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Transformation of Peatland Management Toward Climate Targets in Europe

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Agriculture and forestry on drained peatlands contribute substantial amounts of anthropogenic greenhouse gas emissions. The transformation of peatland management toward "wet" land use takes on an increasingly critical role in achieving zero net carbon emissions by 2050. Yet, the translation of European Union climate target ambitions into peatland relevancy on emission reduction remains unclear. The study presents an analysis of the current status and future pathways of peatland transformation in European countries. Our data are collected by a survey with 60 experts in 8 countries and a workshop with 16 experts in 3 countries. The analysis shows expected trends for drained peatlands, indicating a shift from drainage-based cropland to grassland or wetland use. Although these trends support emission reduction, nations with lucrative peatland areas are likely to resist shifting to less profitable land uses. Three categories of management practices were identified based on water level. Among them, grassland paludiculture and grassland with elevated water tables are appreciated by experts. The transition pathways for Finland, Germany, and the Netherlands reflect the consensus that peatland emissions have to be reduced drastically. However, differences in soil types, geoclimatic zones, and diverse management approaches among countries pose a challenge when assessing and implementing the potential of mitigation. Experts highlighted the desirability and feasibility of spatial coordination to align the interests of land managers. Similar hurdles appear for the transition pathways, especially missing economic incentives. The transition demands wider public support, financial action, and reconciling differing stakeholder interests along transparent and stringent pathways.

Introduction

Protecting and restoring peatlands is essential for mitigating climate change and preserving biodiversity and ecosystem services [1]. Globally, peatland accounts for less than 3% of the land area but are the largest long-term carbon store in the terrestrial biosphere and among the Earth's most important stores [2]. In regions with high population pressure, peatlands are often drained for food production [3]. In the European Union (EU), peatlands are characterized by temperate and boreal climates, profound human impact, and significant emission accounting for 220 Mt CO_2 year^{-1} [1,4,5]. Drained peatlands in Europe are dominantly used for agricultural production, followed by forestry and peat extraction [6]. Another pressing issue is soil subsidence caused by peatland carbon loss after drainage, leading to soil subsidence rates of 1 to 2 cm year^{-1} in temperate zones such as central and northern Europe [7].

As the EU affirmed the core goal of the Paris Agreement, which set zero net carbon emissions by 2050, peatlands play an increasingly important role in reaching these ambitious targets. The European Commission made a proposal for a legally binding target of net-zero emissions by 2050 as part of the EU climate policy framework and the European Climate Law [8]. However, since emissions from peat soils are reported in the sector land use, land use change and forestry (LULUCF), emissions and storage are excluded from the overall emission reduction target. LULUCF is only to preserve the net sink at its current strength (see "no-debit rule"), creating insufficient incentives for reducing peat-related emissions [9]. Furthermore, the recently adopted EU nature restauration law recognized that restoring drained peatlands is one of the most cost-effective measures to reduce emissions in the agricultural sector and improve biodiversity [10]. EU member states are required to implement restoration initiatives for organic soils utilized in agriculture, specifically drained peatlands, covering a minimum of 30% of such lands by 2030, with at least a quarter to be rewetted. This percentage increases to 40% by 2040, with a stipulation that at least one-third should be rewetted, and further to 50% by 2050, with the same requirement for rewetting at least one-third of the area [10]. At the national level, net-zero emission targets are determined by member states, where relevant societal, context-dependent, and systemic structures need to be identified for the establishment of different pathways to meet the transformation challenges ahead [11]. The 2019 Dutch Climate Agreement explicitly states that the target for peat meadows is an emission reduction of around 1 Mt CO_2-eq by 2030. However, this Climate Agreement has no juridical status and is fully based on voluntary cooperation of governments and stakeholders. In Germany, a government target agreement ("Moorschutzstrategie") on peatland protection has been signed in 2021, representing a milestone for recognizing the crucial role of peatlands in achieving national climate targets [12]. The German peatland strategy aims to reduce annual greenhouse gas (GHG) from peat soils by at least 5 Mt CO_2-eq by 2030 [12]. Yet, the translation of those ambitions into peatland relevancy on emission reduction remains unclear.

Research efforts on mitigation measures are conducted all over Europe, contributing to new methods to measure or quantify the GHG mitigation potential of used peatlands [13,14]. Effective measures to support emission reduction include the restoration of natural peatland conditions and rewetting of drained peatlands [15,16]. Productive peatland use based on the water level (e.g., open ditches or pipes), adjusted land use and management (e.g., wet cropland or grassland use), and paludiculture play a considerable role in mitigating GHG emissions while providing a range of other ecosystem services [17,18]. It is important to note that rewetting drained peatland may initially introduce methane (CH_4) emissions. Günther et al. [15] showed that, over time, rewetted peatlands have much lower overall GHG emissions compared to when they were drained. However, as they often imply high costs of conversion and management, farmers need sufficiently attractive economic incentives to initiate a transition [19].

While small-scale pilot projects aimed at adapting mitigation measures on drained peatlands have been extensively tested in the EU, achieving large-scale implementation necessitates substantial shifts across social, cultural, economic, and political domains [20]. This behavioral transformation entails not only the engagement of land users but also the establishment of new markets to promote alternative socioecological models of production and consumption. Additionally, existing policies, subsidies, and land tenure systems must be adjusted to accommodate such structural changes [21]. Consequently, this multifaceted process can be viewed as a transformative process. This peatland transformation can be understand through the lens of socioecological system (SES) transformation [22]. The SES theory provides an interdisciplinary framework that integrates social and ecological perspectives to study the complex interactions between human societies and natural environments in the face of change through adaptation and transformation [23]. Specifically, peatland rewetting is an example of transformative change, referring to fundamental shifts in the structure, function, and dynamics of SES that lead to new trajectories of development and governance.

Identifying the available transition pathways is vital for assessing the dynamics of transformation as well as developing policies [24]. For the transformation toward meeting climate targets, pathways have often been developed from a global perspective, e.g., in global land use sectors [25]. However, transformation studies for peatlands at the national level are still rare [26]. Few exceptions exist, e.g., by Tanneberger et al. [27], who provided national emission reduction pathways for organic soils in Germany and explained the underlying assumptions. They assume that all land use categories on organic soils will follow the global Intergovernmental Panel on Climate Change (IPCC) trajectories, which implies that CO_2 emissions are reduced to net zero around the year 2050 (and become negative afterwards), whereas CH_4 emissions must be halved and N_2O emissions must be reduced by 20% [27]. Although Tanneberger et al. [27] showed the magnitude and possible timing of actions, such "top down" approaches designed by scientists may look highly radical to practitioners. Grethe et al. [3] presented a rewetting pathway for Germany, following an 80% rewetting pathway with additional 20% shallow grassland for all agriculturally used peatlands today, leaving some room for maneuver in the design of the transformation until 2045. Globally, the transformation of peatland management faces consistent challenges, particularly economic pressures from conventional agriculture and insufficient funding for large-scale restoration. By addressing these common issues and learning from European countries' transition pathway, other regions can gain valuable insights to bolster worldwide efforts to protect and restore peatlands.

Measures concerning peatlands will continue to be voluntary for farmers and private landowners. The EU's nature restoration legislation has recognized this [10]. At the national level, both the German and Dutch peatland strategies emphasize voluntary incentive-based approaches involving stakeholders [12]. Since the implementation of mitigation measures depends on stakeholders' willingness and the overall feasibility of peatland rewetting (including soil physical and hydrological parameters and socioeconomic factors), exploring experts' understanding of trends and transition pathways of peatlands could facilitate a more holistic picture of national strategies and policies. Understanding transformation dynamics is contingent upon insights from various stakeholders, such as farmers, landowners, industry, technology developers, users, government departments, professional associations, and nongovernmental organizations (NGOs) [28]. Research on transformative innovation highlights the significance of understanding the perception of others to drive innovation forward and to prevent exclusion [20]. However, to our best knowledge, the insights from stakeholders for transforming drained and managed peatlands toward reaching climate targets remain unexplored. Therefore, the objective of this study is to capture insights from experts on peatland management status and future paths in European countries.

