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A living lab approach to promote sustainable management of agricultural peatlands in Finland

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Solution-oriented approaches are crucial for identifying the leverage points to promote sustainable management of agricultural peatlands in Finland. This study used a living lab approach to co-create policy measures and actions to mitigate and reduce greenhouse gas emissions from drained agricultural peatlands. This study contributed to narrowing the gap between high-level sustainability ambitions and their practical implementation by demonstrating how a living lab can operationalise transdisciplinary collaboration in a contested land-use context. The living lab required collaboration between different scientific domains and the wider society by including interdisciplinary scientists and practitioners from outside academia. The living lab enabled mutual learning processes between science and society to promote a shared understanding between science and society for the co-creation of acceptable solutions and transition pathways. The dichotomy between the cultivation of drained peatlands for food production and the urgent need to mitigate climate change by reducing greenhouse gas emissions could be solved by targeting interventions or leverage points that can change mind sets and values regarding the importance of productive peat fields in producing food to ensure food and nutrition security, farmers' livelihood, and rural vitality in Finland. Restructuring agricultural policies in Finland as well as in the EU could be easier if there is a shared perception between science and society that removing drained peat fields from cultivation would not threaten these key aspects. This study revealed conditional openness among farmers to reduce cultivation on less productive peat soils if adequate incentives are provided, therefore resistance to change is not absolute but closely tied to concerns over fairness, livelihoods, and regional viability, thus highlighting the importance of just transition measures.

Key words: climate change, greenhouse gas emissions, food system, transdisciplinary collaboration, co-creation, just transition

Introduction

Unsustainable development occurs when economic, social, environmental, and political systems are exploited in ways that deplete resources, harm ecosystems, create inequalities, and jeopardise the well-being of present and future generations (Kates et al. 2005, Rockström et al. 2009). Despite substantial attention to sustainability in science and policy, societies are increasingly operating beyond safe planetary boundaries, partly because dominant sustainability approaches have struggled to engage with the structural and socio-political root causes of unsustainable development (Abson et al. 2017). These root causes are complex, path-dependent, and deeply embedded in existing production systems, underscoring the need for solution-oriented approaches for transformational change.

The Dasgupta Review calls for fundamental changes in how societies think, act, and measure economic success in order to protect and enhance both human prosperity and the natural world (Dasgupta 2021). While such calls for transformation are now widely recognised at policy level, there remains a persistent gap between high-level sustainability ambitions and their translation into context-specific, socially acceptable practices on the ground. Achieving transformative change requires robust and continuous commitment from actors at multiple levels. Accordingly, sustainability science has increasingly emphasised the involvement of actors from outside academia to integrate diverse forms of knowledge, reconcile values and preferences, and foster ownership of both problems and solution options (Walter et al. 2007, Lang et al. 2012, Lin 2023, Käyhkö et al. 2025). The three primary goals of sustainability science defined by Kates et al. (2001) — understanding nature–society interactions, steering these interactions towards sustainability, and fostering social learning — remain only partially realised in practice.

Transdisciplinary research is particularly relevant when knowledge is uncertain, problem framings are contested, and the stakes are high (Pohl and Hirsch Hadorn 2008). These conditions are clearly present in the management of peatlands drained for agricultural use (hereafter, agricultural peatlands), where scientific uncertainty persists regarding the climate and ecological performance of alternative land-use pathways, societal problem framings diverge between food production and climate change mitigation, and the stakes are high in terms of climate targets, just transitions for rural communities, and long-term sustainability. Yet, despite growing recognition of peatlands as critical for climate change mitigation (Humpenöder et al. 2020, Strack et al. 2022), there is limited empirical research on how transdisciplinary approaches can be operationalised in practice to reconcile these competing objectives in concrete land-use and policy contexts.

Living labs have emerged as a state-of-the-art approach to research and innovation across several domains, including agriculture; and they are designed to enable co-creation in real-life settings through multi-method approaches and active multi-stakeholder participation (Cascone et al. 2024). A central feature of living labs is their emphasis on mutual learning between science and society, whereby knowledge is co-produced through iterative interaction among diverse stakeholders (Hakkarainen and Hyysalo 2013, Hossain et al. 2019). Although living labs are increasingly promoted as promising platforms for sustainability transitions, empirical evidence on how such mutual learning processes translate into policy-relevant and socially acceptable solutions in contested land-use systems remains limited — particularly in relation to climate change mitigation measures that directly affect livelihoods and rural land-use practices. This challenge is especially pronounced in the use of agricultural peatlands, where efforts to reduce greenhouse gas (GHG) emissions often require fundamental changes in land management with significant implications for farmers and rural communities. Thus, beyond the broader need to operationalise transdisciplinary approaches, there is a need to better understand how mutual learning processes shape the co-production, negotiation, and implementation of sustainability interventions in practice. This represents a critical research gap, as the effectiveness and legitimacy of sustainability interventions depend not only on their technical performance but also on their social acceptability and governance feasibility.

The use of carbon-rich peatlands constitutes a particularly pressing sustainability challenge (Vasander et al. 2003, Temmink et al. 2023). Extensive drainage for agriculture, forestry, and peat extraction has resulted in substantial anthropogenic GHG emissions, estimated globally at 119–232 Mt carbon dioxide equivalents (CO₂eq.) in 2023, with agricultural use generating the highest emissions per unit area (van Giersbergen et al. 2025). In Finland, approximately 342 000 hectares of drained peatland under cropland or grassland were estimated to emit 9.8 Mt CO₂eq. from agricultural production, making peatland cultivation the largest source of emissions within the Agriculture and Land Use, Land-Use Change and Forestry (LULUCF) sectors (Statistics Finland 2025). Beyond climate impacts, peatland drainage has contributed to biodiversity loss, increased nutrient loading to ground and surface waters, elevated flood risks, and land subsidence (Maljanen et al. 2010, Bonn et al. 2016, Minayeva et al. 2017, Ikkala et al. 2021, Koivunen et al. 2023). Although the biophysical rationale for protecting and restoring peatlands is well established, far less is known about how socially acceptable transition pathways can be co-developed with land users and other stakeholders in agricultural peatland contexts, where land-use change directly affects food production, rural livelihoods, and local identities.

These challenges are closely intertwined with questions of justice in sustainability transitions. Lonkila et al. (2024) highlight that making the transition fair requires going beyond simply compensating losses, but also about dealing with the underlying inequalities that already exist. In the agricultural context, Puupponen et al. (2022) show that Finnish dairy farmers are concerned about potential restrictions on the use of agricultural peatlands, which are often perceived as distributionally unjust since farmers typically have limited choice over the location of their farms and the soil types of their fields. Moreover, constraints on cultivation methods and production lines may threaten livelihoods and undermine past investments. These concerns are echoed in broader discussions among Finnish food system stakeholders, who additionally emphasise the importance of food security, the diversity of farming systems, and the need to ensure that farmers' perspectives are meaningfully included in decision-making processes (Huttunen et al. 2024). Together, these findings underscore that mutual learning processes can serve as critical arenas in which questions of fairness, responsibility, and legitimacy are actively negotiated.

In Finland, peatland use has deep historical roots, supported by long-standing subsidy schemes and regulatory frameworks aimed at converting “unproductive” land into productive and prosperous landscapes (Lampela et al. 2026). While public awareness and policy support for peatland restoration are increasing, including through updated national policies and the EU Nature Restoration Law, stakeholder consensus on how to implement these goals in agricultural peatlands remains limited (Tolvanen et al. 2013, Sommer and Frank 2024, Lampela et al.

2026). This creates a concrete governance problem: ambitious climate and biodiversity targets exist, but there is a lack of practically grounded, co-created policy instruments and implementation pathways that are perceived as legitimate and feasible by farmers and local communities. Addressing this gap requires not only transdisciplinary engagement, but also carefully designed processes of mutual learning that can translate diverse forms of knowledge and values into actionable and context-sensitive policy measures.

Against this backdrop, the objective of this study was to apply a living lab approach to co-create policy measures and actions to mitigate and reduce GHG gas emissions from agricultural peatlands through transdisciplinary collaboration between actors from science and society. This study further adopted a leverage points approach to identify key intervention points within the food system, with a particular focus on deep and transformational leverage points related to how knowledge is produced, shared, and used in sustainability transitions. Specifically, this study addressed two research questions: RQ1 — how a living lab operationalises transdisciplinary collaboration between science and society for reducing GHG emissions from agricultural peatlands in Finland; and RQ2 — how different stakeholders frame the trade-offs between food production, rural livelihoods, and climate change mitigation.

The living lab brought together farmers, local community members, scientists, government representatives, private companies, and non-governmental organisations (NGOs). Farmers and local communities were considered key stakeholders, as changes in farming practices and land management are central to reducing GHG emissions from agricultural peatlands and require local legitimacy to be socially viable. The living lab explicitly facilitated mutual learning processes between science and society, enabling iterative knowledge exchange, joint problem framing, and the co-development of socially acceptable solutions. Through these mutual learning processes, this study attempted to foster a shared understanding of trade-offs and synergies, while identifying incentives from both public and private sectors to support the implementation of feasible policy measures. Ultimately, this study sought to promote three principal outcomes for the food system: (i) food and nutrition security, (ii) livelihoods and fair incomes, and (iii) environmental sustainability together with climate change mitigation.

Material and methods

The transdisciplinary research process of the living lab

The transdisciplinary approach integrates multiple scientific disciplines around shared societal problems and actively involves practitioners from outside academia to steer the food system towards more sustainable pathways, requiring collaboration across scientific domains and engagement with the wider society (Herrero et al. 2019, Lang et al. 2012, Brandt et al. 2013). Figure 1 illustrates how this transdisciplinary research process was operationalised in the living lab.

