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."

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SUMMARY

Organic soils are an outcome from a long development where vegetation living on the soil surface adds senesced plant parts (litter) into soil, and this decomposing litter forms partly decomposed organic soil substrate. Organic soils are typically in areas where high ground water table creates anoxic, organic matter decomposition slowing, conditions. Lowering ground water table below the soil surface increases oxygen availability and enhances aerobic decomposition processes in soil organic matter.

European Union, and most nations worldwide, acknowledge drained organic soils to contribute substantially to anthropogenic greenhouse gas (GHG) emissions. Currently, both the agriculture, forestry and other land use (AFOLU) guidelines (IPCC 2006) and guidance from the IPCC Wetlands Supplement (IPCC 2014) may be used for reporting the annual GHG emissions and removals for soils under anthropogenic land uses. Area-based emission factors (EFs), describing the net annual soil greenhouse gas emissions/removals, have been developed to reflect the impacts of ecosystem type, land management and environmental conditions.

Organic soils are formed in Baltic region Northern part (Finland) and Southern part (Estonia, Latvia and Lithuania) after the latest glaciation period. In this cool climate region, organic soils form considerable land type in relatively flat terrain characterized by higher precipitation than evaporation. Organic soils in the region include peat soils (characterized typically by thick organic layer and higher organic matter proportion) and organic soils with proportionally higher mineral content (e.g. gleysols). Highest proportion of peat soils is in Finland, while abundance of other organic soils increase in Baltic States. Organic soils in the region have been drained especially for forestry and agriculture. Peat mining for energy production is identified as another anthropogenic land use in some countries. Permanent draining is typical for agricultural land, while only part of the forests growing on organic soils can be characterized as drained. By area, forest growing organic soils form the main land use category in Finland, Latvia and Lithuania, and agriculture is the most abundant land use in Estonia. In agriculture, the proportion of perennial grasslands and annual cropping lands on organic soils vary by country. In general, most northern parts of the region are grassland dominated due to increasingly demanding climatic conditions and poorer organic soil characteristics.

All Baltic States and Finland follow IPCC Guidance (AFOLU and IPCC Wetlands supplement) in their national GHG inventories. All countries implement sampling-based National Forest Inventory (NFI) to estimate their organic soil areas in specific land use, and may include further details on nutrient status etc. site characteristics in applied classification. For accounting GHG emissions, EF's based on Tier levels (1, 2 and 3) differ by country and land use type. The lowest Tier 1 level is chosen if site type condition specific data is not available in the country. Lack of applicability can be due to differing climate-, soil environment-, and/or management conditions in the country in comparison to the existing data. Other reasons for choosing default Tier level include, for example, (i) because the impact of some specific emission source likely forms a modest

component in a total emission or (ii) the GHG source has minor significance in the country.

CO_2 EFs in these countries included all Tier (1-3) levels. The highest CO_2 EF Tier 3 level was available for forests in Finland, where advanced gain-loss method in modelling is used for estimating forest biomass change and a large pool of GHG data has been collected in boreal climate region. The most applied CO_2 EF for forest was Tier 2 (Estonia, Latvia and Finland), while the default EF was applied in Lithuania. For CO_2 EFs in organic soils in agriculture, Finland used all three Tier levels, Estonia Tiers 1 and 2, and Latvia and Lithuania Tier 1 EFs. For other land uses on organic soils, Tiers 1 and 2 were applied in Finland and Estonia, and Tier 1 in Latvia and Lithuania.

CH_4 EFs included Tiers 1 and 2. Forest soil nutrient characteristics were taken in account in Estonia and Finland. Large CH_4 data pool and inclusion of site draining characteristics allowed use of Tier 2 for forest EF in Finland. For agriculture soils, CH_4 EFs were reported in Estonia (Tier 2), Latvia and Lithuania (Tier 1).

N_2O EFs for forest were Tier 2 level in Estonia and Finland, where soil nutrient characteristics were considered and country specific or comparable condition GHG data was available. Latvia and Lithuania applied Tier 1 EFs for forest. For organic soils in agriculture, Estonia applied Tier 2 level EF for grasslands and Tier 1 for croplands, and all other countries applied the default Tier 1.

In general, the higher EFs are most often applied for forest on organic soil. Recent analysis on existing GHG data on forests on drained organic soils indicated large difference in GHG data availability from boreal and temperate climate zones, where at least 2/3 of the GHG data (over 100 annual soil GHG estimates for CO_2, CH_4 and N_2O gases) is from boreal climate zone. Even in Finland, richest in monitored sites and provided estimates, there is no possibility to inspect this GHG data by category level including forest management options. Lack of applicable data, largely due to a lack of environmental data, hampers developing EFs that are more dynamic. In addition to GHG fluxes quantifying soil gas dynamics, details on the soil and vegetation characteristics and environment conditions at the monitoring sites are necessary to analyse for synthesizing the general dependencies between the fluxes and environmental parameters. For forming higher Tier EFs for CO_2 in the temperate region, studies on aboveground litter production and decomposition dynamics are needed. The accuracy of EFs can be improved as more peer-reviewed data become available and the data quantifies a wider set of specific management options and ecological conditions for a given country or region.

ABBREVIATIONS

AFOLU = agriculture, forestry and other land use C = carbon

CH_4 = methane

CO_2 = carbon dioxide

CCM = climate change mitigation

DOM = dead organic matter

EF = emission factor

GHG = greenhouse gas

GWT = groundwater table

IPCC = Intergovernmental Panel on Climate Change

LULUCF = land use, land-use change and forestry

NFI = National Forest Inventory

N_2O = nitrous oxide

SOC = soil organic carbon

SOM = soil organic matter

UNFCCC = United Nations' Framework Convention on Climate Change

WRB = World Reference Base for soil resources

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1. ORGANIC SOILS – CHARACTERISTICS, FORMATION AND MANAGEMENT HISTORY IN NORTHERN REGIONS

The main substrate in organic soils is incompletely decayed remains of the plants that grew on what was once the surface. Soils formed from organic material are classified as 'histosols'. In the Intergovernmental Panel on Climate Change (IPCC) Wetlands Supplement (Takahiro Hiraishi et al., 2013) organic soils are identified on the basis of criteria 1 & 2, or 1 & 3 shown below:

1. Thickness of organic horizon ≥10 cm. A horizon of <20 cm must have ≥12% soil organic carbon (SOC) when mixed to a depth of 20 cm.
2. Soils that are never saturated with water for more than a few days must contain >20% SOC by weight (about 35% organic matter).
3. Soils that are subject to periods of water saturation and have either:
    1. ≥12% SOC by weight (c. 20% organic matter) if the soil has no clay; or
    2. ≥18% SOC by weight (c. 30% organic matter) if the soil has ≥60% clay; or
    3. an intermediate proportional amount of SOC for intermediate amounts of clay.

Organic soils are formed from accumulated dead organic matter (DOM). Organic soils can be seen as outcome from long development where vegetation living on the soil surface adds litter (senesced plant parts) into soil and the amount of C in added litter exceeds the amount of C lost in decomposition process in the recently added litter and in formerly added organic C substrates. Organic soils are typically found in wetlands, where high GWT forms anoxic conditions (i.e. below the GWT) and organic matter decomposition is generally slow (e.g., Straková et al., 2012).

The development of northern peatlands began 16 500 years ago, and they expanded during the Holocene period (the past 12 000 years after the latest glaciations) on land that became exposed when glaciers retreated (MacDonald et al., 2006). Most of the organic soils we have present day are located in temperate and boreal regions. Peatlands and other organic soils hold about 20–25% of global soil C stock but occupy only 2-3% of the world's ice-free land surface (Takahiro Hiraishi et al., 2013; Mokma, 2005).

In northern Europe, organic soil drainage for agriculture was initiated by the Romans in the lands that they conquered, but there is archaeological evidence of older organic soils use (peat cutting) in the pre-Roman period more than 2000 years old (Rieley, 2014). These activities initiated by Romans were relatively small-scale, while the extensive peatlands use of Holland (draining, colonization and use as meadow/pasture/arable land) started from the 8th century. Agriculture on drained peatlands has always depended on local socio-economic conditions, and the agricultural use of peatlands has changed over time with many areas having been abandoned. Peatland drainage and conversion to agriculture have virtually ceased in boreal and temperate zone countries. Use of peat as a fuel in factories, heating plants and electricity generating stations increased during the first half of the 20th Century. Peat is used for energy mostly in Europe, which accounts for, over 95% of peat extraction and consumption globally.

Permanent drainage (i.e. lowering of GWT below the soil surface permanently) leads to an increase in the depth and volume of aerated soil below the surface. Increase in oxygen availability leads to enhanced aerobic decomposition of the organic matter, resulting in an increase in the emission of CO_2 and N_2O to the atmosphere (Takahiro Hiraishi et al., 2013). However, the presence of oxygen in soil also hinders anaerobic processes and the associated emission of CH_4 from organic matter decomposition.

Typically, organic soils in drained conditions form net source of greenhouse gas (GHG) emissions into the atmosphere. In organic soils with high mineral content, C loss through decomposition processes may over decadal long period, create a mature topsoil layer with decreased organic matter content. In soils formed solely from organic C, soil surface subsides as the soil decomposes and C moves out from the system. Rates in losses of organic soil matter and GHG emissions in drained organic soils are several times faster than the opposite processes where C is stored into soil.

Human activities impact terrestrial C sinks, through LULUCF activities. Both in the European Union (EU) and on a worldwide scale, drained organic soils are acknowledged to contribute substantially to anthropogenic GHG emissions. Currently, both the IPCC (2006) agriculture, forestry and other land use (AFOLU) guidelines (Eggleston et al., 2006) and the IPCC (2014) Wetlands Supplement (Takahiro Hiraishi et al., 2013) may be used for reporting the annual GHG emissions and removals for soils under anthropogenic land uses. Area-based emission factors (EFs), describing the net annual soil GHG emissions/removals, have been developed to reflect the impacts of ecosystem type, land management and environmental conditions. Reducing these emissions is the most cost-effective climate change mitigation (CCM) option within the land use and agricultural sectors.

In this report we compile the current knowledge on the extent and status of organic soils in Baltic countries and Finland, summarize how EFs (Tier 1 and 2 levels) are compiled for estimating soil GHG emissions from organic soils in these countries, and provide "lessons learned" analysis and suggestions for GHG monitoring work aiming EFs above Tier 1.

2. ORGANIC SOILS – FOCUS IN BALTIC COUNTRIES AND FINLAND

2.1 Estonia

Estonia lies on the eastern shores of the Baltic Sea, borders the Gulf of Finland in the north and lies between Latvia and Russia. It is a flat country with average elevation only 50 m and covering 45,227 km².

Estonia's climate is characterized by its location at the northern edge of the temperate climate zone and in the transition zone between maritime and continental climate. Local climatic differences are due to the neighbouring Baltic Sea, which warms up the coastal zone in autumn and winter and has a cooling effect, especially in spring and early summer. The topography, particularly the heights in the south-eastern part of Estonia, has minor effect on temperature, but plays an important role in the precipitation distribution and especially on duration of snow cover. Summers are moderately warm, the mean air temperature in July is 16 – 18°C and winters are moderately cold with the mean air temperature in February between -1.8°C to -3.3°C in West Estonian islands -3.5°C to -5°C in coastal zone and -5°C to -7°C in inland areas. However, monthly mean temperatures may drop as low as -9.5°C in winter and rise as high as 23.2°C in summer. Mean annual precipitation is in range of 580-760 mm, with lowest amount in West-Estonia and islands (560-610 mm) and highest in Central- and East-Estonia and in upland areas.

