution to the national economy, is uniquely positioned to lead the way in the transition to a CE within the agricultural sector. The environmental conditions in the region for producing food are among the best in Finland and may improve further as the climate changes [16, 17]. Significant amounts of untapped food production side streams have been identified in the region [18, 19]. There is a concrete desire to promote a circular economy in both the provincial strategy [20] and the business sector [21].

The region also faces acute ecological pressures. The Archipelago Sea, which mostly belongs to Southwest Finland, is the only Finnish marine area on HELCOM's [22] list of critically polluted hot spots, mainly due to nutrient runoff from agriculture. Finland has committed to deleting the Archipelago Sea from the list by 2027 [23], which has served as a political driver to make concrete decisions to curb nutrient emissions from agriculture. Despite this context, the adoption of CE principles among local farms remains limited.

Understanding the barriers to this transition is essential for developing effective policies and support mechanisms.

The research questions are as follows:

1. What are the key barriers preventing farmers in Southwest Finland from transitioning to a circular economy?
2. How do these barriers manifest in everyday farming practices and decision-making?
3. What factors should be addressed to overcome these barriers, and which actors hold responsibility for doing so?

Theoretical Framework: Circular Economy Transition in Agriculture

The Transition of Agriculture to a Circular Economy

The CE offers a strategic approach to agriculture by optimising the use of limited resources, minimising environmental impacts, and enhancing the sector's economic viability [2, 24, 25]. To achieve this, it is paramount to understand the methods by which agricultural systems can adopt CE principles and establish metrics for evaluating progress.

Implementing a CE in agriculture involves narrowing resource cycles [8]. Instead of relying on external energy sources transported over long distances and allowing nutrients to leach into the environment, the goal is to maximise the efficiency and longevity of resources already present within the system [26]. This can be accomplished through various strategies, such as improving resource efficiency by reducing the reliance on virgin raw materials, minimising waste and emissions, and adopting regenerative farming practices like organic fertilisation, diverse crop rotation, and no-till farming [27–30]. The selection of these methods must consider the specific context of the farm and its integration into the broader agricultural and food systems, as well as its relationship with nature and society [26, 31].

The transition to the CE in agriculture is intricately linked to the broader societal objective of liberating ourselves from fossil fuel dependency [30]. A crucial aspect of this transition is the identification of alternatives to oil-based fuels and natural gas-dependent fertiliser production. Furthermore, agriculture has the potential to contribute to fossil-free energy production by utilising its byproducts as feedstock for biogas generation. Through such measures, agriculture can play a vital role in advancing the CE and promoting a broader sustainability transition across societies [28]. However, key challenges remain, starting from the lack of a universally accepted definition of circular economy [26, 32, 33].

Transition Barriers

Policy Barriers Some politicians may feel a responsibility to defend farmers so that they can continue their business as before [9]. The monetary and other public support granted to agricultural activities encourages maintaining the current situation rather than continuously developing [10, 34]. Farmers, however, object to their business being controlled from the outside and not having the right to decide how they develop their operations [12]. In the agricultural transition, the main regulatory issue is that the policies and legislation maintain the dominant regime and restrain change [10]. In agriculture, inadequate and inconsistent

legislation makes it particularly difficult to collect and treat side streams [34]. Ghisellini et al. [35] call for legislation that directs agriculture closely connected to nature to adapt to the natural functioning of ecosystems. They see regulation as important, specifically in the transition phase from linear to circular.

Economic Barriers A special economic issue in the agricultural transition is the already difficult financial situation of the sector in Finland and many other countries. This reduces farmers' willingness and readiness to invest in unconventional practices [34]. If investments bring no immediate benefits or risk reducing income, most prefer to stick to the established methods [13]. By following the principles of the linear economy, the surrounding society prefers to support conventional production [13], which hampers the economic viability of CE activities [36]. Conti et al. [9] view agriculture as constrained by the dominant growth narrative of capitalist economics, where even short-term reductions in growth are discouraged.

Sociocultural Barriers In the agri-food sector, markets are still shaped by linear economy conventions, making it difficult to trade side streams and recycled inputs due to the lack of established buying and selling networks and uncertainty in both supply and demand [10, 36]. Part of the problem lies in technological and food-related biases, for instance, municipal waste-based fertilisers are often avoided due to concerns about contaminants [9]. These attitudes are reinforced by limited communication, knowledge gaps, and a lack of credible, inspiring showpieces [10]. The agricultural sector needs more validated practices and visible innovators to show that breaking with convention can lead to better performance and growth. While farmers are sometimes criticised for conservatism, transition is also hindered by fragmented and poorly communicated information [10, 34]. Even when guidance exists, it is often fragmented or difficult to access. Given their limited time and resources, many farmers rely on familiar, low-risk practices rather than investing in learning and experimenting on their own. Long-standing habits, such as growing the same crops year after year, are reinforced by intergenerational knowledge and concerns that change could reduce yields or damage soil and crop health [9, 11, 37].

Technological Barriers Agriculture is marked by strong technological path dependency: existing tools and practices are so entrenched that many farmers see little reason to replace them with more efficient alternatives [9]. This inertia is compounded by the fact that CE technologies in agriculture are no more advanced than those in other sectors are, and when available, they often increase the costs borne by farmers [34]. Training in CE technologies is limited, leaving farmers to initiate learning independently. A notable example is the switch from mineral to organic fertilisers, which raises concerns about soil compaction. Unprocessed manure and digestate contain high water content and lower nutrient density, requiring larger application volumes or multiple passes, both of which increase compaction risks [11]. Additionally, farmers are cautious about adopting unfamiliar nutrient management techniques, such as gypsum treatment, and prefer clear, context-specific evidence of benefits [15]. While long-term research supports the positive effects of gypsum under appropriate conditions [38, 39], farmers remain hesitant without practical, field-based validation. This caution is understandable given the potential agronomic risks and lack of accessible, targeted guidance.

