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We need targeted policy interventions in the EU to save soil carbon

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Globally, annual emissions from managed organic soils accounts for up to 5% of all anthropogenic greenhouse gas (GHG) emissions. Climate-wise management and restoration of degraded organic soils could reduce GHG emissions quickly and at relatively low costs. The European Union (EU) Member States that have large areas of organic soils with high GHG emissions are Sweden, Finland, Germany, Ireland, Poland, Netherlands, and the Baltic countries. To meet the climate targets and objectives of the Paris Agreement the land-use sector is indispensable and mitigation policies targeting organic soils will be needed. The international regulatory framework is broad and quite unspecific. In contrast, the European Union has initiated binding regulation for the land-use sector through the EU Climate Law, the EU LULUCF regulation, and the proposed EU Nature Restoration Law. However, even this regulatory approach is not on track to deliver on its binding ambitions, indicating the need for more effective implementation measures also on organic soils in the EU and its member states. Furthermore, we argue that appropriate policy selection should consider current knowledge regarding the climate impacts of management options of organic soils. Lastly, we need more studies on GHG emissions, and standardized methods for GHG inventories, to resolve uncertainties surrounding the impacts of management to GHG emissions. Successful policy implementation requires more efforts but also improved scientific justification through continuous consideration of climate policy integrity and strengthening of the reliability of GHG inventories.

KEYWORDS

climate change, land use, climate policy, carbon sink and source, organic soils, peatland restoration and management, deforestation, forest management

Introduction

The goal of the Paris Agreement is to limit the global average temperature increase to well below 2°C from pre-industrial levels, and to pursue efforts to limit it to 1.5°C [Paris Agreement, art. 2.1(a)]. The Paris Agreement also aims to achieve a balance between anthropogenic greenhouse gas (GHG) emissions and removals in the second half of this century (Article 4.1). These collective goals are to be achieved through Nationally Determined Contributions (NDCs), in which Parties to the Paris Agreement define their national climate goals and targets. A crucial element of the Paris Agreement's mitigation architecture is that the NDCs are updated at 5-year intervals (Paris Agreement, Article 4.9). This will be done considering the outcomes of a 5-yearly assessment of collective progress towards the Agreement's goals through a

comprehensive process known as the Global Stocktake (Paris Agreement, Article 14 and Decision 1/CMA.5). Many Parties to the Paris Agreement as well as various non-state actors have also adopted national net-zero goals. The European Court of Human Rights has recently ruled in a landmark case obliging states to have appropriate plans in place to become carbon neutral or reach net-zero GHG, and to define carbon budgets (ECtHR 2024). The European Union (EU) aims to achieve climate neutrality by 2050 and negative GHG emissions thereafter (Regulation 2021/1119, Art. 2.1). The EU is thus a pioneer in initiating regulation for the land-use sector, with specific targets for each member state to enhance forest carbon sinks and to reduce GHG emissions from land use.

Globally, the land-use sector will play an important role in the Paris Agreement's implementation, with roughly a quarter of total pledged mitigation in the NDCs until 2030 expected to be related to land-use (den Elzen et al., 2022; Nabuurs et al., 2022). One-third of the cost-efficient climate change mitigation measures needed by 2030, could be provided by improved land management actions, including restoration and conservation of global forests, wetlands, grasslands, and croplands (Griscom et al., 2017; Roe et al., 2019). While the Paris Agreement itself does not specify the role of the land-use sector, the 2050 global net-zero goal implies substantial changes in land use and land management practices (IPCC, 2019; Nabuurs et al., 2022). In this paper, we discuss the role of the land-use sector, in particular, how the management of forests, peatlands, and other organic soils, help achieve the global climate targets, including the EU 2050 climate neutrality objective and implementation of the Paris Agreement.

Current emission trends in the land-use sector

Land-use change is a major driver of global terrestrial carbon fluctuations. Currently, annual GHG emissions from deforestation are 6,500 million tonnes of carbon dioxide equivalent (Mt CO_2 eq.), while fossil fuel GHG emissions are 36,600 Mt CO_2 eq) (Friedlingstein et al., 2022). This suggests that avoiding deforestation has a high global climate change mitigation potential. However, in the EU, avoided deforestation may contribute only 2% (11 Mt CO_2 eq.), and afforestation only 12% (54 Mt CO_2 eq.) of the total mitigation potential of the forest sector (Verkerk et al., 2022).