During the second half of the 20th century the annual mean air temperature in Estonia increased by 1.0 – 1.7°C (J. Jaagus & Kull, 2011). For the period of 1965-2005 a statistically significant trend of mean annual temperature increase of c. 0.3±0.1°C per decade) was detected for both the Baltic Sea region and Estonia (Männik et al., 2015). Seasonality plays an important part in climate warming in Estonia. A statistically significant increase in the monthly mean temperature is present only during the period from January to May, with the greatest increase in March (up to 4°C). During the period 1961–2004 the winter seasonal air temperature increased by 3.2°C on average (J. Jaagus, 2006). Another study found similarly that significant mean monthly temperature increase over the period of 1965 – 2005 was detected for January, April and July for both the Baltic Sea region and Estonia (Männik et al., 2015). The climatological winter has drastically shortened during last decades and thus also the number of days with ice and snow has reduced (J. Jaagus, 2006; Jaak Jaagus, 1997; Sooäär & Jaagus, 2007, 2007). For the rest of the year, practically no change in the annual mean air temperature has been identified (J. Jaagus, 2006).

The seasonal variation in precipitation is similar throughout the country, the driest months being February and March. From then on, precipitation gradually increases until July and August, after which it decreases towards winter and spring. The lowest annual precipitation may be less than 350 mm on the coast, but inland regions sometimes have more than 1,000 mm. The highest daily rainfall recorded is 130.8 mm while it is not uncommon that there is no precipitation during the full month. Due to climate change increased precipitation is expected in the cold season (mainly in the form of rain, instead of snow) and this is in good accord with changes in wind climate. During 1966 – 2005, generally, south-westerly and westerly winds have increased, whereas north-easterly, easterly and south-easterly winds have decreased. The winds of maximum frequency have changed from south-east to south-west (J. Jaagus & Kull, 2011).

Estonia’s flat and low-lying landscape combined with humid temperate climate favors development of water-logged organic soils. Based on Estonian Soil Map (1:10 000) peatlands cover 20.3% (8133 km²) of Estonian soil covered land area (Figure 1).

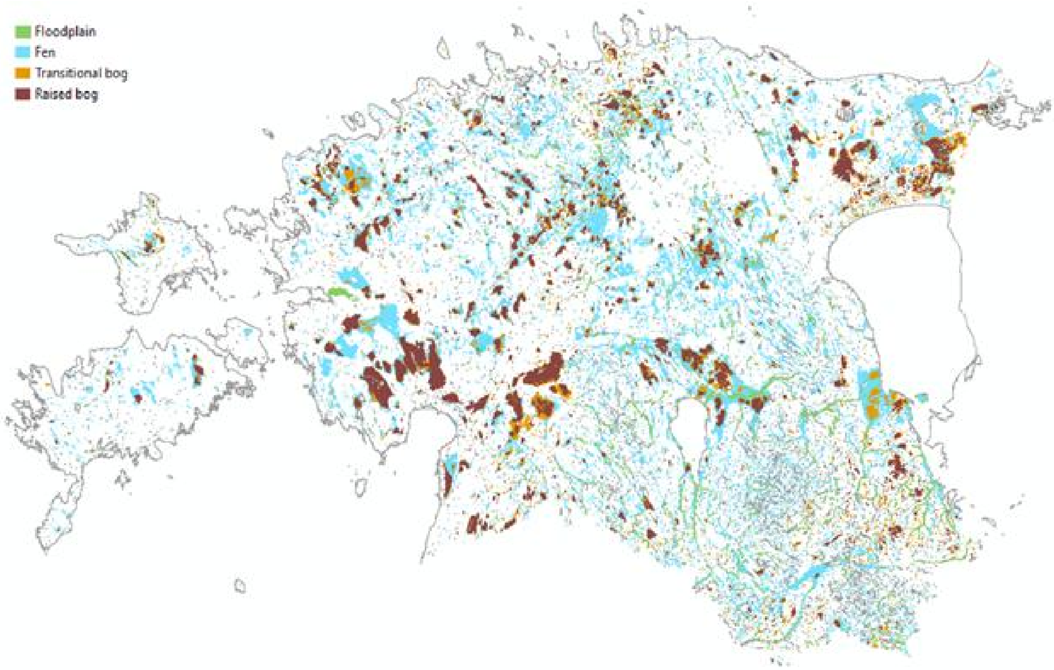


Figure 1: Distribution of organic soils by type in Estonia (adapted from Paal & Leibak, 2011).

Significant part of that is drained, Estonian mire inventory showed that mires cover only 5.5% (c. 250 000 ha is still accumulating peat) of Estonia (Paal & Leibak, 2011) and if undrained peatland forests are included, the mire area might be c. 8% (Figure 2).

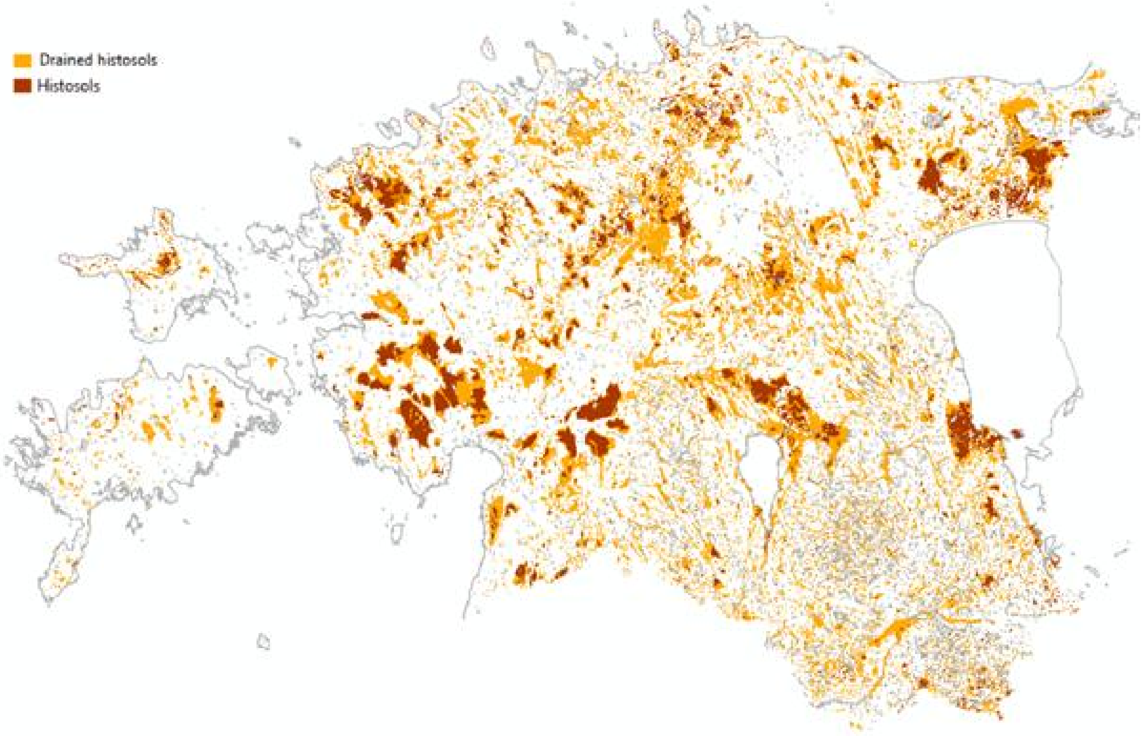


Figure 2: Distribution of mires on undrained histosols and peatlands on drained histosols in Estonia[1].

Calculations by Kõlli et al. (2009) show that 593.8±36.9 Tg of SOC is accumulated in Estonia’s soil cover (which totals 42 400 km² after exclusion of water bodies and infrastructure). In forest lands most of the SOC (56.3%) retained in the soil cover is found in organic soils, followed by hydromorphic mineral soils (32.4%). On arable lands automorphic mineral soils (53.8%) are the main accumulators of SOC in soil EPL, followed by hydromorphic mineral and organic soils. On grasslands hydromorphic mineral soils contains most of the SOC (R Kõlli et al., 2009). However, it should be mentioned that in peatlands full carbon stock is not estimated as soil survey did not record full depth of the peatlands but only upper part.

For GHG reporting under the United Nations’ Framework Convention on Climate Change (UNFCCC) organic soils in Estonia are currently not taken from Estonian Soil Map (1:10 000) but as recorded during statistical National Forest Inventory (NFI). During a field study, soil types (mineral/organic) are also estimated and all sample plots are assigned with the soil type “mineral” or “organic”. For undrained soils the “organic” soil type is defined with an organic layer of more than 30 cm in depth and for drained soils more than 25 cm in depth. The soil is drained when the distance from the drainage ditch is up to 100 m. Thus NFI classification of “organic soil” differs somewhat from traditional organic soil classification where required minimum peat depth is >30 cm.

It is assumed that almost 600 000 ha of peatlands have been ameliorated for agricultural purposes (mainly fens and floodplains, less transitional bogs) and more than

1 Calculations are based on Estonian Soil Map (1:10 000), drainage information from Estonian Topographic Data Base (1:10 000) and Land Amelioration Information System.

350 000 ha are drained for forestry (fens, floodplains, transitional mires, bog margins). In addition 21 000 ha of peatlands (mainly bogs, excluding non-industrial small-scale excavation) are used for peat industry.

The NFI determines more land categories than in the IPCC 2006 guidelines, therefore an aggregation has been made, which is shown in Table 2.1.ES1. Not all national and IPCC land-use categories have an exact match, few national land-use categories can be forest land or grassland, which is specified in the field ((Ministry of the Environment, 2019).

Table 1: Estonian national definitions for land-use categories and relevant land-use categories defined by IPCC 2006 in 2017 (area in kha, Ministry of the Environment, 2019, Table 6.6).

Land use category	Forest land	Cropland	Grassland	Wetlands	Settlements	Other
	kha					
Forest land (M)	2 157.4					
Unstocked forest land (MM)	173.2					
Arable land (excluding PK, PR) (PM)		661.2				
Permanent crops (PK)		2.3				
Long-term cultural grassland (PR)		368.1				
Bushes (P)	18.9		48.8			
Natural grassland (RM)	33.8		204.6			
Swamp, bog (S)	52.4		17.7	139.0		
Inland water bodies (SV)				258.6		
Peat quarry (KT)				13.3		
Opencast pit (excl. KT) (K)					9.5	
Settlements (excl. T, TR) (A)					195.8	
Roads and railways (T)					67.4	
Lines, power lines, etc. (TR)					69.8	
Unusable mineral land (KK)	2.7		3.5			31.7
Other land (Y)						4.5
Total	2 438.4	1 031.6	274.4	410.8	342.5	36.2

2.2 <u>Latvia</u>

Latvia lies in a temperate climate zone where active cyclone determines rapid changes in weather conditions. Annual mean precipitation is 600-700 mm. The analysis of long-term climatological data series in Latvia has shown that the climate has changed during the last centuries. Air temperature has increased for the whole period of observations (from the 1795); however it has been more visible during winter and spring and for the last decades. Ice and snow cover period in Latvia has become shorter during last decades. The absence and lowering of the ice cover during winter causes the prolonged growing season. In the period from 1961 to 2010 typical growing season in Latvia has been from 184 to 200 days a year, in the South-western districts up to 208 days per year (State Ltd. "Latvian Environment, Geology and Meteorology Centre", 2017).