Materials and Methods

Gap Approach and PEST Analysis

The gap approach is a widely applied analytical framework used to identify and understand the differences between an existing (current) state and a desired (target) state in social, organizational, or policy contexts [40–42]. By systematically examining these discrepancies, the approach helps reveal the key barriers or challenges that prevent achieving the targeted goals. This enables prioritizing interventions and resources effectively to bridge the gap and reach the desired outcome. The gap framework has proven useful across diverse fields, such as sustainability transitions, organizational change, and public policy evaluation, providing a structured method to diagnose issues and devise strategies for improvement.

Since the gap approach is not in itself a research method, a separate method is needed for barrier identification. To identify the key barriers to the CE transition, we employed PEST analysis. This method is traditionally used to group the most significant external factors influencing a firm's operations. The method was developed by Francis J. Aguilar in the 1960 s [43, 44], which was later expanded to incorporate Environmental factors (PESTE) and Legal factors (PESTEL). In this study, we use the original PEST framework, with the letter S, instead of Social, referring more broadly to Sociocultural factors. We combine Legal Barriers with Policy Barriers, as politicians are responsible for making laws in Finland and the European Union.

We treat the environment here as a cross-cutting context that constrains and interacts with political, economic, sociocultural, and technological barriers, rather than as a separate barrier category. This reflects a theoretical understanding of agriculture–environment relations, where "the environment" comprises distinct, system-specific contexts rather than a single entity with its own agency [3, 8, 45].

PEST(EL) analysis has been used to study factors affecting the adoption of new practices and technologies, among others, in the context of carbon capture and storage solutions [46], waste management [47–49], automotive industry [50, 51], and agri-food supply chains [52]. As Gupta [44] and Sandberg et al. [53] note, PEST, PESTE, and PESTEL are "mnemonics", differing mainly in factor categorisation, with overlapping, nonexclusive categories.

Survey

We sent the survey to primary agricultural entrepreneurs who had declared an address located in Southwest Finland and who participated in the application for agricultural subsidies in 2022. The survey was open from 30 November to 14 December 2022. The survey is part of a broader investigation into the challenges and opportunities faced by agricultural entrepreneurs in adopting CE practices, intended to inform policy recommendations and support mechanisms. In this article, we present the main features of the survey and its objectives; a comprehensive description of the survey methodology, including the development of the questionnaire and sampling procedures, can be found in Hynni et al. [54]. The questionnaire is also accessible in Appendix 1.

To follow the gap approach, we built a questionnaire to identify obstacles and factors explaining these obstacles to the transition to CE modes of operation at the farm scale. In the survey, CE practices referred to replacing nonrenewable mineral fertilisers with organic alternatives, utilising production side streams both on and off the farm and improving nutri-

ent management. The respondents were also asked to define the concept of circular economy in their own words and to assess how effectively current agricultural policy supports the transition toward CE practices.

The questionnaire included closed-ended and open-ended questions, enabling respondents to provide quantitative data and qualitative insights into their experiences and perceptions of CE practices. The quantitative findings from the survey are reported in Hynni et al. [54]. In this article, we focus on the analysis of qualitative data.

Classification of the Open-Ended Survey Responses

In the survey, the respondents had the opportunity to describe in their own words the factors they see as hampering or preventing the introduction or use of CE practices. We compiled the responses into question-specific Excel tables and used conventional content analysis [55] to classify each answer according to the barriers it addressed. The same response could be classified into multiple barrier categories. If the respondent indicated that they saw no barriers, such answers were classified into the No Barriers category.

The barrier categories were determined inductively. We did not provide the respondents with premade barrier categories in the survey because we thought this approach would help us discover barriers that previous studies had not identified. We executed the classification in three stages: first, we allowed categories to flow organically from the data. Second, we combined categories to reduce their number to a maximum of ten per question and repeated the same categories as much as possible from question to question. Third, we recombined the categories following the PEST framework [43, 44, 53] (Table 1; see also Chapter 2.2).

The classification was carried out by a single researcher, with the co-authors overseeing the process and participating in related discussions. The robustness of the method was ensured by coding the survey responses in multiple stages. The strength of conventional content analysis is in providing a detailed, nuanced account of the text, offering more depth than purely quantitative or summative approaches [55]. This is important to consider when interpreting the results.

Results

Survey Sample

We sent the survey to 4,167 primary farmers in Southwest Finland by email. There were 389 approved responses to the survey, from which the calculated total response rate was 9.3%. We present here the main features of the survey sample; more detailed information on the sample representativeness and the survey results can be found in Hynni et al. [54].

The average age of the respondents was 53.6 years. The youngest respondent was 18, and the oldest was 86 years old. 85% of the respondents were men and 15% were women. 33% had a university of applied sciences degree and 29.8% had a vocational school degree. 7% had completed only primary school. 36% of the respondents received at least three-quarters of their income from agriculture, 31% at most one quarter. The average size of the respondents' farms was 81.4 hectares, of which an average of 31.2 hectares (38%) were rented land.

Table 1 Categories used in the content analysis and their definitions

PEST category	Conventional content analysis	Definition
Policy and regulation barriers	Regulation/Policy	Agricultural policies and/or regulation do not sufficiently support the transition to a CE
Economic barriers	Economic Factors	The transition to a CE costs money that only a small percentage of farms have the means to invest
	Risk of Reduced Yields	A farmer fears that the change in operating methods will reduce yields and thus sales income
	Products Needed for Own Use	Production side streams are too valuable a resource to be diverted to off-farm use
Sociocultural barriers	Availability of Products/ Solutions	There are no CE products or solutions available
	Quantity/Quality of Byproducts	A farm generates too few or inappropriate side streams from a utilisation perspective
	Market/System Challenges	CE operations are not suitable for the current state of the food sector
Technological barriers	Technological Challenges	The transition to a CE also requires a transition to novel technologies

We supplemented the content analysis of the Policy and Regulation Barrier category with responses to a separate question about redesigning agricultural policy

64% of the respondents operated a farm whose main form of production was the cultivation of cereals or oilseeds, and 19% operated some other form of plant production. 18% operated a farm with predominant livestock production. 64% of the respondents' farms had at least one form of secondary production, the most common of which was the cultivation of cereals or oilseeds. Furthermore, 36% of the respondents engaged in other businesses alongside agriculture, such as machinery contracting. 85% of the respondents' farms were in conventional production, and the rest were in full or partial organic production.