Transdisciplinarity is defined as a reflexive, integrative, and method-driven scientific principle that simultaneously addresses societal challenges and interconnected scientific problems by integrating knowledge from diverse societal actors and multiple scientific disciplines (Lang et al. 2012). In this study, the central societal problem is the drainage of peatlands for agricultural food production, which generates substantial greenhouse gas emissions and accelerates climate change, while the corresponding scientific problem concerns knowledge gaps and uncertainties related to the role of drained peatlands in climate change mitigation (see Figure 1). The main engagement arena comprised of farmers and local community members collaborating with interdisciplinary researchers from the natural sciences (peatland and soil sciences) and the social sciences (economics, political science, sociology, and communication studies).

The transdisciplinary research process (see Figure 1) relies on mutual learning between science and society embedded in societal and scientific discourses that sought to integrate societal and scientific pathways (Lang et al. 2012) to address: (1) limited understanding of peatlands' role in climate change mitigation; (2) divergent perceptions among farmers, local communities, government representatives, private companies, and NGOs regarding the importance of peatlands; (3) limited communication between natural and social scientists; (4) differing interpretations of on-site GHG emission studies; and (5) challenges in aligning scientific findings with practical knowledge. The living lab enabled capacity building and mutual learning among researchers and non-academic actors to co-create solution-oriented, socially robust, and transferable knowledge, fostering shared understanding among food system actors to support substantial reductions in GHG emissions from agricultural peatlands.

The Living Lab Integrative Process (Zimmermann et al. 2023) was used to co-create the “problem space” and subsequently the “solution space” through participatory problem framing and team building (e.g. selecting land-use

practices, integrating stakeholders, identifying barriers), followed by co-designing solutions, examining interventions, and evaluating policy measures to reduce GHG emissions from agricultural peatlands. The goal was to enable the identification of leverage points to promote food system transformation for sustainable management of agricultural peatlands in Finland (see Figure 1).

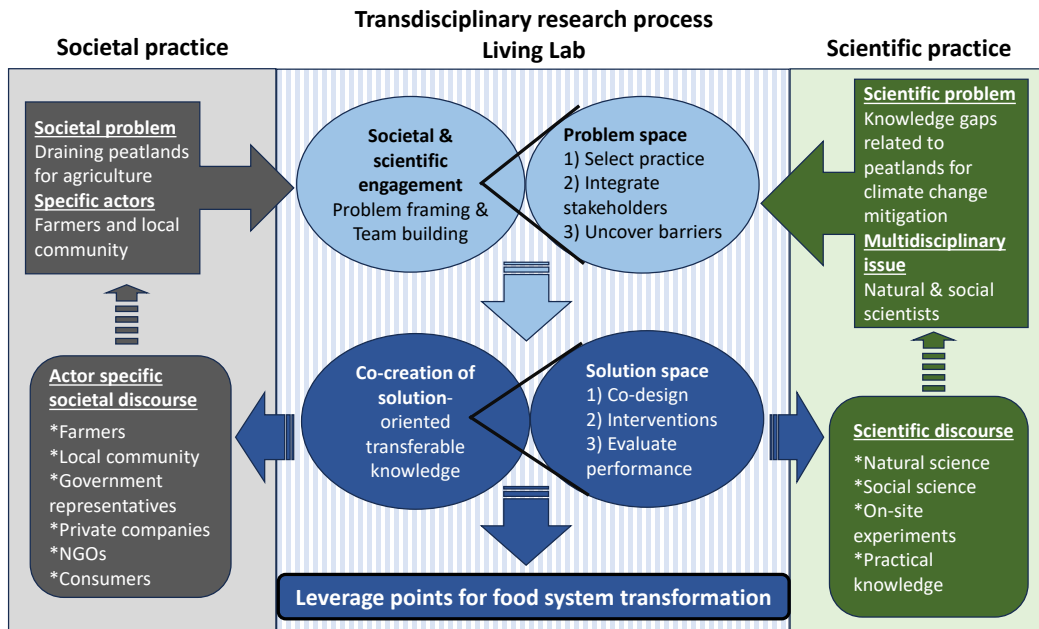


Fig. 1. Transdisciplinary research process via a living lab to identify the leverage points for food system transformation (adapted from Lang et al. 2012 and Zimmermann et al. 2023)

Meadows (1999) identified a hierarchy of twelve leverage points, where shallow interventions are relatively easy to implement but bring only minor changes to a system, meanwhile deep leverage points may be difficult to accomplish but more likely to cause transformational changes in a system. Abson et al. (2017) aggregated Meadows' twelve leverage points equally into four broad types of system characteristics — parameters, feedbacks, design, and intent — from the shallowest to the deepest, whereby the capacity of the leverage point to affect change is constrained by its hierarchy in the system. Subsequently, shallow leverage points are potentially constrained or structured by deep leverage points. The paradigms, mind sets, and values (i.e. intent for food and nutrition security) in the food system are essential in shaping the institutions of the food system (i.e. design of the EU Common Agricultural Policy). The institutions in the food system would determine the characteristics and strength of the feedback loops in the system (e.g., "greening" requirements where farmers must follow specific environmental practices to receive full direct payments). The intent, design, and feedback loops shape the parameters for interventions to adjust behaviour in sustainable land-use management. Understanding the interactions and power dynamics between deep and shallow leverage points is crucial in solving sustainability issues in the food system. Deep leverage points hold more transformative power but face greater resistance, while shallow leverage points are easier to manipulate but often reinforce existing power structures.

Design of the living lab

Living labs are designed to address complex issues involving diverse stakeholders in real-life environments from different backgrounds and disciplines focusing on the iterative process of co-developing solutions, including testing and validating sustainability initiatives (Niitamo et al. 2006, Dell'Era et al. 2019, Hossain et al. 2019). The cultivation of drained peatlands for food production is a complex and politically driven issue in Finland (Huan-Niemi et al. 2023), therefore a living lab was used for co-creating policy measures that account for local, regional, and national needs to mitigate GHG emissions from agricultural peatlands. The interventions for reducing GHG emissions from agricultural peatlands in Finland may be easier if regions with lower share of agricultural peatlands are targeted first, and agriculture is not the main source of income for the local community (Huan-Niemi et al. 2023). Therefore, the research and evaluation of the living lab was implemented in Nurmes (Valtimo), located at the North Karelia region (eastern part) of Finland, because Nurmes has a lower share of agricultural peatlands compared to the western and northern part of Finland. Furthermore, Nurmes has a substantial proportion of pensioners;

consequently, acquiring agricultural land for farm expansion is not a pressing issue as farmland is available due to retiring farmers (Simola 2024). Two mentors, retired farmers who are active in the local community, were recruited to the living lab for guidance and advice dealing with farming and the local community in Nurmes. The farmers and local community members in Nurmes were recruited by the mentors for the semi-structured interviews conducted in the living lab. The mentors brought trust and reliability among farmers and local community members in Nurmes as well as practical and local knowledge to the living lab.

This study was continuing the first stage (first three years of a 6-year research project) of the research (Phase 1: see Figure 2) to produce action-oriented knowledge for sustainable management of peat soils in Finnish agriculture, whereby the research results were published in Huan-Niemi et al. (2023). In the first stage (Phase 1), action-oriented knowledge emerged when integrated ways were utilised with various kinds of knowledge involved in the shared design/co-creation of solutions needed for sustainable management of agricultural peatlands (Caniglia et al. 2021). Action-oriented knowledge could promote critical actions to significantly reduce GHG emissions from agricultural peatlands by identifying and defining incentives from both the public and private sectors in Finland. The research results from Phase 1 (Huan-Niemi et al. 2023) indicated that an iterative research process was not sufficient to transform the food system towards sustainability, hence a deliberative research process would be needed to engage the most affected stakeholders (farmers) together with local communities and other actors in the food system in a practical, meaningful, and collaborative way. The iterative research process (Huan-Niemi et al. 2023) was continuously refining and improving the research approach, methodology, findings based on feedback, new insights, results obtained in previous cycles to ensure that the research was rigorous, thorough, and continuously aligned with its objectives (see Appendix 1). The deliberative research process (Burchardt 2014) was enabling the integration of knowledge from researchers and stakeholders in a collaborative transdisciplinary undertaking aiming at a mutual learning process as well as to increase the legitimacy and acceptance of solutions (see Appendix 2).

In Figure 2, the blue arrows represented the iterative process of planning of the activity, observing and evaluating the data collected from the activity, reflecting on the results of the activity, and back to planning the next activity after in-depth analysis (horizontal line of the diagram in Figure 2). The co-created information/knowledge after in-depth analysis was channelled to each living lab activity to serve as the background and base information for the conducted living lab activities: semi-structured interviews, focus group discussions, and different workshops. The grey arrows were to show that the previous activities served as a base for the next activity of the living lab after the deliberative research process to enable the integration of knowledge from researchers and stakeholders via mutual learning processes. The intention was to find policy-relevant and socially acceptable solutions in contested land-use systems — particularly in relation to climate change mitigation measures that directly affect livelihoods and rural land-use practices.

