EU LIFE Programme project
"Demonstration of climate change mitigation potential of nutrients rich organic soils in Baltic States and Finland"

REPORT

ON IMPLEMENTATION OF THE PROJECT

DEMONSTRATION OF CLIMATE CHANGE MITIGATION MEASURES IN NUTRIENTS RICH DRAINED ORGANIC SOILS IN BALTIC STATES AND FINLAND

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"LIFE OrgBalt compiled the first regional Baltic/ Finnish GHG emission factors for managed nutrient-rich organic soils (current and former peatlands), which have been made available for the customary scientific review and further verification for national GHG inventories in the hemiboreal region in Finland and the Baltic countries. While the project analysed selected CCM measures for drained organic soils in agriculture and forestry and developed spatial models and tools, it also identified remaining knowledge gaps. To bridge the remaining limitations and fill the gaps, it is essential to continue GHG measurements and model development, as well to broaden and complete the scope of the evaluated CCM measures in the after-LIFE-project period, notably by including rewetting and restoration of peatlands that are currently considered to be among the most recommended CCM measures on drained peatlands in the EU. In addition, the developed Simulation and PPC models still include limited macroeconomic considerations and lack assessment of all environmental impacts. For all these reasons, these models should be used carefully in CCM strategy development for identification of gaps in climate neutrality transition policy and funding frameworks and need further optimization for broader applicability as decision-making tools."

State Regional Development Agency Republic of Latvia · SILAVA · Ministry of Agriculture Republic of Latvia · Latvia University of Life Sciences and Technologies · Luke · Lithuanian Research Centre for Agriculture and Forestry · Baltijas Krasti · Succow Stiftung · Greifswald Mire Centre

SUMMARY

This document first summarizes the state of the art concerning data available for estimating the soil greenhouse gas exchange and emission factors for drained peatlands used for agriculture and forestry, and identifies the most urgent data gaps remaining after the completion of the LIFE OrgBalt project. Short sections are dedicated to paludiculture as a specific, novel land use with significant potential for reducing greenhouse gas emissions from organic soils, and rewetting for ecosystem restoration, which is a potential after-use for drained agricultural and forest lands. The state of the art of models and decision support tools for comparing different land management options is also briefly examined. Next, societal and political challenges for climate change mitigation actions on drained organic soils are examined. Finally, an action plan for moving forward in the after-life of the LIFE OrgBalt project is outlined.

ABBREVIATIONS

C = carbon

CCF = Continuous Cover Forestry

CCM = climate change mitigation

CH_4 = methane

CO_2 = carbon dioxide

CO_2eq = Carbon dioxide equivalents

EF(s) = Emission Factor(s)

GHG = greenhouse gas

IPCC = Intergovernmental Panel on Climate Change

N_2O = nitrous oxide

PPC = public-private cooperation

WTL = soil water-table level

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1. INTRODUCTION

The C balance of peatlands and other organic soils is greatly influenced by human activities, such as land reclamation by drainage for agriculture, forestry and infrastructure and peat extraction. These actions have significant effects on the hydrology and soil water-table levels (WTLs) of peatland landscapes. Consequently, global peatlands have been estimated to have shifted from being a C sink to a C source into the atmosphere (Leifeld et al., 2019).

Soil C loss rate in drained peatlands can be estimated with different methods. Inventory methods typically involve measuring changes in soil C content over time, accounting for factors such as subsidence and mineralization. These estimates are often based on the assumption that the loss of organic material due to compaction, shrinkage, and oxidation is proportional to the observed soil subsidence (Eggelsmann, 1976; Ewing et al., 2006). Flux methods, on the other hand, involve directly measuring the exchange of CO_2 between the soil and the atmosphere using techniques such as eddy covariance or chamber-based measurements complemented by mass-based data collection (e.g., Jauhiainen et al., 2019). These flux measurements can provide more accurate and real-time data on C exchange, allowing for a better understanding of the processes influencing C emissions from drained organic soils. Chamber-based flux monitoring is widely applied for monitoring both CO_2 and N_2O and CH_4 fluxes, the two most important non-CO_2 GHGs in organic soil-atmosphere transfer.

IPCC (2014) provides default emission factors (EFs; so called Tier-1) for CO_2, CH_4 and N_2O for several land use types on drained organic soils, such as peatlands. The Wetlands assessment (IPCC, 2014) also provides minimum criteria for the EF data requirements but does not provide actual guidance for measurement data collection agreed by an expert team. Only a limited amount of data fulfilling the data requirements existed, and thus the data could only be utilized in relatively broad top-level categories, which included a potentially wide range of site and climate characteristics. Data available in IPCC (2014) Tier 1 default EF categories included different soil types and preceding land use histories and management types in the data used, which resulted in relatively high uncertainties around the averages (e.g., Aitova et al., 2023; Jauhiainen et al., 2023). Due to the review type of data collection in IPCC (2014), it is likely that differences in spatial and temporal data collection and coefficients/literature values used in several studies further contributed to resulting uncertainty in default EFs. Moreover, the available data involved imbalanced geographical distribution of measurement sites, resulting in undetermined uncertainty in the EFs for regions with no or limited data, such as for the hemiboreal region in the Baltic states Estonia, Latvia, and Lithuania.

Accuracy of the estimates can be increased by successful selection of sufficiently comparable measuring sites. Soil characteristics, land-use history, land management, and environmental conditions (including WTL and temperature regimes) should be comparable in sites that are planned to be included in pooled data categories. Improvements in data representativeness for any site type can only be achieved by increasing the number of replicated sites, ensuring comprehensive data collection that accurately describes the site and soil conditions, and providing rigorous reporting that highlights not only the key results but also the full range of relevant site and monitoring characteristics (e.g., Jauhiainen et al., 2019). As more individual case studies become available, well-documented data can be used for modelling. More specific EFs with lower uncertainty are the aim in focused research projects, such as the LIFE OrgBalt, that have been established and work on drained organic soils with specific soil and management characteristics. Good scientific practices are followed by applying coherent and harmonized monitoring approaches, collecting site-specific and site-type-specific data, and setting an emphasis for open reporting.

The aims of this report are to i) evaluate the state of the art of soil and ecosystem greenhouse gas (GHG) exchange data related to peatland use for agriculture, forestry, and paludiculture, including other forms of rewetting as potential after-use of the sites, recognizing the contribution of the LIFE OrgBalt project, ii) identify the most critical remaining knowledge gaps to be filled to support effective climate change mitigation with actions on peatlands, and iii) outline the role and way forward for the research community in this context.

2. State of the Art

2.1 Agriculture

At the time when the IPCC (2014) default EFs were compiled, data fulfilling the data requirements existed from altogether 27 sites (Fig. 1), and, consequently, EFs could only be estimated for very broad categories. Croplands have just one EF encompassing both boreal and temperate conditions. Grassland has specific EFs for boreal and temperate conditions, for the temperate conditions there are further specific EFs for deep- and shallow-drained grassland. Since IPCC (2014), more recent meta studies (Tiemeyer et al., 2020; Evans et al., 2021; Koch et al., 2023) have assessed drained agriculture soil GHG balances, and provided data from additional sites. The LIFE OrgBalt project increased data availability for drained organic soils in the hemiboreal conditions represented by the Baltic states by altogether 20 sites: 8 sites on cropland and 12 sites in grassland.