Global forest carbon sinks (3,500 Mt CO_2 eq, Friedlingstein et al., 2022) sequester the carbon equivalent of approximately 10% of global fossil fuel GHG emissions. The global estimate for annual GHG emissions from drained organic soils ranges from 800 Mt CO_2 eq. to 2000 Mt CO_2 eq. (Günther et al., 2020; Friedlingstein et al., 2022), which accounts for up to 5% of all anthropogenic GHG emissions. Reducing GHG emissions from managed drained peatland forests may require maintenance of tree cover, which facilitates re-wetting of the site and may lead to reduced emissions of CO_2 and N_2O (e.g., Lehtonen et al., 2023). Meanwhile, if the degraded temperate or boreal peatland habitat does not naturally include trees, then restoration of its carbon sequestration potential requires conditions that favor peat forming vegetation rather than tree cover.

In the EU, total GHG emissions from all other sectors (3,540 Mt CO_2 eq.) are partially mitigated by the land use, land-use change and forestry (LULUCF) sector, which is a net carbon sink (230 Mt CO_2 eq.). The LULUCF sector reduced EU´s net GHG emissions by 6.5% in 2021 (European Environment Agency, 2023). The most significant GHG emission sources of the LULUCF sector are organic soils, which cover 4% of the total land area of managed forests, croplands and grasslands, and their CO_2 emissions reached 98 Mt in 2021 (European Environment Agency, 2023). The CO_2 emissions from organic soils corresponds to approximately 40% of total EU net removals from the LULUCF sector. The definition of organic soils used in the GHG reporting follows IPCC (2006) guidance.

Land-use sector in international climate law

The 1992 United Nations Framework Convention on Climate Change (UNFCCC) introduced a general obligation for the Parties to mitigate their anthropogenic GHG emissions [Article 4.1.(b)], including those arising from agriculture and forestry [Article 4.1(d)]. Under the 1997 Kyoto Protocol, developed countries were for the first time obligated to report GHG emissions and removals associated with specific land uses–mainly focusing on deforestation and afforestation–following rules and templates that evolved and became more sophisticated over time (Krug, 2018). The 2015 Paris Agreement was the first international climate agreement that included a provision of sinks globally. Accordingly, Parties "should take action to conserve and enhance, as appropriate, sinks and reservoirs of GHGs as referred to in Article 4, paragraph 1 (d), of the Convention, including forests" (Article 5.1.). At first glance, this provision is similar to the obligations contained in the 1992 UNFCCC; its significance comes, however, from the Paris Agreements temperature goal (Art. 2.1.a) and the net-zero goal of achieving a balance between sources and sinks of GHGs in the second part of the century (Art. 4.1) (Savaresi and Perugini, 2021). Achieving these goals is estimated to require significant mitigation measures in the land-use sector.

The Paris Agreement did not introduce specific rules for accounting the contribution of the Land Use, Land Use Change, and Forestry (LULUCF) sector to the Parties' NDCs. Instead, it guides parties to draw upon existing guidance established under the UNFCCC and the Kyoto Protocol. The NDCs must describe the accounting systems used, which must be consistent with IPCC Guidelines and the guidance adopted by the Paris Agreement's governing body, known as the CMA (UNFCCC, 2019). In practice, the Paris Agreement leaves Parties a wide range of discretion to provide their own definitions for the LULUCF-sector activities covered and to develop their own accounting approaches - such as net-net, gross-net, and accounting against a reference level. In practice, different Parties have employed diverse methodologies and approaches to account for the contribution of the LULUCF sector to the achievement of their NDCs, resulting in ambiguous rather than ambitious mitigation plans (Fyson and Jeffery, 2019). The plans have also been highly reliant on CO_2 removal on large land areas with an underwhelming focus on targeting GHG emission sources (Dooley et al., 2022; Stuart-Smith et al., 2023).

Carbon neutrality target and land-use sector in EU climate law

While the international regulatory framework for land use is quite broad and unspecific, the EU is one of the Parties that have introduced novel and binding legislation in the land-use sector. The EU's current long-term objective is to achieve climate neutrality by 2050 and to have net negative GHG emissions after 2050. These objectives have been enshrined in the 2021 European Climate Law (Regulation 2021/1119, Article 2.1). A recent review concluded that total mitigation potential of the forest sector could be up to 464 Mt CO_2 eq. per year by 2050, of which peatland restoration is reported to provide the largest (25%) proportion of additional potential (115 Mt CO_2 eq. yr^{-1}) (Verkerk et al., 2022). The estimated climate change mitigation potential of peatlands is based on two studies. One of these, namely, Humpenöder et al. (2020), includes all types of peatlands and not only forested peatlands. In general, mitigation of the carbon loss from boreal and temperate peatland ecosystems requires restoration of the hydrology and water table that reduce CO_2 emissions and facilitate growth of peat forming plant species such as *Sphagnum* mosses. In the LULUCF sector, agricultural soils, with emissions over 40 Mt CO_2 in 2021 (European Environment Agency, 2023), could provide additional mitigation potential.