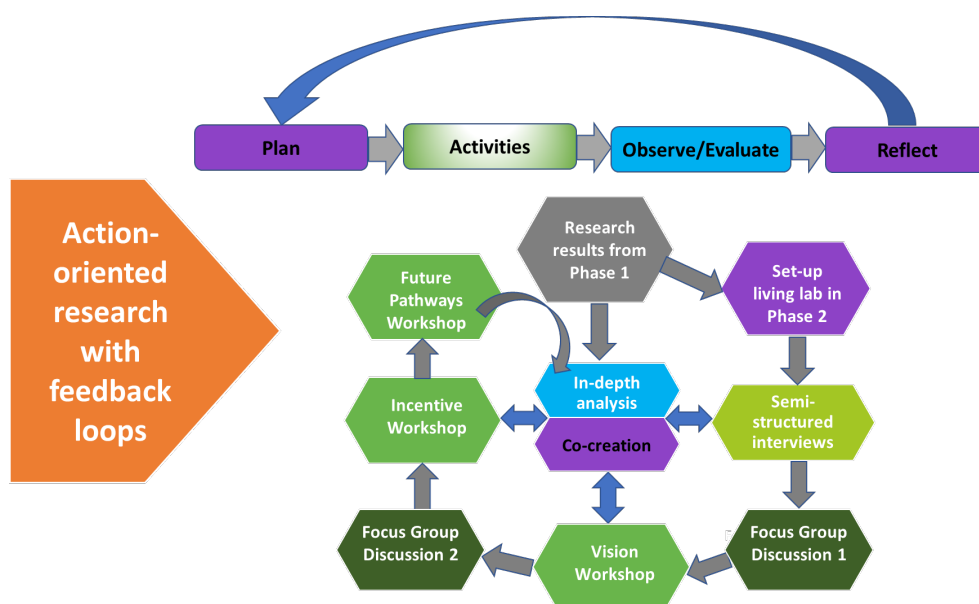


Fig. 2. Action-oriented research via a living lab (adapted from Huan-Niemi et al. 2023)

The living lab was set-up to incorporate the deliberative research process to promote mutual learning among diverse stakeholders from the food system under the second stage (following three years of a 6-year research project) of the research (Phase 2: see Figure 2). The living lab activities were implemented in a 3-year period and supported by informational feedback loops from semi-structured interviews, focus group discussions, workshops as well as the in-depth analysis of the conducted activities (see Figure 2). The living lab activities were to facilitate mutual learning processes between science and society to enable iterative knowledge exchange, joint problem framing, and the co-creation of policy-relevant knowledge and socially acceptable measures to mitigate and reduce GHG emissions from agricultural peatlands in Finland.

The living lab created a transdisciplinary, real-life platform for continuous interaction among diverse food system actors such as farmers, local community members, scientists, government representatives, private companies, and NGOs. The different actors' participation in the living lab activities was based on informed consent. According to the Finnish National Board for Research Integrity, no ethical review was needed because the participation was informed, voluntary, not addressing sensitive issues of minority groups, and would not harm the participants. In addition, the personal data and details of the participants were kept anonymous as well as all living lab activities adhered strictly to the rules of the General Data Protection Regulation (GDPR).

The living lab activities

Design and interpretation of the semi-structured interviews

The interviews were executed to collect essential background and base information for developing a shared understanding among relevant actors in the food system and finding important policy measures as well as incentives to mitigate/reduce GHG emissions from agricultural peatlands. The interviews (a combination of thematic and narrative interviews) were conducted with nearly fifty stakeholders (see Appendix 3) from the local, regional, and national levels consisting of farmers (n=10), local community members (n=11), government representatives (n=10), private companies (n=11), and NGOs (n=7). The stakeholders were interviewed on the issue of cultivating peatlands in Finland for food production and the urgent need to mitigate climate change by reducing GHG emissions. All interviews were recorded and transcribed for further analysis by the researchers in the living lab. The thoughts and views from consumers were conveyed by private companies (food companies and retailers) who have interactions with consumers.

The transcripts from the interviews were analysed using qualitative content analysis to extract and synthesise stakeholders' perceptions of peatland cultivation and sustainable management as well as to inform the design of the workshop processes and focus group discussion. For the interviews with farmers and local community members, the analysis focused on the meanings attached to peatlands, current peatland uses, and views on potential solutions for reducing GHG emissions from peatlands in the Nurmes context. Interviews with government representatives centred on interpretations of the role and value of peatlands and on perceptions of the potential and importance of reducing GHG emissions at the national level. In the interviews with private companies and NGOs, the analysis examined meanings attributed to peatlands, actions already implemented or envisioned, and perceptions of the roles of their respective organisations and sectors in reducing GHG emissions from peatlands. Interviews with farmers and local community members lasted between an hour and 2.5 hours, while interviews with government representatives, private companies, and NGOs lasted between 30 minutes and one hour.

Design of the focus group discussions

The need for more information instigated the focus group discussions with peatland scientists from Nordic and Baltic countries. The semi-structured interviews demonstrated that there was a need to explore and assess the available measures for mitigating/reducing GHG emissions from agricultural peatlands. Therefore, peatland scientists from Nordic and Baltic countries with similar or quite similar climatic conditions (boreal or hemi-boreal region) were invited to the first focus group discussion for exploring and assessing the different measures for mitigating/reducing GHG emissions from agricultural peatlands along with the impact on water quality and biodiversity. The measures for mitigating/reducing GHG emissions encompassed a range of general management options proposed in both public and scientific forums. There were altogether nine participants in the focus group discussion from Finland (n=2), Sweden (n=2), Latvia (n=2), Estonia (n=2), and Lithuania (n=1) along with a moderator and co-moderator from Finland. A Menti poll was conducted to rank the explored measures according to the participants' opinions on the effectiveness of the list of measures for reducing GHG emissions, their impact on water quality, and their impact on biodiversity over a 20-year time scale.

The same peatland scientists, who had participated in the first focus group discussion, were invited to the second focus group discussion (refinement of the research question, methodology, and approach) to concentrate only on GHG emissions from agricultural peatlands. To facilitate the discussion, the peatland scientists compiled estimates of GHG emission factor from soils (measured in tons of CO₂ equivalents per hectare per year) for combined carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) emissions from agricultural peatlands across various management options in boreal and temperate climate zones (the emission factors are presented in the Results section for focus group discussions). Many of the estimates for the emission factor were derived from the Tier 1 category of the Intergovernmental Panel on Climate Change (IPCC) reporting framework (IPCC 2014). If available, the peatland scientists incorporated estimates from recent scientific literature that addressed management practices not encompassed within the IPCC framework. Therefore, consensus was required from all participants on the ranking of the different measures according to emissions factors (refer to the Results section: Table 2).

Furthermore, the ranking of different measures for agricultural peatlands also take into account their feasibility and ease of implementation by farmers and local community members (results from the Vision workshop described below) because in the first focus group discussion, peatland scientists requested specific feedback concerning the feasibility and ease of implementation at the farm level. There were altogether five participants in the second focus group discussion from Finland (n=1), Sweden (n=1), Latvia (n=1), Estonia (n=1), and Lithuania (n=1) along with a moderator and co-moderator from Finland. The second focus group was smaller to facilitate debate and in-depth discussions on the scientific evidence for each discussed measure to mitigate/reduce GHG emissions from agricultural peatlands. Both focus group discussions were recorded and transcribed for further analysis by the moderators.

Design of the Vision Workshop

The aim of the workshop was to provide more information and set a base for understanding the role of peatlands in addressing climate change together with sustainable management of peat fields at the farm and local level. The interviewed farmers (together with their spouses) and local community members were invited to the Vision Workshop organised onsite in Nurmes. There were twenty-six participants in the workshop consisting of natural and social scientists (n=8), farmers (n=8), and local community members (n=10). The ranking of the different measures to reduce GHG emissions from agricultural peatlands (refer to the Results section: Table 2) by peatland scientists in the first focus group discussion was explained and discussed in the workshop in addition to providing specific information on the agricultural peatlands in Nurmes. Furthermore, results from the interviews with farmers and local community members were discussed, thus questions raised in the interviews were answered in the workshop. The main goal was to build a shared understanding on peatlands not only among farmers and local community members, but also among the multidisciplinary scientists. Finally, a Menti poll was administered (only for farmers and local community members) to rank the different measures for agricultural peatlands according to their feasibility and ease of implementation on farm along with their preferences for future management of peat fields.

Design of the Incentive Workshop

The objective of the workshop was to bring together actors from public and private sectors to reflect on their role in sustainable management of peatlands as well as to jointly co-create solutions and policy actions that could achieve significant reductions in GHG emissions from agricultural peatlands. The interviewed representatives from governmental organisations, private companies, and NGOs were invited to the Incentive Workshop that was held onsite in Helsinki. There were twenty-three participants in the workshop consisting of natural and social scientists (n=9), government representatives (n=7), private companies (n=4), and NGOs (n=3). The workshop served as a forum for discussing the stakeholders' views on using peatlands for food production along with the crucial need to mitigate climate change by reducing GHG emissions. Relevant information regarding GHG emissions from agricultural peatlands was shared in addition to the polling results and reasons behind the rankings of measures to mitigate GHG emissions from agricultural peatlands by scientists (according to scientific evidence) versus farmers and local community members (according to feasibility and ease of implementation on farm).

Design of the Future Pathways Workshop

The goal of the workshop was to collaboratively identify incentives from both the public and private sectors in Finland as well as to develop a shared understanding between relevant actors in the food system for creating actions and related policy measures to significantly reduce GHG emissions from agricultural peatlands. The workshop built on prior workshops held in Nurmes (Vision Workshop) and Helsinki (Incentive Workshop) as well as

the conducted interviews. All interviewed stakeholders were invited to the Future Pathways Workshop organised onsite simultaneously in Nurmes and Helsinki as well as online via Microsoft Teams. Farmers and local community members along with one scientist (as the moderator) attended the workshop held onsite in Nurmes whereby online participation was also possible. Scientists, government representatives, and private companies attended the workshop held onsite in Helsinki with online participation as well. The workshops in Nurmes and Helsinki were connected through video conferencing between the two sites via Microsoft Teams. There were twenty-eight participants in the workshop consisting of natural and social scientists (n=10), farmers (n=4), and local community members (n=5), government representatives (n=6), and private companies (n=3). The participants both onsite and online formulated future pathways for agricultural peatlands by using the Backcasting method to foresee the future along with the necessary steps to determine current and viable actions for sustainable management of agricultural peatlands in Finland.