We aim to find answers to the research question "What is the future land use of drained peatlands, and what are the transition pathways to achieving net-zero emission targets in the EU?" by exploring transformation research methodologies with different societal actors. More specifically, we address the following research questions:

1. What are experts' expected trends of the main land use of peatlands?
2. What are current and potential management practices for peatlands?
3. What are experts' views on transition pathways for peatland use in the context of climate neutrality at national scale?
4. What are policy implications on the transformation of peatland management?

Materials and Methods

Following the theoretical framework of SES transformation research [22] and transition pathways [24], we seek to study complex societal problems with the aim of supporting fundamental societal change processes toward sustainability in the long run [11]. Expert opinions are often used in transition and transformation assessments that could not be provided otherwise [29]. For this reason, as the transformation of drained peatland toward net-zero emissions lacks objective data, expert opinions are particularly useful to describe, explain, and evaluate the process. The expertise and experience contributed by experts included researchers, stakeholders acting as multipliers for farmers (e.g., farmer's associations and NGOs), policy makers, and governmental representatives. We acknowledge that expert opinions draw criticism as an unreliable form of evidence due to their subjectivity, potential for intentional inaccuracies, and limited generalizability. To avoid this, we selected experts for our study based on their extensive knowledge on the peatland issues (e.g., emissions, technologies, market, and policy). The number of potential experts was per se limited, as peatland rewetting is at the margins of currently intensive dryland agriculture. The qualitative approach is suitable to gather in-depth insights from the actors who are most important to this transformative change process. This allowed us to extend our analysis beyond conventional data analysis, encompassing nuanced considerations and addressing the inherent uncertainties present in the field of environmental science [30].

In a first step, an expert survey was carried out to establish a sound knowledge basis on perceptions about peatland use and management status in European countries ("Data collection based on expert survey" section). With that, we aim to explore how the dominant land use types show expected trends in changes with regard to used peatlands. Based on the prevalent land use types, different pathways for peatland management are being considered in the sample countries to provide a cross-national overview for Europe. In a subsequent step ("Data collection based on expert workshop" section), an online workshop with 3 countries as selected case studies was organized to dive deeper into the transformation pathways toward net-zero emission targets and the role of peatland rewetting. The workshop format allowed an extension of the insights on expert's perception of mitigation measures and their applicability within current and future framework conditions. As a method often used in policy and transformation research [31], we applied a qualitative approach to analyze our data gathered by the survey and workshop. Our research approach is demonstrated in Fig. 1.

Data collection based on expert survey

The web-based survey was launched in August 2018 and remained online until December that year. The survey aimed to investigate the status and trends in peatland use (identifying peatland agriculture, peatland forestry, and peat extraction-related activities) to understand possible implications for GHG emissions, degradation, and policies in the context of peatland management. The survey covered the following questions: (a) if the area of drained peatland for agriculture (cropland and grassland), forestry, and peat extraction will decrease or increase, or if the sites will be abandoned; (b) the perceived reason for changes in drained peatland area; and (c) expected land use changes on peatlands and their drivers and bottlenecks. More information about the survey, e.g., questions, can be found in Section S1.

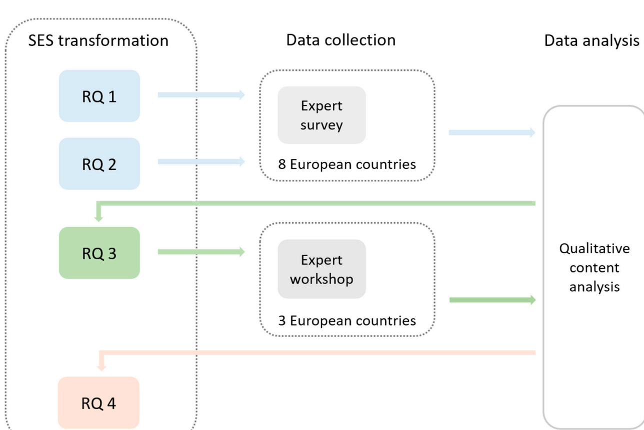

Fig. 1. Research approach.

We carried out a web-based survey in 8 peatland-rich European countries (Denmark, Finland, Germany, the Netherlands, Norway, Poland, Sweden, and the United Kingdom). The criteria for country selection included their considerable emissions under degrading peatland and the representation of different land use focuses (Table 1). On a global scale, Finland, Germany, Poland, Sweden, the United Kingdom, the Netherlands, and Norway are among the top 28 countries with the actual largest total emissions from degrading peat soils (Table 1). At the same time, Finland, Sweden, Norway, Germany, and United Kingdom are ranking high in the countries with the actual largest peat carbon stocks on a global scale (top 28) [32]. For many years, Germany and the Netherlands have been known as countries with large-scale drainage-based agricultural production systems, which have been societally desired for food production [6]. In Scandinavia and the United Kingdom, commercial forestry on peat soils is a vibrant long-term business, strongly supporting GHG emissions and further peatland degradation [33]. Although indicating a comparably lower share of degraded peatland area, the northern European countries, namely, Norway and Sweden with less than 20% to 40%, are equally affected by continuous degradation processes, as all countries across Europe, where degradation processes are driven by drainage-based agriculture, forestry, and peat extraction. Selected countries represent different land use focuses. In Denmark, Germany, and Poland, the dominant land use is arable and grassland agriculture. In the Netherlands, the dominant area of land is used as pastures or mosaics. The country area of Norway, Sweden, and Finland is dominantly covered by forests. In the United Kingdom, the land use types are more scattered, with 27% of the countries area covered by arable agriculture and 29% by pastures and mosaics [6]. The Peatland map of Europe can be found in Tanneberger et al. [34]. The distribution of organic soils of EU countries is based on the study of Martin and Couwenberg [35].

The survey was targeted toward experts in peatland management. A list of experts was developed through scientists active in the field of peatland management and research from the PEATWISE project and further associated research institutes. We collected expert information (contact, affiliation, and relevancy in the peatland domain) within the project PEATWISE based on a snowball method, resulting in an uneven distribution of expert contacts per country, and subsequently uneven distribution of participation from each country (Section S2). Survey results were analyzed, and aggregated results were reflected back to scientists from the PEATWISE project to increase data validity by feedback loops. This step was conducted for Denmark, Finland, Germany, the Netherlands, Norway, and Sweden as these could be covered by scientists from the PEATWISE project. For Poland and the United Kingdom, results were cross-checked literature-based where possible. Besides Poland and the United Kingdom, additional literature has been used for each country to underpin and contextualize new findings for each country. The online survey was sent to 101 experts, and we received responses from 60 (for more details, see Section S2).