A comparison between the survey respondents and the overall population of farmers in Southwest Finland in 2022 [56] indicates that the sample is highly representative. The age distributions and distributions of farmers by main production types are sufficiently similar to enable relevant analyses.

Results of the Classification

How Farmers Defined Circular Economy

The first substantive survey question asked respondents to define the concept of circular economy. Although the question was mandatory, 12% either declined to answer or provided invalid responses.

Overall, farmers most often described circular economy in practical, farm-based terms, especially as making use of side streams (Table 2). These definitions emphasised keeping materials in productive use by redirecting by-products and surplus flows back into farming or into other sectors. The goal, as several respondents framed it, is to reduce dependence on inputs brought in “from outside”:

Table 2 Most common definitions of the circular economy in the survey responses

Definition	% of respondents who mentioned the definition	Survey question
Utilization of side streams	25	12. Definition of circular economy
Recycling	20	
Circulation of matter	18	
Reuse	15	
Sustainable use of resources	13	

"*The utilization of previous production inputs and byproducts, materials classified as waste etc., so that the non-circular economy production inputs brought into the process from outside are as small a part of the total production inputs as possible*." -R99

"*On my own farm, we try to use livestock manure to replace the purchased fertilizers, even if we could obtain gas from the manure for heating and traffic fuel*." -R269

Farmers also equated circular economy with recycling, treating it as a central mechanism for turning waste into resources. In these definitions, recycling was not limited to materials alone but was sometimes extended to goods, raw inputs, and even energy flows.

A third recurring framing focused on the circulation of matter, particularly nutrient loops that resemble agricultural cycles. These answers often used short expressions to convey an intuitive "loop" logic:

"*From field to field*" -R161

Political Barriers Identified by Farmers

Across responses, farmers described policy and regulation as shaping what is practically possible, sometimes directly by limiting actions and sometimes indirectly by influencing markets and public acceptance. Regarding recycled fertilisers, one prominent concern was that consumer and public skepticism discourages their use in food production (Table 3). Respondents linked this to concerns about heavy metals, drug residues, and hormones. In their view, even if recycled fertilisers were agronomically feasible, perceived food-market risk pushes farms back toward mineral fertilizers.

Table 3 Most frequently mentioned policy barriers in the survey responses

Policy barrier	% of respondents who mentioned the barrier	Survey question
Inadequate financial steering/incentives and support	40	26. A view on agricultural policy development targets
	17	24. Barriers on improving nutrient management
Too much bureaucracy	22	26. A view on agricultural policy development targets
	5.0	19. Barriers to producing energy from side streams
Too strict regulation	14	17. Barriers to introducing and using recycled fertilizers

Respondents also criticised strict fertilising regulations, particularly phosphorus limits, which they felt restrict the full use of animal manure. Several highlighted that the barriers are not only regulatory but also practical: even where manure use is permitted, support for transport and spreading was described as insufficient or difficult to access.

For energy production from side streams, barriers were less frequently reported but followed a similar pattern: respondents pointed to bureaucratic obstacles such as complex permitting and certification processes. These administrative burdens were framed as discouraging investment and experimentation, especially when the potential benefits are long-term but the administrative costs are immediate.

More broadly, some respondents expressed deeper frustration with agricultural governance. Farmers described policy as short-term and inconsistent, which they felt undermines the long planning horizon needed for circular investments:

> "– *the erratic agricultural policy prevents long-term investments*." -R156

When asked how policy could better support CE principles, respondents most often proposed stronger financial steering: better compensation for circular practices, higher producer prices, direct subsidies for investments (e.g. equipment), and funding to allow farms to test new solutions..

A second cluster of suggestions focused on regulatory reform, either through reducing the overall burden or shifting from a penalty-driven system toward one that rewards positive practices:

> "*by removing regulations on the use of manure etc., there would often be a desire, but reporting etc. has been made so laborious that it is not done because of it. Easier to get fertilisers from the store*." -R184

Finally, a small number of respondents noted that farms in groundwater protection areas face additional fertilisation restrictions, further narrowing their range of options within environmental legislation.

Economic Barriers Identified by Farmers

Economic constraints emerged as the most consistently reported obstacle across several circular practices (Table 4). In relation to nutrient management, respondents repeatedly described alternative fertilisers and new practices as costly and financially risky. Recycled fertilisers were often perceived as more expensive than mineral fertilisers, even during periods when mineral fertiliser prices have been exceptionally high.

For energy production from side streams, economic barriers were described as even more decisive. As R135 put it, "*basic agriculture cannot cover experiments or take risks for one's own account.*" Others emphasised that energy production from side streams is only viable in regions where there is a surplus of organic material.