Similarly to most part of Northern Europe, several factors contribute to the formation and development of peatlands in Latvia, including moderate climate characterized by higher precipitation than evaporation, slightly undulated relief, clayey, poorly permeable deposits in relief depressions, and hydrological regime. The set of climatic, hydrological and geological conditions determines that peatlands can develop in Latvia in two ways: by land paludification and by filling-in of shallow water bodies (Kalniņa, 2019).

Peat accumulation areas nowadays cover more than 10% of Latvia`s territory. The largest mires areas occur in Eastern part of Latvia in Latgale region (3.4%), the lowest in the central part, in Zemgale region. Over the last hundred years mires had been drained (15% for agricultural use, 3.9% for peat extraction) and overgrown with forest as a result of human activity and natural processes (Kalniņa, 2019).

For GHG reporting under the UNFCCC organic soils in Latvia are reported in forest land, cropland, grassland and wetland land use categories. Information on area of organic soils is taken from different sources depending on land use category. The data source for area of organic soils in forest land is NFI and area of organic soils is reported according to the structure of distribution of the forest stand types.

For area of cropland and grassland on organic soils data sources have been changed recently. Until National GHG inventory submission 2018 data source for area of organic soils in farmland was summary of land surveys done before 1990 and based on field measurements completed in 60s, 70s and early 80s (L.U. Consulting, 2010). Value used was 5.18±0.5% of total farmland area. Since National GHG inventory submission 2018 area of organic soils in cropland and grassland is reported according to the research results (Lazdiņš et al., 2016) and in 2017 there were 99.9 kha of organic soil in cropland and 52.3 kha in grassland.

In total 41.3% of organic soils in Latvia are occupied by forest land, 40.1% – by wetlands (excluding peat extraction areas and flooded wetlands), 9.6% – by cropland, 5.0% – by grassland, 3.2% – peat extraction areas and 0.7% by flooded wetlands (according to the IPCC land use definitions, Ministry of Environmental Protection and Regional Development, 2019).

Research results show ongoing mineralization processes of organic soils in Latvia and project continuous mineralization for at least 40 years if linear mineralization rate is considered. Area of organic soil in cropland in 2015 was 65% from the initial value in the 1960s – 1980s, but in grassland -67% from the initial area of organic soils (Petaja et al., 2018).

According to research based on intersectional analysis of digitized soil maps (created between 1960s and 1980s) and NFI plots, the most common type of organic soils in Latvia in cropland and grassland is fen peat soil (Sapric Histosol or Histic Gleysol), 67%. The most common (65%) soil type in grassland is fen peat (Sapric Histosol or Histic Gleysol), but the most common soil types in cropland are fen peat (Sapric Histosol or Histic Gleysol) and Humic-peaty gley sod (Gleysols, Planosols or Stagnosols). The proportion of semihydromorphic soils (national soil classification), which can fulfil the criteria of organic soils, is higher in cropland than grassland (Petaja et al., 2018).

According to Latvian soil classification, semihydromorphic soils are soils developed in planes or depressions on fine -textured parent material. Soil profile is water-saturated for a long period within a year including the growing season. This soil class includes Gley, Podzolic-gley and Alluvial soils (Kārkliņš, 2016). Regardless of soil type, groundwater is mostly located below 30 cm, i.e. the majority of the area on organic soils in cropland and grassland can be characterized as deeply drained according to IPCC 2006 guidelines (Petaja et al., 2018).

Drained organic soils comprise c. 95% of the total area of forest on organic soils in Latvia, but the systems are not always working properly and rewetting takes place due to wearing of drainage systems (Ministry of Environmental Protection and Regional Development, 2019). Research results in Latvia conclude that in the hemiboreal vegetation zone, drainage of organic soils in forest land is not always causing carbon storage reduction. Carbon stock may even increase after drainage. This is caused by the increase of above and belowground litter production rates. Subsidence followed by drainage is caused mostly by physical shrinkage of aerated soil surface not by peat oxidation (Lupiķis & Lazdins, 2017).

Cultivated organic soils play an important part in management of agricultural land in Latvia. According to Ministry of Environmental Protection and Regional Development (2019) in year 2017 total area of cultivated organic soils is 152.2 kha (about 8% of total farmland area). In 2016 Latvia University of Life Sciences and Technologies carried out research on assessment of the contribution of organic soils to Latvian agriculture. One of the main findings was that although the biggest proportion of organic soils is observed in Eastern part of Latvia (Latgale region), areas of organic soils are distributed throughout the whole territory of Latvia and affect 48% of agricultural holdings (Figure 3, Pilvere, 2016).

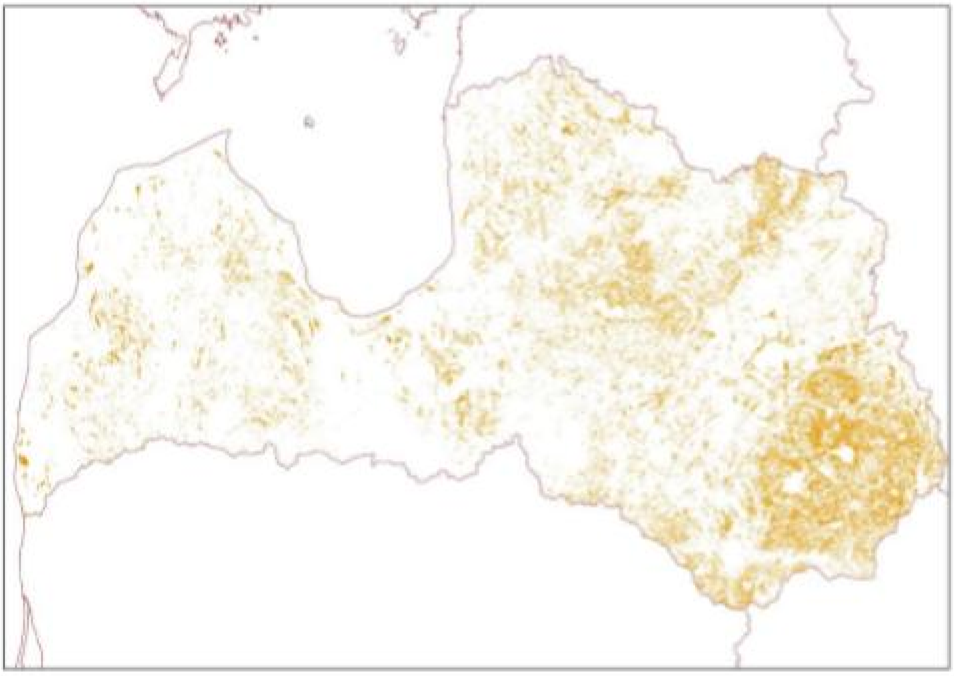


Figure 3: Distribution of hydromorphic soils in Latvia in 2016 (Pilvere, 2016).

About 78% of cultivated organic soils in agriculture are actively managed (part of them receive support payments), but there are also areas that are not actively used and are partly covered with bushes (about 12%). Two main cultivation strategies of organic soil areas are grasslands, meadows and pastures (about 61%) and annual crops (about 29%, cereals, oilseeds legumes, Pilvere, 2016).

Further studies are needed in Latvia to acquire information on carbon stocks in organic soils in different land use categories. Data from international forest soil monitoring project BioSoil give information on carbon stock in litter as constant value 12.14±2.8 t C ha^{-1} and on initial carbon stock in mineral forest soil at 0-30 cm depth (reference C stock) being 82.6±7.8 t ha^{-1}, but since only several sample plots are included in naturally wet forest soils, carbon stock changes there have large uncertainty. Carbon stock changes in mineral soil in forest land, cropland and grassland have been modelled in pilot study of implementation of Yasso model, Yasso model will be further used to characterize soil C stock changes due to land use using the statistics based input values.

Study on evaluation of SOC stock in mineral soil in cropland and grassland in Latvia, where no land use changes were observed for at least 20 years, showed that the mean SOC stock in soil at 0-40 cm depth in cropland is 83.0 t ha^{-1}, in grassland 88.6 t ha^{-1}, but the mean SOC stock in agricultural soils at 0 – 40 cm depth 85.6 t ha^{-1}. Study showed no statistically significant difference between SOC stock in cropland and grassland (Bardule et al., 2017).

2.3 Lithuania

Lithuania occupies the total of 6528648 ha area. Lithuania is in the temperate climate zone and the sub-region of Atlantic-European continental mixed and broad-leaved forests, with annual temperature ranging from 6.5°C to 7.5°C and annual precipitation ranging widely from 600 to 900 mm in different regions. Length of the growing season varies between 185-196 days and the effective temperature sum – from 2000°C to 2300°C depending on the region.

Lithuania, despite being the southernmost of all three Baltic States, still has significant areas of organic soils, varying from smaller to larger extent in different land-use categories. According to the different estimations total peat soil area in the country varies from 459.4 (see Table 2.3LT1) to 653.9 tha (Valatka et al., 2018) and, respectively, the share from 8 to 9.9% of the total area (Slepetiene et al., 2018).

Recently, a study on areas of organic soils (drained and undrained peatlands) was performed in Lithuania (Valatka et al., 2018), providing GIS layer of peatlands in Lithuania (Figure 4).

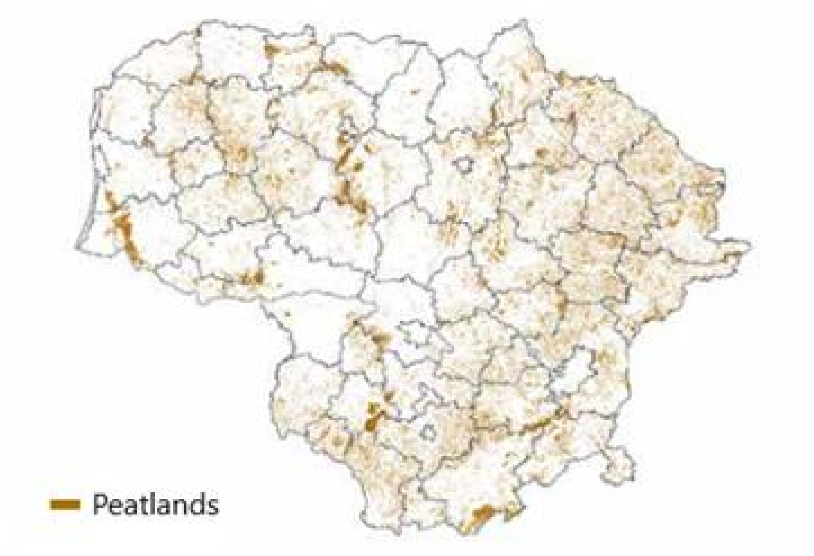


Figure 4: Peatland areas in Lithuania (from Valatka et al., 2018).

Figure 4 shows that the peatlands prevail in western (delta of Nemunas river and Žemaičių upland) and south-eastern parts (Baltic Upland) of Lithuania. In addition it was determined that total area of low moor peat soils comprises about 513 kha (78% of all peat soils), transitional moor soils 89 kha (14%), and high moor soils 52 kha (8%).

According to the present Lithuanian soil classification LTDK-99 (Buivydaitė et al., 2001) Histosols are divided into three subgroups:

1. Terric Histosols (Sapric Histosols according to WRB 2014 (2015)) – eutrophic (nutrients rich low moor) soils having not thinner than 40 cm (if drained -30 cm) highly decomposed surface peat layer (histic horizon).
2. Terri-Fibric Histosols (Hemic Histosols, WRB 2014 (2015)) – mesotrophic (transitional moor) soils having not thinner than 50 cm surface peat layer that is intermediate in degree of decomposition.
3. Fibric Histosols (Fibric Histosols, WRB 2014 (2015)) – oligotrophic (high moor) soils having not thinner than 60 cm poorly decomposed surface peat layer.