Data collection based on expert workshop

The 3 peatland-rich EU countries Finland, Germany, and the Netherlands were chosen as case studies for a subsequent workshop

Table 1. Overview of survey countries' characteristics

	DK	FIN	GER	NL	NO	PL	SE	UK
Member of the EU	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Arable land, permanent crops [6]	63%	5%	38%	19%	2%	44%	7%	27%
Pastures and mosaics [6]	11%	4%	18%	42%	3%	15%	2%	29%
Forest [6]	11%	72%	31%	8%	35%	33%	66%	10%
Estimated peatland area (km^2) [34]	2,029	ca. 90,000 (>0 cm peat)	12,800	2,733	44,700 (>0 cm peat)	14,950	66,450	26,838
Grassland on organic soils [35]	516.2	669.1	9,704.8	2,774	n.a.	7,616.9	277.2	5,661.5
Cropland on organic soils [35]	1,274.3	2,625.2	3,421.4	608	n.a.	1,601	1,370.1	1,945.3
GHG emissions from peatlands (Mt CO_2 year^{-1}) [32]	3	37.4	43.3	6	6	31.0	14.4	29.8

DK, Denmark; FIN, Finland; GER, Germany; NL, the Netherlands; NO, Norway; PL, Poland; SE, Sweden; UK, United Kingdom

in 2021, based on their relevance in terms of mitigation potential on drained peatlands (Table 1). The workshop was conducted online in 2021. The objectives and leading questions followed by the workshop were as follows: (a) What can be the pathway for a transition in different countries and which role can alternative land use options play?, and (b) How can EU policy help to start the transition and support it in the long run? Section S3 provides the protocol of the workshop. Participants included 16 experts (policymakers from national, regional, and local levels, water authorities, farmers groups) and 12 researchers from the 3 countries. Section S4 provides an overview of workshop participants.

Finland is the second-largest emitter of GHG from peatlands in the EU, with Germany leading as the top emitter. The outstanding position of Germany can be explained by the fact that more than 95% of German peatlands are drained and 80% of total peatland area are intensively used for agriculture, predominantly as grassland and arable land on sites with low groundwater tables [27]. For conducting the workshop, we used insights from the previous online survey ("Data collection based on expert workshop" section) to better understand potential transition pathways in different countries, the role of alternative land use options, and how EU policy with its economic and regulatory instruments at the national scale can support a transition. Germany and the Netherlands have their "climate action plans" to substantiate carbon neutrality (overall GHG emissions) until 2045 and 2050, with interim targets for 55% reduction by 2030 compared to 1990 levels. With a more ambitious target, the Finnish government is committed to achieve carbon neutrality by 2035. However, pathways for the land use sector at a national level are rarely explored and the emission trajectories for peatlands remain largely unknown [27].

The workshop focused on a holistic (not sectorial) approach to reconcile different stakeholder groups for their joint national transition pathway. In a first step, workshop participants were introduced to different GHG mitigation measures on peatlands (as developed from "Data collection based on expert survey" section) followed by smaller group discussions (per country) to examine potential pathways per country until 2050 including the discussion on intermediate steps (2035 targets) to reach land use-based GHG mitigation on peatlands. To put the role of peatlands within the debate on climate neutrality into a better context, we asked experts for their feedback concerning the role of peatlands in reaching climate neutrality in their country, followed by a discussion of the difficulties of achieving this target. In a next step, the topic of economic and regulatory instruments guiding toward sustainable use of peatlands in Finland, Germany, and the Netherlands was presented. Subsequently, potential policy improvements necessary to achieve climate-friendly peatland use were discussed with the participants in smaller group as well as plenum discussions, focusing on the identification of policy sectors and crucial actors for their implementation in the future. Based on an online mapping (Mural) and voting tool (Mentimeter), experts were engaged in smaller group discussions (per country) as well as plenum discussions during the event of the workshop. The workshop asked all participants to respect each other's viewpoint, reconcile their differences, and work together.

Data analysis

Both survey and workshop are thematically categorized in a qualitative research process [36]. The result of the online survey was organized in Excel. The workshop was recorded, documented, and partially transcribed as sentences and phrases and analyzed via qualitative content analysis [36]. Deductive concept-driven coding was used to identify relevant information for both survey and workshop according to the codebook (see Section S5), which was designed iteratively based on the theoretical framework and research questions. The statements on a specific topic are organized by thematic categories. The main categories reflect our 4 research questions, including (a) trends of land use, (b) current and potential management practices, (c) transition pathways, and (d) policy implication. Subcategories within one main category were created. As is frequently observed in qualitative research, this process tends to be iterative, involving the repetition of certain steps while adjusting the codebook along the way. To present and interpret the findings, the condensation of the data uses the researchers' own language [36].

Results

Expected trends

Based on our expert survey, we identified perceptions on trends in peatland use for 2050. When considering expected trends in peatland use, national shares of land use with their economic implications need to be taken into account. Expected trends for drained peatland agriculture reveal a decrease from drainage-based cropland use toward grassland use or even wetland. In Finland, the expected trends (for 2050) are the opposite. For both area drained for agriculture and for forestry, an increase in peatland drainage area is expected. Expected main trends are summarized in Table 2.

With regard to perceptions on area of drained peatland for agricultural production, we find that, for agricultural production (including cropland and grassland use), expert expectations for changes in the area of drained peatlands differ between countries. Experts from Denmark, Germany, the Netherlands, and the United Kingdom expect a decrease in drained peatland area used for agriculture. They expect a land use change toward wetland or at least toward grassland if previously used as cropland (Germany, the Netherlands). In the case of the United Kingdom, a trend toward wetland or settlement has been mentioned. In Denmark, Germany, the Netherlands, and the United Kingdom, these expected shifts were unanimously justified by restoration activities. For Finland and Norway, an increase of area drained for agriculture is expected, either to remain the same or implying a change from cropland to grassland. Experts from Norway, Sweden, and Poland further expect changes from agricultural land toward land abandonment.

Regarding perceptions on area of drained peatland for forestry, we find that the area of drained peatland for forestry in 2050 is predominantly expected to decrease (Denmark, Germany, Poland, and the United Kingdom). For Germany and the United Kingdom, restoration activities are expected to cause a land use change toward wetland. In Denmark, restoration activities are expected too, but no land use change is expected. In Finland, an increase in peatland drainage for forestry without land use change is expected. For Sweden, the area of peatland drained for forestry is expected to remain the same, and a shift in land use toward wetland is expected. No statements were made from Norwegian and Dutch participants.

Regarding perceptions on area of drained peatland for peat extraction, for all countries with response data concerning their expected trends in the area of peatland drained for peat extraction (Denmark, Finland, Germany, Norway, and Sweden), we find that a decrease of the drained area is expected. In all cases, a change in land use is expected too. In Denmark and Germany, a change toward grassland use or as wetland was concluded due to restoration activities. In Finland and Sweden, the decrease of drained peatland area for peat extraction was explained by a diversification of energy sources, and a follow-up land use is also expected to be diversified for forestry or as wetland. In Finland, grassland was mentioned as an expected land use option too. In Norway, experts expect a decrease due to restoration activities and changes to wetland. For the Netherlands, experts highlighted the irrelevance of peat extraction on their peatlands; therefore, no trends can be drawn from here. In Poland and the United Kingdom, no data were available for this section, except their overall expected land use changes: in Poland toward forestry or wetland and in the United Kingdom toward wetland.

Regarding countries with peatlands dominantly used for forestry, trends are similar. For Finland, a spatial increase of drained peatlands for forestry is expected, and for Sweden, the area is expected to remain the same. Countries with major agricultural peatland use expect a decrease in drained area for forestry, either to remain under forestry use (Denmark) or with expected land use changes toward wetlands (Germany, Poland, the United Kingdom). We therefore conclude that in countries with highly productive peatland use regions, agriculture, or forestry, changes toward less profitable land uses are expected less. This is especially true for countries and regions with a general high land use pressure and related high land prices.

Current and potential management practices

Based on the water level, survey experts have categorized management practices as mitigation measures on peat soils into 3 categories: (a) rewetting (mean annual water table, −15 cm to +10 cm), (b) water table elevation including active and controlled drainage or passive elevation due to subsidence (mean annual water table, −45 cm to −15 cm), and (c) drainage-based land use (mean annual water table, −85 cm to −45 cm). Section S6 gives a more detailed overview.