When considering changes in mineral fertiliser use, farmers also raised concerns about yield and quality risk. Several anticipated yield decreases or described maintaining yields with alternative inputs as uncertain. Underlying these concerns was the question whether the nutrient composition and release dynamics of replacement fertilisers can reliably meet

Table 4 The most frequently mentioned economic barriers in the survey responses

Economic barrier	% of respondents who mentioned the barrier	Survey question
(Initial) financial costs are too high	44	15. Barriers to changing the amount of mineral fertilizers used
	37	19. Barriers to producing energy from side streams
	26	17. Barriers to introducing and using recycled fertilizers
	20	24. Barriers to improving nutrient management
	6.1	21. Barriers to selling, exchanging, or transferring byproducts
Risk of declining income due to soil/plant quality deterioration	21	21. Barriers to selling, exchanging, or transferring byproducts
	19	17. Barriers to introducing and using recycled fertilizers
	10	15. Barriers to changing the amount of fertilizers used
	7.3	19. Barriers to producing energy from side streams
	5.8	24. Barriers to improving nutrient management
Economic unprofitability	21	19. Barriers to producing energy from side streams
	20	21. Barriers to selling, exchanging, or transferring byproducts
	13	24. Barriers to improving nutrient management
The transition requires additional work	10	24. Barriers to improving nutrient management
	5.3	19. Barriers to producing energy from side streams
	4.0	15. Barriers to changing the amount of mineral fertilizers used
	3.9	21. Barriers to selling, exchanging, or transferring byproducts
	3.4	17. Barriers to introducing and using recycled fertilizers

crop needs. Some respondents suggested that switching might force changes in crop choices or rotations, which would be difficult for farms with established production systems.

Some farmers also questioned whether diverting processing side streams to energy production is economically sensible if it reduces soil organic matter inputs or otherwise undermines field productivity, an example of how economic reasoning was frequently intertwined with long-term agronomic considerations.

When asked about selling, exchanging, or transferring by-products, farmers again highlighted weak profitability. Prices were described as too low or absent, while logistical costs (collection + transport) were often borne by the farmer alone. In addition, respondents stressed that agricultural by-products, such as straw and manure, may already be valuable on-farm, and removing them could disrupt nutrient balances:

"*I would suspect that the structure and properties of the soil will be adversely affected if the straw and plant waste are collected regularly*. –" -R277

Similarly, in responses about enhancing nutrient management, many pointed to the high cost of measures such as structural liming and the time required to implement them. Some respondents framed this as a broader economic contradiction: crops grown for sale generate income, whereas crops or measures adopted mainly to improve nutrient balance can appear as an expense unless they are compensated or clearly improve profitability.

Sociocultural Barriers Identified by Farmers

Sociocultural barriers were often described in terms of availability and connections. Almost half of the respondents referred to limited availability as a barrier to using recycled fertilisers (Table 5). In some cases, this meant that recycled fertilisers were simply not accessible locally in others, the issue was that supply fluctuates because it depends on how much residue is generated elsewhere. Even livestock farms noted that onsite manure production may be insufficient relative to the acreage they cultivate.

A related and frequently mentioned barrier to adjusting mineral fertiliser use was the lack of nearby partners. Respondents described difficulty finding farms or firms with whom they could exchange nutrients or by-products reliably. The issue was not only "no partners" but also systemic mismatches: those needing materials could not locate suppliers, while those producing side streams struggled to identify users:

"*I have not found a partner in Finland that would refine plastics and gauze into anything other than energy*." – R374

Several respondents also characterised the market for recycled products as underdeveloped. From their perspective, circular exchange requires networks, logistics, and intermediaries that currently do not exist or place too much responsibility on individual farms. For energy use of side streams, respondents noted that viable options are few—often reduced to the idea of building a biogas plant—while supporting services (manure handling, collection, etc.) are scarce. Some respondents also suggested that farms have become more isolated over time, making cooperation harder:

Table 5 Most frequently mentioned sociocultural barriers in the survey responses

Sociocultural barrier	% of respondents who mentioned the barrier	Survey question
Too few potential business partners in the vicinity of the farm	47	17. Barriers to introducing and using recycled fertilizers
	21	15. Barriers to changing the amount of mineral fertilizers used
	13	21. Barriers to selling, exchanging, or transferring byproducts
Underdeveloped market and systems	8.0	19. Barriers to producing energy from side streams
	7.2	21. Barriers to selling, exchanging, or transferring byproducts

"*This kind of culture was lost in the era of cheap oil, and rebuilding systems takes time*." -R270

Finally, a small number of respondents pointed to personal factors such as age or health, which made them less interested in reforming their fertilization practices and starting a new type of business. Most of these mentions (7/10) were in relation to energy production.

Technological Barriers Identified by Farmers

Technological barriers were most commonly raised in relation to fertiliser handling and application, where farmers contrasted the convenience of mineral fertilisers with the practical demands of organic alternatives. Respondents described how organic fertilisers differ in consistency and handling requirements, often making current equipment unsuitable (Table 6). This creates a barrier even where willingness exists, because adopting organic inputs can require additional machinery, contractors, and new work phases.

The most frequently cited issue was the risk of soil compaction. Respondents explained that spreading equipment designed for mineral fertilisers is typically incompatible with organic alternatives. Modern application equipment for organic fertilisers is also heavier, increasing the risk of damaging soil structure – particularly on clay soils common in Southwest Finland. The challenge was seen as most acute in spring when fields are soft after snowmelt and the application window is narrow. Early-sown crops such as sugar beet can further tighten this timing, while no-till farms face additional constraints because incorporation is not possible:

"*Getting replacement amounts of nutrients to the field often requires additional work and equipment (or a contractor), increased field traffic (at the wrong time) is challenging in terms of the structure of the clay soil*." -R278

Beyond compaction, respondents highlighted long-distance transport and limited access to appropriate machinery or contractors. These issues were often connected: because organic fertilisers require larger application volumes than mineral ones, logistics and equipment

Table 6 Most frequently mentioned technological barriers in the survey responses

Technological barrier	% of respondents who mentioned the barrier	Survey question
Risk of soil compaction due to heavier equipment	18	17. Barriers to introducing and using recycled fertilizers
	5.3	15. Barriers to changing the amount of mineral fertilizers used
Longer transport distances	11	17. Barriers to introducing and using recycled fertilizers
	2.6	15. Barriers to changing the amount of mineral fertilizers used
Accessibility of contractors and equipment	9.5	17. Barriers to introducing and using recycled fertilizers
	2.3	15. Barriers to changing the amount of mineral fertilizers used

needs scale quickly. As one respondent noted, compared with mineral fertilisers, organic options may require substantially greater spreading volumes and a dedicated work stage:

> "*Logistical challenges of recycled fertilisers. A large area would tie up large resources. Compared with chemical fertilisers, the application amounts of recycled fertiliser and manure are 20 times greater. Additionally, separate equipment and a separate work phase are needed for application*." -R9

Overall, farmers described technological constraints not as isolated technical problems but as practical bottlenecks that shape whether circular inputs are feasible within tight seasonal windows and existing machinery systems.