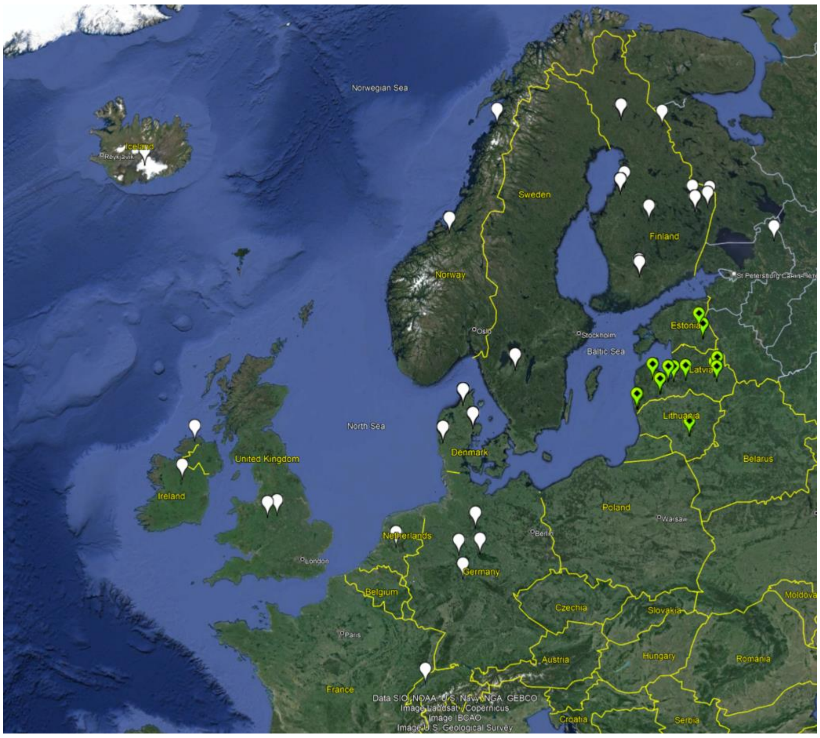

Figure 1. Data from drained organic soil sites on agricultural lands (including both croplands and grasslands) for forming EFs in the IPCC (2014) assessment, indicated by white pointers, and sites studied in LIFE OrgBalt, indicated by green markers (source map: Google Earth 2024).

The cumulative long-term impact on soil C stocks resulted from draining organic soils for agriculture has been studied by inventory methods, e.g., by Schothorst (1977) and Weinzierl & Waldmann (2015). The method requires data on surface level reference points both for undrained and drained conditions in addition to soil physical and chemical data, and the lack of reference data from undrained conditions limits wider application of the method. One of the largest studies on grasslands and croplands using an application of this method is by Fell et al. (2015) in the temperate zone (Germany). Inventory method results are typically provided as mass-based change in soil C stock per area, but they can also be reported as CO_2eq (carbon dioxide equivalents). IPCC has accepted inventory method-based data in Tier-1 EFs, but it cannot be used for monitoring short-term (annual) soil C-stock changes required in higher Tier-levels, nor for studying non-CO_2 GHGs.

Due to their wider applicability and faster data collection, research has largely moved towards flux-based monitoring. Organic soils in agricultural use include an ample set of different soil characteristics, management conditions, and environmental (mainly soil temperature, moisture, and WTL related) conditions for several species of crops grown, and these factors are known to impact the CO_2 loss rate from the soil (Oleszczuk et al., 2008; Norberg et al., 2016; Tiemeyer et al., 2016; Minasny et al., 2017, Bader et al., 2018; Fairbairn et al., 2023, Purvina et al., 2024, Maljanen et al., 2024). The first models moving more holistic inclusion of multiple factors include Tiemeyer et al. (2020) and Koch et al. (2023). Studies aiming to estimate annual GHG balances (to be used for EFs) should carefully consider, and report, which conditions in the identified factors are dominant in the planned monitoring sites. CO_2 is typically considered the most important GHG by the overall impact of drained organic soils used for agricultural production (IPCC, 2001; Maljanen et al., 2007; Tubiello et al., 2015, 2016; Tiemeyer et al., 2016; Säurich et al., 2019). Soil organic matter derived CO_2 emissions, along with estimates of C-input to soil by vegetation, are key components in the assessment of soil as a source or sink of atmospheric CO_2 (Kuzyakov, 2006; Tiemeyer et al., 2016). There is ample evidence to support that enhancing soil aeration by reducing the WTL through permanent drainage, mechanical disturbance such as regular ploughing, and implementing lime and fertilizer applications, can enhance the conditions for soil organic matter mineralization and the subsequent production of CO_2 (e.g., Nykänen et al., 1995; Lohila et al., 2004; Maljanen et al., 2007).

Methane emissions are generally lower in drained organic soils compared to undisturbed conditions in wetlands due to the transition of a wider surface soil layer to aerobic conditions (Abdalla et al., 2016). However, practices such as soil disturbance and fertilization can create microenvironments favorable for CH_4 net emissions (Maljanen et al., 2010). Furthermore, seasonal variations and land management contexts play vital roles in emission rates (Maljanen et al., 2024), warranting further research to develop adaptive management strategies. However, the CH_4 release from drainage ditches can be significant (IPCC, 2014).

The production and release of N_2O from soil in fertilized agricultural ecosystems are influenced by several factors, including soil physical conditions, chemical properties, and microbial activity (Kasimir-Klemedtsson et al., 1997; Höper, 2002; Henault et al., 2012; Butterbach-Bahl et al., 2013; Oertel et al., 2016; Smith, 2017). These emissions are associated with the soil organic C concentration and soil moisture levels (Attard et al., 2011), as well as nitrogen availability and fertilization practices (Pärn et al., 2018; Maljanen et al., 2024). The application of organic and synthetic fertilizers can result in substantial N_2O emissions, particularly when soil moisture levels are high (Henault et al., 2012). However, different studies have reported conflicting and unclear relationships between fertilization rates and N_2O emission (Maljanen et al., 2003; Regina et al., 2004; Kettunen et al., 2005; Van Beek et al., 2010). Grassland renewal (or conversion from grassland to cropland) can strongly enhance N_2O emissions (Offermanns et al., 2023). The C/N ratio of peat is suggested to be an important factor in regulating N_2O emissions from drained northern peat soils (Klemedtsson et al., 2005; Maljanen et al., 2010), while other studies found strong correlation to pH (Wang et al., 2017). Spatial differences in N_2O and CH_4 emissions in agriculturally utilized peat soil are influenced by soil properties, such as nutrient content, which can vary significantly at a small scale, resulting in variations in GHG emissions (Smith, 2017: Maljanen et al., 2024). Further, temporal variability especially following fertilisation events can be high.