In the first category, currently applied management practices on rewetted peatlands are biomass production (Germany, the Netherlands, Poland, and the United Kingdom) and grazing activities (Germany, Norway, and Poland). Forestry on rewetted peatlands is applied in Germany, Norway, and Poland. With regard to the developed mitigation measures, paludiculture for grazing, more specifically with sheep, cows, and water buffaloes, was mentioned (Germany, the Netherlands), as well as paludiculture for biomass production, e.g., with sphagnum (peat moss) (Germany, the Netherlands, Sweden, and the United Kingdom).

Within water level category 2, “water table elevation”, only grassland use options were mentioned as currently applied and developed mitigation measures. Currently, biomass production on grasslands as conventional forage was mentioned by experts from Denmark, Germany, the Netherlands, and Sweden. Additionally, in the Netherlands, wet crops were listed, and in the United Kingdom, grazing was mentioned. As further developed mitigation measures, experts from Finland, Germany, the Netherlands, Norway, and the United Kingdom mentioned biomass production as conventional forage. In Sweden, renewable biomass production with reed canary grass and tall fescue is also under development, whereas in Germany grazing-based management options with mitigation potential are developing. In Finland, forestry on peatlands with elevated water tables is further developed.

Finally, in water level category 3, the “drainage-based land use”, experts perceived management options on cropland as having a potential to mitigate GHG emissions, besides mitigation measures on grassland and forestry. In Denmark, Finland, Germany, Poland, and Sweden, biomass production and grazing on grassland was mentioned as currently applied mitigation measures. On cropland, adjusted and no tillage were mentioned as mitigation measures in Finland, continuous vegetation is a mitigation measure currently being developed in the United Kingdom, and foil-covered row spacing in maize crops is implemented in the Netherlands. On grassland, crop rotation, carbon adding, and reduced tillage were mentioned by experts from Finland, clay adding in the Netherlands, mineral soil adding in Sweden, mulching in the United Kingdom, and improved fertilization in Norway. Regarding forestry, wood and ash fertilizers are considered mitigation measures currently developed in Sweden, as well as native hard woods in the United Kingdom and unevenly aged forests in Finland.

Considering experts’ feedback on perceived solutions toward more climate-friendly peatland management, grassland paludiculture under rewetted conditions as well as grassland use with

Table 2. Expected main trends in peatland use: Area of drained peatland in 2050. () refers to low response rates for the respective question in the survey and therefore to a potentially biased statement. ↓ expected to decrease; ↑ expected to increase.

Area of drained peatland in 2050	Country	Direction	Abandon	Rationale	Expected land use change toward
Agriculture (cropland and grassland)	DK	↓		Restoration	Wetland
	FIN	↑		Remain the same	Agriculture
	DE	↓		Restoration	Cropland to grassland Cropland/grassland to wetland
	NL	↓		Restoration	Remain grassland Cropland to grassland Cropland/grassland to wetland or settlement
	NO	↑	x	Not given	Cropland to grassland
	PL	(↓)	(x)	Decrease or abandoned	Grassland to cropland Cropland/grassland to forestry
	SE		(x)	Remain the same or abandoned	Cropland to grassland
	UK	↓		Restoration	Cropland/grassland to wetland or settlement
Forestry	DK	↓		Restoration	Remain forestry
	FIN	↑		Remain the same	Remain forestry
	DE	↓		Restoration	Wetland
	NL			Not given	Forestry on peatlands not relevant
	NO			Not given	No data
	PL	↓		Restoration	No data
	SE			Remain the same	Wetland
	UK	↓		Restoration	Wetland
Peat extraction	DK	↓		Restoration	Grassland or wetland
	FIN	↓		Diversification of energy sources	Grassland, forestry, wetland
	DE	↓		Restoration	Grassland, wetland
	NL			Not given	No relevant peat extraction
	NO	↓		Restoration	Wetland
	PL			Not given	Forestry or wetland
	SE	↓		Diversification of energy sources	Forestry or wetland
	UK			Not given	Wetland

elevated water tables were recommended as they are better solution to minimize the trade-off between agricultural production and peatland protection. For countries with prevailing peatland forestry, grassland paludiculture (Sweden) and grassland use with elevated water tables (Finland, Norway, Sweden) were mentioned. For Finland, Norway, and Sweden, the main emphasis remains on drainage-based land use with adjusted management components to grassland and cropland agriculture.

Transition pathways

To give a comprehensive overview on possible transformation pathways, we integrate our qualitative results based on the workshop results. There are different interests and viewpoints from different stakeholder groups. Farmers' associations argued that they lack a viable business model for rewetted peatlands and, therefore, need sufficient positive incentives to transition from their drainage-based management practices. One representative farmer's associations said, "If attractive revenue models and long-term (10 to 15 years) compensation schemes can be presented, this will greatly motivate farmers and land managers to consider adopting mitigation measure." While the national government is keen to meet its climate commitments, it remains cautious about financial burdens and potential legal challenges. In contrast, scientists are more ambitious in achieving the climate targets and call for more actions (e.g., negative incentive).

Most workshop participants from Germany consider the 2050 climate neutrality target to imply climate-neutral peatlands (CO_2 emissions from peatlands are reduced to net zero) by 2050 and are determined to deliver. Most participants from the Netherlands disagree, implying that overall emission targets should not be synonymous with emission reductions from peatlands. There was consensus that peatland emissions have to be reduced drastically, but net zero might not be possible to achieve for technical, natural, or management reasons. All participants acknowledge the high level of ambition and difficulty to achieve climate-neutral peatlands by 2050; especially, Dutch participants were rather pessimistic. Few alternatives to compensate peatlands for net-zero emissions can be provided. While experts expect a decrease of intensively used drained peatlands in 2035 in all 3 countries, their anticipated pathways for the various mitigation measures are very different ("Expected trends" section).

The Finnish experts estimate that the current structure of peatland use might remain, but the management will be improved in a climate-friendly way, implying that half of the forestry can be managed in wet conditions and agriculturally used peatland can be preserved with no tillage (Fig. 2). However, using peatlands for food production might be unavoidable in areas of Finland where peat soil coverage is proportionally higher.

German experts expect a proportional land use change by shifting arable land and grassland to nature, wet grassland, and paludiculture. But the development of paludiculture is highly dependent on the income solutions for farmers. Submerged drains are not expected to play a big role (Fig. 3).

In the Netherlands, experts anticipate that peat meadows will be largely maintained due to the need for land to spread manure and levels of grass fodder production, but will have better water regulation by submerged and pressurized drainage technologies. Also, some forms of paludiculture are expected to play a more prominent role if revenue models can be demonstrated to generate sufficient income for farmers (Fig. 4). Midway targets for mitigation measures on peatlands also warranted discussion: Representatives from the Dutch national government aimed to raise the water table on 50% of the peat area by 2035, while the water authority aimed for 100% by 2035. This calls for future, open discussions between sectors on the reasons for these contrasting goals.

To increase farmers' and land managers' acceptance, experts from all 3 countries highlighted the importance to present farmers with alternative business perspectives and revenue models. More precisely, the potentials for building up local markets for products from rewetted land (e.g., pellets for energy, building materials, and horticultural substrates) need to be strengthened at regional scale and supported by policies, e.g., bio-economy policies for paludiculture biomass (Germany).