Discussion: Barriers to Circular Agriculture – and Suggestions to Overcome them

While the Results above are presented in the order of the PEST framework, in the Discussion we prioritise the barrier categories according to their perceived significance in the survey data. We justify the significance not only quantitatively with percentages, but also qualitatively by interpreting the difficulty and urgency of overcoming the barriers.

Economic Barriers

When deciding how to fertilise their fields, farmers in our study described economics as the primary filter through which alternative practices are evaluated. Organic fertilisers were perceived as more expensive than mineral ones. This price gap has persisted despite the recent surge in artificial fertiliser prices, driven by natural gas shortages and the war in Ukraine, because organic fertiliser prices have also risen [57]. Consistent with the global literature review by Mehmood et al. [34] and the survey study among landowners in North Savo region, Finland, by Sivonen et al. [13], our findings suggest that many farmers interpret changes in fertilisation as a financial risk rather than as a straightforward environmental upgrade.

Several survey respondents expressed concern that adopting organic fertilisers and new nutrient management practices might negatively affect crop yields and quality. However, most existing studies on the CE transition do not address yield impacts directly; instead, they emphasise potential benefits such as improved soil fertility (e.g., [34]). Approximately 30% of the informants in Kokkonen's [15] study conducted in the Archipelago Sea catchment area considered that an important reason for not using gypsum treatment was that they believed it would potentially reduce yields. In the study by Sivonen et al. [13], yield stability was rarely mentioned in the open-ended responses. Lima et al. [11] reported that some farmers in Sweden struggle to identify alternative nutrient management methods that meet crop requirements as effectively as mineral fertilisers do.

Even when respondents acknowledged the potential benefits of change, economic considerations often determine whether those changes are implemented. The farmers in our study perceived the financial and time costs of introducing organic fertilisers and enhancing nutrient management as outweighing potential savings or gains. This perception persists

even though, for instance, gypsum and its delivery are currently offered free of charge to farmers in Southwest Finland. The survey responses suggest that many farmers may not be fully aware of the financial support available for circular economy measures.

However, the lack of awareness among farmers is unlikely to be the primary barrier to their adoption of circular economy practices in a financially sustainable manner. As Conti et al. [9] suggest based on their global literature review, the greater profitability of environmentally harmful activities highlights a deeper systemic flaw in the Western economic model, where benefits are postponed and outcomes remain uncertain. Collecting and processing side streams entails upfront costs, whereas their market or exchange value remains relatively low.

The logic was evident particularly in responses about energy production from side streams, which was repeatedly described as capital-intensive and difficult to finance without complementary revenue streams. Previous studies (e.g., [12, 58, 59]) have identified high initial costs and limited access to financing as key barriers to CE adoption across sectors. Based on the findings of their case study on biogas production in Southwest Finland, Åkerman et al. [36] further argue that side stream utilisation becomes financially viable only when addressing a regional surplus issue. In our survey, R367 made a similar point: "– *That way, for example, "gate fees" are obtained, which helps to generate cash flow also from other than energy delivery. Collecting field biomass from plant waste, straw* etc. *is not profitably possible owing to the distances and variability of weather conditions.*". This highlights how logistical uncertainty and dispersed biomass supply can turn an otherwise promising CE option into a high-risk investment at farm and regional level.

Given these realities, agriculture is unlikely to undergo a broad transition to a circular economy unless it becomes economically viable for farmers. Fortunately, policymakers in Finland have tools at their disposal. Members of the Finnish Parliament could support CE-related investments through targeted tax incentives and Members of the European Parliament through reallocation of agricultural subsidies. Policymakers are fully entitled to favour small-scale or low-income farmers in such decisions.

However, in EU member states, agricultural subsidies are restructured only once per Common Agricultural Policy (CAP) funding period, typically several years long. While national implementation varies annually, these structural timelines mean that subsidy reallocations cannot address acute nutrient challenges in Southwest Finland, or elsewhere in the EU, in the short term.

Sociocultural Barriers

Many farmers in our survey justified their reliance on mineral fertilisers by citing the limited availability, or proximity, of alternatives. Even when organic fertilisers were currently accessible, their long-term availability would remain uncertain. As the respondents pointed out, mineral fertilisers, can be reliably produced on demand, require less storage space, and can be safely stored for long periods. Switching to organic options requires confidence that fertilizers will continue to be readily available. As Grafström & Aasma [58] in their theoretical analysis argue, this uncertainty stems from the broader linear economic system and the underdeveloped markets for recycled products.

In some cases, the underlying belief is that one's own practices are superior and have been strengthened over generations [9]. The Brazilian study by Gonçalves et al. [37]

revealed that farmers who had practised field burning for generations continued to view it as the best method, despite known health and environmental risks, illustrating how tradition can outweigh evidence in agricultural decision-making. However, our study did not find any indications that this would be a significant barrier to the reform of agriculture in Southwest Finland.

Furthermore, many farmers are reluctant to act as early adopters of unproven methods, preferring to wait until there is more reliable information about their utility [15]. Respondents described a preference for waiting until others have tested it, particularly when a practice could affect yields, compliance, or workload. This was most clearly visible in attitudes toward technological solutions such as gypsum treatment (see also 5.4): farmers were not necessarily rejecting the method in principle, but they wanted clearer evidence about outcomes, side effects, and practical requirements before committing.