The EU climate neutrality objective will be challenging to achieve without either new disruptive technologies (Capros et al., 2019) or realizing a combination of forest climate change mitigation and GHG emission reductions in the land-use sector including peatlands (Verkerk et al., 2022). Such GHG emission reductions of the land-use sector are estimated to represent the most cost-efficient mitigation potential (Roe et al., 2021). Current management practices, including relatively high harvesting levels, and an observed increase in tree mortality due to large scale disturbances has led to current and expected future decrease of the forest land carbon sink (Korosuo et al., 2021). The respective roles of GHG emission reductions and removals for achieving the EU climate neutrality objective have not been defined in the European Climate Law (Kulovesi et al., 2024). More clarity will be provided after the June 2024 EU elections by the new European Commission, through a legislative proposal to include the 2040 target in the European Climate Law.

The EU has adopted a 55% net GHG emission reduction target for 2030 from 1990 levels (Regulation 2021/1119). In this context, it has passed legislation aiming to increase net removals in the LULUCF sector from 280 to 310 Mt CO_2 eq. by 2030 (Regulation 2023/839). At the same time, the EU has capped the contribution of the LULUCF sector to the achievement of its overall 2030 target to 225 Mt CO_2 eq. As a result, the EU's actual net GHG emission reduction target for 2030 is estimated at around 57% from 1990 levels.

The two iterations of the LULUCF Regulation, adopted in 2018 and 2023, have successively reformed and consolidated the way in which its Member States account and report GHG flows in the LULUCF sector. The 2023 Regulation introduced a binding EU-wide LULUCF target of 310 Mt CO_2 eq. by 2030, alongside allocating national targets for each Member State. It furthermore introduced a set of provisions designed to enhance the monitoring, reporting, and verification processes of GHG emissions and removals. Lastly, the LULUCF Regulation laid the groundwork for introducing a certification mechanism for carbon removals through the legal proposal on sustainable carbon farming. The possibility to integrate land-use and forestry emissions and removals into the carbon markets or extend carbon pricing in other ways are also actively discussed both by EU institutions and the scientific community (ESABCC, 2024, 13). While the EU approach represents a major push for a coherent policy in the land-use sector, regulation in the agricultural and climate domains remain contradictory as agricultural approaches that may even undermine reaching climate goals are subsidized (Chen et al., 2023). Currently the lack of progress towards the legally binding EU 2030 target is evident in agriculture and the LULUCF sector, despite the adopted legally binding regulatory approach (ESABCC, 2024). This indicates a need to intensify efforts in the EU and at the national level. Furthermore, it seems necessary to further explore how synergies between policies dealing with climate, agricultural, biodiversity and water quality aims could be realized more effectively. Table 1 summarizes EU and international law obligations in this area.

Discussion

The Kyoto Protocol, negotiated in 1997, was the first climate agreement that committed countries to reduce the GHG emissions, but regulation of the land-use sector was mainly limited to deforestation and afforestation in industrialized countries with limited importance to forest carbon sinks. In the Paris Agreement, the role of forests was acknowledged and the framework to include them into global climate plans was introduced in the Nationally Determined Contributions (NDC). The EU NDC includes the impact of the LULUCF sector, and the EU further established managed forest reference levels as a benchmark for the forest carbon sinks by its member states (Korosuo et al., 2021), which created an incentive to maintain and enhance forest carbon sequestration on forest land.