The participants discussed the desirability and feasibility of spatial coordination between peat sites in their countries, inspired by the Dutch collective model. In that context, all countries acknowledged that it would be beneficial to have regional coordinating institutions who can align the interests of farmers and land managers on peatlands in specific areas. Furthermore, all countries acknowledged that such institutions can play an important role in drafting mitigation options, which are flexible and can be adapted depending on a region's geographic characteristic and specific peatland uses. In that context, locally adaptable programs were identified as key to enabling a fair transition for all actors if peatland management should occur at the landscape level. Experts even discussed that cross-sectoral workshops can assist in capacity building and knowledge transfer and the general necessity to involve water management institutions.

Policy implication

Policy implication is based on both survey and workshop. Peatlands are facing different economic pressures and related land uses in the 8 countries under consideration ("Data collection based on expert survey" section), most of them leading to considerable organic soil degradation due to ongoing drainage activities. For agriculture, economic pressures for peatland users and owners are currently high in Denmark, Germany, the Netherlands, Poland, and the United Kingdom, where agricultural use of peatlands exceeds commercial forestry use. In Finland, Norway, and Sweden, the main land use is forestry at the national scale. Peatland use trends reflect implications of current land use policies and might therefore provide a glimpse into trends in policy changes as well. Land availability was identified as a key factor. Experts from Denmark, Finland, Germany, the Netherlands, and Norway stated that decreasing land availability leads to high land prices, implying a pressure for farmers to produce high-yielding products (Denmark, Germany, and the Netherlands), leading to land use conflicts with mitigation measures while maintaining a (lower-yielding) production function or resulting in low availability of land for nature conservation and peatland restoration (Finland, Germany, the Netherlands, and Norway).

Missing economic incentives are perceived as the main bottleneck, while another not less important factor is the associated economic risks and costs of applying mitigation measures. Experts from the Netherlands and Germany, in particular, mentioned that high investment costs in water infrastructure (as a matter of fact, many peatlands in Germany do not become wet by themselves anymore) and economic perspectives of peatland rewetting (by that excluding intensive land use from the peatland) are hindering the adoption of mitigation measures on higher water levels. Providing incentives and support mechanisms not only for those peatland regions where farmers fear less risk of income loss but also for all peatland-rich regions requires fundamental changes and a transition at the national and regional scale with regard to policy frameworks and expert perceptions of their role in peatland management and climate change mitigation.

Our results suggest that transition pathways can most likely be induced at the level of policy makers. We see similar hurdles for all the countries represented in our survey and workshop (see also Section S7 for workshop results). EU policy and funding are considered the most relevant promoting factors for the implementation of mitigation measures. Experts from Denmark, Germany, the Netherlands, Poland, and the United Kingdom referred to EU subsidies and agri-environmental programs as promoting factors in the sense that money is already available to implement measures on peatland, e.g., to reduce grazing levels on peatlands (United Kingdom) or prohibit grassland renewal (Germany). Besides the more general indication of the financial availability of EU common agricultural policy (CAP), experts from all 4 countries mentioned more explicit projects supporting peatland protection and financing pilot projects. Those are focusing on nature conservation on peatland sites, e.g., the protection of peatlands as Natura 2000 habitats (Poland), or on

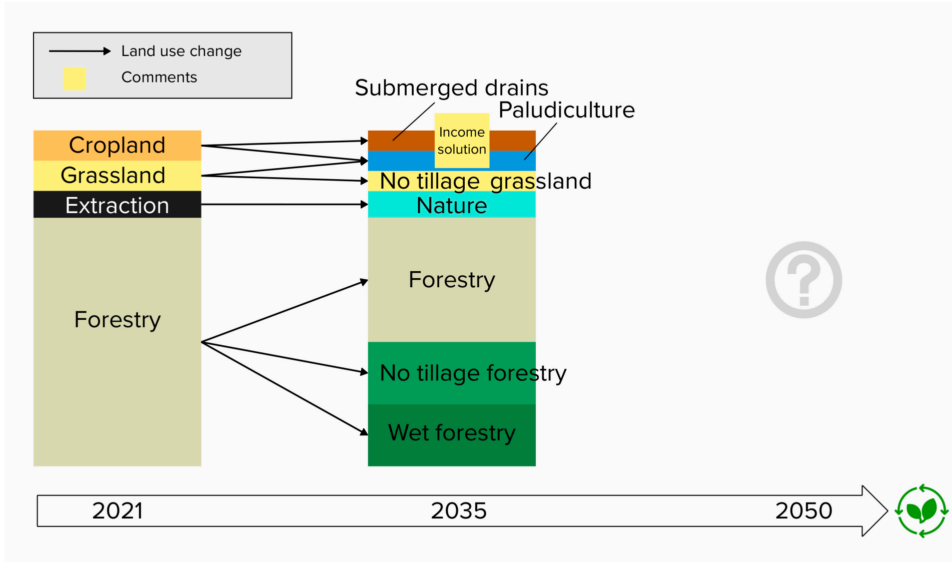

Fig. 2. Experts' anticipated transition pathway for Finland.

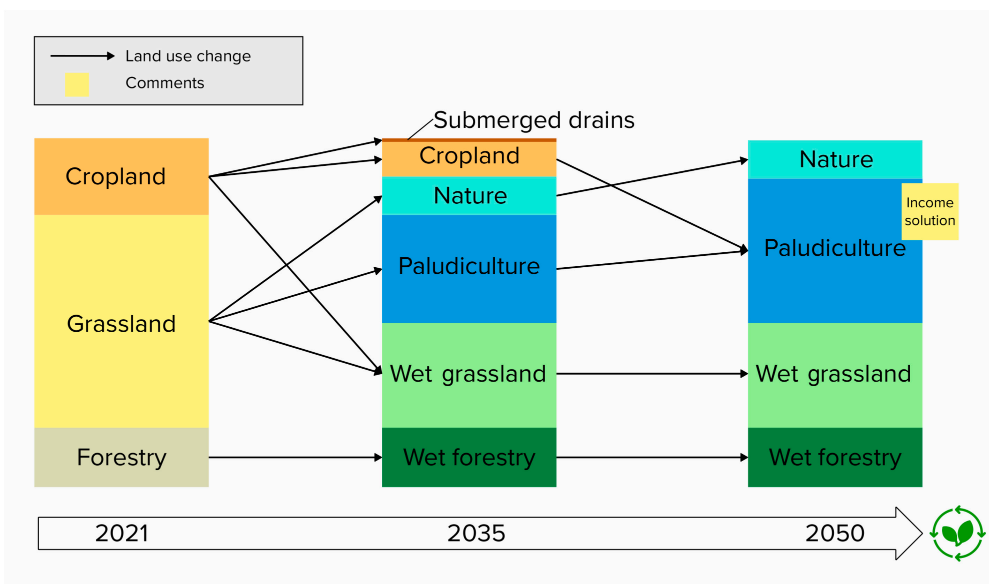

Fig. 3. Experts' anticipated transition pathway for Germany.

projects carried out, e.g., by regional landscape conservation agencies (Germany). At the same time, experts from 5 of 8 countries (Finland, Germany, the Netherland, Norway, and the United Kingdom) perceived the current EU and national economic incentive structure as insufficient driving force behind mitigation measures. The main point of critique has been the non-eligibility of wet peatlands as agricultural land by the EU CAP and related issues at national legislation, which is not covering all forms of land use on peatlands, especially wet peatlands with paludiculture crops (Finland, Germany, and the Netherlands).