The steps for the Backcasting method were: 1) set the vision for 2050; 2) established a timeline; 3) worked backward to determine the critical milestones needed at different timeline to reach the goals; 4) analysed feasibility and acceptability of the proposed actions and policies; and 5) created an action plan or concrete steps to take actions in the near-term. Backcasting is a strategic planning method that starts by defining a desirable future goal and works backward to the present to identify the necessary steps, actions, and policy changes required to achieve it. Unlike forecasting, which projects current trends forward, the Backcasting method is used for complex, long-term challenges where transformative change is needed. Backcasting is particularly effective in situations where the current trend is not leading to a desirable future, especially concerning real-world peatland governance in Finland.

Results

The results from the conducted living lab activities addressed two research questions (RQ1 and RQ2) by showing how the living lab operationalised transdisciplinary collaboration between science and society for reducing GHG emissions from agricultural peatlands in Finland (RQ1) as well as unveiling how different stakeholders framed the trade-offs between food production, rural livelihoods, and climate change mitigation (RQ2). Results from the living lab generated empirical insights into mutual learning processes and the co-production of knowledge in a real-world peatland governance context.

The living lab implemented transdisciplinary collaboration between science and society by creating an iterative, real-life platform for the co-creation of policy-relevant knowledge and socially acceptable measures to mitigate GHG emissions from agricultural peatlands in Finland (RQ1). In contrast to a conventional case study, which primarily documents and analyses a predefined situation, the living lab enabled continuous interaction, experimentation, and feedback between farmers, local community members, scientists, policymakers, private companies, and NGOs. Through semi-structured interviews, focus group discussions, and successive workshops, scientific knowledge on emission factors and mitigation potentials was integrated with local and farmers' knowledge on farming practices, economic constraints, and social acceptability. The two-step prioritisation of sustainable measures for peatland management — first by farmers and local community members based on feasibility and ease of implementation, and subsequently by peatland scientists based on mitigation effectiveness — demonstrated how the living lab facilitated reciprocal learning and the co-production of actionable knowledge. The process further led to the co-identification of public and private incentives necessary for translating abstract climate goals into context-sensitive and practically feasible policy options.

Diverse actors in the food system (participants of the living lab) framed the trade-offs between food production, rural livelihoods, and climate change mitigation in distinct but partially overlapping ways (RQ2). Farmers and local community members emphasised farm-level feasibility, income security, and the continuity of local food production, while peatland scientists prioritised mitigation potential and ecological effectiveness, and concurrently policymakers and private actors highlighted regulatory feasibility and incentive structures. Initially divergent problem framings were progressively aligned through deliberative dialogue, as the participants of the living lab gained insight into each other's constraints, values, and knowledge bases. Building on earlier living lab activities, the last workshop enabled participants to jointly articulate long-term sustainability goals for 2050, co-create policy measures and incentive systems for 2035, and define near-term actions. This forward-looking, pathway-oriented co-creation process helped stakeholders collectively frame the complex challenge of using drained peatlands for food production and identify acceptable transition pathways for reducing GHG emissions from agricultural peatlands. Overall, the living lab induced mutual learning between interdisciplinary scientists and actors from outside academia to produce a coherent, stakeholder-endorsed framework for the sustainable management of agricultural peatlands in Finland — outcomes that extend beyond what a conventional case study approach could achieve.

Semi-structured interviews

Table 1 is showing the list of seven agreements together with the two different perspectives among the diverse food system actors interviewed in the living lab. The most important agreement (based on the authors' interpretation) is to cease the clearance and drainage of peatlands for agriculture as well as the willingness to remove thick peat fields (i.e., fields with thick organic soil layer) from cultivation for *environmental sustainability and climate change mitigation*. Policy measures aimed at reducing GHG emissions in Finland from agricultural peatlands may be easier in areas where there are less peat fields and agriculture is not the main source of income for the local community (i.e. Nurmes). Farmers and local community members in Nurmes support no more clearing and drainage of peatlands for agricultural use because acquiring agricultural land for farm expansion is not a pressing issue as well as farmland is available due to retiring farmers in Nurmes. The interviewed stakeholders would target primarily fields with thick peatlands and low yields for afforestation and restoration instead of productive peat fields that are cultivated. Furthermore, a land exchange system for farmers would be needed to provide fields with mineral soils for cultivation in exchange for peat fields earmarked for afforestation and restoration.

Table 1. The list of common understandings along with different perspectives and views among the interviewed actors in the food system

Agreement among actors in the food system	Farmers	Local community members	Government representatives	Private companies & NGOs
1) Importance of agriculture: producing food, ensuring farmers' livelihoods, maintaining farm and rural vitality, and preserving cultural landscapes.	✓	✓	✓	✓
2) Primarily target fields with thick peatlands and low yields by removing these fields from cultivation as well as restoring or afforesting these fields.	✓	✓	✓	✓
3) No more clearing of peatlands for cultivation or agricultural use.	✓	✓	✓	✓
4) There is a lot of uncertainty and lack of information, and more research is needed.	✓	✓	✓	✓
5) Land exchange system to provide fields with mineral soils for farmers in need of exchanging peatlands from cultivation.	✓	✓	✓	✓
6) There is no political will to solve the issue of peatlands in cultivation.	✓	✓	✓	✓
7) The costs of reducing emissions from peatlands cannot be compensated through the market.	✓	✓	✓	✓
Different perspectives among food system actors	Farmers	Local community members	Government representatives	Private companies & NGOs
1) The removal of peatlands from cultivation does not jeopardize Finland's food security and is not significant for the national economy.	X	X	✓	✓
2) The huge role of peatlands in GHG emissions, and the strong pressure on agriculture to reduce GHG emissions.	X	X	✓	✓

Relevant to *livelihoods & fair income*, stakeholders emphasised on the importance of agriculture to ensure the livelihoods of farmers along with maintaining farm and rural vitality. All interviewed stakeholders have the perception that agriculture is significant for producing food, ensuring farmers' livelihoods, maintaining farm and rural vitality, and preserving cultural landscapes. At the same time, interviews from the private sector indicated that the market system has the potential to change the current food system; specifically, private companies' own climate goals and the EU legislation on corporate responsibility and sustainability reporting that induce motivation to limit GHG emissions in supply chains. Consequently, changes in the procurement criteria of large food companies could have significant impact on the food supply chain. Actors from the food companies explained that there are indications of companies' reluctance to purchase food products with large carbon footprint caused by drained peatlands. The implementation of the EU taxonomy regulation could accelerate the 'green transition' of the finance sector, hence affecting the economic viability of farms with peat fields. The market-driven transformation may prohibit a just transition for farmers and local communities with high shares of agricultural peatlands.

Moreover, all groups of interviewed stakeholders believe that there is no political will in Finland to solve the issue of peatlands in cultivation even though drained peatlands are a significant source of GHG emissions and a contributing force to climate change. Actors from the private sector and NGOs indicated that they have been so far reluctant to take leadership in issues connected to peatlands and independently take actions, especially for cooperative based food companies. Additionally, the interviewed stakeholders have different perspectives on the role of cultivating peatlands in Finland to preserve *food & nutrition security* (see Table 1). Farmers and local community members gave the impression that peatlands should not have a strong role in agriculture for climate change mitigation because peatlands are needed for food production in Finland, and they do not agree to remove productive peat fields from cultivation; however, they agree to target and remove fields with thick peat soils and low yields from cultivation by restoring or afforesting these peat fields. All interviewed stakeholders agreed that there is a lot of uncertainty and lack of information related to peatlands (including the magnitude of GHG emissions from drained peatlands) and more research is needed. Currently, the costs of reducing emissions from peatlands cannot be entirely compensated through the market system due to the lack of information and uncertainty in the compensations systems.

Focus group discussions

The first focus group discussion revealed more concrete information on the available and effective measures for sustainable management of agricultural peatlands because based on the results from the semi-structured interviews, the actors of the food system wanted additional information on the available measures for peatlands. The second focus group discussion provided in-depth information on the ranking of these measures according to the estimated emission factors as well as ease of implementation at the farm level together with acceptance of local community (see Table 2).