We suggest that the carbon sink of forest soil and biomass can be realistically increased by climate-wise management practices, e.g., by reduced logging, by mitigated soil GHG emissions and by forest conservation (Verkerk et al., 2022; Mäkipää et al., 2023). In the EU, these measures together may increase the annual carbon sink by 200 Mt CO_2 eq. by 2050, while the mitigation potential of wood products is limited (Verkerk et al., 2022). The restoration of peatlands may provide the largest (115 Mt CO_2 eq. yr^{-1}) climate change mitigation potential in the EU LULUCF sector, but the estimate is highly uncertain. Potential forest management practices that may increase carbon sinks include forest fertilization, lengthened rotation periods and avoidance of clear-cutting with transition to continuous cover forestry especially on peatland forests. In the short term (e.g., by 2030), these measures are less efficient than decreased harvest level, and they cannot compensate the effect of potentially increasing the harvesting level (Verkerk et al., 2022). However, the increasing frequency of forest disturbance in Europe may offset the effect of management strategies aiming to increase the forest carbon sink, since wind, bark beetle and fire damages can induce fast large-scale ecosystem carbon loss (Seidl et al., 2014). This indicates a need for considering the long-term

TABLE 1 Major international agreements and EU legislation that currently frame or promote climate change mitigation measures of the land use, land-use change and forest (LULUCF) sector globally and in the EU.

Legal instrument	Central Provision(s)	Relevance to mitigation measures of the LULUCF sector
UNFCCC (1992), the United Nations Framework Convention on Climate Change	Article 4.1 (a) and (d), also see[1]	Established obligations to develop national GHG emission inventories, and promote the sustainable development, conservation and enhancement of GHG sinks and reservoirs
Decision 13/CP.9, Good practice guidance for land use, land-use change and forestry in the preparation of national greenhouse gas inventories under the Convention, UN Doc. FCCC/CP/2003/6/Add.1 (2004)	Paragraph 2	Annex I Parties (developed countries) to the UNFCCC should use the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry in their national inventories
Decision 24/CP.19, Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention, UN Doc. FCCC/CP/2013/10/Add.3 (2013)	Paragraphs 4 and 13	Requires Annex I Parties to use the 2006 IPCC Guidelines for National Greenhouse Gas Inventories as guidance for the preparation of GHG inventories. It also invites the Parties to use the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, on wetlands
Paris Agreement (2015)	Articles 4.1 and 5	Parties should achieve a balance of GHGs between emissions and sinks in second half of the century to reach long term goals; all parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of GHGs and support the existing framework under the UNFCCC.
Decision 18/CMA.1, Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement, FCCC/PA/CMA/2018/3/Add.2 (2018)	Paragraph 55	When reporting the GHG emissions and subsequent removals from natural disturbances on managed lands in GHG inventories, parties must report information on the approach taken, and how it is consistent with IPCC guidance, as appropriate, and indicate if the estimates are indicated in national totals
EU LULUCF regulation (Regulation EU 841/2018) amended by 2023 revision (Regulation EU 2023/839)	Article 4, Annex IIa, Articles 12–13	Established new accounting rules concerning the LULUCF sector, as well as binding land sector targets, both for the EU and individual Member States. The revision introduces a 310 Tg CO_2 eq. target for EU LULUCF sector in 2030, requiring the net sink to increase. During 2021–2025 each Member State shall ensure that accounted GHG emissions from land use are compensated by at least an equivalent amount of accounted removals (a.k.a. "no debit" rule). Flexibilities for member states are provided (Articles 12–13), but most become applicable only if the EU-wide target is reached
The European Climate Law (Regulation EU 2021/1119)	Article 2, Articles 3–11	Enshrines into law the target of at least 55% GHG emissions reductions by 2030 and establishes the European Union's climate neutrality target by 2050 (Article 2). Articles 3–11 establish the new process to ensure progress and achievement of these legally binding goals, and they cover the LULUCF sector
EU Nature Restoration Law (pending approval)[2]	Articles 4, 6 and 9	EU countries must restore habitat types covered by the new law to a good condition (30% by 2030, 60% by 2040, and 90% by 2050), expected to contribute to climate mitigation considerably. However, member states lead implementation. Weak enforcement provisions and multiple reservations are included For peatlands restoration targets applicable to member states are 30% by 2030 of which at least a quarter shall be rewetted, rising by 2040 to 40% and by 2050 to 50% respectively, both of which at least a third shall be rewetted
EU Common Agricultural Policy 2023–2027 (Regulations EU 2021/2115 on CAP financing & EU 2021/2116 on Member State Strategic Plans)	E.g., Article 13 & Annex III of Regulation EU 2021/2116; Article 97 of Regulation EU 2021/2115	Member states must ensure appropriate protection of wetlands and peatlands as carbon stores; only a minor part of financing is going towards agriculture that aligns with the EU´s environmental priorities; member states have to assign at least 25% benefiting public goods (including climate mitigation) through eco-schemes, although a majority of funding remains unaffected by climate objectives European Commission, (2023)

[1]https://unfccc.int/topics/land-use/workstreams/land-use–land-use-change-and-forestry-lulucf/reporting-of-the-lulucf-sector-by-parties-included-in-annex-i-to-the-convention.