Most research on GHG emissions has focused on deep peat soils, which have high levels of soil organic C. Only a few studies have recognized the significant contribution of soils with lower soil organic C concentrations that do not meet the IPCC's definition of organic soils (provided in IPCC, 2006), to overall GHG emissions (Leiber-Sauheitl et al., 2014; Eickenscheidt et al., 2015; Tiemeyer et al., 2016; Liang et al., 2024; Purvina et al., 2024).

Efforts are being made to find methods that enable sustainable agricultural practices while addressing the decline in peat C stocks and soil subsidence caused by drainage. The management options studied have included non-till farming (Maljanen et al., 2003; Elder et al., 2008; Regina & Alakukku, 2010; Honkanen et al., 2024) and cover crop incorporation at different WTLs (Wen et al., 2019). Non-till farming could potentially decrease soil respiration by lowered soil disturbance at least in mineral soils (Chatskikh et al., 2008; Akbolat et al., 2009), but organic soils are understudied in this respect (Regina & Alakukku, 2010; Honkanen et al., 2024). Overall, the results so far on GHG emissions and annual soil GHG balance can be considered inconclusive due to unquantified multiple contributing factors and the low number of replicated studies available. To implement effective measures for reducing GHG emissions, it is important to identify the locations and causes of the highest levels of emissions and understand how these emissions are influenced by various factors.

LIFE OrgBalt core contributions to the state of the art can be listed as:

- Reports in progress:
    - Annual net CO_2 fluxes from drained organic soils used for agriculture in the hemiboreal region of Europe; by Arta Bārdule et al., submitted to *Biogeosciences*
    - Methane and nitrous oxide fluxes from hemiboreal drained peatlands under grasslands; by Hanna Vahter et al., in preparation
    - Methane and nitrous oxide fluxes from hemiboreal drained peatlands under croplands; by Arta Bārdule et al., in preparation

2.2 Forestry

About 15 Mha have been drained for forestry in boreal and temperate zones, for improved growth of existing tree stands or afforestation of originally treeless peatland (Paavilainen and Päivänen, 1995; Joosten and Clarke, 2002). IPCC (2014) provided default Tier-1 EFs for drained organic soils in forest land, and the available data, including more recently published data, was reassessed up to year 2019 by Jauhiainen et al. (2023). Data for EFs was available from a considerably wider set of sites than for agricultural lands; however, most of these sites were located in Finland, while other parts of the boreal zone, and the whole temperate zone, showed a very limited number of sites (Fig. 2). While the IPCC (2014) EFs were based on 13 studies for CO_2, 23 for CH_4, and 20 for N_2O, data availability was notably increased in by 2019 (28 studies for CO_2, 33 for CH_4, and 32 for N_2O), Jauhiainen et al. (2023). In the database of Jauhiainen et al. (2023), 49 annual soil balance estimates were based on soil C stock inventories and 161 on flux measurements (including 4 by eddy covariance method and 157 by chamber measurements). Flux methods using closed chambers formed the dominant method on data collection, being eligible for forming EF-data on Tier 2 and -3 levels. All published CH_4 and N_2O EF data were based on studies made by closed chamber monitoring. In about 95 % of the studies the soil type was peat, and the other soil types included were defined as gleysols, gyttja or muck.

Based on the site and soil data reported, Jauhiainen et al. (2023) were able to estimate EFs for a non-peat organic soil types (defined as 'Other organic soils') in the temperate zone, as well as for various subcategories based on site type, nutrient regime, and productivity in the boreal zone. The LIFE OrgBalt project increased data availability for drained organic forest soils in the hemiboreal conditions represented by the Baltic states by altogether 26 sites (Fig. 2).

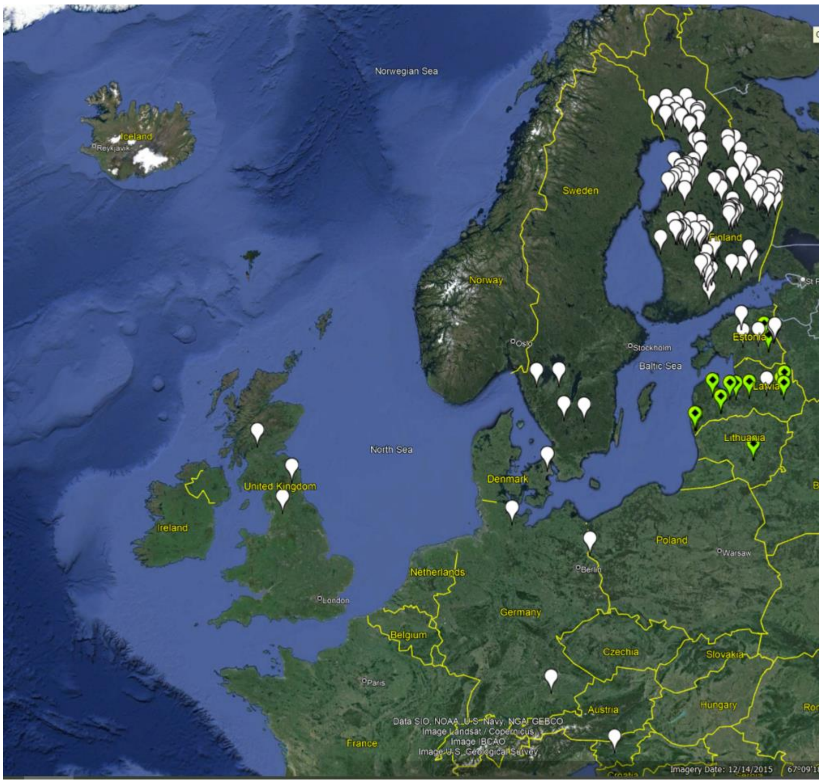

Figure 2. Data from drained organic forests soil sites for forming EFs in the assessment by Jauhiainen et al. (2023), indicated by white pointers, and sites studied in LIFE OrgBalt, indicated by green markers (source map: Google Earth 2024).

Some drained organic forest soils have formed by afforesting former agricultural lands or cutaway peat extraction areas, where the different management histories may lead to legacy effects and different GHG exchange levels as compared to sites that were drained for forestry to begin with (Lohila et al., 2007; Mäkiranta et al., 2007; Meyer et al., 2013). Jauhiainen et al. (2023) were able to evaluate these, and estimated specific EFs for sites afforested after agricultural use and peat extraction areas in the boreal zone, while one pooled EF was estimated for afforested land in the temperate zone.

The traditional forest management in forests on organic soils, similarly to forests in general, has been rotation-based forestry with final felling after 60–100 years. Management operation impacts, or relatively short-lasting conditions in developing tree stands, i.e. clearcut areas and young tree stands, have not been represented in data used for making EFs, with only few exceptions. An alternative forest-management option is continuous-cover forestry (CCF), which involves selective cuttings and natural regeneration. It has been postulated that CCF could reduce the harmful environmental consequences of clear-cutting, such as loss of soil C and increased emissions of CO_2 and N_2O, as well as loading of C and nutrients to water courses

(Nieminen et al., 2019). Different stages of forest rotation and alternative forest management practices are increasingly included in research (Ball et al., 2007; Korkiakoski et al., 2019, 2020, 2023; Leppä et al., 2020; Saarinen et al., 2020: Peltoniemi et al., 2023) and likely move monitoring to site conditions most common in specific region or country.