Table 2. Ranking results (from 1–9, 1 being the most preferred) from the focus group discussions with peatland scientists, concerning the different land-use/management measures according to their emission factors and ease of implementation at the farm level

Focus group discussion with peatland scientists (1 +2); Ranking the different land-use/management measures according to their <u>emission factors</u> and <u>ease of implementation</u>.		
Different measures to reduce GHG emissions	Boreal and Temperate zone GHG emission factors for organic soils (tons CO₂ eq. ha⁻¹ y⁻¹)⁽¹⁾⁽²⁾	Data availability (CO₂, CH₄, N₂O) / Notes
1. Protection of intact peatlands	--	Considered as avoided emissions by IPCC
2. Afforestation of former cropland/grassland	34.4*/24.9* → 4.3**	*Drained cropland/grassland from IPCC 2014; **Jauhainen et al. 2023
3. Restoration and rewetting of degraded peatlands	34.4*/24.9* → 3.1**	*Drained cropland/grassland from IPCC 2014; **IPCC 2014
4. Conversion of annual crops to permanent grasslands	34.4* → 24.9**	*Drained cropland from IPCC 2014; **Drained grassland from IPCC 2014
5. Wet grassland (water table 30 cm below surface)	28.7* → 14.9** ⁽³⁾	*Drained grassland from Wilson et al. 2016; **IPCC 2014
6. Paludiculture (emerging plants) on former cropland/grassland	37.0*/23.5* → 17.7**	*Drained cropland/grassland from Wilson et al. 2016; **Bianchi et al. 2021
7. No-till farming on cropland/grassland	--	Data not found for either climate zone
8. Cover crops on cropland	--	Data not found for either climate zone
9. Adjustable drainage on cropland/grassland	--	Data not found for either climate zone

¹⁾ Global warming potential (GWP) conversion factors 28 for CH₄ and 265 for N₂O were applied in the data before summing up with the CO₂ data; ²⁾ Arrows (→) separate the emission factor on the original land use and potential emission factor in the alternative land use;

³⁾ For comparison, Maljanen et al. (2010) provides emission factor 15.4 tons CO₂ eq. ha⁻¹ y⁻¹ for boreal abandoned agricultural peatlands.

The top-ranked measure according to peatland scientists is the protection of intact peatlands from clearance and drainage for agricultural use because this helps in avoiding the formation of anthropogenic GHG emission (see Table 2). Afforestation is ranked second because it is easier to plant trees that have higher capacity to sequester carbon into biomass and remove carbon from the atmosphere, compared to the restoration and rewetting of peat fields. The conversion of annual crops to permanent grassland is ranked higher because it is much easier to

implement even though this measure has a higher emission factor compared to wet grassland and paludiculture that require raising the water table close to the ground surface. The measures at the bottom of the list (adjustable drainage, cover crops, and no-till farming) are ranked low due to the lack of data or no scientific evidence to support that these measures are efficient in mitigating GHG emissions from peat fields. The data available for the bottom measures is still too limited for estimating emission factors, and the recorded observations so far show only minor effects on reducing GHG emissions from peat fields.

Vision Workshop

The workshop gave a deeper understanding on the role and management of peatlands in addressing climate change among farmers and local community members in Nurmes. The ranking of various measures for agricultural peatlands to reduce GHG emissions by peatland scientists (Table 2) supplied the needed information not only for farmers and local community members, but also the interdisciplinary scientists in the workshop. Results from the interviews conducted with farmers and local community members (Table 1) and questions raised in the workshop set the base for developing a shared understanding on peatlands among farmers, local community members, and the interdisciplinary scientists. Information from in-depth discussions with farmers and local community members at the Vision Workshop in Nurmes revealed that the top three ranked measures are much easier and more cost effective to implement at the farm level compared to the bottom ranked measures (see Figure 3).

Question: Rank the measures according to their feasibility and ease of implementation on peatlands on a scale of 1 (easy) to 9 (very difficult)	Results: Ranking by farmers and local community members in Nurmes, North Karelia (Easy at the top, difficult at the bottom)	
i) Evaluate the suitability of the measure for the drained peatland used for grassland/cropland/pasture and also rank the 'Protection of intact peatlands' measure appropriately according to your opinion. ii) Consider over a period of 20 years. iii) Also, take into account the establishment and maintenance costs of the listed measures.	1st	Conversion of annual crops to permanent grasslands
	2nd	Cover crops on cropland
	3rd	Protection of intact peatlands
	4th	No-till farming on grassland/cropland
	5th	Restoration of degraded peatlands
	6th	Afforestation of former grassland/cropland
	7th	Wet grassland (water table 30 cm below surface)
	8th	Adjustable drainage on grassland/cropland
	9th	Paludiculture on former grassland/cropland

Fig. 3. Menti poll results from the Vision Workshop to show the ranking of different measures for agricultural peatlands according to feasibility, ease of implementation, and preference by farmers and local community members in Nurmes

Raising the water level at the peat fields is considered undesirable. Farmers are sceptical about wet grassland because they already have difficulties with the bearing capacity of peat fields while using heavy machineries. Furthermore, paludiculture will force farmers to change their line of production, for example, from milk or grain producing farms to berry or non-food producing farms as well as dealing with the complicated process of raising the water level close to the ground surface. In addition, the investment costs are high with uncertainty in production methods as well as undeveloped markets in Finland for products produced by paludiculture. The current status of paludiculture is still largely experimental, slowly moving from pilot studies to early-stage implementation; thus, the implementation of paludiculture remains scarce (Wichmann and Nordt 2024).

Incentive Workshop

Stakeholders from government, private companies, and NGOs agreed that there is a lack of incentives for sustainable management of peatlands. There is an acute need for relevant actors to initiate independent actions and take leadership in issues relating to peatlands, especially the Ministry of Agriculture and Forestry. The polling results and reasons behind the rankings for different measures to mitigate GHG emissions from peatlands by scientists (scientific evidence) versus farmers and local community (according to their feasibility and ease of implementation on farm) fostered a deeper comprehension on the available measures to mitigate/reduce GHG emissions for agricultural peatlands. The results from the focus group discussions with peatland scientists along with results from in-depth analysis of the conducted interviews — government representatives' perceptions of the potential and importance of peatlands in reducing GHG emissions at the national level together with private companies' and NGOs' perceptions of their respective organisations and sectors in reducing GHG emissions from peatlands as well as farmers' and local community members' views on the potential solutions for reducing GHG emissions from agricultural peatlands in the Nurmes context — set the base for developing a shared understanding on the policies and incentives needed from the public and private sectors to reduce GHG emissions from drained peatlands among representatives from government, private companies, and NGOs together with the interdisciplinary scientists. The co-created incentives, policy measures, and viable solutions (Table 3 and Table 4) in the workshop served as a background for establishing the needed policy measures and incentive systems in the Future Pathways Workshop.

Table 3. Feedback from government representatives in the Incentive Workshop

What kind of policy measures and solutions would be needed to achieve significant reductions in greenhouse gas emissions from agricultural peatlands? How should the current policies change?

- State purchase of drained peatlands and using re-parcelling scheme (reallocation & exchange of fields)
 - Mapping of low-yielding fields for re-wetting and putting planned/ongoing projects on the map
 - Establishment of restored wetlands and a national restored wetlands map
 - Development of reliable statistics for agricultural peatlands
 - Calculating emission reductions from agricultural peatlands as a benefit at the farm level
 - Effective communications concerning the benefits of policy measures for drained peatlands
 - Development of a toolkit to find the best policy measures for peatlands
 - Finding and raising the needed funds for planned projects on restoration of drained peatlands
 - The Ministry of Agriculture and Forestry has a critical role in implementing the policy measures
-

Table 4. Feedback from private companies and NGOs in the Incentive Workshop

How can the actions of companies and organizations support policy planning and implementation?

- Supplementary payment an incentive to maintain permanent grassland on peat fields
 - Corporate social responsibility pathway for companies: from voluntary measure by paying additional payments to mandatory requirements (not a realistic option yet in the case of peat fields)
 - Funding for peatland restoration projects through companies' climate goals
 - Training of farmers with facts and information related to peat fields, while respecting the opinions of farmers
 - Sharing good examples from pioneer farmers who have implemented the policy measures
 - Effective communication: maintain a positive tone without accusations; offer the media positive stories such as trips to restored wetlands; landowners and other stakeholders are actively involved in relaying the positive messages
 - A dedicated network, Peatland Action Group (e.g., Baltic Sea Action Group), is needed to move issues about peatlands forward — ELY Centre's climate unit could be the representative network
-

Future Pathways Workshop

This workshop brought together all participants of the living lab to reach a consensus on the policy measures and possible solutions to reduce GHG emissions from agricultural peatlands in Finland as well as to co-create a shared understanding among the participants relating to the two different perspectives among food system actors (see Table 1). Consequently, a mutual understanding was reached among the participants to acknowledge the key role

of peatlands in mitigating climate change by reducing the immense GHG emissions from peat fields. However, farmers and local community members still hold on to the perspective that productive peat fields are needed for food production to ensure food & nutrition security in Finland as well as certain regions in Finland with high shares of drained peatlands are dependent on peat fields for animal feed and food production.

The formulated future pathways (see Figure 4) for sustainable management of agricultural peatlands utilised knowledge gained from previous living lab activities. The participants in the workshop together set the goals for 2050 as well as co-created the needed policy measures and incentive systems for 2035 in order to achieve the goals in 2050. Furthermore, the participants in the workshop co-created actions that are needed currently (2025) to accomplish the targets set for 2035 (see Figure 4). The workshop assisted in identifying and framing the complex problem of using peatlands for food production as well as developing acceptable solutions to mitigate/reduce GHG emissions from peatlands. The transdisciplinary research process in the workshop have induced a mutual learning process between scientists and actors from outside academia to provide a coherent framework for sustainable management of peatlands in Finland.