In addition, Histosols are divided to the shallow (surface peat layer up to 100 cm) and deep (more than 100 cm) peat soils based on the peat depth. For example, shallow Terric Histosols are classified as Pachiterric Histosols, while deap – Bathiterric Histosols.

Forest types reflect the trophicity of above mentioned Histosols in Lithuanian forests (Karazija, 1988).

At sites of the most eutrophic *Terric Histosols* (*Sapric Histosols*) forest type *Carico-iridosa* prevails with productive forest stands of *Alnus glutinosa* with admixture of Betula pendula (rarely *Fraxinus excelsior* and *Picea abies* occur) while at less eutrophic Caricosa forest site – not productive stands of *Betula pubescens* and *Alnus glutinosa* with admixture of *P. abies* and *Pinus sylvestris*.

At mesotrophic Terri-Fibric Histosols (Hemic Histosols) forest type Caricosa-sphagnosa prevails with not productive forest stands of *P. sylvestris* and birchs (mainly *B. pubescens*, to some extent – *B. pendula*).

At oligotrophic Fibric Histosols forest type Ledo-sphagnosa prevails with extremely not productive stands of *P. sylvestris*.

Soils for National Greenhouse Gas Inventory are classified using national Forest site classification methods, prepared by Vaičys et al. (2006). In the 1960's-1970's, under the guidance of Prof. M. Vaičys, all forest soils in Lithuania were mapped according to this classification of the humidity and fertility of forest sites based on soil-typological groups. The new above mentioned Lithuanian Soils Classification (LTDK-99) was quite recital, and was difficult to use for forest inventories which are based on forest soil site types, therefore it was harmonized with forest soil site types used in forest inventory, forestry, forest related science etc. The final harmonized forest soil type classification is presented in Figure 5.

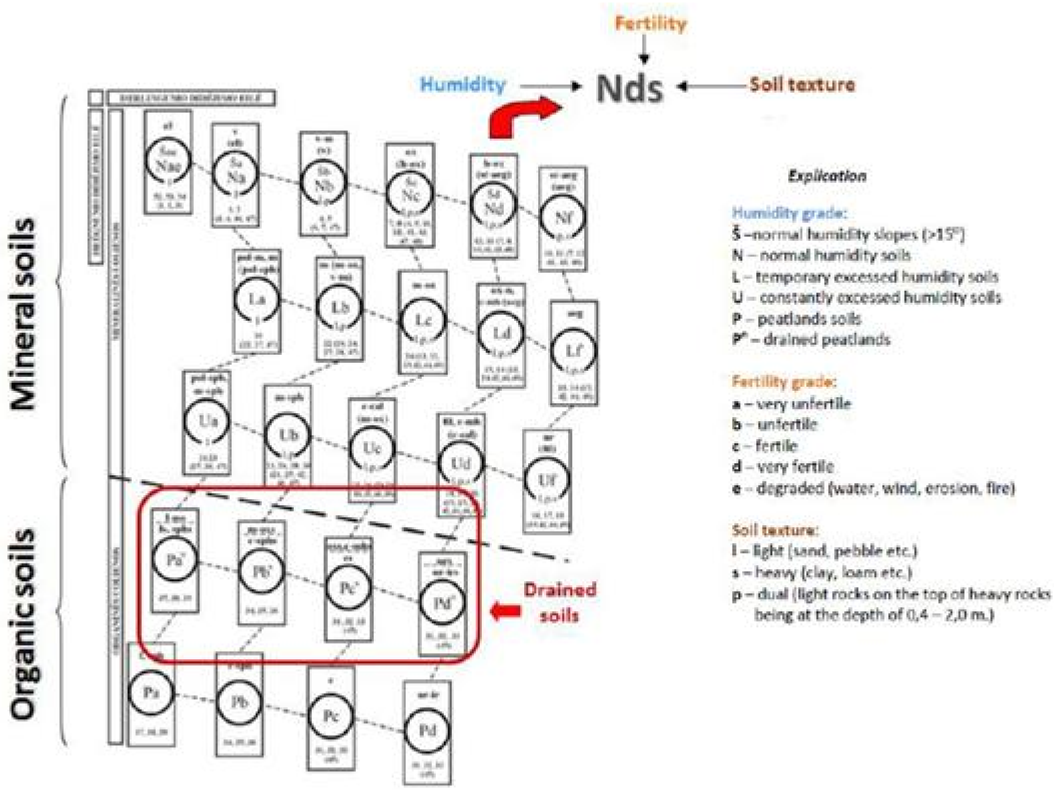


Figure 5: Lithuanian classification of forest site types (modified from Buivydaitė et al., 2001).

In 2016 Institute of Forestry of LAMMC carried out several studies regarding C stocks and C stock changes in different land-use categories, C stocks in mineral soils of cropland, grassland and newly afforested areas were estimated as a result. National C stock values in soils under different land-use types were estimated taking samples from permanent sampling plots of NFI. National C stock values in cropland, grassland and newly afforested / reforested areas were used for C stock changes estimation in mineral soils. In the future National GHG Inventory Report submissions Lithuania is planning to further improve accuracy of LULUCF GHG inventory with implementation of different C stock values for different soil groups in forest land, cropland and grassland, meaning the expansion of land-use change matrix to different soil groups. Soil C stock values for C stock changes estimation is presented in Table 2.

Table 2: National SOC stock values (surface 0-30 cm layer) in different land uses in Lithuania, t C ha⁻¹ [min; max]

	Forest land	Cropland	Grassland
	t C ha⁻¹ [min; max]		
I - sandy soils (Arenosols, Podzols).	53.2 [51.2; 55.2]	70.3 [66.6; 74.1]	61.0 [57.3; 64.7]
II - HAC soils, normal moisture regime	69.9 [64.8; 75.0]	74.4 [72.2; 77.3]	78.9 [72.5; 78.2]
III - HAC soils, temporary over-moistured regime	107.7 [103.3; 110.0]	-	98.0 [79.8; 116.3]
IV - wetland mineral soils	99.7 [93.3; 115.1]	-	-
V - wetland (not drained) organic soils	180.8 [68.3; 293.3]	-	180.8 [68.3; 293.3]

Due to the difference in area of organic soils and EFs applied for each land-use category, amount of GHG emissions and thus its significance to the total country's GHG emissions varies greatly among land uses in Lithuania. Areas of organic soils, as reported in National GHG Inventory Report (MoE/EPA/SFS, 2019; not published data of 2018) are presented in Table 3. The areas of organic soils in forest land, cropland and grassland estimated as a share from total land use area, based on statistical data provided by NFI, areas of peat extraction sites are provided by Lithuanian Geological Survey.

Table 3: Organic soils (kha) in different land uses in Lithuania (MoE/EPA/SFS, 2019; not published data of 2018)

Year	Forest land		Cropland	Grassland		Wetlands	
	Drained	Undrained	Drained	Drained	Undrained	Drained peat extraction sites	Previously drained degraded peatlands
	kha						
1990	141.7	137.5	78.8	56.0	3.3	18.0	48.9
1991	142.1	138.0	76.4	59.3	3.3	18.0	43.3
1992	142.6	138.4	74.2	60.3	3.2	18.0	40.5
1993	142.9	138.8	73.2	61.7	3.2	15.7	40.9
1994	143.1	139.0	70.8	62.7	3.2	18.7	36.7
1995	143.3	139.1	68.6	64.4	3.2	18.6	35.2
1996	143.6	139.4	67.5	64.8	3.2	18.5	34.1
1997	143.8	139.6	65.6	65.0	3.2	16.6	35.5
1998	144.0	139.8	62.7	65.3	3.2	16.8	35.3
1999	144.2	140.0	60.0	65.7	3.2	16.8	34.2
2000	144.6	140.4	56.4	66.6	3.1	17.6	30.5
2001	144.7	140.5	52.9	67.5	3.1	17.7	30.1
2002	145.0	140.8	49.9	67.8	3.1	14.4	33.0

Year	Forest land		Cropland	Grassland		Wetlands	
	Drained	Undrained	Drained	Drained	Undrained	Drained peat extraction sites	Previously drained degraded peatlands
2003	145.4	141.2	47.4	68.0	3.1	12.6	34.0
2004	145.9	141.7	45.8	68.2	3.1	13.3	31.7
2005	146.4	142.2	44.8	68.0	3.1	13.8	29.6
2006	146.9	142.7	48.2	66.6	3.0	14.3	27.5
2007	147.5	143.2	51.8	65.8	3.0	14.0	25.8
2008	147.9	143.6	55.1	65.2	3.0	13.9	25.5
2009	148.2	143.9	57.4	64.0	3.0	14.0	25.4
2010	148.6	144.3	56.1	64.8	3.0	14.0	24.6
2011	149.2	144.9	56.2	63.3	3.1	13.8	24.8
2012	150.0	145.6	55.9	64.6	3.2	13.8	22.8
2013	150.4	146.0	55.8	63.7	3.2	13.8	22.8
2014	150.9	146.5	57.5	64.0	3.2	14.4	19.8
2015	151.5	147.2	58.6	63.0	3.3	14.7	19.1
2016	151.9	147.5	59.9	62.8	3.3	14.9	17.3
2017	152.4	148.0	60.9	63.3	3.3	14.9	14.9
2018	152.6	148.2	61.0	65.1	3.4	14.1	15.0

Total GHG emissions from drained organic soils in Lithuania vary from ~60 kilotonnes of CO_2 eq. in Grassland to ~435 kT in Forest land and ~1167 kT of CO_2 eq. In Cropland, according to MoE/EPA/SFS (2019). Emissions from drained organic soils in Lithuania constitute c. 8% of total country emissions (20 705 kT of CO_2 eq.) excluding LULUCF. Emissions from drained organic soils are reported under LULUCF sector in Lithuania's annual GHG Inventory.

Extensive drainage of peat soils in Lithuania took place in Soviet period during 1960-1980. As could be seen from Table 2.3LT2, at present all organic soils (mainly Sapric Histosols) in cropland and almost all in grassland (95%) are drained while in forests drained organic soils (mainly Fibric Histosols) comprise 51%. However, it is noted that closed drainage systems permanently worsening and 20% of these systems require of the repair (Valatka et al., 2018).

As it could be seen from the Table 3, the largest area of drained organic soils is covered with forest land (in total 152.6 kha or 55% of total drained area), almost equally sharing drained and undrained land. It is recommended to apply the rewetting of nutrient poor Fibric Histosols in forests (Valatka et al., 2018). Total area of drained organic soils in cropland comprises 61.0 kha (13%) and 65.1 kha (15%) in grassland. It is recommended that organic soils in cropland should be converted to perennial grassland or, in our opinion, to forest land (afforestation with short rotation plantations).

2.4 Finland

Due to the northern and humid conditions of Finland, and the relatively flat topography, peatlands are characteristic for the landscape. The climate in Finland is humid boreal with mean temperature ranging from -2 to 5°C and annual precipitation from 450-750 mm depending on the region. Length of the growing season varies from 105-185 days in the different regions of the country and the effective temperature sum from 600°C to 1400 °C.

The total area of undrained mires in Finland is c. 4 million ha (Turunen, 2008). Extensive drainage of peat soil area in Finland took place during two decades (1960-1980, Figure 6). The highest proportion of drained peatlands (>80%) is in Southern, Eastern and Western parts of Finland, and the percentage is lowest in Lapland in Northern Finland. Currently over half of organic soil area has been drained for different uses. Since 1950, drainage for forestry the most extensive land use (c. 55% of the area) applied to Finnish mires. The second most extensive land use is agriculture (c. 36%), while other clearly identifiable uses in energy production, road building and peat harvesting represent smaller proportions.