[2]provisional analysis based on triologue outcome in November 2023, assuming that final outcome will be accepted by the EU council and parliament.

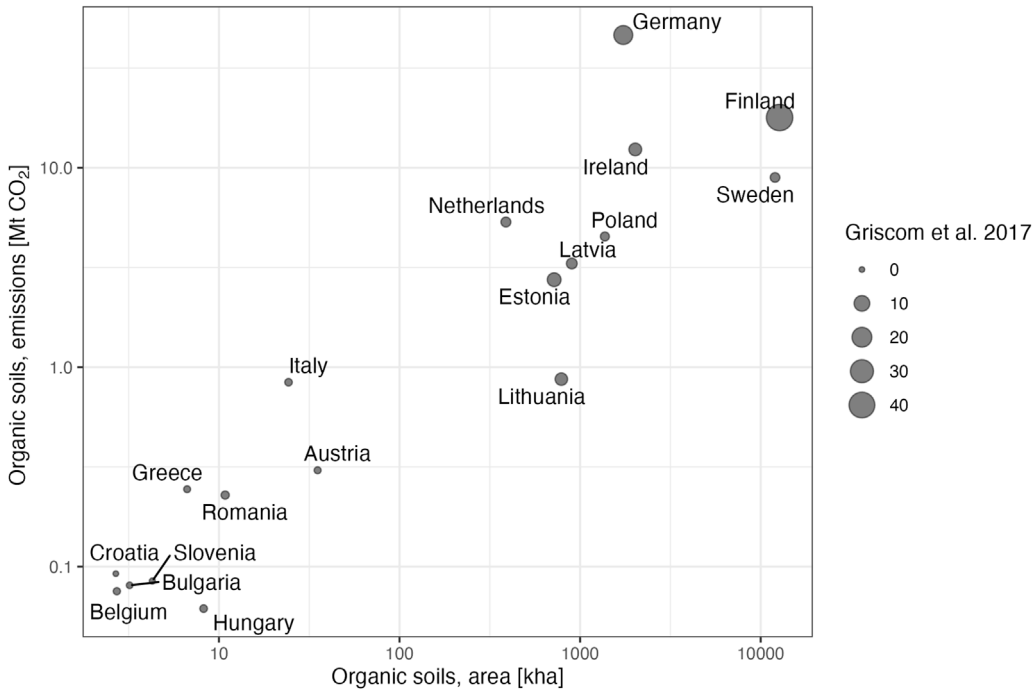

FIGURE 1
Land areas of organic soils for forest land, cropland, grassland, and wetlands under UNFCCC reporting for 2021, based on the 2023 submissions of the countries that reported organic soils, *y*-axis for corresponding organic soils CO_2 emissions, while size of the circle indicates estimated emission reduction potential by Griscom et al. (2017) (peatland restoration and avoided peatland impacts).

resilience of forest ecosystems for both climate adaptation and climate mitigation.

In the EU, the restoration of the degraded organic soils is estimated to be the most efficient forest-based climate change mitigation measure (Humpenöder et al., 2020; Verkerk et al., 2022). Without restoration, drained organic soils continue to emit CO_2, while rewetting reduces climate warming by decreasing microbial soil oxidation and CO_2 emissions. The rewetting may also increase soil CH_4 emissions, but quantified CH_4 emissions do not undermine the mitigation effect (e.g., Laine et al., 2019; Gunther et al., 2020). According to national estimates, for example, in Finland and the UK, current GHG emissions from organic soils, and their corresponding mitigation potential, seems to be lower (Figure 1) than reported in Humpenöder et al. (2020). However, all estimates come with very high uncertainty (e.g., Alm et al., 2023; NIR Finland, 2023), and further advances are needed in the soil modelling that assists GHG inventories. In the EU, countries that have a large area of organic soils are Sweden, Finland, Germany, Ireland, Poland, Netherlands, and the Baltic countries (Figure 1). These countries also have the largest GHG emissions from organic soils, and thus a large mitigation potential (European Environment Agency, 2023; Figure 1). Such a large GHG emission reduction potential of organic soils emphasizes an urgent need for an extension of restoration actions, complemented by regenerative cropland and forest management methods that can simultaneously fulfill societal demand for food, wood, water, as well as biodiversity and climate policy targets. The mitigation potential of productive forested peatlands is estimated for Finland, which includes transition from rotation forestry to continuous cover forestry, a climate-wise and economically profitable option (Juutinen et al., 2020). It resulted in a slight increase (1 Mt CO_2 eq. per year) in forest carbon sink, partly due to reduced GHG emissions from peat soils and partly due to reallocation of harvests (Lehtonen et al., 2023). Restoration of degraded peatlands is already considered in the EU's proposed Nature Restoration Law with specified targets for land area to be restored (Table 1) and this promising option needs further evaluation and large-scale pilots to establish the most appropriate implementation options. Furthermore, it is essential to reduce uncertainties in estimates of GHG emission reductions of restoration practices, to create a solid basis for climate policy and for improved sectoral coherence of policies.