Experts suggested that, to guide trends toward decreased peatland drainage, national policies and strategies should play an increasing role for peatlands by creating legally binding goals. If such national targets and strategies can gain juridical importance, they might give a strong signal for protecting peatlands and open additional financial streams (e.g., national climate fund) for peatland rewetting. In addition to using EU co-funding, national governments can finance their own large-scale research projects (e.g., the Dutch National Research Programme on Greenhouse Gas Emissions from Peat Meadows, abbreviated as NOBV), pilot projects (e.g., model and demonstration projects in peatland regions of Brandenburg, Germany), and payment schemes. However, some participants from the expert workshop expressed the need for established demonstration sites instead of more experimental pilot projects. Both options can be ways to counteract the perceived lack of knowledge by collecting environmental data, gaining technical experiences, and increasing

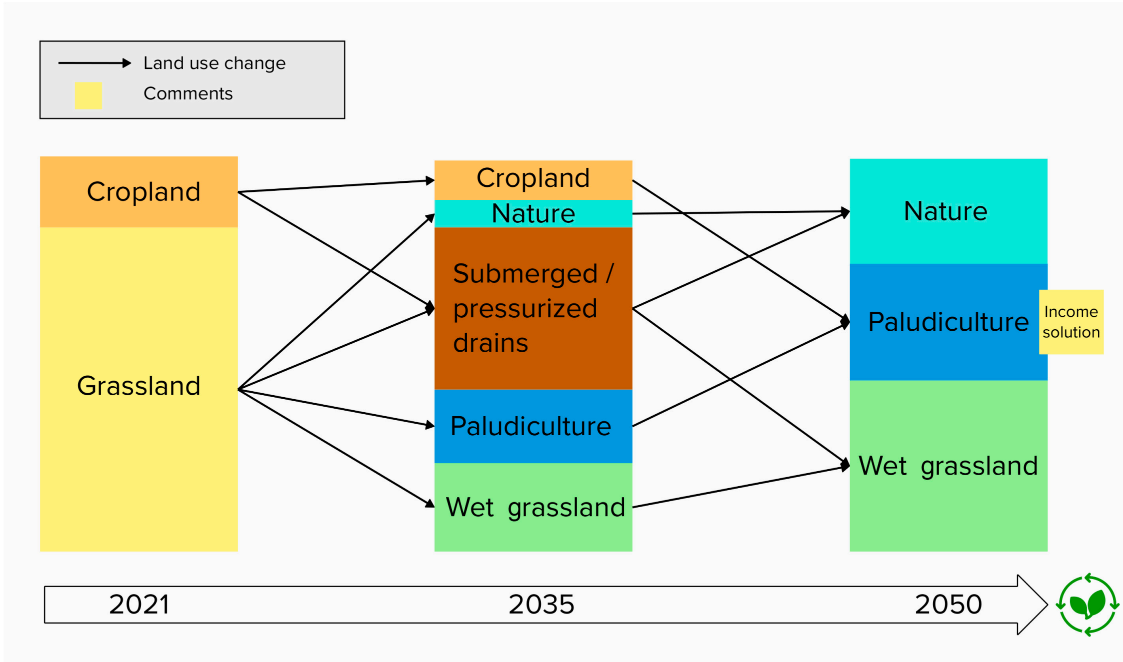

Fig. 4. Experts' anticipated transition pathway for the Netherlands.

local stakeholder acceptance. Other sectoral policies, such as water, nature, and property laws, may also affect the ease or permission for implementation.

In light of the growing public interest and political pressure within the climate mitigation debate, the lack of information regarding effects of peatland rewetting, including economic impacts of growing wet-adapted crops regarding farming techniques, commercialization options, and long-term financial support systems, remains the main bottleneck and source of stakeholder skepticism toward land use changes. The lack of information and data on the administrative and policy level, e.g., about different water elevation measures (Germany and the Netherlands), is causing insecurity among policy makers. In Norway and Poland, the lack of information and data concerning peatland drainage in general and peatland protection programs was classified as obstructive from the governmental (Poland) and scientific (Poland) perspective. Several established measures were highlighted (meadow bird programs in the Netherlands, grassland extensification in Germany, and perennial grasses in Finland), which do not directly target the water table and should be refined to support the transition.

Experts find that at the same time, the increased societal awareness to reduce GHG emissions (Germany and the Netherlands), the awareness of long-term impacts of peatland drainage, like soil subsidence (the Netherlands), and increased expert and scientific knowledge (the Netherlands, Norway, Poland, and Sweden) are drivers to push the implementation of mitigation measures. In the Netherlands, a great share of experts even referred to the raising societal awareness of long-term impacts of peatland drainage, especially the risks and costs of soil subsidence.

Besides uncertainties based on insufficient information, conflicting policies and interests seem to further complicate measure implementation. Regional policies and incentive structures like regional water management policies and biomass-based renewable energy incentives (Germany) or spatial planning for settlement and strict nature conservation policies (Poland) were perceived as bottlenecks. Nature protection policies and interests have been perceived either as conflicting, if mitigation measures with perceived mitigation potential were described as rather production-oriented, e.g., on peatland areas for forestry in Poland, or as hindering for nature conservation efforts on peatlands, e.g., in the case of the United Kingdom, where managed burning activities can reduce the likelihood of successful peatland restoration, but are in some areas important land care measures for grouse moor management and to reduce wildfire risk.

Discussion

Acceptance on the transition

Neither the expected trends nor transition pathways presented in our findings are the radical paradigm shift required to achieve climate pathways as suggested by Tanneberger et al. [27]. We support the findings from Ziegler et al. [37] that the transformation faces strong, adverse path dependency. This peatland transformation—as every other socioecological transformation in a complex system—requires changes at different levels and places, such as goals, rules, and mindsets [38]. Radical change will require alternative cultural "symbotypes" and sufficient pressure to prefer one of the alternatives [38]. De Jong et al. [39] stated that Dutch farmers are raised with the philosophy of using agricultural land to its maximum value; switching toward paludiculture requires a paradigm shift, with a way of farming that is more suited to extensive farming. However, publications like the Peatland Atlas [40] appeal to abandon one-dimensional utilitarian way of thinking and move to more complex thinking that understands and respects peatlands as more than mere usable landscapes.

Given the fact that drained peatlands are traditionally managed to produce food and generate income, the discussion about regulation of property and use rights in a command-and-control manner triggers resistance and the fear of "wet expropriation" with land users. Depending on the regional and landscape characteristics, peatland regions with currently low profitability of cultivation measures, the implementation potential of alternative land uses is higher. Mitigation measures therefore imply socioeconomic risks for land users and landowners in peat-rich regions. In Northern Europe, Kløve et al. [14] propose that strategies for peatlands should be tailored to local conditions and socioeconomic needs, given the expansive nature of peatland coverage, which often constitutes the predominant soil type in the region. Chen et al. [21] discovered that while enhancing water management through the implementation of submerged and pressurized drainage systems is advisable in the Netherlands, this approach is met with less favor in Finland and Germany. The study of Buschmann et al. [41] supports these findings by concluding that mainly economic variables (harvesting levels, including the consideration of mitigation costs, drainage infrastructure, land prices, and commercialization opportunities) determine the preferences for land use alternatives. Similarly, Schaller et al. [42] reflected on the relation of production intensive peatland sites with negative attitudes toward land use and management changes.

To increase acceptance of peatland re-wetting, it is vital to create local networks between farmers, administration, industry, and consumers. Regional coordinating institutions for land managers and farmers on peatlands were acknowledged as highly relevant to support transformation pathways in the complex interplay of peatland use targets and actors. The close link to appropriate incentive structures that actually induce change remains a cornerstone as stated by Norris et al. [43], where farmers need to be provided with feasible business models. Still, coordinating institutions, such as cooperatives, can provide farmers with information support, e.g., with regard to funding sources or potential business models for adopting mitigation measures with adapted crops [43], strengthening farmers' acceptance and finding the most suitable options for each region [44]. To facilitate a transition on a voluntary basis, market access is key for increasing farmers' and consumers' acceptance for paludiculture products [39].