There has been progress in reporting and inclusion of original site-specific and site-type specific data in forming soil CO_2, CH_4 and N_2O balance, with major importance especially for soil CO_2 balance formed in flux methods from a combination of (i.) gaseous fluxes (most often) used for measuring emission from soil and (ii.) mass-based fluxes providing measures for soil C inputs as above- and below-ground litters. Jauhiainen et al. (2019) provided an analysis on data structure in studies describing soil C balance in drained organic forest soils. The most typical data lacking for completion of the soil CO_2 balance estimate in the reporting was the annual rate of litterfall (Jauhiainen et al., 2019). Extensive studies on annual aboveground litter production and decomposition with impact assessment to soil CO_2 balance have been made for the boreal zone in Finland (Ojanen et al., 2013, 2014). Comparable integrated assessments for the temperate region, and for afforested sites, formerly used for peat mining or as cropland, are still lacking. There is space for further improvements on using original site-specific- and site-type-specific data. Use of open databases and cloud-based data-repositories as a part of reporting in individual studies is useful for data accessibility, for example, in syntheses and modelling.

We currently have the understanding that the GHG fluxes from drained organic forest soils generally depend on site nutrient status, size and characteristics of the tree stand, soil temperature, and the WTL regime (e.g., von Arnold et al., 2005a, 2005b; Mander et al., 2008; McNamara, et al., 2008; Ojanen et al., 2010, 2013, 2014). Reporting auxiliary data, e.g. soil chemical and physical characteristics, vegetation community (tree stand composition and stock, ground vegetation), weather and climate (e.g., amount and distribution of precipitation and temperature), and position in the landscape (e.g., altitude, latitude) has been previously infrequent in reporting (Jauhiainen et al., 2019) although they may influence soil C- and N dynamics and potentially enable forming correlations between soil GHG balance estimates in collated EF data pools. Based on the tested identification of such correlations between soil GHG balance and environment characteristics, there appear to be such parameters that indicate correlation between soil-vegetation-climate related conditions and the soil GHG balance that could be utilized for forming higher-tier EFs (Jauhiainen et al., 2023). To name some indicative correlations found by Jauhiainen et al. (2023), soil CO_2 balance correlated positively with soil C:N, stand type, and mean temperature over 30 years that together explained 41% of the variation. Only 28% of the variation in soil CH_4 balance could be explained by a combination of the variables site nutrient status, site productivity class, and February mean temperature. WTL regime is known to correlate with the CH_4 balance but WTL-related variables were not commonly included in reporting. Soil N concentration, stand type, and July mean temperature over 30 years were combined in the best multiple model which was able to explain 51% of the variation in soil N_2O balance. Further improvements on reporting auxiliary data for post-publishing use of the GHG data is still needed, and open access publications with availability of supplemental materials and data repositories can help in work towards this direction.

LIFE OrgBalt core contributions to the state of the art can be listed as:
- Reports in progress:
    - Soil and forest floor carbon balance in drained and undrained hemiboreal peatland forests; by Aldis Butlers et al., submitted to *Biogeosciences*
    - Annual net CO_2 fluxes from drained organic soils used for agriculture in the hemiboreal region of Europe, by Arta Bardule et al., submitted to *Biogeosciences*
    - Initial impact of forest management on forest floor greenhouse gas fluxes in hemiboreal coniferous forests with drained nutrient-rich organic soils; by Valters

Samariks et al., submitted to *Forest Ecology and Management*
    - Soil trenching – are microbial communities alike in experimental peatland plots measuring total and heterotrophic respiration? by Krista Peltoniemi et al., submitted to *Soil Biology and Biochemistry*
    - Emission factors of soil CH4 and N2O from drained and undrained hemiboreal peatland forests; by Muhammad Kamil-Sardar et al., in preparation
    - The impact of loggings on the forest floor CH_4 and N_2O emissions of boreal forestry-drained peatlands; by Paavo Ojanen et al., in preparation
    - Continuous cover forestry in drained peatlands: What happens to heterotrophic respiration?; by Aino Korrensalo et al., in preparation

LIFE OrgBalt contributions through project networking can be listed as:

- Reports published:
    - Bārdule, A., Butlers, A., Lazdiņš, A., Līcīte, I., Zvirbulis, U., Putniņš, R., Jansons, A., Adamovičš, A., & Razma, Ģ. (2021): Evaluation of soil organic layers thickness and soil organic carbon stock in hemiboreal forests in Latvia. Forests, 12(7): 1–15, https://doi.org/10.3390/f12070840
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2.3 Paludiculture

Paludiculture, a land-use system focused on cultivating annual or perennial crops in rewetted and wet peatlands while maintaining high WTLs, is gaining recognition for its potential in sustainable agriculture and ecosystem restoration (Tanneberger et al., 2020). Furthermore, it hosts potentials for viable wet agriculture and forestry or renewable energy practices (Wichtmann et al., 2016) This practice is particularly important in organic soils, where conventional drainage based agriculture and forestry results in soil degradation and C loss.

To assess the CCM potential of paludiculture, there are still limited data available. In literature reviews, the EF comparison is based on combined information from separate studies and sites, provide baseline EFs for evaluations if data from on-site trials are not yet available (Bianchi et al., 2021; Kekkonen et al., 2019; Lehtonen et al., 2021; Myllyviita et al., 2024). Positive climate impacts formed by introduced wet-soil management, e.g. by paludiculture and rewetting, can be expected based on these reviews but the magnitude depends on the reference, drainage-based land use, scenario.

Several crops are suitable for paludiculture on nutrient rich organic soils (current and former fens), include common reed, cattail, sedge reeds and wet meadow vegetation, black alder and on nutrient poor organic soils (current and former bogs), peat moss. On-site trials with different species to test the efficiency of peatland rewetting as a mitigation measure and to eventually contribute to reporting of GHG emissions from paludiculture activities include:

- Peat moss farming (*Sphagnum* sp.): Beyer and Hoeper (2015), Guenther et al. (2017), Daun et al. (2023), Oestmann et al. (2022)
- Reed canary grass (*Phalaris arundinacea*): Karki et al. (2014), Kandel et al. (2019a, 2019b, 2020)
- Cattail (*Typha latifolia*): Johnson (2016), Martens et al. (2021), van den Berg (2024)

- Common reed (*Phragmites australis*): Martens et al. (2021)
- Alder (*Alnus* sp.): Huth et al. (2018)
- Sedges (*Carex acutiformis*): Bockermann et al. (2024)
- Perennial grasses in a mesocosm study: Karki et al. (2019)[1]

Existing studies on paludiculture have explored various aspects such as WTL management, soil management, and the impact of fertilization on biomass production and GHG emissions. Studies (Kandel et al., 2019a, 2019b, 2020; Karki et al., 2019; van den Berg, 2024) focusing on WTL trials showed potential reduction in overall GHG emissions without sacrificing crop productivity in high WTL conditions. A study by van den Berg (2024) looked at soil management techniques, specifically the removal of topsoil to reduce the impact of recently accumulated easily degradable C-substrates and nutrients on soil processes and GHG emissions. The findings showed a significant reduction in phosphorus and iron levels in the soil, although the impact on soil C-store and -emissions depended on the species grown and inspected timescale. The impact of nitrogen fertilization on paludiculture biomass production and GHG emissions was analyzed in studies conducted by Kandel et al. (2019a, 2019b, 2020).