The climate change mitigation measures of the land-use and forest sector are associated with high uncertainty, which has slowed down the development of regulation based on carbon markets (e.g., Bellassen et al., 2022; Verkerk et al., 2022). In the changing climate, uncertainty of the mitigation measures is further increased due to higher frequency of the biotic and abiotic disturbances (incl. insect outbreaks, wind damages, drought and forest fires), which challenge the permanency of the carbon stock. The voluntary land-based carbon markets have also faced continuous critique focusing on baseline definition and permanency of mitigation outcomes. In total, existing voluntary carbon offsets may lead to delayed GHG emission reductions due to lack of permanence and delayed GHG emission reductions actions (Guizar-Coutiño et al., 2022). The LULUCF regulation allows an option to transfer carbon credits between the member

states, which member states may opt if they do not reach reference level during the commitment period of 2021–2025 (Korosuo et al., 2021). The uncertainties of the forest carbon sink estimates are reported in the national GHG inventories, and inventory reports show that some countries do not report soil GHG exchange for organic soils or they apply constant default emission factors. Given such uncertainties, it is not always clear whether a reported category is a sink or source of GHG emissions. Thus, carbon markets or carbon trading between the EU countries engaging the land-use sector do not have a solid foundation as long as carbon stock changes and GHG fluxes are reported with high uncertainty. This implies that other forms of regulation (cf. Table 1) may currently need to take precedence.

The most cost efficient and prominent measures to mitigate climate change in the land-use and forest sector can be found from the management of boreal peatlands (e.g., Roe et al., 2021). In general, forest carbon sinks may not be permanent, and sequestrated carbon can be lost due to natural disturbances or harvests, but this is not the case for wet boreal peatlands, where CO_2 emission reductions of peat soils have effects comparable to reduced CO_2 emissions from fossil fuels. After peatland rewetting, existing soil carbon can persist in the peat for thousands of years, and the risk of peat fire is reduced in comparison to a drained peatland. In comparison with CO_2 emissions from fossil fuels, the CO_2 emission estimates of the organic soils are, however, highly uncertain. In the recently updated GHG inventory method of forested organic soils in Finland, the uncertainty of soil CO_2 exchange is around 30% (Alm et al., 2023).

Conclusion

The LULUCF sector has a high climate change mitigation potential, which is acknowledged in international and EU climate law. However, mitigation potential of forest management, peatland restoration and avoided peatland degradation is not fully appreciated. Since the extant NDCs are not sufficient for limiting the global average temperature increase well below 1,5°C from pre-industrial level, there is urgent need to identify and advance additional mitigation measures. In the EU, current CO_2 emissions from organic soils (98 Mt CO_2 eq.) correspond to 40% of the net removals of the LULUCF sector. Thus, climate-wise management of organic soils and peatland restoration provide relevant mitigation potential in order to make the EU's binding climate targets reachable. Implementation efforts at the EU and national levels and new policy instruments, including reform of the Common Agricultural Policy, are essential to realize the relatively cost-efficient GHG emission reductions of organic soils. Further standardization of the GHG inventory methods between countries seems necessary to improve transparency and comparability of the reported GHG emission estimates. Simultaneously, uncertainties in the GHG emission estimates of organic soils must be reduced through further scientific measurement in various ecosystem types. Furthermore, advances are needed in the soil modeling that assist GHG inventories and implementation efforts.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://unfccc.int/ghg-inventories-annex-i-parties/2023.

Author contributions

RM: Conceptualization, Funding acquisition, Project administration, Resources, Writing–original draft, Writing–review and editing. OB: Writing–original draft, Writing–review and editing. AL: Writing–review and editing, Visualization, Writing–original draft. MP: Writing–review and editing. KK: Writing–review and editing, Conceptualization, Funding acquisition.