Moving into transition

Our findings on the transition of productive land use on peatlands is supported by several studies [4,39], calling for new concepts, crops, techniques, and policy frameworks. Future policies and subordinated regulatory and economic instruments need to be carefully designed to meet the demand and expectations for target-orientated, effective, and just implementation. Burdening local land users with the cost of climate change mitigation for the benefit of the global community is comprehensibly recognized as unjust. Consequently, setting incentives for adapted management is a suitable option to reconcile the need for climate change mitigation on drained peatlands and their users' interest to adapt but maintain production options. The incentive structure under current EU CAP promotes drainage-based production on peatlands [19]. Considering farm economics, the monetary income, expenditure and profit flow, taxes, and subsidies are the main drivers for certain land use and production systems. Besides market prices for goods and services, governmental interventions such as subsidies can support peatland farmers' livelihoods and, with that, change incentives to follow not only the production of marketable goods but also services provided by peatlands and nature [45].

While economic instruments can help the transition, on their own they are insufficient to achieve the ambitious climate target set by the EU and Member State level. Regional acceptance should always be promoted by comprehensively applying the principle of voluntariness. Only in the medium to long run, voluntary measures need to be complemented by regulation, e.g., appropriation for land (and climate) preservation, to deliver on phasing-out drainage-based agriculture [3] or, to take a more recent example, the prohibition of deepening ditch water levels on peat soils (federal state of Bavaria, Germany, and Sweden). Economic incentives such as growing markets and demand for bio-energy products should be supported at the national or regional scale, e.g., by subsidies for bioenergy production from wet-adapted crops [46], which have shown to be economically viable besides their capacity to mitigate GHG emissions [19]. Looking into the energy sector, Tanneberger et al. [27] stress that wind power and solar energy plants also need to be considered as business perspectives in the context of peatland rewetting.

Starting at the EU level, EU climate policy and the CAP, as the most important policy with regard to drained peatland management, need to set correct incentives for national and subsequently regional subsidy programs to allow a transformation toward wet peatland use [21]. Other policies, e.g., in the energy sector, need to be coherent to strengthen GHG mitigation targets and to avoid counteracting policy targets [46]. Climate-friendly peatland use can contribute to the target of net-zero emissions; however, scientifically sound solutions and demonstration sites can only contribute to higher acceptance from farmers and land managers, to some extent. The development of regional business models need further acknowledgement and a joint development of transition pathways together with regional actors.

The transition on peatlands will not work by just replacing drainage-based agriculture by mitigation measures. It should rather be embedded in the transitions to a climate-neutral society with a circular bio-economy, demanding much more sustainable biomass. Similarly, Ziegler [20] pointed to strategies to move paludiculture from the margin to a transformation based on the framing, institutional conversion, and productive niche work. The broad transitions require substantial changes in our lifestyles, e.g., diet, construction, and transportation [3]. Peatland policies need to foresee this tendency and simultaneously work together with solutions beyond climate mitigation measures, e.g., providing seed money to start building supply chains of both paludiculture biomass and carbon credits [47].

Limitations of the approach

We present a qualitative analysis of experts' perceptions generated through a survey and a workshop. In order to minimize the bias, we included a heterogeneous group of participants from different sectors and governance levels. We are aware that the selection of expert groups as well as the number of participants are sources of bias and do not represent the full range of perspectives on the topic of peatland use and management. Nevertheless, no participant represents NGOs with climate focus, citizens, and future generations. NGOs, such as the International Union for Conservation of Nature (IUCN) and the Nature and Biodiversity Conservation Union (NABU), often advocate for peatland rewetting due to its environmental benefits. The perspective of future generations tends to support actions that promote climate mitigation. However, as the need for peatland action is urgent, it is important to have this study to further advice and improve the exchange between stakeholders at the EU and Member State level.

The perceived trends and knowledge on mitigation measures were cross-checked by expert feedback loops per country. Emission reduction potential and costs depend on many factors and are site-specific. To counter the risk of outdated information in relation to national transformation pathways, we checked the recent policy documents (Dutch Climate Agreement, German National Peatland Protection Strategy, and Finnish government resolution on the sustainable and responsible use of peatlands and mires) and did not find significant change in our framework conditions.

Conclusion

We captured insights from experts on the status and future paths of peatland management toward net-zero emission targets in European countries. Neither the expected trends nor the transition pathway presented in our findings indicates a radical paradigm shift.

Based on an expert survey, the anticipated trends in peatland utilization indicate that, with the exception of Finland, 7 other countries are witnessing a shift away from drainage-based cropland and forestry use, moving toward grassland use or even wetland. While the perceived trends align with emission reduction efforts, countries with highly productive peatland use regions are anticipated to show less inclination toward transitioning to less profitable land uses. According to the 3 categories of management practices based on the water level, currently applied management practices (biomass production, grazing activities, grassland use with elevated water tables and forestry) and potential options (paludiculture for grazing, biomass production) are identified. Among those, grassland uses are appreciated by experts.

We have investigated possible transformation pathways for Finland, Germany, and the Netherlands. There was consensus that peatland emissions have to be reduced drastically. However, whether EU climate mitigation efforts in peatlands should aim net-zero emissions by 2050 is highly debated by experts due to its difficulty for technical, natural, or management reasons. The participants discussed the desirability and feasibility of spatial coordination to align the interests of land managers in hydrologically connected peat areas. Similar hurdles appear for the transition pathways in all the countries incorporated in this study, especially missing economic incentives.

The EU countries' transition pathway—which involves adopting wet grassland and paludiculture, adjusting agricultural subsidies, and fostering a robust market for sustainable products—not only preserves its own peatlands but also serves as a model for other peatland-rich regions, such as the United Kingdom, Russia, Belarus, Indonesia, and Malaysia. The transformation of peatlands cannot be achieved solely by substituting drainage-based agriculture with re-wetting. Instead, it must be integrated into the broader shift toward a climate-neutral society and a circular bio-economy. Our findings emphasize the need for new concepts, techniques, markets, and policy frameworks that take diverse regional conditions into account.

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Data Availability

Data are freely available upon request.

Supplementary Materials

Sections S1 to S7

References

1. Leifeld J, Menichetti L. The underappreciated potential of peatlands in global climate change mitigation strategies. *Nat Commun*. 2018;9(1):1071.
2. Joosten H, Sirin A, Couwenberg J, Laine J, Smith P. The role of peatlands in climate regulation. In: Bonn A, Allott T, Evans M, Joosten H, Stoneman R, editors. *Peatland restoration ecosystem services: Science, policy practice*. Cambridge (UK): Cambridge University Press; 2016. p. 66.
3. Grethe H, Martinez J, Osterburg B, Taube F, Thom F. Klimaschutz im Agrar-und Ernährungssystem Deutschlands: Die drei zentralen Handlungsfelder auf dem Weg zur Klimaneutralität. Stiftung Klimaneutralität; 2021.
4. Tanneberger F, Appulo L, Ewert S, Lakner S, Brolcháin Ó, Peters J, Wichtmann W. The power of nature-based solutions: How peatlands can help us to achieve key EU sustainability objectives. *Adv Sustainable Syst*. 2021;5(1):2000146.
5. Greifswald Mire Centre. Briefing Paper on the role of peatlands in the new European Union's Common Agriculture Policy (CAP). 2019.
6. Joosten H, Tanneberger F, Moen A. *Mires and peatlands of Europe*. Schweizerbart; 2017.
7. Biancalani R, Avagyan A. Towards climate-responsible peatlands management. Mitigation of Climate Change in Agriculture Series (MICCA). 2014(9).
8. European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Stepping up Europe's 2030 climate ambition investing in a climate-neutral future for the benefit of our people, com/562 final. 2020.
9. Peters J, Unger Mv. Peatlands in the EU Regulatory Environment. Bundesamt für Naturschutz. Bonn (Germany): Federal Agency for Nature Conservation; 2017.
10. European Parliament. EU Nature restoration law: MEPs strike deal to restore 20% of EU's land and sea. Press Releases. 2023.
11. Wittmayer J, Hölscher K, Wunder S, Veenhoff S. *Transformation research: Exploring methods for an emerging research field*. Dessau-Roßlau (Germany): German Environment Agency; 2018.