Data from some trials on *Sphagnum* cultivation (peat moss farming) can be used for estimating emissions both for paludiculture and rewetting (Beyer and Hoeper, 2015; Guenther et al., 2017; Oestmann et al., 2022; Daun et al., 2023). The longest full life cycle Paludiculture-trial, lasting 7 years, has been on *Sphagnum* cultivation (Daun et al., 2023).

The aim of LIFE OrgBalt to contribute to this section; had been limited due to , lack of project funds for paludiculture research in Germany and Covid restrictions which inhibited to organise joined in-situ visits for suitable paludiculture and reference site site selection in the Baltic partner countries and Finland at the critical early phase of the LIFE OrgBalt. An unfortunate consequence is an under-representation of paludiculture and wet CCM measures analysed in LIFE OrgBalt.

2.4 Rewetting for wetland ecosystem restoration

Default (Tier-1) emission factors for rewetted organic soils, including separate EFs for poor and rich soils in temperate and boreal zone, are provided in IPCC (2014). Data on rewetting in literature was reassessed in more detail by Wilson et al. (2016a) where specific EFs based on pre-rewetting land uses, including forest land, croplands, grasslands, peat extraction sites with nutrient status considerations. Other literature reviews including rewetting as a comparison to managed land uses with closer to soil surface water level condition are produced by Bianchi et al. (2021), and Aitova et al. (2023) for temperate zone, and Kekkonen et al. (2019) and Lehtonen et al. (2021) for boreal zone. It is worth noting that the emissions of GHGs from rewetted peatlands vary greatly depending on their previous land use and the Tier 1 EFs for rewetted peatlands does not consider the variations in emissions based on the previous land use of the sites.

Studies on rewetting and or restoration of organic soils:

- Agricultural lands (including partial rewetting): Hendriks et al. (2007), Jacobs et al. (2007), Leiber-Sauheitl et al. (2014), Schrier-Uijl et al. (2014), Guenther et al. (2015), Poyda et al. (2016), Renou-Wilson et al. (2016), Antonijević et al. (2023)
- Peat extraction: e.g., Beetz et al. (2013), Wilson et al. (2016)

[1] Focus on WTL impact to GHG emissions and productivity - but not from the paludiculture aspect

- Forest land: Rigney et al. (2018)
- Land abandonment: Hendriks et al. (2007), Wilson et al. (2009), Wang et al. (2018), Renou-Wilson et al. (2019)
- Multi year studies on GHG and C-balances after rewetting: Herbst et al. (2013), Wilson et al. (2016b), Nugent et al. (2018), D'Acunha et al. (2019), Kandel et al. (2019b), Antonijević et al. (2023)
- Modeling based approach: Liu et al. (2020), Premrov et al. (2021)

LIFE OrgBalt contributions through project networking can be listed as:

- Reports published:
  - Butlers, A. & Lazdins, A. (2022): Case study on greenhouse gas (GHG) fluxes from flooded former peat extraction fields in central part of Latvia. Research for Rural Development 2022, Annual 28th International Scientific Conference Proceedings, 2022, Vol 37: 44-49. https://doi.org/10.22616/rrd.28.2022.006

2.5 Models and decision support tools

Models and decision support tools are facilitating orientation in manifold and different site and climatic conditions, land-use and land-management options, and socio-economic constraints. Such tools have not been readily available, while the main modeling efforts have so far been directed to developing more specific ecosystem models (e.g., He et al., 2016; Laurén et al., 2021; Palviainen et al., 2024), and more general land surface models (e.g., Fisher & Koven, 2020). In the LIFE OrgBalt project, specific effort was directed to developing practical tools that could be applied by land managers and decision makers, resulting in two main tools, called the Simulation model and the public-private cooperation (PPC) model. Further, other modeling efforts focused on mapping peat layer thickness (Ivanovs et al., 2024) and wetness (depths to water, Ivanovs et al. (2024) after Murphy et al., 2008). Since the development of both the Simulation and PPC models was started from scratch, it is clear that they are still at a stage where further development is required, even though they are already functionally ready and applicable. The models do not currently include, e.g., macroeconomic considerations and integration of external environmental impacts, which limits their applicability.

Models and tools are by nature simplified expressions of alternatives based on complex data. Alternative choices in the models are limited by the data available, while their reliability is limited by the weakest data that has a high impact on the outcome. Users of decision-support tools benefit from transparency regarding these issues, which can be achieved by providing the list the choices as well as assumptions and their limitations included, and a brief explanation of why certain key alternative choices may have been excluded. Further research gaps concerning model development are not listed separately in the following, but they are considered in the context of the land uses.

LIFE OrgBalt core contributions to the state of the art can be listed as:

- Reports published:
  - Ivanovs, J., Haberl, A., & Melniks, R. (2024): Modeling Geospatial Distribution of Peat Layer Thickness Using Machine Learning and Aerial Laser Scanning Data. Land, 13: 466, https://doi.org/10.3390/land13040466

3. MAJOR REMAINING KNOWLEDGE GAPS RELATED TO SOIL GREENHOUSE GAS EXCHANGE RESEARCH

3.1. Agriculture

Even after the extensive research done in the LIFE OrgBalt project, the data base for comparing different management options under different site- and climatic conditions still appears somewhat limited for supporting effective CCM. The main, but not all, "business as usual" management options in the Baltic context were well covered, while insufficient efforts could be made with novel options that may not appear appealing to land managers without hard data on their benefits. Novel practices have been suggested based on inference, but actual data are still either lacking altogether, or accumulating very gradually on a case-study basis. Also, even though carefully premeditated and harmonized protocols were applied across the study sites, some aspects in the monitoring protocols were not optimal, largely because of trade-offs between monitoring intensity and the number of sites monitored. While it was considered essential to monitor several sites, increased intensity would be needed to fully capture the variation in fluxes due to seasonality, weather conditions, and management cycles for rigorous modeling.