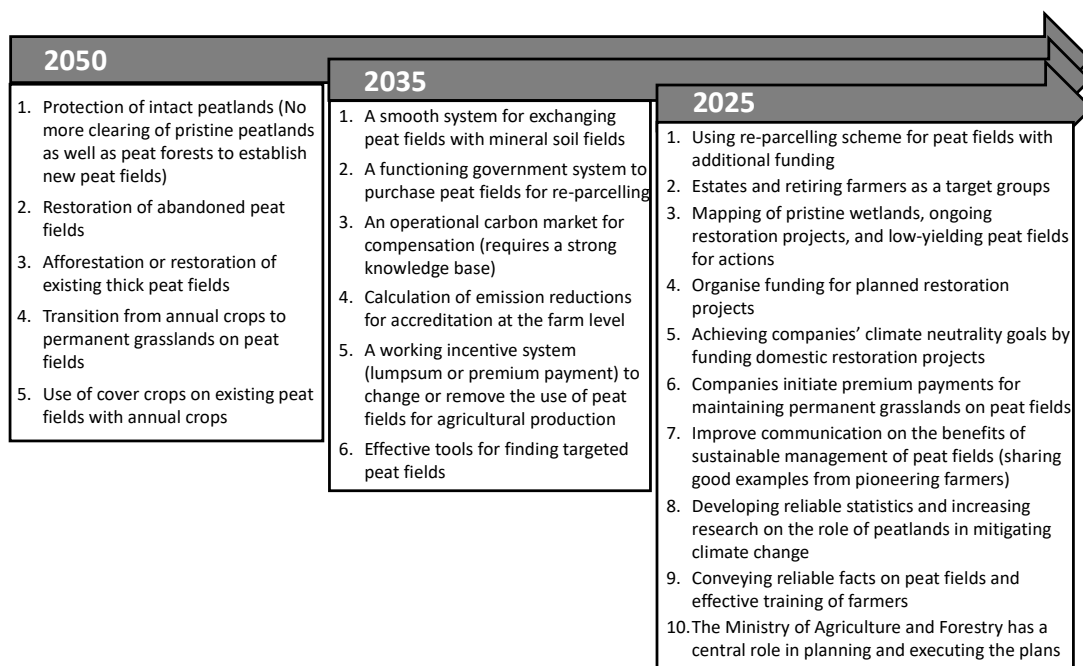


Fig. 4. Future pathways via the Backcasting method to set future goals and determine the current actions needed in Finland for sustainable management of agricultural peatlands

Leverage points to promote food system transformation

The transdisciplinary research process could identify both shallow and deep leverage points for food system transformation (Abson et al. 2017) to promote sustainable management of agricultural peatlands in Finland. The results from the semi-structured interviews, focus group discussions, and workshops, combined with in-depth analysis of the empirical material, revealed key leverage points for transforming the food system in Finland (see Figure 5). Paradigms, mindsets, and values shaping the prioritisation of food and nutrition security (intent) play a central role in structuring agricultural institutions and policies, including the EU Common Agricultural Policy and Finnish agricultural policies (design). In turn, the political will of institutions and social structures to address drained peatlands at national and EU levels, together with recognition of the key role of peatlands in climate change mitigation (intent and design), determines the characteristics and strength of system feedbacks. These include the introduction of stringent regulations or substantial incentives for protecting intact peatlands, increased research on drained peatlands in response to knowledge gaps, and farmer training based on existing knowledge for sustainable management of peatlands.

Pursuing transformational solutions demands a reconsideration of how knowledge is produced and how solutions are translated into concrete implementation (Abson et al. 2017). Practitioners in the public and private sectors who operate within sustainability challenges — such as the agricultural use of drained peatlands — are often deeply familiar with the complexity of these systems. Consequently, actors beyond academia play a crucial role in identifying and framing problems and in developing socially acceptable solutions. When such solutions are supported by key stakeholders, they may eventually influence political will and expand opportunities for policy reform. Fischer and Riechers (2019) argue that significant behavioural change occurs when the desire for change aligns with practical means for action. In this regard, applying a leverage points perspective (see Figure 5) may offer strategic advantages for sustainability science.

Transdisciplinarity and the co-creation of knowledge beyond academia are increasingly emphasized as ways to bridge the gap between researchers and practitioners (Polk 2015, Lin 2023, Käyhkö et al. 2025). However, it cannot be assumed that all stakeholders possess the capacity or sustained interest to participate throughout long-term research processes. Transdisciplinary projects often span several years, and stakeholders may initially underestimate the time and resources required for meaningful engagement. Others may be unable to participate from the outset. This represents a key limitation of the living lab's transdisciplinary process. Such approaches demand substantial time, financial resources, and institutional commitment (Lang et al. 2012, Polk 2015). Therefore, compelling mechanisms are needed to strengthen both the capacity and motivation of stakeholders and researchers from multiple disciplines to engage in sustained co-creation.

Another challenge in transdisciplinary research is the risk that collaboratively produced outcomes become vague or ambiguous in order to avoid conflict among stakeholders (Lang et al. 2012). In this study, no consensus emerged on setting highly ambitious targets; consequently, the co-created goals for 2050 remain relatively broad (see Figure 4). The reason for the lack of consensus is that farmers and local community members often emphasise that productive peat fields are essential for ensuring food and nutrition security. Moreover, Finnish farmers are concerned about the profitability of farming, being blamed for the environmental impact of farming in society, and the future of agricultural peatlands (Puupponen et al. 2022). The living lab explicitly facilitated mutual learning processes between science and society, enabling iterative knowledge exchange, joint problem framing, and the co-development of socially acceptable solutions to alleviate concerns on the transition towards carbon-neutral production among farmers and local community members, who have vital roles in ensuring that changes in farming practices and land management are socially viable and locally legitimate.

Certain regions in Finland with high shares of drained peatlands rely heavily on peat soils for animal feed and food production, making the issue economically and socially sensitive. Therefore, there is a need to move beyond just compensating for losses and develop restorative policy measures that acknowledge existing structural injustices in relation to the deep historical roots of peatland use supported by long-standing subsidy schemes and regulatory frameworks. Consequently, additional policies are crucial to ensure a fair transition for regions with high shares of drained peatlands in Finland by designing broad policy mixes beyond solely environmental policies, while acknowledging that broader systemic injustices may persist (Lonkila et al. 2024, Huttunen et al. 2024).

According to Lonkila et al. (2024), there are very few effective policy measures put into practice, and the efforts to change farming practices on agricultural peatlands are stuck in a political deadlock. There is no simple solution to social resistance; overcoming it requires continuous reflection, learning, and the willingness to confront uncomfortable questions that may yield challenging answers (Raven et al. 2009). Ensuring a just transition for farmers and rural communities with high shares of agricultural peatlands is therefore imperative. Safeguarding livelihoods and maintaining rural viability must be integral components of any sustainability strategy. In this context, the mutual learning fostered through the transdisciplinary research process is paramount, as it creates space for stakeholders to openly exchange perspectives, challenge assumptions, and jointly navigate tensions between competing goals. Strengthened communication among diverse stakeholders — particularly in the co-creation of immediate, pivotal actions — can support the gradual transformation towards sustainable management of agricultural peatlands in Finland.

Conclusions

This study contributes to narrowing the gap between high-level sustainability ambitions and their practical implementation by demonstrating how a living lab can operationalise transdisciplinary collaboration in a contested land-use context. In the case of agricultural peatlands in Finland — where climate change mitigation, food production,

and rural livelihoods intersect — the process created a structured space for mutual learning, shared problem framing, and the co-creation of socially grounded transition pathways. Although the living lab did not yield fully transformative outcomes or binding, ambitious targets, it revealed conditional openness among farmers to reduce cultivation on less productive peat soils if adequate incentives are provided. This suggests that resistance is not absolute but closely tied to concerns over fairness, livelihoods, and regional viability, highlighting the importance of just transition measures.

Importantly, the transdisciplinary research process enabled the identification of both shallow and deep leverage points for food system transformation. The empirical work revealed that paradigms, mindsets, and values shaping the prioritisation of food and nutrition security (intent) underpin agricultural institutions and policies (design), including the EU Common Agricultural Policy and Finnish agricultural frameworks. Political will and institutional recognition of peatlands' role in climate mitigation (intent and design) influence system feedbacks, such as regulations, incentives, research investments, and farmer training. Together, intent, design, and feedbacks shape concrete parameters — subsidies, land re-parcelling schemes, restoration funding, and private-sector procurement criteria — that steer behaviour on the ground. At the same time, adjustments at the parameter and reinforcing feedback levels may gradually challenge prevailing mindsets, potentially shifting the dominant intent to cultivate productive peat fields. Transformative change in such path-dependent systems cannot be achieved within short project cycles; however, understanding the interactions and power dynamics between deep and shallow leverage points provides strategic guidance for aligning practical measures with broader paradigm shifts. Sustained commitment across governance levels, coupled with continued co-creation between science and society, is therefore essential for enabling a just and effective transition toward the sustainable management of agricultural peatlands and for transitioning food systems within planetary boundaries.