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Conflict of interest

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

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Supplementary material

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References

Alm, J., Wall, A., Myllykangas, J.-P., Ojanen, P., Heikkinen, J., Henttonen, H. M., et al. (2023). A new method for estimating carbon dioxide emissions from drained peatland forest soils for the greenhouse gas inventory of Finland. *Biogeosciences* 20, 3827–3855. doi:10.5194/bg-20-3827-2023

Bellassen, V., Angers, D., Kowalczewski, T., and Olesen, A. (2022). Soil carbon is the blind spot of European national GHG inventories. *Nat. Clim. Chang.* 12, 324–331. doi:10.1038/s41558-022-01321-9

Capros, P., Zazias, G., Evangelopoulou, S., Kannavou, M., Fotiou, T., Siskos, P., et al. (2019). Energy-system modelling of the EU strategy towards climate-neutrality. *Energy Policy* 134, 110960. doi:10.1016/j.enpol.2019.110960

Chen, C., Loft, L., and Matzdorf, B. (2023). Lost in action: climate friendly use of European peatlands needs coherence and incentive-based policies. *Environ. Sci. Policy* 145, 104–115. doi:10.1016/j.envsci.2023.04.010

den Elzen, M. G. J., Dafnomilis, I., Forsell, N., Fragkos, P., Fragkiadakis, K., Höhne, N., et al. (2022). Updated nationally determined contributions collectively raise ambition levels but need strengthening further to keep Paris goals within reach. *Mitig. Adapt Strateg. Glob. Change* 27, 33. doi:10.1007/s11027-022-10008-7

Dooley, K., Keith, H., Larson, A., Catacora-Vargas, G., Carton, W., Christiansen, K. L., et al. (2022). The land gap report 2022. Available at: https://www.landgap.org/.

ESABCC [European Scientific Advisory Board on Climate Change] (2024). *Towards EU climate neutrality, Assessment Report 2024*. Luxembourg: Publications Office of the European Union. Available at: https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities.

European Commission (2023), Approved 28 CAP Strategic Plans (2023-2027). *Agric. Rural Dev.* Available at: https://agriculture.ec.europa.eu/system/files/2023-06/approved-28-cap-strategic-plans-2023-27.pdf.

European Environment Agency (2023). *Annual European Union greenhouse gas inventory 1990–2021 and inventory report 2023*. Copenhagen: Submission to the UNFCCC Secretariat. Available at: https://unfccc.int/documents/627851 (Accessed November, 2023).

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Gregor, L., Hauck, J., et al. 2022. Global carbon budget 2022. *Earth Syst. Sci. Data*, 14, 4811–4900. doi:10.5194/essd-14-4811-2022

Fyson, C. L., and Jeffery, M. L. (2019). Ambiguity in the land use component of mitigation contributions toward the Paris Agreement goals. *Earth's Future* 7, 873–891. doi:10.1029/2019EF001190

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., et al. (2017). Natural climate solutions. *PNAS* 114 (44), 11645–11650. doi:10.1073/pnas.1710465114

Guizar-Coutiño, A., Jones, J. P. G., Balmford, A., Carmenta, R., and Coomes, D. A. (2022). A global evaluation of the effectiveness of voluntary REDD+ projects at reducing deforestation and degradation in the moist tropics. *Conserv. Biol.* 36 (6), e13970. doi:10.1111/cobi.13970

Günther, A., Barthelmes, A., Huth, V., Joosten, H., Jurasinski, G., Koebsch, F., et al. (2020). Prompt rewetting of drained peatlands reduces climate warming despite methane emissions. *Nat. Commun.* 11, 1644. doi:10.1038/s41467-020-15499-z

Humpenöder, F., Karstens, K., Lotze-Campen, H., Leifeld, J., Menichetti, L., Barthelmes, A., et al. (2020). Peatland protection and restoration are key for climate change mitigation. *Environ. Res. Lett.* 15, 104093. doi:10.1088/1748-9326/abae2a

IPCC (2006). in *Greenhouse gas inventories programme*. Editors H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (Japan: IGES).*2006 IPCC Guidelines for national greenhouse gas inventories, prepared by the national*

IPCC (2019). in *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Editors [P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, et al. (The Intergovernmental Panel on Climate Change IPCC). Available at: https://www.ipcc.ch/srccl/.