We identified the following knowledge gaps and other issues to be considered in future research:

- **General:**
  - Certain uncertainty in the comparison of total GHG emissions from drained organic soils between countries is caused by different approaches in the definition of organic soils. To address this issue, it would be useful to establish standardized definitions and criteria for organic soils across countries for identification of organic soil systems forming the most GHG emissions when drained. This would ensure consistency in reporting and facilitate accurate comparisons of emissions. This concerns all land-use types but may be the most critical for agriculture that transforms the soil most intensively.
  - Future monitoring of GHG emissions and site conditions should be designed to directly benefit the development and implementation of Tier 3 level methodologies utilizing models that are best verified using the results from several sites monitored using harmonized methodologies.
- **Site selection and measurement protocols**:
  - Due to variability in interannual climatic conditions, a 2-year study that has been considered the minimum for EF estimation may not provide representative emission data due to the fluctuation of climatic conditions impacted and boosted by climate change for any system studied, even if the management practices and site conditions are considered to be stabile. There is a need for long-term monitoring and data collection on the impacts of CCM practices in organic soil agriculture. This data is essential for validating models that predict long-term outcomes of agricultural practices.
  - Methods quantitatively proportioning aboveground autotrophic respiration from ecosystem respiration could be further developed for cropland and grassland that represent even-aged monocultures and often short rotation systems.
  - There is a lack of soil chemistry data, especially different forms of nitrogen, collected in different seasons. Understanding of available soil nitrogen dynamics, deriving from litter deposition above- and below-ground, fertilization and mineralization of soil organic matter, as well N-dynamics in soil, water and in biota is needed in addition

to annual soil C and GHG balances. Widely differing annual GHG emission budgets, especially in croplands, indicate the insufficient data pool.

- **Carbon Sequestration Potential**:
  - There is still insufficient understanding of the soil C balance (i.e. C loss rate) in different agricultural systems that utilize organic soils. Specifically, research is needed to quantify how different agricultural practices (e.g., different crop species, crop rotation, cover cropping, and reduced tillage) influence long-term C storage in these soils. Additionally, studies should explore the factors that affect the longevity and stability of the sequestered C to develop reliable estimates of options leading to improvements in soil C sustainability (or speeded up C losses) .
  - There is a need to explore the dynamics of soil C inputs and decomposition processes in both cropland and grassland ecosystems, specifically examining the contributions of vegetation characteristics, and above- and below-ground litter on the C dynamics. Such data could be used in modelling temporal variations in C fluxes.
- **Greenhouse Gas Emissions Dynamics**:
  - The dynamics of GHG emissions in response to various agricultural practices on organic soils remain poorly understood. This includes the need for detailed research on emissions of CO_2, CH_4, and N_2O under different management practices. Understanding the triggers of emissions, particularly under anaerobic conditions prevalent in organic soils, is essential for formulating practices that minimize GHG releases while maximizing productivity.
- **Impact of Climate Variability**:
  - The effects of climate variability — including extreme weather events, altered precipitation patterns, and rising temperatures — on organic soil agriculture and its implications for GHG and C storage are not well-studied. Research should have interest on these factors to estimate trade offs resulted under different management between crop productivity, soil health, GHG emissions, and the overall ecosystem functions of organic soils in different climate scenarios.

Three most urgent attention-requiring research topics on croplands and grasslands can be summarized as: (i) enhancing the monitoring and reporting of GHG emissions and site conditions with the aim of directly contributing to the development and implementation of advanced methodologies at the Tier 3 level, thereby enabling more effective mitigation strategies to be formulated, (ii) taking into account the potential impact of future climatic conditions on soil health and GHG emissions, also by considering the influence of different management practices and crops that may become more prevalent in the future, and (iii) integration of water and matter dynamics on catchment scale to evaluate and adapt/optimise good agricultural practices and CCM measures on organic soils.

3.2. Forestry

As reviewed above, data availability from a wide range of drained peatland forests, particularly in the boreal region, is already very good. However, by far most of the currently available data represent forests under "as is" conditions, i.e., not considering the impacts of different management options (Jauhiainen et al., 2023). The focus of on-going research has already shifted to evaluating the impacts of, and comparing, different forest management options (e.g., Korkiakoski et al., 2019, 2020; Ojanen and Minkkinen, 2019; Peltoniemi et al., 2023). However, the available data is still too scanty for formulating specific emission factors (EFs) for different management options or chains (Jauhiainen et al., 2023). In addition, the composition and role of the understory in litter formation and C supply into soil after partial harvest in CCF is poorly understood although the understory becomes subject to rapid changes after disturbance and changes in microclimate (Bergstedt & Milberg, 2001; Mäkiranta et al., 2010; Hamberg et al., 2019). Consequently, such research should be further strengthened and expanded. Much of our current views on the relative impacts of different management types or forest operations are still based rather on inference than direct evidence.

A key challenge for evaluating the impacts of basically all management options put forward as mitigation measures is the time scale to be considered. Several ecosystem characteristics evolve dynamically along with tree stand development over time; e.g., the capacity of the stand to accumulate C in its biomass, ground vegetation abundance and composition, litter inputs (both quantity and quality) from the different vegetation components, and soil water-table level, all of which may affect the soil GHG exchange. Further, many of these characteristics may vary significantly according to the main tree species of the stands. Since it is impossible to measure sites with all different combinations of the factors in effect, including weather and climatic conditions, it is essential to develop peatland forest ecosystem models for comparing different management options implemented on organic soils. Simultaneously, we should maintain long-term measurements in flagship sites selected to represent key forest and management types, to produce validation data for the models. To save resources, such measurements should be well harmonized and guided by current and anticipated future model formulations.

We identified the following knowledge gaps and other issues to be considered in future research:

- **General:**
    - Future monitoring of GHG emissions and site conditions should be designed to directly benefit the development and implementation of Tier 3 level methodologies utilizing models that are best verified using the results from several sites monitored using harmonized methodologies.
    - The SUSI model is available for simulating the functions of drained peatland forests and evaluating management impacts on, e.g., stand productivity and GHG balance. However, it has been designed to function under typical conditions in Finland. Some conditions in the Baltic states, e.g., the geometry and ditch spacing of the drainage systems, are too different for the model to be directly applicable. The model could, however, be developed to be applicable under a wider range of conditions. We are still generally lacking, e.g., a mechanistic decomposition model that would be robustly operational in drained and undrained peatland forests and could be added as a module to SUSI or other models.
- **Site selection and measurements**:
    - Due to variability in interannual climatic conditions, a 2-year study that has been considered the minimum for EF estimation may not provide representative emission data due to the fluctuation of environmental parameters impacted and boosted by climate change for any system studied, even if the management practice and site conditions are considered to be stabile. Also, obtaining annual data for years differing in weather conditions would aid modeling.
    - Identification of reliable N_2O emission predictor variables is needed.
    - Long-term impacts of different forest management practices (clearcuts, sheltercuts, thinnings, different soil treatments, etc.) on soil chemistry and potential consequences to resulting GHG emissions need further research.
    - Effective monitoring and verification of C stocks, GHG emissions, and overall forest health in organic soils are essential yet challenging. There is a need for the development of standardized methodologies that can accurately assess changes in site conditions and C dynamics over time. This includes leveraging remote sensing and ground-based techniques for comprehensive monitoring.
- **Carbon Sequestration and Loss Mechanisms:**