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References

- Abson, D.J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., von Wehrden, H., Abernethy, P., Ives, C.D., Jäger, N.W. & Lang, D.J. 2017. Leverage points for sustainability transformation. *Ambio* 46: 30–39. <https://doi.org/10.1007/s13280-016-0800-y>
- Bianchi, A., Larmola, T., Kekkonen, H., Saarnio, S. & Lång, K. 2021. Review of greenhouse gas emissions from rewetted agricultural soils. *Wetlands*: 41: 1–7. <https://doi.org/10.1007/s13157-021-01507-5>
- Bonn, A., Allott, T., Evans, M., Joosten, H. & Stoneman, R. 2016. *Peatland restoration and ecosystem services - science, policy and practice*. Cambridge, United Kingdom: Cambridge University Press. <https://doi.org/10.1017/CBO9781139177788>
- Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D.J., Newig, J., Reinert, F., Abson, D.J. & von Wehrden, H. 2013. A review of transdisciplinary research in sustainability science. *Ecological Economics* 92: 1–15. <https://doi.org/10.1016/j.ecolecon.2013.04.008>
- Burchardt, T. 2014. Deliberative research as a tool to make value judgements. *Qualitative Research* 14: 353–370. <https://doi.org/10.1177/1468794112469624>
- Caniglia, G., Luederitz, C., von Wirth, T., Fazey, I., Martín-López, B., Hondrila, K., König, A., von Wehrden, H., Schöpke, N.A., Laubichler, M.D. & Lang, D.J. 2021. A pluralistic and integrated approach to action-oriented knowledge for sustainability. *Nature Sustainability* 4: 93–100. <https://doi.org/10.1038/s41893-020-00616-z>
- Cascone, G., Scuderi, A., Guarnaccia, P. & Timpanaro, G. 2024. Promoting innovations in agriculture: Living labs in the development of rural areas. *Journal of Cleaner Production* 443: 141247. <https://doi.org/10.1016/j.jclepro.2024.141247>
- Dasgupta, P. 2021. *The Economics of Biodiversity: The Dasgupta Review*. London: HM Treasury.
- Dell’Era, C., Landoni, P. & Gonzalez, S.J. 2019. Investigating the innovation impacts of user-centred and participatory strategies adopted by European Living Labs. *International Journal of Innovation Management* 23: 1950048. <https://doi.org/10.1142/S1363919619500488>
- Fischer, J. & Riechers, M. 2019. A leverage points perspective on sustainability. *People and Nature* 1: 115–120. <https://doi.org/10.1002/pan3.13>
- Hakkarainen, L. & Hyysalo, S. 2013. How Do We Keep the Living Laboratory Alive? *Learning and Conflicts in Living Lab Collaboration*. *Technology Innovation Management Review* 3: 16–22. <http://doi.org/10.22215/timreview/749>

- Herrero, P., Dedeurwaerdere, T. & Osinski, A. 2019. Design features for social learning in transformative transdisciplinary research. *Sustainability Science* 14: 751–769. <https://doi.org/10.1007/s11625-018-0641-7>
- Hossain, M., Leminen, S. & Westerlund, M. 2019. A systematic review of living lab literature. *Journal of Cleaner Production* 213: 976–988. <https://doi.org/10.1016/j.jclepro.2018.12.257>
- Huttunen, S., Tykkyläinen, R., Kaljonen, M., Kortetmäki, T. & Paloviita, A. 2024. Framing just transition: The case of sustainable food system transition in Finland. *Environmental Policy and Governance* 34: 463–475. <https://doi.org/10.1002/eet.2096>
- Huan-Niemi, E., Huttunen, S., Paloviita, A., Puupponen, A., Lehtonen, H. & Niemi, J. 2023. Action-oriented knowledge for sustainable management of organic soils in Finnish agriculture. *Agricultural and Food Science* 32: 36–49. <https://doi.org/10.23986/afsci.120743>
- Humpenöder, F., Karstens, K., Lotze-Campen, H., Leifeld, J., Menichetti, L., Barthelmes, A. & Popp, A. 2020. Peatland protection and restoration are key for climate change mitigation. *Environmental Research Letters* 15: 104093. <https://doi.org/10.1088/1748-9326/abae2a>
- Ikkala, L., Ronkanen, A.-K., Utriainen, O., Kløve, B. & Marttila, H. 2021. Peatland subsidence enhances cultivated lowland flood risk. *Soil and Tillage Research* 212: 105078. <https://doi.org/10.1016/j.still.2021.105078>
- IPCC 2014. 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. In: Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. & Troxler, T.G. (eds.). Intergovernmental Panel on Climate Change (IPCC), Switzerland. <https://www.ipcc-nggip.iges.or.jp/public/wetlands/>
- Jauhiainen, J., Heikkinen, J., Clarke, N., He, H., Dalsgaard, L., Minkkinen, K., Ojanen, P., Vesterdal, L., et al. 2023. Reviews and syntheses: Greenhouse gas emissions from drained organic forest soils - synthesizing data for site-specific emission factors for boreal and cool temperate regions. *Biogeosciences* 20: 4819–4839. <https://doi.org/10.5194/bg-20-4819-2023>
- Kates, R.W., Parris, T.M. & Leiserowitz, A.A. 2005. What is sustainable development? Goals, indicators, values, and practice. *Environment: Science and Policy for Sustainable Development* 47: 8–21. <https://doi.org/10.1080/00139157.2005.10524444>
- Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., et al. 2001. Sustainability science. *Science* 292: 641–642. <https://doi.org/10.1126/science.1059386>
- Koivunen, I., Muotka, T., Jokikokko, M., Virtanen, R. & Jyväsjärvi, J. 2023. Downstream impacts of peatland drainage on head-water stream biodiversity and ecosystem functioning. *Forest Ecology and Management* 543: 121143. <https://doi.org/10.1016/j.foreco.2023.121143>
- Käyhkö, J., Hildén, M., Hyttinen, I. & Korhonen-Kurki, K. 2025. The emerging institutionalisation of knowledge co-production in sustainability research. *Ambio*. <https://doi.org/10.1007/s13280-025-02161-5>
- Lampela, M., Renou-Wilson, F., Andersen, R., Wilson, D., Artz, R.R.E., Ciliverd, H., Turunen, J., Tolvanen, A., et al. 2026. Northern Peatlands in Transition in the 21st Century - Land Use, Status, Policies and Future Trajectories: Comparisons Between Finland, Ireland and Scotland. *Environmental Management* 76: 73. <https://doi.org/10.1007/s00267-025-02376-y>
- Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M. & Thomas, C.J. 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science* 7 (Suppl 1): 25–43. <https://doi.org/10.1007/s11625-011-0149-x>
- Lin, B.B. 2023. Getting to solutions: Moving beyond theory to practical methods for change. *Ambio* 52: 1415–1417. <https://doi.org/10.1007/s13280-023-01904-6>
- Lonkila, A., Lukkarinen, J.P., van Oers, L., Feola, G. & Kaljonen, M. 2024. Just destabilisation? Considering justice in the phase-out of peat. *Environmental Innovation and Societal Transitions* 52: 100867. <https://doi.org/10.1016/j.eist.2024.100867>
- Maljanen, M., Sigurdsson, B.D., Guðmundsson, J., Óskarsson, H., Huttunen, J.T. & Martikainen, P.J. 2010. Greenhouse gas balances of managed peatlands in the Nordic countries-present knowledge and gaps. *Biogeosciences* 7: 2711–2738. <https://doi.org/10.5194/bg-7-2711-2010>
- Meadows, D. 1999. *Leverage Points: Places to Intervene in a System*. Hartland: The Sustainability Institute.
- Minayeva, T., Bragg, O.M. & Sirin, A.A. 2017. Towards ecosystem-based restoration of peatland biodiversity. *Mires and Peat* 19: 01. <https://doi.org/10.19189/MaP.2013.OMB.150>
- Niitamo, V.P., Kulkki, S., Eriksson, M. & Hribernik, K.A. 2006. State-of-the-art and good practice in the field of living labs. *IEEE International Technology Management Conference (ICE)*, Milan, Italy. <https://doi.org/10.1109/ICE.2006.7477081>
- Pohl, C. & Hirsch Hadorn, G. 2008. Core Terms in Transdisciplinary Research. In: Hadorn, G.H., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U. & Zemp, E. (eds). *Handbook of Transdisciplinary Research*. Dordrecht: Springer. https://doi.org/10.1007/978-1-4020-6699-3_28
- Polk, M. 2015. Transdisciplinary co-production: Designing and testing a transdisciplinary research framework for societal problem solving. *Futures* 65: 10–122. <https://doi.org/10.1016/j.futures.2014.11.001>
- Puupponen, A., Lonkila, A., Savikurki, A., Karttunen, K., Huttunen, S. & Ott, A. 2022. Finnish dairy farmers' perceptions of justice in the transition to carbon-neutral farming. *Journal of Rural Studies* 90: 104–112. <https://doi.org/10.1016/j.jrurstud.2022.01.014>
- Raven, R.P.J.M., Mourik, R.M., Feenstra, C.F.J. & Heiskanen, E. 2009. Modulating societal acceptance in new energy projects: Towards a toolkit methodology for project managers. *Energy* 34: 564–574. <https://doi.org/10.1016/j.energy.2008.08.012>
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., et al. 2009. A safe operating space for humanity. *Nature* 461: 472–475. <https://doi.org/10.1038/461472a>
- Simola, S. 2024. *Farmers' perceptions on good farming and solutions to reduce greenhouse gas emissions in agricultural peatlands*. Master's Thesis. University of Helsinki. Faculty of Biological and Environmental Sciences. Helsinki: Viikki Campus Library. <http://hdl.handle.net/10138/575532>