Farmers also described barriers that arise not from the farm itself but from the immaturity of markets for recycled agricultural inputs. Because these markets are still emerging, respondents reported concrete difficulties in buying, selling, exchanging, or donating recycled products. Several conveyed a sense of exclusion from the system that they saw as being built around them rather than with them. Regulatory barriers also deter participation. While some respondents framed strict rules as insurmountable, others, echoing the findings of the circular economy study conducted by Kirveennummi and Vehmas [12] in the Turku region, viewed them as necessary. The tension reflects broader questions about whether economic activity should be primarily market-driven or publicly guided.

A further constraint was the mismatch between supply and demand for recycled materials, which respondents experienced as a coordination failure rather than a lack of interest. Uncertainty exists on both sides, and no established networks support the exchange of these inputs. Farmers struggle to find reliable partners for acquiring or offloading recycled fertilisers. This issue was also identified by Olvermann et al. [10] in their study among farmers in OECD countries, and by Åkerman et al. [36]. One respondent linked the decline in inter-farm cooperation to the era of cheap oil, a sentiment echoed by Aarikka-Stenroos et al. [60] in their triangulation study conducted in Finland.

Farmers interested in joint biogas production described parallel coordination and logistics problems: few feasible options exist for establishing plants, and long distances, weak networks, and a shortage of contractors hinder collaboration. Transporting unprocessed side streams over long distances has proven to be economically unviable [11, 31, 36].

Interestingly, only a few survey responses concerning reducing mineral fertiliser use considered alternatives beyond organic fertilisers. Broader nutrient management practices are currently more common on organic farms. On conventional farms, such practices are often adopted primarily to secure agri-environmental compensation. These findings suggest that farming culture is shaped by low-cost, easy-to-use mineral fertilisers. However, Sivonen et al. [13] reported that 90% of farmers in the North Savo region aim to improve their farm's natural nutrient cycle. This hints at a genuine interest in better practices, albeit constrained by a limited perception of available options.

The core market and system challenge in CE agriculture might be summarised as follows: the linear economy became so embedded in our food system thinking that it gave rise to distribution chains fundamentally incompatible with CE principles. Mehmood et al. [34] touched on this indirectly by noting that reconfiguring supply chains is part of the CE transition, which also provides opportunities to create new jobs. More critically, Conti et al.

[9] identified an entrenched productivist and technocentric mindset in food system development, one that threatens long-term sustainability. This mindset permeates not only business and politics but also agricultural and food research.

In Finland's market economy, political institutions are expected to shape the framework within which markets operate by (i) setting stable, long-term targets that reduce policy uncertainty; (ii) clarifying and streamlining permitting and compliance requirements; (iii) creating market rules that make products comparable; and (iv) reducing first-mover risk through instruments such as investment aid, operating support, public guarantees, or results-based payments tied to verified environmental outcomes. Meanwhile, companies are tasked with forging partnerships and developing new networks that secure feedstock and build logistics chains, and lower adoption friction for farms. Moving recycled inputs from projects to a predictable, investable market will likely require broad, cross-sectoral dialogue on the macroeconomic implications of reducing reliance on fossil-based and other nonrenewable resources. This discussion needs to include agricultural organisations, waste operators, logistics, agri-tech, fertiliser producers, and researchers as well.

Policy Barriers

Farmers consistently described the current policy environment as a barrier to improved nutrient management because regulations and incentives are perceived as misaligned with on-farm decision-making. This perception aligns with findings by Galvão et al.'s [59] global bibliometric study and by Kirchherr et al.'s [61] triangulation study among sustainability professionals in EU countries, who noted that policies rarely promote CE solutions. Respondents' accounts also help explain why such misalignment persists: as Grafström & Aasma [58] argue, policymakers often neglect CE advancement because of competing priorities and short policy cycles, which encourage short-term decisions. Conversely, some politicians may resist policy shifts to protect farmers from potential risks [9].

The respondents also expressed frustration over the lack of private-sector investment, which they attributed to low interest in agriculture. As a result, even when public funding is available, respondents felt that projects must fit dominant norms to be considered viable, leaving limited room for locally adapted experimentation. This dynamic contributes to a perceived lack of agency: farmers described being expected to deliver environmental improvements while having little influence over the criteria by which innovations are financed and evaluated. Similar frustrations were recorded in studies by Olvermann et al. [10] and Mehmood et al. [34].

Bureaucracy emerged as a consistent complaint — even in the absence of change. Farmers described regulatory processes as overly complex and time-consuming. They reported that the fragmented and inconsistent nature of available information adds to this burden, making it harder to navigate policy requirements and take advantage of potential support, as Olvermann et al. [10] noted. Several respondents voiced a desire to focus on their primary work, growing crops and raising livestock, rather than on administrative tasks.

Our findings suggest that there is room to improve how policymakers in Finland engage with the realities of agricultural entrepreneurship, especially on small-scale farms. While this might seem like a relatively straightforward task, agriculture is only one of many sectors that policymakers must understand. Strengthening the role of agricultural experts and consultants in advising decision-makers could help bridge this gap.

Regulatory indifference is also visible in how current laws have failed to keep pace with the evolving conditions of food production. This applies to a major part of the world, not just Finland. In Europe, attention has focused on the EU's CAP, which has repeatedly been seen as failing to set legally binding targets that would help mitigate rapidly escalating crises such as climate change and biodiversity loss [59, 60]. Updating the legal framework to enable the large-scale use of organic recycled fertilisers is a pressing need. Additionally, reducing bureaucratic hurdles in the permitting processes for biogas and recycled fertiliser production would encourage innovation. In practice, this could mean, for example, loosening the permit requirements without compromising safety and setting deadlines for processing permit applications. More broadly, reforms should support diverse nutrient management strategies for farmland.

Technological Barriers

Fertiliser equipment has traditionally been designed for mineral fertilisers, which are dry and consistent in quality. In contrast, organic fertilisers are more variable and often require entirely different machinery. Many farmers in our survey pointed to this technology–input mismatch, describing organic and recycled fertilizers as more heterogeneous in terms of nutrient composition, moisture content, and contamination risk. Similar technological lock-in has been noted by Grafström & Aasma [58] and Aarikka-Stenroos et al. [60].