  - Research is needed to further unravel how different tree species and soil types influence the soil C storage and sequestration dynamics. Further studies should also explore the role of tree age, biomass growth rates, and root systems in trees and understory in supporting soil C storage.
  - There is insufficient understanding of the specific mechanisms that drive C storage and sequestration, especially following different management operations. The contributions of vegetation characteristics, and above- and below-ground litter on the C dynamics have still not been rigorously evaluated. In forest systems, this should cover the various forest rotation phases (stand characteristics) and the dynamics of decomposition of organic matter depending on the composition of the inputs. Further, such data would be needed for modelling.
- **Long-Term Effects of Forestry Practices:**
  - The long-term impacts of various forestry practices on C dynamics and GHG emissions in organic soils are not well understood. There is a need for longitudinal studies to assess how practices such as selective logging, thinning, and clear-cutting, wet forestry influence C stocks and emissions over time scales of several rotation periods (decades-centuries). Understanding how these practices affect soil health and ecosystem functioning is crucial for developing sustainable forestry management strategies.
- **Interactions with Climate Change:**
  - Research gaps exist in understanding how climate change itself will affect forest growth and C dynamics in organic soils. This includes examining how changes in temperature, precipitation patterns, and extreme weather events impact water availability, tree health, growth rates, species distribution, and soil C storage. Insights into these interactions are necessary to develop adaptive management strategies for forestry in the face of climate change.
  - Research should consider not only the currently important or typical systems, but monitoring should also include systems that are likely becoming more typical in climate conditions in the future (e.g. pure Norway spruce stands can be expected to become increasingly replaced by be mixed Birch-Norway spruce stands in nutrient-rich organic soils).

Three most urgent attention-requiring research topics on drained organic forest soils can be summarized as, (i) understanding the impact of management-related ecosystem disturbances on soil carbon balance and greenhouse gas (GHG) balance across various management practices and forest development stages, (ii) investigating the role of understory vegetation on soil carbon and nutrient dynamics, as well as the influence of belowground litter inputs on soil carbon storage dynamics considering different site types with varying nutrient and soil water-table regimes, and forest management practices, and (iii) examining the effects of changing climatic conditions on forest stand and understory species and biomass development, and using model-based approaches to estimate the impacts on soil carbon storage and GHG emissions and water and matter dynamics from drained organic forest soils on catchment scale.

3.3. Paludiculture

Paludiculture, as an innovative approach to managing organic soils and wetlands, has significant potential for CCM. Despite its potential benefits, paludiculture faces challenges related to policy, knowledge dissemination, and market access. There is still a need for more extensive research and demonstration projects to educate farmers and stakeholders about its advantages and management techniques. Furthermore, adequate support from governments is crucial to incentivize the adoption of paludiculture practices, which may include financial subsidies or technical assistance. Overall, fostering a greater understanding of paludiculture and its role in sustainable agriculture could contribute to both climate change mitigation and the preservation of organic soils.

We identified the following specific knowledge gaps related to paludiculture on organic soils:

- **Carbon Sequestration Potential and Mechanisms**:
  - There is limited understanding of the specific potential for C sequestration in paludiculture systems. Research is needed to quantify the rates of C accumulation in different paludiculture systems and to model long-term C sequestration potentials and needs to focus on how C storage is optimised under different management schemes. This includes further research-based examples studying the role of various crop species, soil types, and hydrological regimes in influencing C dynamics.
- **Long-Term Impacts of Management Practices**:
  - The long-term effects of different paludiculture management practices on C storage, GHG emissions and C balances need further investigation. There is a need for longitudinal studies that assess how practices such as crop selection, water level management, and harvest methods influence soil C storage, and GHG emissions across various time scales over multiple crop cycles. Understanding the sustainability of these practices under changing climate conditions is vital.
- **Hydrological Responses:**
  - Studies should focus on understanding how variations in water level, flooding duration, and hydrological connectivity influence not only plant growth and yield but also the overall C balance of the system.

3.4. Rewetting for wetland ecosystem restoration

Rewetting of organic soils, particularly peatlands, is a critical strategy for climate change mitigation, yet several significant knowledge gaps exist in this area of research. We identified the following specific knowledge gaps in rewetting of organic soils:

- **Carbon Dynamics Post-Rewetting**:
  - One of the primary knowledge gaps pertains to understanding the C dynamics following rewetting after both agricultural and forestry use. Much of the current literature deals with rewetting following peat extraction, which is a very different situation. Research is needed to quantify how rewetting affects C sequestration rates, the release of stored C in both gaseous and water-borne forms, and overall GHG emissions (i.e., CO_2 and CH_4) in various soil types and climatic conditions.
  - Longitudinal studies can provide insights into how quickly C reservoirs can be stabilized and how long-term C storage can be maximized in rewetted ecosystems that may develop towards different vegetation composition. Understanding the timeframes and processes associated with biodiversity recovery will help predict the ecological benefits that can accompany successful rewetting initiatives.
- **Hydrology and Water Management**:
  - Effective rewetting requires an in-depth understanding of hydrological dynamics and water management practices on landscape- and catchment-scale. Knowledge gaps exist regarding optimal water levels to maintain after rewetting considering the requirements of different plant communities, as well as the effects of different water management strategies on C sequestration and GHG emissions. Research should investigate how varying water regimes influence soil moisture, plant growth, and microbial activity in organic soils.
- **Long-Term Monitoring and Assessment**:

- There is a significant gap in long-term monitoring programs specifically designed to track the impacts of rewetting on C dynamics and ecosystem services. Establishing baseline data and conducting consistent assessments over time are essential for evaluating the success of rewetting efforts in mitigating climate change.

4. SOCIETAL AND POLITICAL CHALLENGES

Even if research produces a huge amount of quality data and provides climate change mitigation measures (CCM), it will not be beneficial if landowners and users are not willing to utilize them or if there are limitations imposed by markets or policy actions. The societal and political challenges related to climate change mitigation efforts on organic soils involve a complex interplay of economic, social, cultural, and regulatory factors. Here are the main challenges:

- **Land Use Conflicts**: In many regions, organic soils, such as peatlands, are often used for agriculture, forestry, or urban development. Efforts to implement climate change mitigation practices, such as rewetting or sustainable land management, can lead to conflicts with existing land uses. Stakeholders, including farmers, landowners, and developers may prioritize short-term economic benefits over long-term environmental objectives and negative external environmental impacts, hindering the adoption of sustainable practices. Also, landowners in peatland-rich versus peatland-poor regions are in a different position concerning the need to adopt novel management practices, which may result in conflicts unless measures for just transition are in place and accepted by landowners.
- **Policy Gaps and Regulatory Frameworks:** Effective CCM on organic soils requires supportive policies and regulatory frameworks that incentivize sustainable practices. However, many regions lack comprehensive policies that specifically address the unique characteristics and needs of organic soils s. This includes insufficient integration of climate change objectives into land-use planning and inadequate funding for research and restoration initiatives.
- **Economic Incentives and Funding**: CCM strategies on organic soils often require significant investment in restoration and management practices. However, securing funding and financial incentives for these initiatives can be challenging. There may be limited access to grants, subsidies, or market mechanisms (like carbon credits, paludiculture value chains) that encourage landowners to adopt climate-friendly practices. This frustrates efforts to implement large-scale rewetting or sustainable land-use strategies.
- **Public Awareness, Community Engagement and Participation**: There is often a lack of public awareness regarding the importance of organic soils in CCM. Educating communities about the benefits of preserving and restoring these ecosystems is essential for fostering support for climate initiatives. Successful CCM requires active participation from local communities and stakeholders. However, engaging diverse stakeholder groups, including farmers and conservation organizations, can be challenging. Conflicting interests, values, and knowledge systems may hinder collaborative decision-making and the development of mutually beneficial strategies.
- **Science-Policy Interfacing**: Bridging the gap between scientific research and policymaking is a significant challenge. Effective communication of research findings and technical knowledge to policymakers is essential for developing evidence-based policies that support CCM on organic soils. However, the translation of scientific research into actionable policy can often be slow and complicated.
- **Adapting to Climate Changes**: The vulnerability of organic soils to climate impacts (e.g., changing hydrology, increased flooding, or vegetation shifts) complicates efforts for

mitigation. Policymakers and stakeholders must balance adaptation and mitigation strategies, ensuring that CCM efforts remain resilient in the face of ongoing environmental changes.