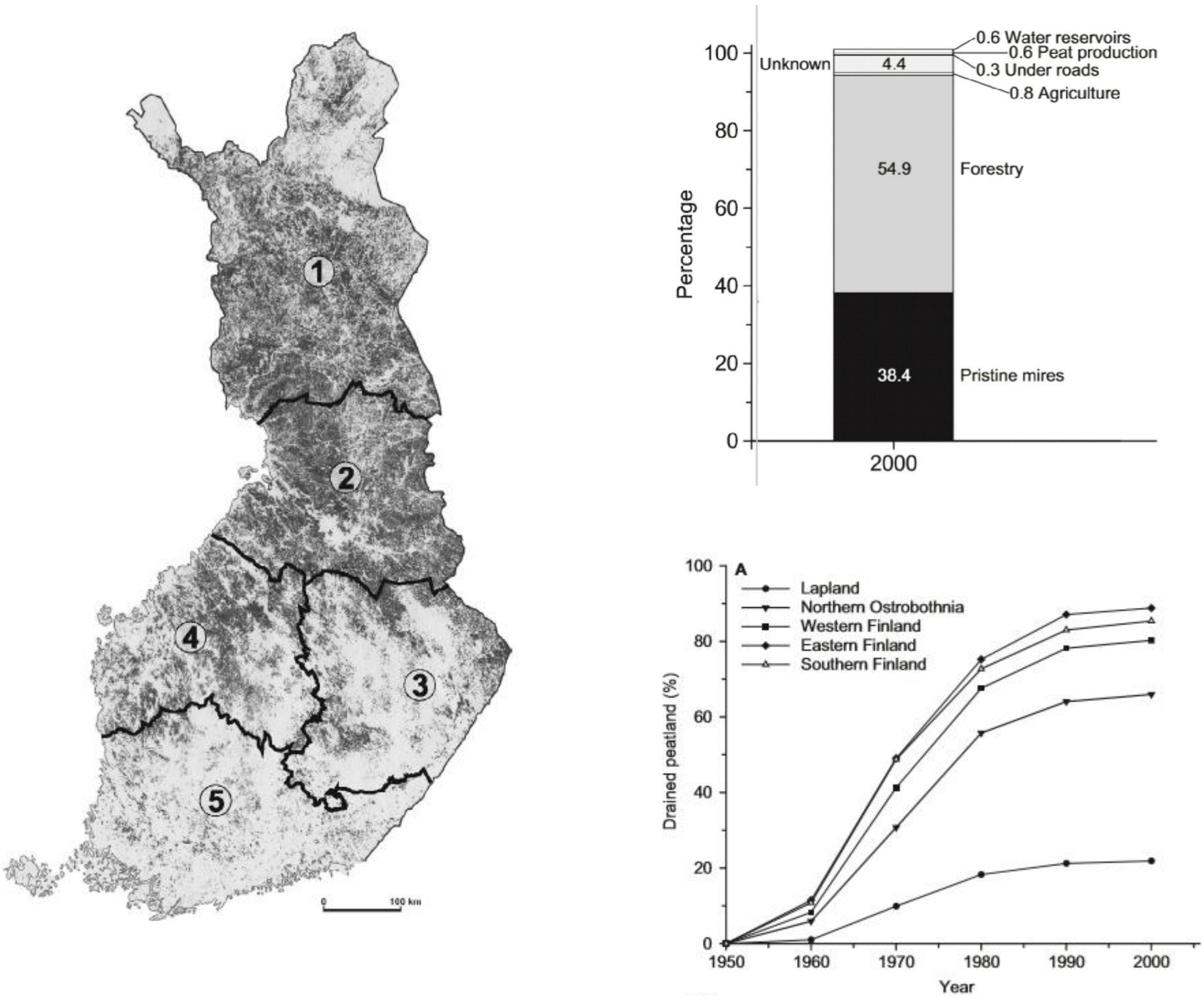


Figure 6: Peatland distribution in Finland by grey (left), percentage of drained peatland area in Finland from 1950 to 2000 (up-right) and mire exploitation (%) in Finland (low-right), (source Turunen, 2008, Figs 1 and 3).

Estimated peat C storage in Finland is about 5300 Tg, which constitutes more than two thirds of the Finnish carbon reservoir (Table 4). The estimated peat C storage is highest in Northernmost Finland (Lapland) and Northern Ostrobothnia by constituting over 50% of the total C-storage in Finland. About 52% of the peat C stock is in drained peat areas.

Table 4: The peat C storage (Tg) of undrained mires, forestry-drained peatlands and cultivated peat soils in five study regions of Finland in year 2000 (Turunen, 2008, Table 2)

No	Study region	2000			
		undrained	drained	cultivated	total
1.	Lapland	1677	392	7	2076
2.	Northern Ostbothnia	414	795	33	1242
3.	Eastern Finland	65	476	19	560
4.	Western Finland	123	664	58	845
5.	Southern Finland	57	478	46	581
Total		2336	2805	163	5304

For GHG reporting under the UNFCCC, land use categories on organic soils in Finland include croplands, forests and wetlands. The data source on the land use categories and areas in GHG reporting are based on the NFI. Organic soils are identified in the field during the NFI measurements for Forest land and Wetlands and partly for other land-use classes in case of land-use change. Further subdivision in land use categories on agricultural and forest lands areas are on the basis of vegetation types (Statistics Finland, 2019, Tables 5.4-7 and 6.4-1).

Agriculture. Finland has the northernmost agricultural regions of the European Union. Utilizing organic soils for food production is unavoidable in a country with high coverage of peat soils. Total area of drained cultivated organic soils in Finland (year 2017) is 327 616 ha. Cultivated organic soils includes 162 802 ha area in cropland growing perennial vegetation, 98 213 ha area for annual crops, and 66 601 ha area on grasslands (Statistics Finland, 2019, Table 5.4-7). Most of the grasslands on organic soils (30 200 ha) are located in Northern Finland, while smaller area (22 600 ha) is in Southern Finland (Statistics Finland, 2019, Table 6.6-1).

The area of cultivated organic soils in has increased by 25 506 ha in 1990-2017 (Statistics Finland, 2019, Table 5.4-7). Most new area taken for cultivation originates from forest areas, and minor areas were cleared from grasslands, abandoned peat extraction sites or other wetlands (Kekkonen et al. 2019). In the most recent years, no pristine peatlands have been cleared for agriculture; the new area has been taken only from already drained sites such as forests and former peat extraction sites (Kekkonen et al., 2019). Animal production and farm enlargement are more common in the eastern and northern parts of the country where the occurrence of peat soils is also high (Table 5). An enlarging animal farm needs new area for both feed production and manure (Kekkonen et al., 2019).

Table 5: Regional distribution of field area, cultivated organic soils and farm number and size (source: Kekkonen et al., 2019, Table 3).

No	Title	Total cultivated, ha	Total organic, ha	Share of organic, %	Number of farms	Average size of farm, ha
1.	Uusimaa	191506	3909	2	3234	56
2.	Varsinais-Suomi	303298	5127	2	5335	55

No	Title	Total cultivated, ha	Total organic, ha	Share of organic, %	Number of farms	Average size of farm, ha
3.	Satakunta	147700	12184	8	3042	46
4.	Häme	195667	9660	5	3570	52
5.	Pirkanmaa	175926	10744	6	3855	43
6.	Kaakkois-Suomi	146429	10275	7	3037	45
7.	Etelä-Savo	88721	6292	7	2401	30
8.	Pohjois-Savo	163061	16249	10	3555	42
9.	Pohjois-Karjala	97653	11593	12	2043	42
10.	Keski-Suomi	107398	8862	8	2599	36
11.	Etelä-Pohjanmaa	256498	42642	17	5564	45
12.	Pohjanmaa	203802	26723	13	4671	42
13.	Pobjois-Pohjanmaa	245911	64025	26	4359	54
14.	Kainuu	40354	10403	26	666	39
15.	Lapi	56147	17547	31	1366	33

Forests. Total forest area on organic soils applied in GHG reporting (year 2017) is 5 928 000 ha, from which drained forest soil area is 4 330 000 ha (undrained 1 598 000 ha, Table 6). The forest area on organic soils has been quite stable over the last decades, but there is a small shift from undrained forest area proportion to drained forest.

Table 6: Areas of forestland on mineral and organic soils in Finland (1000 ha) (source: Statistics Finland, 2019, Table 6.4-1).

Year	Mineral	Organic								Total
		Undrained	Herb-rich type	Vaccinum myrtillus type	Vaccinum vitis-idea type	Drwarf shrub type	Cladina type	Drained organic	Total	
2007	15888	1552	671	1139	1634	880	43	4367	5919	21807
2008	15879	1565	657	1137	1640	876	44	4364	5919	21798
2009	15874	1577	643	1135	1645	871	45	4339	5916	21787
2010	15864	1589	630	1133	1651	868	45	4327	5916	21780
2011	15857	1602	617	1131	1657	864	46	4315	5917	21774
2012	15852	1601	619	1132	1656	864	46	437	5918	21770
2013	15848	1600	621	1132	1656	864	46	4319	5919	21767
2014	15847	1599	623	1133	1656	865	46	4323	5922	21769
2015	15848	1699	624	1133	1656	865	46	4324	5923	21771
2016	15850	1598	626	1133	1657	866	46	4328	5926	21776
2017	15853	1598	627	1133	1658	866	46	4330	5928	21781

3. CURRENTLY APPLIED EMISSION FACTORS AND PROJECTIONS OF GHG EMISSIONS IN BALTIC COUNTRIES AND FINLAND

3.1 Estonia

The methodology used in Estonia for calculating emissions and removals from the LULUCF sector follows the IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006) and this paragraph is based on Estonia National Inventory Report document "Greenhouse gas emissions in Estonia 1990-2017. National inventory report. Submission to the UNFCCC Secretariat. Common Reporting Formats (CRF) 1990–2017. Estonia 2019". Estonia uses according to the guidelines for LULUCF the six top-level land categories (Forest land, Cropland, Grassland, Wetlands, Settlements, Other land), divided into Land remaining in the land-use category and Land converted to another land-use category. Since 2011, the area of Estonia has been reported using the Approach 2 method that allows tracking land-use transitions between categories. CH_4 and N_2O emissions from drained organic forest soils (CRF 4(II)) in Estonia are reported for the first time in the 2019 submission. In previous submissions, these emissions were estimated only under the Wetlands category.

Currently, Estonia does not have country-specific EFs for soils and litter for most of the land-use categories. As an interim approach, carbon stock change estimates of these pools are based on EFs from the Sweden National Inventory Report 2018. Soil and litter estimates based on Swedish EF-s are also considered as a Tier 2 method. Country-specific EFs were implemented for peatland emissions (Table 7 and 8).

Studies by Kõlli et al. (2010, 2011) were used for developing new country-specific factors for estimating C stock changes in mineral soils during land-use changes between Forest land, Cropland and Grassland (Tier 2) and Estonia's own country-specific dead wood related EFs used in estimation are based on Köster et al. (2015).