12. BMU. National Peatland Protection Strategy. Federal Minister for the Environment. Nature Conservation and Nuclear Safety. 2021.
13. Weideveld STJ, Liu W, van den Berg M, Lamers LPM, Fritz C. Sub-soil irrigation does not lower greenhouse gas emission from drained peat meadows. *Biogeosci Discuss*. 2020.
14. Kløve B, Berglund K, Berglund Ö, Weldon S, Maljanen M. Future options for cultivated Nordic peat soils: Can land management and rewetting control greenhouse gas emissions? *Environ Sci Pol*. 2017;69:85–93.
15. Günther A, Barthelmes A, Huth V, Joosten H, Jurasinski G, Koebsch F, Couwenberg J. Prompt rewetting of drained peatlands reduces climate warming despite methane emissions. *Nat Commun*. 2020;11(1):1644.
16. Joosten H, Tapio-Biström M-L, Tol S. *Peatlands: Guidance for climate change mitigation through conservation, rehabilitation and sustainable use*. Rome (Italy): Food and Agriculture Organization of the United Nations; 2012.
17. Wichtmann W, Schröder C, Joosten H. Paludiculture—Productive use of wet peatlands. Stuttgart (Germany): Schweizerbart Science Publishers; 2016.
18. Wittnebel M, Tiemeyer B, Dettmann U. Peat and other organic soils under agricultural use in Germany: Properties and challenges for classification. *Mires Peat*. 2021;27(19):24.
19. Wichmann S. *Economic incentives for climate smart agriculture on peatlands in the EU*. Greifswald (Germany): Institute of Botany Landscape Ecology, University of Greifswald Partner in the Greifswald Mire Centre; 2018.
20. Ziegler R. Paludiculture as a critical sustainability innovation mission. *Res Policy*. 2020;49(5):103979.
21. Chen C, Loft L, Matzdorf B. Lost in action: Climate friendly use of European peatlands needs coherence and incentive-based policies. *Environ Sci Pol*. 2023;145:104–115.
22. Folke C. Resilience (Republished). *Ecol Soc*. 2016;21(4):44.
23. Fedele G, Donatti CI, Harvey CA, Hannah L, Hole DG. Transformative adaptation to climate change for sustainable social-ecological systems. *Environ Sci Pol*. 2019;101:116–125.
24. Geels FW, Schot J. Typology of sociotechnical transition pathways. *Res Policy*. 2007;36(3):399–417.
25. Roe S, Streck C, Obersteiner M, Frank S, Griscom B, Drouet L, Fricko O, Gusti M, Harris N, Hasegawa T, et al. Contribution of the land sector to a 1.5 °C world. *Nat Clim Change*. 2019;9(11):817–828.
26. Mander Ü, Espenberg M, Melling L, Kull A. Peatland restoration pathways to mitigate greenhouse gas emissions and retain peat carbon. *Biogeochemistry*. 2023;167(4):523–543.
27. Tanneberger F, Abel S, Couwenberg J, Dahms T, Gaudig G, Günther A, et al. Towards net zero CO2 in 2050: An emission reduction pathway for organic soils in Germany. *Mires and Peat*. 2021;27.
28. Truffer B, Voß JP, Konrad K. Mapping expectations for system transformations: Lessons from sustainability foresight in German utility sectors. *Technol Forecast Soc Chang*. 2008;75(9):1360–1372.
29. Olsson P, Folke C, Hughes TP. Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. *Proc Natl Acad Sci*. 2008;105(28):9489–9494.
30. Loisel J, Gallego-Sala AV, Amesbury MJ, Magnan G, Anshari G, Beilman DW, Benavides JC, Blewett J, Camill P, Charman DJ, et al. Expert assessment of future vulnerability of the global peatland carbon sink. *Nat Clim Chang*. 2021;11(1):70–77.
31. Bercht AL. How qualitative approaches matter in climate and ocean change research: Uncovering contradictions about climate concern. *Glob Environ Chang*. 2021;70:102326.
32. UNEP. *Global Peatlands Assessment—The State of the World's Peatlands: Evidence for action toward the conservation, restoration, and sustainable management of peatlands.* Nairobi: UNEP; 2022.
33. Crump J, Avagyan A, Baker E, Barthelmes A, Velarde C, Dargie G, et al. Smoke on water: Countering global threats from peatland loss and degradation—A rapid response assessment. Report No.: 8277011687. 2017.
34. Tanneberger F, Tegetmeyer C, Busse S, Barthelmes A. And 55 others: The peatland map of Europe. *Mires Peat*. 2017;19(22):1–17.
35. Martin N, Couwenberg J. Organic soils in national inventory submissions of EU countries. *Proc Greifswald Mire Centre*. 2021;5:86.
36. Mayring P. Qualitative content analysis: Theoretical foundation, basic procedures and software solution. Klagenfurt: Social Science Open Access Repository; 2014.
37. Ziegler R, Wichtmann W, Abel S, Kemp R, Simard M, Joosten H. Wet peatland utilisation for climate protection—An international survey of paludiculture innovation. *Clean Engr Technol*. 2021;5:100305.
38. Costanza R. A theory of socio-ecological system change. *J Bioecon*. 2014;16(1):39–44.
39. de Jong M, van Hal O, Pijlman J, van Eekeren N, Junginger M. Paludiculture as paludifuture on Dutch peatlands: An environmental and economic analysis of Typha cultivation and insulation production. *Sci Total Environ*. 2021;792:148161.
40. Inka D, Tobias W, Sabrina H, Jan P. Peatland atlas. Berlin (Germany): Heinrich-Böll-Stiftung; 2023.
41. Buschmann C, Röder N, Berglund K, Berglund Ö, Lærke PE, Maddison M, Mander Ü, Myllys M, Osterburg B, van den Akker JJH. Perspectives on agriculturally used drained peat soils: Comparison of the socioeconomic and ecological business environments of six European regions. *Land Use Policy*. 2020;90:104181.
42. Schaller L, Kantelhardt J, Drösler M. Cultivating the climate: Socio-economic prospects and consequences of climate-friendly peat land management in Germany. *Hydrobiologia*. 2011;674(1):91–104.
43. Norris J, Matzdorf B, Barghusen R, Schulze C, van Gorcum B. Viewpoints on cooperative peatland management: Expectations and motives of Dutch farmers. *Land*. 2021;10(12):1326.
44. Kekkonen H, Ojanen H, Haakana M, Latukka A, Regina K. Mapping of cultivated organic soils for targeting greenhouse gas mitigation. *Carbon Manage*. 2019;10(2):115–126.
45. Rawlins A, Morris J. Social and economic aspects of peatland management in northern Europe, with particular reference to the English case. *Geoderma*. 2010;154(3-4):242–251.
46. Regina K, Budiman A, Greve MH, Grønlund A, Kasimir Å, Lehtonen H, Petersen SO, Smith P, Wösten H. GHG mitigation of agricultural peatlands requires coherent policies. *Clim Pol*. 2016;16(4):522–541.
47. Chen C, Loft L, Sattler C, Matzdorf B. Developing regional voluntary carbon markets for peatlands: Innovation processes and influencing factors. *Clim Pol*. 2023;23(2):238–253.