Juutinen, A., Shanin, V., Ahtikoski, A., Rämö, J., Mäkipää, R., Laiho, R., et al. (2020). Profitability of continuous cover forestry in Norway spruce-dominated peatland forest and the role of water table. *Can. J. For. Res.* 51, 859–870. doi:10.1139/cjfr-2020-0305

Korosuo, A., Vizzarri, M., Pilli, R., Fiorese, G., Colditz, R., Abad Viñas, R., et al. (2021) "Forest reference levels under Regulation (EU) 2018/841 for the period 2021-2025," in *JRC science for policy report*. Luxembourg: Publications Office of the European Union. doi:10.2760/0521

Krug, J. H. A. (2018). Accounting of GHG emissions and removals from forest management: a long road from Kyoto to Paris. *Carbon Balance Manage* 13, 1. doi:10.1186/s13021-017-0089-6

Kulovesi, K., Oberthür, S., van Asselt, H., and Savaresi, A. The European climate law: strengthening EU procedural climate governance? 36, *J. Environ. Law*, 2024;, 23, 42. doi:10.1093/jel/eqad034

Laine, A. M., Mehtätalo, L., Tolvanen, A., Folking, S., and Tuittila, E.-S. (2019). Impacts of drainage, restoration and warming on boreal wetland greenhouse gas fluxes. *Sci. Total Environ.* 647, 169–181. doi:10.1016/j.scitotenv.2018.07.390

Lehtonen, A., Eyvindson, K., Härkönen, K., Leppä, K., Salmivaara, A., Peltoniemi, M., et al. (2023). Potential of continuous cover forestry on drained peatlands to increase the carbon sink in Finland. *Sci. Rep.* 13, 15510. doi:10.1038/s41598-023-42315-7

Mäkipää, R., Abramoff, R., Adamczyk, B., Baldy, V., Biryol, C., Boselad, M., et al. (2023). How management affects soil C-sequestration and greenhouse gas fluxes in boreal and temperate forests? – a review. *For. Ecol. Manag.* 529, 120637. doi:10.1016/j.foreco.2022.120637

Nabuurs, G.-J., Mrabet, R., Abu Hatab, A., Bustamante, M., Clark, H., Havlík, P., et al. (2022). "Agriculture, forestry and other land uses (AFOLU)," in *IPCC, 2022: climate change 2022: mitigation of climate change. Contribution of working group III to the sixth assessment report of the intergovernmental panel on climate change*. Editors P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, et al. (Cambridge, UK and New York, NY, USA: Cambridge University Press). doi:10.1017/9781009157926.009

NIR Finland (2023) "Greenhouse gas emissions in Finland 1990 to 2021," in *National inventory report under the UNFCCC, 15 april 2023*. Helsinki: Statistics Finland. Available at: https://unfccc.int/documents/627718.

Roe, S., Streck, C., Beach, R., Busch, J., Chapman, M., Daioglou, V., et al. (2021). Land-based measures to mitigate climate change: potential and feasibility by country. *Glob. Change Biol.* 27, 6025–6058. doi:10.1111/gcb.15873

Roe, S., Streck, C., Obersteiner, M., Frank, S., Griscom, B., Drouet, L., et al. (2019). Contribution of the land sector to a 1.5 °C world. *Nat. Clim. Chang.* 9, 817–828. doi:10.1038/s41558-019-0591-9

Savaresi, A., and Perugini, L. (2021). Balancing emissions and removals in the land sector: the view from the EU. *Carbon Clim. Law Rev.* 15 (1), 49–59. doi:10.21552/cclr/2021/1/7

Seidl, R., Schelhaas, M. J., Rammer, W., and Verkerk, P. J. (2014). Increasing forest disturbances in Europe and their impact on carbon storage. *Nat. Clim. Change* 4, 806–810. doi:10.1038/nclimate2318

Stuart-Smith, R., Rajamani, L., Rogelj, J., and Wetzer, T. (2023). Legal limits to the use of CO_2 removal. *Science* 382, 772–774. doi:10.1126/science.adi9332

UNFCCC [United Nations Framework Convention on Climate Change] 2019. Decision 18/CMA.1 Modalities (2019). *Procedures and Guidelines for the transparency framework for action and support referred to in article 13 of the Paris agreement FCCC/PA/CMA/2018/Add.2*.

Verkerk, P. J., Delacote, P., Hurmekoski, E., Kunttu, J., Matthews, R., Mäkipää, R., et al. (2022) "Forest-based climate change mitigation and adaptation in Europe,", 14. European Forest Institute. doi:10.36333/fs14