Table 7: Methods and EFs used for estimating the emissions/removals of GHG from the LULUCF sector in Estonia[2]

GHG SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O
4.LULUCF	T1, T2, T3/ CS, D, OTH	T1, T2/ CS, D	T1, T2/ CS, D
4.A.1 Forest land remaining forest land	T1,T2/ CS,D,OTH	T2/D	T2/D
4.A.2 Land converted to forest land	T1,T2/ CS,D,OTH	NA/NA	T1/D
4.B.1 Cropland remaining cropland	T1,T2/ CS,D,OTH	NA/NA	NA/NA
4.B.2 Land converted to cropland	T2/ CS,D,OTH	NA/NA	T1/D
4.C.1 Grassland remaining grassland	T1,T2/ D,OTH	T2/D	T2/D
4.C.2 Land converted to grassland	T2/ CS,D,OTH	NA/NA	NA/NA
4.D.1 Wetlands remaining wetlands	T2/ CS,D	NA/NA	NA/NA

[2] T1 – IPCC Tier 1; T2 – IPCC Tier 2; T3 – IPCC Tier 3; NA – not applicable; CS – Country specific; D – IPCC default value; OTH – other (in the case of missing country-specific data, EFs from Sweden).

GHG SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O
4.D.2 Land converted to wetlands	T2/ CS,D,OTH	NA/NA	NA/NA
4.E.1 Settlements remaining settlements	NA/NA	NA/NA	NA/NA
4.E.2 Land converted to settlements	T2/ CS,D,OTH	NA/NA	T1/D
4.F.2 Land converted to other land	T2/ CS,D,OTH	NA/NA	T1/D
4.G. HWP	T2,T3/ CS,D	-	-
4(II) Emissions from drainage	NA/NA	T1,T2/CS,D	T1,T2/CS,D
4(III) N_2O from mineralization	-	-	T1/D
4(IV) Indirect N_2O emissions from managed soils	-	-	T1/D
4(V) Biomass burning	NA250/NA	T2/D	T2/D

All information about land use type, land use class area and changes between land use classes used in Estonia’s national inventory reporting are currently based on NFI data, which itself is based on a statistical method (Adermann, 2010). Land-use changes are tracked on NFI sample plots that cover the whole country and are re-inventoried every fifth year. Formerly, the NFI registered only the present type of land use, while starting from 2009, the transition of land use is determined on each sample plot, as well, and assessed in retrospect for the past 20 years, if necessary.

Table 8: Sectoral report for land use, land-use change and forestry GHG emissions or removals (kt Ceq) in Estonia in 2017 (Ministry of the Environment, 2019)

GHG SOURCE AND SINK CATEGORIES	CO_2	CH_4	$N_2O^{(2)}$
	Net emissions/removals (kt C eq.)		
4. Total LULUCF	-2121.15	2.46	0.90
A. Forest land	-2243.68	2.46	0.83
1. Forest land remaining forest land	-2047.21	0.00	0.00
2. Land converted to forest land	-196.47	NO,IE	0.00
B. Cropland	235.11	NO,NA	0.00
1. Cropland remaining cropland	177.86	NO	NO
2. Land converted to cropland	57.24	NO	0.00
C. Grassland	37.79	0.00	0.00
1. Grassland remaining grassland	50.15	0.00	0.00
2. Land converted to grassland	-12.36	NO,IE	NO,IE
D. Wetlands	748.84	0.00	0.00
1. Wetlands remaining wetlands	745.68	NO,IE	NO,IE
2. Land converted to wetlands	3.16	NO,IE	NO,IE
E. Settlements	218.22	NO,NE	0.04
1. Settlements remaining settlements	NO	NO	NO,NA
2. Land converted to settlements	218.22	NO	0.04
F. Other land	25.46	NO	0.00
1. Other land remaining other land			
2. Land converted to other land	25.46	NO	IE
G. Harvested wood products	-1142.90		

For estimating carbon stock changes in biomass under the Land remaining forest land category, the Tier 2 approach and Method 2 – the stock-difference method (Equation 1 below) was applied. The NFI annually provides data for growing stock and area for Forest land remaining forest land, also on Land converted to forest land.

$$\Delta C_B = \frac{C_{t2} - C_{t1}}{t_2 - t_1} \text{ where :} \quad (1)$$

ΔC_B – annual change in carbon stocks in living biomass

(B) (the sum of above-and below-ground biomass), tonnes C yr^{-1};

C_{t2} – total carbon ∈ biomass calculated at time t 2, tonnes C;

C_{t1} – total carbon ∈ biomass calculated at time t 1, tonnes C.

Carbon stock change in the dead wood pool was calculated following the Equation 2 below. Values of dead wood densities and C content were acquired from Köster et al. (2015).

$$\Delta C_{DOM} = \frac{A * (DOM_{t2} - DOM_{t1})}{T} * CF \text{ where :} \quad (2)$$

ΔC_{DOM} – annual change ∈ carbon stocks ∈ dead wood (DOM), tonnes C yr^{-1};

A – area of managed Forest land remaining forest land, ha;

DOM_{t1} – dead wood stock at t 1 for managed Forest land remaining forest land, tonne d.m. ha^{-1};

DOM_{t2} – dead wood stock at t 2 (the previous time) for managed Forest land remaining forest land, tonne d.m. ha^{-1};

T = (t 2 − t 1) – time period between time of the second stock estimate and the first stock estimate, yr;

CF – carbon fraction of dry matter (0.487 tonnes C).

Estonia does not have sufficient data regarding litter stocks, thus under Forest land remaining forest land, the conservative Tier 1 method was implemented, assuming that carbon stocks are in equilibrium.

Due to insufficient country-specific data regarding carbon stock changes in forest mineral soil, the EF from Sweden (0.175 t C ha^{-1} yr^{-1}) was implemented for Land remaining forest land. For the conversion categories, EFs from Sweden were applied (Table 9), except for Cropland and Grassland converted to forest land, where national EFs are applied.

Table 9: Cumulative Land-use changes to forest land in 2017 and implemented soil EFs (Ministry of the Environment, 2019, Table 6.11).

Land-use change	kha	%	EF mineral soil, t C ha^{-1}	EF organic soil, t C ha^{-1}
Cropland→ Forest land	25.7	30%	0.167273	-6.1
Grassland→ Forest land	37.1	44%	-0.055274	-0.34
Wetlands→ Forest land	7.6	9%	-	-0.34
Settlements→ Forest land	4.9	6%	0.17	-0.34
Other land→ Forest land	9.0	11%	0.17	-0.34
Total	84.2	100%		

Equation 3 (below) was applied for estimating carbon loss from drained organic forest soils and emissions from organic forest soils after Land is converted to forest land.

$$L_{Organic} = \sum_{c} (A * EF)_c \text{ where:} \quad (3)$$

$L_{Organic}$ – annual carbon loss from drained organic soils, tonnes $C\,yr^{-1}$;
A – area of drained organic soils, ha ;
EF – emission factor for CO_2 from drained organic soils, tonnes C $ha^{-1}\,yr^{-1}$

Swedish EFs (Table 6.11 and Table 6.14) for drained organic forest soils. Approximately 22% of all Estonian forest soils are organic soils, of which about 50% are drained according to NFI.

The Tier 2 method and Equation 3 (above) were implemented to estimate the loss of carbon from drained grassland soils. The EFs from Sweden (Table 10) were implemented due to the lack of country-specific data.

Table 10: Cumulative land-use changes to Grassland in 2017, soil and litter EFs (Ministry of the Environment, 2019, Table 6.26).

Land-use category	Area, kha	%	EF mineral soil, t C $ha^{-1}\,yr^{-1}$	EF organic soil, t C $ha^{-1}\,yr^{-1}$	EF litter, t C $ha^{-1}\,yr^{-1}$
Grassland remaining grassland	239.5	-	-	-1.41324	-
Forest land→ Grassland	4.9	14%	0.08325	-1.35	-0.75
Cropland→ Grassland	27.5	79%	0.56326	-6.10	NA
Wetlands→ Grassland	0.4	1%	-	-1.35	NA
Settlements→ Grassland	1.1	3%	0.11	-1.35	NA
Other land→ Grassland	1.0	3%	0.11	-1.35	NA
Total Land to grassland	34.9	100%			

EFs from the 2013 IPCC Wetlands supplement (Tier 1) was applied for estimating CH_4 and N_2O emissions from drained organic forest land and drainage ditches (EF 217 kg CH_4 $ha^{-1}\,yr^{-1}$). Forest land was divided into nutrient-rich (EF 2.0 kg CH_4 $ha^{-1}\,yr^{-1}$ and 3.2 kg N $ha^{-1}\,yr^{-1}$) and nutrient-poor areas (EF 7.0 kg CH_4 $ha^{-1}\,yr^{-1}$ and 0.22 kg N $ha^{-1}\,yr^{-1}$) based on site quality class as recorded in NFI.

All cropland organic soil is considered drained in Estonia. The Tier 2 method was applied in order to estimate CO_2 emissions from cultivated organic soils, both for the Cropland remaining cropland and Land converted to cropland subcategories. The EF from Sweden (Table 11) was implemented due to the lack of country-specific data.

Table 11: Cumulative land-use changes to Cropland in 2017 and soil EFs (Ministry of the Environment, 2019, Table 6.21).

Land use category	**Area, kha**	**%**	**EF mineral soil, t C $ha^{-1}\,yr^{-1}$**	**EF organic soil, t C $ha^{-1}\,yr^{-1}$**
Cropland remaining cropland	1 019.6	-	0.09311	-6.1
Forest land→ Cropland Grassland→ Cropland Wetland→ Cropland	0.5 11.5 0.1	4% 95% 1%	-0.77 -0.42 -	- -6.1 -6.1
Total Land to cropland	12.1	100%		

In case of organic soils N_2O emissions occur as a result of cultivation of organic soils due to enhanced mineralization of old, N-rich organic matter. The rate of N-mineralization is determined by N-quality of histosols, management practices and climatic conditions. In Estonia the IPCC 2006 Tier 1 method was applied to estimate N_2O emissions from cultivated organic soils (Equation 4 below). Since 2019 submission, in addition to croplands, areas of drained grasslands are included in emission estimates of cultivated organic soils. allocation of non-drained grasslands is included under the LULUCF sector. N_2O emissions from cultivation of organic soils were 0.438 kt in 2017 in Estonia. The estimation was carried out based on the data of NFI.

$$N_2O_{direct} = \frac{FOS * EF_2 * 44}{28} \text{ where} \quad (4)$$

FOS – area of cultivated organic soils, ha;

EF_2 – emission factor for organic soil mineralization due to cultivation, kg;

$N_2O-N\,ha\,year^{-1}$ (default values from IPCC 2006, tables 11.1 and 11.3).

The Tier 2 method and Equation 6.4 (shown earlier in this section) were implemented to estimate the loss of carbon from drained grassland soils. The EFs from Sweden (Table 12) were implemented due to the lack of country-specific data.

Table 12: Cumulative land-use changes to Grassland in 2017, soil and litter EFs (Ministry of the Environment, 2019, Table 6.26).

Land-use category	Area, kha	%	EF mineral soil, t C ha^{-1} yr^{-1}	EF organic soil, t C ha^{-1} yr^{-1}	EF litter, t C ha^{-1} yr^{-1}
Grassland remaining grassland	239.5	-	-	-1.41324	-
Forest land→ Grassland	4.9	14%	0.08325	-1.35	-0.75
Cropland→ Grassland	27.5	79%	0.56326	-6.10	NA
Wetlands→ Grassland	0.4	1%	-	-1.35	NA
Settlements→ Grassland	1.1	3%	0.11	-1.35	NA
Other land→ Grassland	1.0	3%	0.11	-1.35	NA
Total Land to grassland	34.9	100%			

According to NFI and national inventory reporting the area of wetlands covers 9.1% of Estonia's territory. It should be noticed that wetlands are here defined according to Ramsar criteria, not soil type based, thus including peatland and inland water bodies. The majority of emissions derives from peat extraction and vary between years mainly due to off-site emissions from the horticultural use of peat.