In Finland, it is common to outsource fertiliser transport and application to contractors. Our respondents, however, reported a shortage of contractors who specialise in organic fertilisers. This matters because each stage, transport, storage, spreading, and side-stream handling, requires separate resources, creating a barrier for farms considering a shift to organic inputs. As Conti et al. [9] argue, investment is a major hurdle in adopting new technologies. Other studies (e.g., [10, 35]) suggest that responsibility lies with policymakers: when farmers cannot afford better technologies, it reflects a failure of political and institutional support. In their case study on the foot-and-mouth disease epidemic in England, Law and Mol [62] go further, asserting that technologies are inherently political, as they reshape socioecological relations across all levels.

Even where suitable machinery exists, respondents emphasised agronomic constraints that make organic fertiliser application technically and environmentally sensitive. The combination of heavy application equipment and the high water content of many organic fertilisers increases axle loads and raises the risk of soil compaction – particularly under Finnish weather conditions and short application windows. Farmers noted that mitigation strategies (e.g., more passes with lighter loads, narrower timing windows, or alternative field traffic patterns) can introduce new trade-offs: more passes increase labour and fuel use, and timing constraints may conflict with crop needs or weather variability. Concerns about soil degradation were voiced by our respondents and echoed in Lima et al.'s [11] study.

Finally, several technological barriers are fundamentally spatial. Using recycled inputs across farm boundaries remains uncommon, which means that producers and users of these materials are often located farther apart than suppliers and users of comparable virgin products. Respondents described transport as a decisive cost driver, especially for high-moisture, low-value materials. In Finland, the spatial separation of livestock and crop production intensifies this constraint [31]: manure-surplus regions face logistical and economic diffi-

culties supplying deficit regions over long distances [11, 36]. This also limits opportunities for shared biogas facilities and storage infrastructure.

Given the novelty of many CE technologies, farmers need access to information, training, and advisory services. Support is also needed to help entrepreneurs evaluate which measures suit their specific conditions and develop the necessary skills for implementation. The Finnish Food Authority, ProAgria, Economic Development Centres, Baltic Sea Action Group, and Biokasvu Oy, among others, already offer advisory services, but their accessibility is questionable given the current profitability situation in agriculture. Members of parliament in Finland and the EU could direct resources allocated to strengthen farmers' circular economy expertise to these organizations.

Overlapping Barriers

The boundaries between different types of barriers to the CE transition are often blurred. Many factors cut across categories, for instance, the fragmentation of the recycled product market is simultaneously a sociocultural, political, and economic barrier. Developing these markets requires entrepreneurs to build social relationships with one another and with other actors in the food sector. However, small-scale farmers often face difficulties entering these markets, whether mature or emerging, due to the substantial initial capital needed. Politicians can help level the playing field by building and maintaining platforms and forums that facilitate networking and cooperation, and by creating regulatory frameworks that support broad participation.

Agriculture has never operated in isolation from external forces. Food production is shaped by geographical features and historical processes, and is further influenced by political, economic, sociocultural, and environmental factors. These forces determine where farms are located, what types of food are produced, and how farms interact with each other and the wider agri-food system. In the context of the CE transition, geography becomes especially important. The feasibility and cost-effectiveness of circular practices depend heavily on farm location, proximity to other farms, and distances to input suppliers and output markets. Transporting organic fertilisers or side streams such as manure depends not only on farm-level choices but also on broader spatial conditions, including infrastructure and logistics.

Although environmental concerns were present in survey respondents' narratives, they rarely emerged as independent barriers. Instead, they were typically expressed through or entangled with political (e.g., regulation), economic (e.g., yield risk), or technological (e.g., uncertainty about environmental impacts) concerns. This finding suggests that environmental issues, while important, do not act as standalone barriers in the context of circular agriculture.

Human activities, including agriculture, are deeply embedded in and dependent on natural ecosystems. Food production relies on ecosystem services such as nutrient cycling, water availability, and biodiversity, while simultaneously shaping these conditions through land use, fertilization, and emissions [3]. Agricultural systems thus both influence and are limited by ecological boundaries, reflecting a complex interplay between human practices and environmental limits.

Although farmers generally want to operate in a way that respects the environment [11, 13], this is not always reflected in their actions. Failing to identify environmental limits as barriers might be a blind spot in current discourse. Thus, we claim that overcoming the CE barriers requires that all actors in the agri-food system fully recognise the foundational

role of the environment in food production. This begins with researchers producing and providing farmers with reliable, consistent information about CE practices and technologies, alongside practical training in their application. At the same time, it is important for researchers and companies to further develop circular technologies and recycled fertilisers according to CE principles to ensure that they meet agronomic needs. Finally, stronger communication between experts and policymakers is needed to craft agricultural policies that respond both to environmental demands and to farmers' real-world challenges.

Notes on the Context and Limitations

The farmer survey was conducted during a period when Russia's war of aggression in Ukraine and the volatility of the energy market affected the prices and availability of agricultural inputs. For this reason, when asking about past and anticipated changes in the use of mineral fertilisers, we used five-year time frames. Regardless, the period may have heightened salience of risk and cost concerns, which could amplify economic barrier mentions relative to calmer periods.

Owing to limited resources, the questionnaire was available only in Finnish. Although a significant portion of the target group consisted of Swedish-speaking farmers, our research team lacked the necessary language skills to produce a Swedish version. This limitation may have affected the response rate and the clarity of some responses and should be considered when interpreting the results. In addition, since responding to the open-ended questions was optional, respondents are unlikely to represent the full diversity of views among Finnish farmers: those with stronger interest in nutrient management or stronger grievances may be overrepresented.

As with qualitative survey data, the findings also depend on respondents' ability to articulate their experiences and intended meanings in writing, and on the researchers' ability to interpret those meanings consistently. This interpretive element is further emphasised by the translation of open-ended responses from Finnish into English. Certain terms (e.g., "by-products", "circular economy", "nutrient balance") may not map perfectly across languages and farming subcultures. We also acknowledge that, in the question regarding measures to improve nutrient management, the examples we provided may have influenced the respondents' answers.