- Sommer, P. & Frank, L. 2024. Peatland rewetting as drainage exnovation - A transition governance perspective. *Land Use Policy* 143: 107191. <https://doi.org/10.1016/j.landusepol.2024.107191>
- Statistics Finland 2025. Greenhouse gas emissions in Finland 1990 to 2023. National Inventory Document under the UNFCCC and Paris Agreement. <https://eu-central-1-statfi.graphassets.com/A7H6ohk0S8qafyCM4bfDaz/cmioizguikfc007vzs42o9cgphthe>
- Strack, M., Davidson, S.J., Hirano, T. & Dunn, C. 2022. The Potential of Peatlands as Nature-Based Climate Solutions. *Current Climate Change Reports* 8: 71–82. <https://doi.org/10.1007/s40641-022-00183-9>
- Temmink, R.J.M., Robroek, B.J.M., van Dijk, G., Koks, A.H.W., Käärmelahti, S.A., Barthelmes, A., Wassen, M.J., Ziegler, R., et al. 2023. Wetscapes: Restoring and maintaining peatland landscapes for sustainable futures. *Ambio* 52: 1519–1528. <https://doi.org/10.1007/s13280-023-01875-8>
- Tolvanen, A., Juutinen, A. & Svento, R. 2013. Preferences of Local People for the Use of Peatlands: the Case of the Richest Peatland Region in Finland. *Ecology and Society* 18: 19. <http://www.jstor.org/stable/26269301>
- van Giersbergen, Q., Barthelmes, A., Couwenberg, J., Lång, K., Martin, N., Tegetmeyer, C., Fritz, C. & Tanneberger, F. 2025. Identifying hotspots of greenhouse gas emissions from drained peatlands in the European Union. *Nature Communications* 16: 10825. <https://doi.org/10.1038/s41467-025-65841-6>
- Vasander, H., Tuittila, E.-S., Lode, E., Lundin, L., Ilomets, M., Sallantausta, T., Heikkilä, R., Pitkänen, M.-L. & Laine, J. 2003. Status and restoration of peatlands in northern Europe. *Wetlands Ecology and Management* 11: 51–63. <https://doi.org/10.1023/A:1022061622602>
- Walter, A.I., Helgenberger, S., Wiek, A. & Scholz, R.W. 2007. Measuring societal effects of transdisciplinary research projects: Design and application of an evaluation method. *Evaluation and Program Planning* 30: 325–338. <https://doi.org/10.1016/j.evalprogplan.2007.08.002>
- Wichmann, S. & Nordt, A. 2024. Unlocking the potential of peatlands and paludiculture to achieve Germany's climate targets: obstacles and major fields of action. *Frontiers in Climate* 6: 1380625. <http://doi.org/10.3389/fclim.2024.1380625>
- Wilson, D., Blain, D., Couwenberg, J., Evans, C.D., Murdiyarsa, D., Page, S.E., Renou-Wilson, F., Rieley, J.O., Sirin, A., Strack, M. & Tuittila, E.-S. 2016. Greenhouse gas emission factors associated with rewetting of organic soils. *Mires and Peat* 17: 1–28. <https://doi.org/10.19189/MaP.2016.OMB.222>
- Zimmermann, F., Mastelic, J., Sentic, A., Frei, D., Lobsiger-Kägi, E., Späni, N. & von Wirth, T. 2023. How to build consensus between multidisciplinary teams on methods and tools for co-designing interventions in the energy transition through Living Labs. In: *Proceedings of the OpenLivingLab Days Conference 2023, European Network of Living Labs (ENoLL)*. Brussels: ENoLL Office. p. 234–241.

Appendix 1. Living lab activities conducted via the iterative research process

<p>Initial Planning and Conceptualization: The process began with defining the research question (mitigate greenhouse gas emissions from agricultural peatlands in Finland), selecting appropriate methodologies, and planning how the research would be conducted [<i>setting up a living lab</i>]. The interdisciplinary researchers and experts (including mentors from Nurmes) participated in co-designing the living lab as well as mapping the transdisciplinary stakeholders with specific knowledge and roles in the food system.</p>
<p>Data Collection and Analysis: The interdisciplinary researchers collected and analysed data based on the initial plan — <i>semi-structured interviews</i> with multiple stakeholders: farmers (10 interviews), local community members (11 interviews), government representatives (10 interviews), private companies (11 interviews), and NGOs (7 interviews). This stage was the first round of generating findings.</p>
<p>Evaluation and Reflection: After analysing the findings from the interviews, the researchers evaluated the interview outcomes against the original objectives (1. develop a shared understanding; 2. identify and define incentives). They reflected whether the data collected was sufficient. More information was needed on the different measures for mitigating GHG emissions from agricultural peatlands as well as the effectiveness and efficiency of the various measures. The need for more information instigated the <i>focus group discussions</i> with peatland scientists from Nordic and Baltic countries.</p>
<p>Feedback and Revision: Based on the evaluations and reflections, the interdisciplinary researchers have received feedback from peers (scientists), mentors (living lab in Nurmes), and different stakeholders (farmers, local community members, government representatives, private companies, and NGOs). The informational feedback loops have helped to identify gaps, weaknesses, or areas that needed improvement.</p>
<p>Refinement: The research question, methodology, or approach was refined. Results from the interviews were used as the base for the discussions in the workshops and focus group discussions. The design of the workshops and focus group discussions were using the acquired feedback and knowledge from earlier implemented activities.</p>
<p>Repeat the Cycle: The revised approach was implemented in the next cycle of data collection and analysis. The iterative process continued until the research objectives were satisfactorily met. The first focus group discussion served as a base for the second focus group discussion with a more refined approach by using emission factors to rank the different measures for peatlands. The <i>Vision Workshop</i> (farmers & local community members) served as a base for the <i>Incentive Workshop</i> (government representatives, private companies, & NGOs). The implemented workshops and focus group discussions served as a base for the final workshop (<i>Future Pathways Workshop</i>) attended by the interdisciplinary researchers and various stakeholders interviewed previously. The formulated future pathways for agricultural peatlands and activities implemented in the living lab serve as a base to discover the leverage points for food system transformation.</p>
<p>Finalisation: The set of findings were analysed by the interdisciplinary researchers after the completion of iterated activities, followed by the publication of research results as well as presentations in conferences and seminars to disseminate solutions and knowledge from <i>co-creation</i> and <i>in-depth analysis</i> of activities implemented in the living lab.</p>

Appendix 2. The deliberative research process in the living lab activities

Semi-structured interviews were conducted with various stakeholders: farmers, local community members, government representatives, private companies, and NGOs (*inclusive participation*) with rules to ensure that everyone could express their thoughts without difficulty. The results from the interviews were shared with the various stakeholders (*information sharing*). The interviews were semi-structured with a mixture of thematic and narrative interviews for free expression of views (*inclusive participation*) along with transparent, clear rules, and procedures that ensure fairness and accountability (*transparency*).

Focus group discussions: The peatland scientists could discuss their thoughts and views on the different measures to reduce GHG emissions from agricultural peatlands, whereby every participant was given time to voice their opinions (*inclusive participation*) with clear rules and procedures (*transparency*). The scientists must rank the different measures based on peer-reviewed and published research (emission factors as indicators) as well as debate on the different views (*reasoned argumentation*). A consensus was reached among the scientists on the rankings for the different measures based on available scientific evidence and not solely on their opinions (*collective decision-making*). The ranking results were shared with the various stakeholders in the workshops (*information sharing*).

Vision Workshop: farmers and local community members could discuss together their thoughts and views from the conducted interviews (*inclusive participation*) as well as the chance to reflect on the varied opinions on peatlands (*reflective thinking*). Relevant information on pristine peatlands and GHG emissions from agricultural peatlands was shared with farmers and local community members to broaden their knowledge related to peatlands (*information sharing*). Then a Menti poll was taken to rank the different measures for agricultural peatlands according to their feasibility and ease of implementation (*collective decision-making*) and their preferences for future management of agricultural peatlands (*inclusive participation*), with clear rules and procedures to ensure fairness and accountability (*transparency*). The ranking results with the reasoning behind the different rankings were discussed in the workshop (*reasoned argumentation*).

Incentive Workshop: stakeholders from government, private companies, and NGOs could discuss together their thoughts and views from the conducted interviews as well as the chance to reflect on the varied incentives or lack of incentives for peatland management (*inclusive participation & reflective thinking*). The different stakeholders co-created policy measures and solutions that are needed to achieve significant reduction in GHG emissions from agricultural peatlands (*collective decision-making*). Relevant information on GHG emissions from agricultural peatlands was shared (*information sharing*). The rankings and reasons behind the rankings of measures to mitigate GHG emissions from peatlands by scientists versus farmers and local community were discussed (*reasoned argumentation*).

Future Pathways Workshop: scientists, farmers, local community members, government representatives, private companies, and NGOs could discuss together their thoughts and views from the conducted interviews and workshops as well as the chance to reflect on the varied opinions on peatlands (*inclusive participation*). The stakeholders could debate and formulate future pathways for agricultural peatlands (*reflective thinking, reasoned argumentation, & collective decision-making*). Relevant information and results from previous living lab activities were shared (*information sharing*). The process was transparent with clear procedures to ensure fairness and accountability (*transparency*). The diverse stakeholders had a voice in the outcome of the workshop (*inclusive participation*).

Appendix 3. Interviewed groups of stakeholders

Interviewed groups	Detailed information
Farmers (n=10)	a variety of farmers were interviewed to represent the spectrum of farmers in Finland – livestock farms, plant production farms, large farms, small farms, and diversified farms. All farms have peat fields except for one farm (diversified farm).
Local community members (n=11)	representatives from the local farmers' union (MTK Pielisen), retired farmers, village associations (Karhunpään kyläyhdistys, Pielisen-Karjalan kehittämissyhdistys), local authorities (Nurmes), regional farmers' union (MTK Pohjois-Karjala), agricultural extension services (ProAgria: regional office), Centre for Economic Development, Transport and the Environment (ELY-keskus: regional office), and National Land Survey of Finland (Maanmittauslaitos: regional office).
Government representatives (n=10)	representatives from the different departments of the Ministry of Agriculture and Forestry, Ministry of the Environment, National Emergency Supply Agency (Huoltovarmuuskeskus), and National Land Survey of Finland (Maanmittauslaitos: national office).
Private companies (n=11)	representatives from food companies (Atria, Fazer, Oatly, Raisio, Vaasan, Valio), retailers (Lidl, S-Group), and financial institutions (S-Bank, OP Financial Group, The Finnish Climate Fund).
NGOs and movements (n=7)	representatives from the national farmers' union (MTK: The Central Union of Agricultural Producers and Forest Owners), agricultural extension services (ProAgria: national office), World Wildlife Fund, Baltic Sea Action Group, Finnish Association for Nature Conservation, and environmental movement (Extinction Rebellion).