CO_2 emissions from peat extraction areas comprise on-site emissions from peat surface and off-site emissions from the horticultural use of peat. On site, soil C losses from peatlands and from land cleared for peat extraction were calculated using Equation 6.4 (shown earlier in this section) and a country-specific EF (Table 13). Equation 5 (below) was implemented for estimating off-site CO_2-C emissions from organic soils managed for peat extraction. The usage of horticultural peat is estimated as 2/3 of the total peat production.

$$CO_2 - C_{WW\ peat\ off\ site} = \frac{W_{t\ dry\ peat} * C_{fraction\ wet\ peat}}{1000}\ \text{where:} \qquad (5)$$

$CO_2 - C_{WW\ peat\ off\ site}$ – off-site CO_2-C emissions from peat removed for horticultural use, kt C yr^{-1};
$W_{t\ dry\ peat}$ – air-dry weight of extracted peat, tonnes yr^{-1};
$C_{fraction\ wet\ peat}$ – carbon fraction of air-dry peat by weight, tonnes C (tonnes of air – dry peat)$^{-1}$ (default 0.40).

Table 13: Cumulative land-use changes to wetlands and peat extraction sites in 2017, soil and litter EFs (Ministry of the Environment, 2019, Table 6.29)

Land-use category	Area, kha	EF organic soil, t C ha⁻¹ yr⁻¹	EF litter, t C ha⁻¹ yr⁻¹
Peat extraction			
Peat extraction remaining peat extraction	13.0	-1.741 (on-site C emissions) -15.63 (total C emissions)	NA
Forest land→Peat extraction	0.29	-1.741	NA
Wetlands→ Peat extraction	NO		NA
Flooded land			
Flooded land remaining flooded land	6.2	NA	NA
Land to flooded land	NO	-	-
Land to other wetlands			
Forest land→ Wetlands Grassland→ Wetlands Settlements→ Wetlands	0.71 0.36 1.15	no emissions, soil C is not considered lost after LUC to unmanaged wetlands	-0.495 NA NA

Equation 6 (below) with a country-specific EF by Salm et al. (2012) (Tier 2) was implemented for estimating CH_4 emissions and Equation 7 (below) for N_2O emissions from organic soils managed for peat extraction.

$$\text{Direct } CH_4\ emissions_{ww\ peat} = \frac{A_{peatland} * EF_{CH_4} * 16}{12} * 10^{-6}\ \text{where:} \qquad (6)$$

$CH_4\ emissions_{WW\ peat}$ – emissions of CH_4, kt CH_4 yr^{-1};
$A_{peatland}$ – area of peat soils managed for peat extraction, including abandoned areas in which drainage is still present, ha;
EF_{CH_4} – emission factor for actively managed peatland soils, kg CH_4- C ha^{-1} yr^{-1}.

$$\text{Direct } N_2O_{WWpeat\ extraction} = A_{peatland} * EF_{N_2O-N} * \frac{44}{28} * 10^{-6}\ \text{where:} \qquad (7)$$

$N_2O_{WWpeat\ extraction}$ – direct N_2O emissions from peatlands managed for peat extraction, kt N_2O yr^{-1};
$A_{peatland}$ – area of peat soils managed for peat extraction, ha;
EF_{N_2O-N} – emission factor for actively managed peatland soils, kg N_2O-N ha^{-1} yr^{-1}.

3.2 Latvia

According to the 2006 IPCC Guidelines land area is divided into six land-use categories (Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land). In Latvia, LULUCF sector comprises emissions and removals arising from Forest Land, Cropland, Grassland, Wetlands and Settlements divided into the subcategories "lands remaining in the same land-use category for the last 20 years" and "lands converted to present land use during the past 20 years". Other land is considered as unmanaged land and does not contain a considerable amount of SOC and the emissions and removals are not reported. In this report we concentrate on subcategory "lands remaining the same land use category" in more detail.

In National GHG emissions inventory forest soils are considered organic as defined in the NFI: a soil is classified as organic if the organic layer (H horizon) is at least 20 cm deep. Greenhouse gas emissions from organic soils are reported in Forest land, Cropland, Grassland and Settlements categories (Table 14 and 15).

Table 14: Summary of net emissions (kt CO_2 eq.) from organic soils by land-use category in Latvia (Ministry of Environmental Protection and Regional Development (2019), Table A).

Land use category (organic soils)	1990	1995	2000	2005	2010	2015	2016	2017
	kt CO_2 eq.							
4.A Forest land	1489.20	1485.27	1489.86	1487.42	1521.19	1610.60	1628.65	1646.70
4.B Cropland	3649.08	3408.21	3257.09	3071.96	3022.73	2998.37	2992.54	3023.17
4.C Grassland	2151.02	2045.09	1830.66	1693.66	1462.17	1238.25	1198.53	1175.06
4.D Wetlands	1396.46	735.77	911.59	1473.23	1397.76	1890.73	1479.97	1649.34
4.E Settlements	3.01	17.79	38.03	84.63	113.32	137.98	142.74	147.50

Emissions from drained organic soils are calculated using default EFs of the IPCC Wetlands Supplement and country specific approach based on the results of scientific studies (for forest land).

Table 15: Calculation methods and EFs (CS = country-specific, D = default) used for calculation of carbon stock changes in organic soils and emissions from drainage and rewetting and other management of organic soils in Latvia in 2017 (Ministry of Environmental Protection and Regional Development, 2019)

CRF	Source	CO_2		CH_4		N_2O	
		Method	EF	Method	EF	Method	EF
4.A	Forest land						
4.A.1	Forest Land Remaining Forest Land	Tier 2	CS - 0.52 t C ha^{-1}	-	-	-	-
4.A.2	Land Converted to Forest Land	Tier 2	CS -0.52t C ha^{-1}	-	-	-	-
4(II)	Emissions and removals from drainage and rewetting and other management of organic soils	Tier 1	D 0.5 t CO_2 -C ha^{-1} yr^{-1} (rewetting) (Table 3.1)	Tier 1	D 2.5 kg CH_4 ha^{-1} yr^{-1} (drainage) (Table 2.3)	Tier 1	D 2.8 kg N_2O-N ha^{-1} (drainage) (Table 2.5)
		-	-	Tier 1	D 217 kg CH_4 $ha^{-1}yr^{-1}$ (drainage ditches)	-	N_2O emissions are negligible and not estimated for rewetting

CRF	Source	CO_2		CH_4		N_2O	
		Method	EF	Method	EF	Method	EF
					(Table 2.4)		
				Tier 1	D 216 kg CH_4 ha^{-1} yr^{-1} (rewetting) (Table 3.3)		
4.B	Cropland						
4.B.1	Cropland Remaining Cropland	Tier 1	D -7.9 t CO_2-C $ha^{-1}yr^{-1}$ (Table 2.1)	-	-	-	-
4.B.2	Land Converted to Cropland	Tier 1	D -7.9 t $CO_2$2-C $ha^{-1}yr^{-1}$ (Table 2.1)	-	-	-	-
4(II)	Emissions and removals from drainage and rewetting and other management of organic soils	-	-	Tier 1	D 0 ±2.8 kg CH_4 $ha^{-1}yr^{-1}$ (drainage) (Table 2.3)	-	-
		-	-	Tier1	D 1165 kg CH_4 $ha^{-1}yr^{-1}$ (drainage ditches) (Table 2.4)	-	-
4.C	Grassland						
4.C.1	Grassland Remaining Grassland	Tier 1	D -6.1 t CO_2-C $ha^{-1}yr^{-1}$ (Table 2.1)	-	-	-	-
4.C.2	Land Converted to Grassland	Tier 1	D -6.1 t CO_2-C $ha^{-1}yr^{-1}$ (Table 2.1)	-	-	-	-
4(II)	Emissions and removals from drainage and rewetting and other management of organic soils	-	-	Tier 1	D 16 kg CH_4 ha^{-1} yr^{-1} (drainage) (Table 2.3)	-	-
		-	-	Tier 1	D 1165 kg CH_4 ha^{-1} yr^{-1} \(drainage ditches) (Table 2.4)	-	-
4.D	Wetland						
4.D.1	Wetlands Remaining Wetlands	Tier 1	D 2.8 t CO_2 -C ha^{-1} yr^{-1} (Table 2.1)	-	-	-	-
4.D.2	Land Converted to Wetlands	Tier 1	D CO_2 ($EFCO_2$) 0.50 t CO_2-C ha^{-1} yr^{-1}	-	-	-	-

CRF	Source	CO_2		CH_4		N_2O	
		Method	EF	Method	EF	Method	EF
			(Table 3.1)				
		Tier 1	D EFDOC_REWETTED 0.24 t CO_2-C ha^{-1} yr^{-1} (Table 3.2)	-	-	-	-
4(II)	Emissions and removals from drainage and rewetting and other management of organic soils	Tier 2	Instant oxidation	Tier 1	D 6.1 kg CH_4 ha^{-1} yr^{-1} (drainage) (Table 2.3)	Tier 1	D 0.3 kg N_2O-N ha^{-1} yr^{-1} (drainage) (Table 2.5)
		-	-	-	D 542 kg CH_4 $ha^{-1}yr^{-1}$ (drainage ditches) (Table 2.4)	-	-
4.E	Settlements						
4.E.1	Settlements Remaining Settlements	Tier 1	D 7.9 t CO_2 -C $ha^{-1}yr^{-1}$ (Table 2.1)	-	-	-	-
4.E.2	Land Converted to Settlements	Tier 1	D 7.9 t CO_2 -C $ha^{-1}yr^{-1}$ (Table 2.1)	-	-	-	-

Information on area of drained mineral and organic soils in forest land is taken from the NFI (total area of forest types on drained soils). Until submission 2018 information on area of organic soils in farmland was taken from summaries of land surveys based on field measurements completed in 60s, 70s and early 80s, but since submission of National GHG inventory 2018 area of organic soils in cropland and grassland is reported according to the research results (Lazdiņš et al., 2016).

Area of cropland and grassland in LULUCF reporting is synchronized with Agriculture reporting, including recalculation of cultivated organic soils. According to the 2006 IPCC Guidelines N_2O emissions from managed organic soils in cropland and grassland are reported under Agriculture sector and by using default EFs (Table 2.5 in the Hiraishi et al., 2013) to reach consistent reporting of emissions with the LULUCF sector.

Latvia reports carbon stock changes separately on naturally dry and wet mineral and organic soils and drained mineral and organic soils. Soils are considered organic as defined in the NFI: a soil is classified as organic if the organic layer (H horizon) is at least 20 cm deep. Conversion of forest stands on drained mineral or organic soil to naturally wet soil is accounted as rewetting.

Carbon stock change in living and dead woody biomass and calculations of GHG emissions are based on activity data provided by the NFI. In forest land it is information on area, living biomass and dead wood and Level I forest monitoring data (soil organic carbon). Changes of the SOC stock and GHG emissions are estimated according to the Tier 2 method with country specific data. Tier 2 method (the carbon loss to be subtracted from the carbon removals for the reporting year) is used in calculations of removals and emissions of CO_2 in living biomass.

Latvia calculates GHG emissions from drainage of organic soils in forest land. CO_2 emissions are calculated by data from national research – emissions from drained soils are reported – 0.52 t C ha^{-1} (Lazdiņš & Lupiķis, 2017) and 2.8 kg N_2O-N ha^{-1} (Takahiro Hiraishi et al., 2013) annually from organic soils. CH_4 emissions from drained organic soils in forest land are calculated according to the equations (equation 2.6, page 2.22) and default EFs (Table 2.3 and Table 2.4, page 2.25 – 2.27 and 2.30) of IPCC 2014. Used CH_4 EF for organic soils of drained forest land is 2.5 kg CH_4 ha^{-1} yr^{-1} and EF for drainage ditches - 217 kg CH_4 ha^{-1} yr^{-1}. Fraction of the total area of drained organic soil occupied by ditches is taken from Table 2.4 in IPCC 2014 and Fracdich is 0.025. Emissions from organic soils in afforested lands are calculated using the same approach as for emissions from drained organic soils on lands remaining forest.