Addressing these societal and political challenges is crucial for advancing effective CCM strategies on organic soils. Collaborative efforts among stakeholders, policymakers, researchers, and local communities are essential for overcoming barriers and achieving sustainable land management goals. Mechanisms for improving the uptake of CCM practices may include:

- Implement financial incentives and market access for landowners and farmers to apply best practices. Rather than imposing restrictions on economic activity, the implementation of these practices should create new opportunities that mitigate potential negative outcomes such as food shortages or increased land management costs.
- Promote knowledge about the significance of organic soil management and peatlands for climate mitigation through informational campaigns and provide training programs for farmers, landowners, and policymakers.
- Install educational programs on all levels but especially on expert level for education and training in land use and related sectors that train ecosystem and hydrological understanding and nature-based measures on landscape and global scale.
- Evaluate and, if feasible, support the growth of markets for climate-friendly products, such as those derived from paludiculture.

LIFE OrgBalt core contributions to examining these challenges can be listed as:

- Reports published:
    - Līcīte, I., Popluga, D., Rivža, P., Lazdiņš, A., & Meļņiks, R. (2022): Nutrient-rich organic soil management patterns in light of climate change policy. Civil Engineering Journal, 10(8): 2290-2304, https://doi.org/10.28991/CEJ-2022-08-10-017
    - Valujeva, K., Freed, E. K., Nipers, A., Jauhiainen, J., & Schulte, R. P. O. (2023): Pathways for governance opportunities: social network analysis to create targeted and effective policies for agricultural and environmental development. Journal of Environmental Management, 325: 116563, https://doi.org/10.1016/j.jenvman.2022.116563

5. WAY FORWARD – ACTION PLAN

What can the research community do? Four points:

1. Produce and deliver existing information to political decision-makers to strengthen incentives for policy actions to phase out harmful subsidies and support transition towards climate neutral agricultural and forestry practices.
2. Engage constructively in discussions and support advisory services that inform land users about the potential of various actions to reduce emissions by applying CCMs.
3. Produce and deliver information to research funders about critical knowledge gaps that require funding for filling.
4. Seek possibilities to form multinational consortia within the framework of funding instruments to collect missing information systematically and harmoniously, as well as develop and update models.

Creating an effective action plan for CCM on organic soils requires a multi-faceted approach that incorporates research, policy, community engagement, and sustainable practices. Below is a proposed action plan with six key components:

1. Research and Data Collection
   - Conduct Comprehensive Surveys: Initiate large-scale surveys of organic soil types, distribution, and current conditions to establish baselines for C storage and GHG emissions.
   - Longitudinal Studies: Establish research programs that focus on long-term monitoring of C dynamics[2], soil health, biodiversity, and ecosystem services in organic soils.
   - Interdisciplinary Research: Promote collaboration among scientists from various fields (e.g., ecology, agriculture, hydrology) to develop integrated research approaches that address the complexities of organic soils and their responses to climate change.

2. Policy Development and Advocacy
   - Develop Tailored Policies: Advocate for the creation of policies that specifically address the restoration and sustainable management of organic soils. These policies should include land-use planning, carbon credit systems, paludiculture market development, and financial incentives for landowners and farmers.
   - Integrate Climate Goals: Ensure that local, regional, and national climate action plans integrate objectives for preserving and restoring organic soils as part of broader climate strategies.
   - Support for Sustainable Practices: Develop policy frameworks that support farmers and landowners in adopting sustainable agricultural practices that enhance soil C storage while maintaining productivity.

3. Community Engagement and Education
   - Stakeholder Involvement: Engage local communities, stakeholders, and indigenous groups in discussions about organic soils, their ecological importance, and CCM. Facilitate participatory decision-making processes.
   - Education and Training: Develop educational programs and workshops to inform landowners, policymakers, and the public about the benefits of organic soils and sustainable land management practices, including rewetting techniques.
   - Demonstration Projects: Establish pilot projects that showcase successful practices in paludiculture, rewetting, and carbon farming, allowing communities to see the benefits firsthand (peer-to-peer learning).

4. Economic Incentives and Funding
   - Establish Funding Mechanisms: Create grant programs and seed funding opportunities to support research, restoration, and management initiatives for organic soils.
   - Market Development: Encourage the development of markets for products derived from sustainable practices on organic soils, such as raw material such as fibres from paludiculture, bioenergy, reclaimed peat products, and organic farming outputs.
   - Incentivize Participation: Develop incentive programs for landowners to engage in carbon farming, paludiculture, and rewetting initiatives, potentially through government subsidies or carbon trading schemes.

5. Monitoring and Evaluation
   - Implementation of Monitoring Systems: Establish protocols for measuring water levels, C sequestration and GHG emissions in organic soils, ensuring that data collection is consistent and scientifically rigorous.

[2] e.g., Peatland monitoring program for climate protection; https://www.thuenen.de/en/institutes/climate-smart-agriculture/projects/peatland-monitoring-program-for-climate-protection

- Ongoing Evaluation: Conduct regular assessments of the effectiveness of climate change mitigation strategies and adjust practices and policies as necessary based on feedback and new research findings.
- Public Reporting: Ensure transparency through public reporting of progress, findings, and outcomes of climate mitigation efforts in organic soils to build trust and encourage wider participation.

6. Collaboration and Knowledge Sharing
   - Networking Opportunities: Form networks of researchers, practitioners, policymakers, and NGOs working on organic soils and climate change to facilitate knowledge sharing and best practices.
   - International Cooperation: Engage in international collaboration on research and policy development concerning organic soils, learning from best practices and data from around the world, such as the Global Peatlands Initiative[3] and European Peatlands Alliance[4].
   - Shared Databases and Resources: Create a centralized platform for data and resources related to organic soils and climate change mitigation, making information accessible to all stakeholders.

This action plan aims to foster a holistic approach to climate change mitigation on organic soils by addressing research needs, enhancing policy frameworks, engaging communities, providing economic incentives, implementing robust monitoring systems, and facilitating collaboration. By taking a comprehensive and integrated approach, it is possible to protect and restore organic soils while significantly contributing to climate change mitigation efforts.

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