Conclusions: Gap Summary

This study identified multiple barriers that farmers face when adopting CE practices. Figure 2 visually synthesises these barriers, illustrating how factors such as limited financial incentives, fragmented markets for recycled inputs, and geographic constraints collectively reinforce the preference for conventional agricultural methods. Additionally, it highlights proposed policy reforms, targeted support mechanisms, and coordinated market development as key strategies to reduce these barriers. Rather than viewing the barriers in isolation, the figure emphasises their interconnected nature and the need for holistic, multi-level interventions to facilitate a viable and attractive CE transition for the region's agricultural sector.

As both a profession and a business, agriculture is especially sensitive to economic pressures. Farmers have had limited access to funding, financial incentives, or regulatory

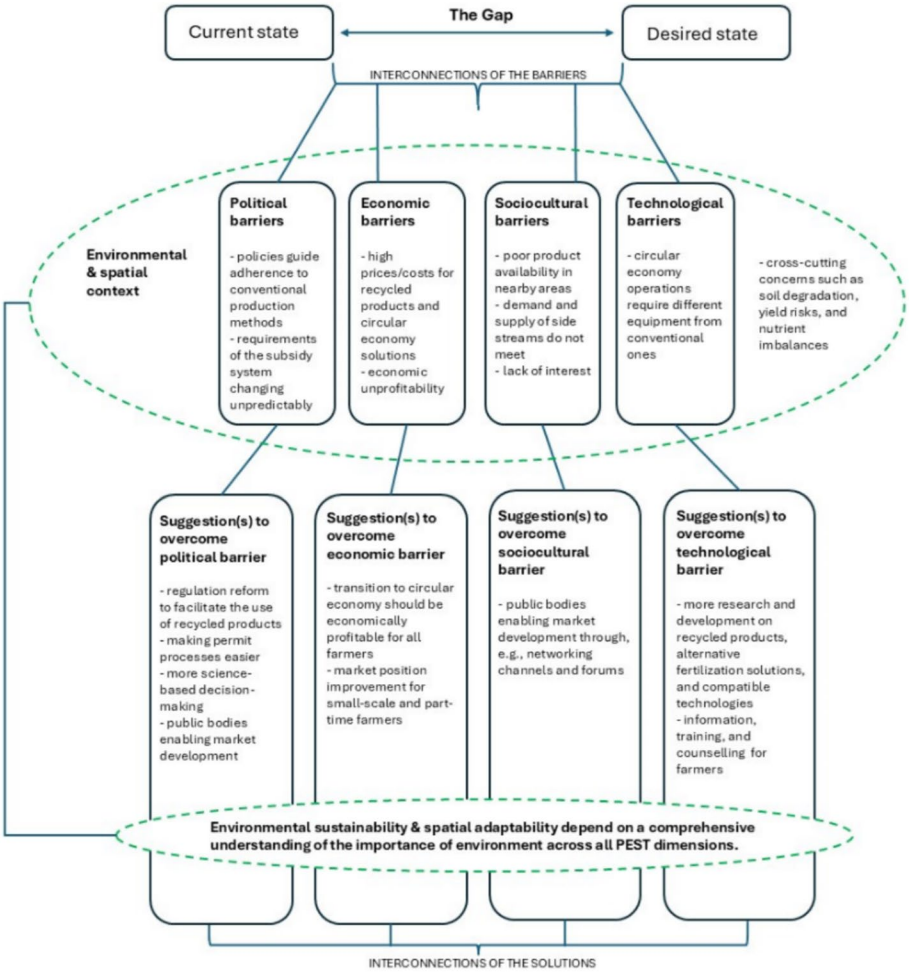

Fig. 2 The main barriers to the transition to a CE in Southwest Finland agriculture, and proposed measures to overcome them

support for transitioning to CE models. In Southwest Finland, the geographical separation between crop and livestock farms further complicates the use of each other's side streams. Combined with an underdeveloped market for recycled agricultural products, this makes conventional practices more appealing – virgin raw materials remain less expensive and readily available, and there is less risk of yield loss or other disruptions.

To make the CE transition viable and attractive, economic feasibility must be ensured. This includes the coordinated development of recycled product markets across the food system and a reorientation of agricultural subsidies to reward sustainable practices. Bureaucratic burdens should be reduced, and farmers should be supported through targeted training and advice tailored to CE-compatible methods and technologies.

The findings of this study also hold broader international relevance. Many of the barriers identified in Southwest Finland resemble those reported in agricultural regions elsewhere,

particularly with respect to economic constraints, technological lock-ins, regulatory inconsistencies, and underdeveloped markets for recycled inputs. At the same time, the points at which our results diverge from previous research highlight the importance of local geographical, institutional, and production-specific conditions in shaping how CE transitions unfold. These insights indicate that while certain barriers are globally widespread, successful transition pathways must be adapted to regional contexts. By applying a structured gap framework to farmer-level qualitative evidence, this study offers a transferable approach that can support the development of agricultural CE strategies in other regions facing similar sustainability challenges.

This study was qualitative, drawing on farmers' narratives and experiences. In addition to such research, practical development work is needed to improve organic fertilisers, nutrient management solutions, and circular food systems suited to specific geographical contexts. However, R&D efforts will have a limited impact unless their results are effectively implemented. To support this, agricultural policy and decision-making should increasingly be grounded in evidence-based knowledge, with a particular focus on the sustainability challenges facing the agri-food sector.

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Authors Contribution **Antti Hynni**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Visualization, Writing—original draft, Writing—review & editing. **Jukka Käyhkö**: Conceptualization, Methodology, Project administration, Supervision, Writing—review & editing. **Tuomas Kuhmonen**: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing—review & editing.

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Declarations

Competing interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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