Conversion of forests on drained organic soils to forest on naturally wet soil is reported as rewetting. The conversion is usually approved by changes in ground vegetation and groundwater table during the site visits. Rewetting takes place due to wearing of drainage systems. It is assumed that rewetted area increases linearly and c. 2 kha of forests are rewetted yearly since 2009. Total rewetted area in 2017 is reported 18.06 kha (Ministry of Environmental Protection and Regional Development, 2019).

GHG emissions of rewetted organic soils are estimated according to the Tier 1 method - CO_2 emissions are calculated by using equations 3.3, 3.4, 3.5 of the IPCC 2014. EF for CO_2-C (0.5 t CO_2-C ha^{-1} yr^{-1}) is taken from Table 3.1 in IPCC 2014. According to the Tier 1 method N_2O emissions from rewetted organic soils are assumed to be negligible and are not estimated, CH_4 emissions are calculated by applying Tier 1 method and using equation 3.7 and default EF (216 kg CH_4-C ha^{-1} yr^{-1}) (Table 3.3) of the (Takahiro Hiraishi et al., 2013).

Total emissions from forest soil due to rewetting in 2017 were 163.10 kt CO_2 eq. (Ministry of Environmental Protection and Regional Development, 2019).

Carbon stock changes in cropland are calculated using recent NFI data by comparison of stock changes in living biomass during recent 5 years and mortality of trees. Carbon stock in living and dead biomass is calculated using the same coefficients as in calculations of carbon stock changes in forested land.

CO_2 emissions from drained organic soils in croplands are calculated using the IPCC Wetlands Supplement Tier 1 method. EF -7.9 t C ha^{-1} annually.

Drained organic soil in cropland is source of CH_4 emissions. CH_4 emissions are calculated by equation 2.6 in (Takahiro Hiraishi et al., 2013). The EF for organic soils (Table 2.3 and table 2.4 in IPCC 2014) is 0±2.8 kg CH_4 ha^{-1} yr^{-1} (cropland, drained) and EF for drainage ditches 1165±830 kg CH_4 ha^{-1} yr^{-1} (deep – drained cropland); respectively, only CH_4 emissions from ditches are calculated. Drainage systems on organic soils are considered. Fraction of the total area of drained organic soil which is occupied by ditches is 0.05 (Table 2.4 in Hiraishi et al., 2013). In category 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils (Total Organic Soils, Drained Organic Soils) area of drainage ditches in cropland remaining cropland and land converted to cropland is reported (4.75 kha in 2017).

The CO_2 EF of drained organic soils in grassland remaining grassland is considered to be 6.1 tonnes CO_2-C ha^{-1} yr^{-1} tonnes C ha^{-1} yearly according to Table 2.1 in Hiraishi et al., 2013). EFs for CH_4 emissions from drained organic soil and drainage ditches are respectively 16 kg kg CH_4 ha^{-1} yr^{-1} and 1165 kg CH_4 ha^{-1} yr^{-1} yearly according to Tables 2.3 and 2.4 in IPCC 2014. Fraction of the total area of drained organic soil which is occupied by ditches is 0.05 (Table 2.4 in Hiraishi et al., 2013). Methane emissions from ditches on organic soils have been included in estimates also for lands converted to grasslands and it is calculated with the same approach as grassland remaining grassland. N_2O emissions from managed organic soils in grassland are reported under Agriculture sector according to the IPCC 2006 guidelines (Eggleston et al., 2006) and the IPCC Wetlands Supplement (Takahiro Hiraishi et al., 2013). Carbon stock changes in organic soil for forest land, cropland and wetlands converted to grassland is reported. The CO_2 EF of drained organic soils is considered to be 6.1 tonnes C ha^{-1} yearly according to Hiraishi et al. (2013).

Under category Wetlands Remaining Wetlands carbon stock change in organics soils (on-site CO_2 emissions) is reported using Tier 1 method. EF for carbon stock changes in organic soils (2.8 t CO_2-C ha^{-1} yr^{-1}) due to drainage is taken from the Table 2.1 in Hiraishi et al. (2013). Carbon stock change in organics soils in Land Converted to Other Wetlands is reported using Tier 1 method. Default EF for CO_2 is 0.50 t CO_2-C ha^{-1} yr^{-1} (Table 3.1 from Hiraishi et al., 2013), but EFDOC_REWETTED value of 0.24 t CO_2-C ha^{-1} yr^{-1} is provided in Table 3.2 in Hiraishi et al., 2013. CH_4 emissions from drained organic soils are calculated according to methodology applied in drained forests on organic soil. As drainage of wetlands in national conditions is occurring only in territories for peat extraction default EFs for drained organic soil (6.1 kg CH_4 ha^{-1} yr^{-1} according to the Table 2.3 of the Hiraishi et al., 2013) and drainage ditches (542 kg CH_4 ha^{-1} yr^{-1} according to the Table 2.4 of the Hiraishi et al., 2013) for peat extraction are utilized. Density of ditches is considered 0.05 ha per 1 ha of peatland (Table 2.4 in the Hiraishi et al., 2013).

N_2O emissions from drained organic soils in wetlands were calculated using the Tier 1 method provided in IPCC 2014. EF -0.3 kg N_2O-N ha^{-1} yr^{-1} (Table 2.5 in Hiraishi et al., 2013).

Emissions from soils in settlements remaining settlements are calculated according to the 2006 IPCC Guidelines. It is assumed that inputs equal outputs so that settlement mineral soil C stocks do not change in settlements remaining settlements. Emissions from organic soils in settlements remaining settlements are calculated using equation 2.26 in the 2006 IPCC Guidelines (equation No. 6 in Eggleston et al., 2006). If soils are drained and the peat is not removed, the emissions are calculated using EFs for cultivated organic soils, due to deep drainage in settlements similar to cropland. Annual EF for cultivated organic soils in cool temperate climatic temperature regime is 7.9 tonnes C ha^{-1} yr^{-1} (Takahiro Hiraishi et al., 2013). Land converted to settlements on organic soils within the inventory time period is treated the same as settlements remaining settlements.

3.3 Lithuania

Lithuania is estimating GHG emissions due to the drainage of organic soils in it's annual GHG Inventory Report, as required by the IPCC (2006) Guidelines. Activity data – areas of drained organic soils – is obtained from NFI, applying the share of drained organic soils to the annually evaluated area of each land use (forest land, cropland, grassland). The share of organic soils (both drained and undrained) has been evaluated from NFI data after soil type was identified in each sampling plot (if available, i.e. area is not built up, under water, etc.) in different land uses. Soil is classified as organic according to Lithuanian soils classification: peat layer must not be thinner than 40 cm or 60 cm of poorly decomposed peat (mainly mossfibres) in bogs. In addition to this, histic horizon must contain not less than 70 – 75% of organic matter by volume (Buivydaite et al., 2001). National definition of organic soils (histosols) was prepared using Food and Agriculture Organization (FAO) guidelines for soil classification (WRB, World Reference Base for soil resources), as applied in Lithuania's National GHG Inventory Report.

Share of organic soils in different land uses was estimated using the most recent NFI (2014 – 2018) data, when soil type was evaluated in different land uses during the field visits in permanent sampling plots. Share of organic soils in each land use category was estimated using data of forest site definition determined during NFI measurement and thus is applied accordingly:

- Forest land – 6.7% of total forest land area is undrained organic soils; 6.9% of total forest land area is drained organic soils;
- Cropland – 1.1% of total cropland area is organic drained soils;
- Grassland – 0.4% of total grassland area is organic undrained soils; 6.2% of total grassland area is organic drained soils.
- Settlements – soil type was not evaluated due to technical difficulties. Share of organic soils in land converted to settlements is maintained accordingly to the share of organic soils in initial land use category.
- Other land – soil type was not evaluated due to technical difficulties. Share of organic soils in land converted to settlements is maintained accordingly to the share of organic soils in initial land use category.
- Wetlands – if reported as peatlands, all area is assumed to be organic and thus included in the GHG estimation from peat extraction sites. If reported as unmanaged, then no GHG emissions or removals have to be reported.

EFs used to calculate GHG emissions due to the drainage are applied as presented in the Eggleston et al. (2006) Guidelines for National GHG Inventories, Vol. 4: Agriculture, Forestry and Other Land Use and are provided in the Table 16.

Table 16: EFs, used to estimate GHG emissions from drained organic soils in Lithuania

Land use type	EF CO_2, t C ha^{-1} yr^{-1}	EF CH_4, kg CH_4-C ha^{-1} yr^{-1}	EF N_2O, kg N_2O-N ha^{-1} yr^{-1}
Forest land	0.68	not present in drained conditions	2.8
Cropland	5		8
Grassland	0.25		8
Wetlands	1.1 (fertile soil); 0.2 (non-fertile soil)		1.8

Lithuania is also estimating biomass C stock changes in vegetation on organic soils. According to previously mentioned information, 13.6 of total forest land is on organic soils, which may be covered with different forest tree species. Biomass C stock changes estimation in Lithuania is estimated applying stock-change method, using methodology provided in (Eggleston et al., 2006). While applying stock-change method for living biomass and dead organic matter (dead wood) estimation in forest land and other land uses (growing stock volume is estimated in cropland and grassland with woody vegetation), Lithuania is not dividing growing stock volume changes according to soil types.

Living biomass pool in GHG inventory refers to above-ground biomass and below-ground biomass. The estimation of C stock changes in living biomass is consistent with the Method 2 further described in the IPCC (2006) Guidelines, which is also called as the stock change method. Estimations of C stock changes by using this method requires biomass C stock inventories for a given forest area in two points in time. Biomass change is the difference between the biomass at time2 and time1, divided by the number of years between the inventories, as stated in eq. 2.8 in the 2006 IPCC Guidelines (Eggleston et al., 2006):

$$\Delta C_{LB} = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)} \quad \text{and} \quad C = (\Delta A_{GB} + \Delta B_{GB}) \cdot CF \text{ (modified eq. 2.8)} \tag{8}$$

where:
ΔC_{LB} – annual change in C stock in living biomass (includes above- and belowground biomass) in total forest land, t C yr^{-1};
C_{t2} – total C in biomass calculated at time t2, t C;
C_{t1} – total C in biomass calculated at time t1, t C;
C – total C in biomass, for time t1 to t2
A – area of forest land remaining forest land, ha;
V – growing stock volume, m^3 ha^{-1};
i – ecological zone (ecological zones not divided)
j – climate domain (Lithuania is in one climate zone)
BCEF – biomass conversion and expansion factor for expansion of growing stock volume to above-ground biomass
R – ratio of below-ground biomass to above-ground biomass, tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$
CF – C fraction of dry matter (broadleaves – 0.48; coniferous – 0.51), t C (tonne d. m.)$^{-1}$, default value from IPCC (2006) Guidelines (Vol. 4, Ch. 4, Table 4.3, p. 4.48).
BCEF = BEF · D
BEF – biomass expansion factor
D – basic wood density, t d. m. m^{-3}

Modification of the Equation 2.8 from IPCC (2006) Guidelines is based on the decision to estimate above and below-ground biomass C stock changes separately, applying root-to-shoot ratio to estimate below-ground biomass C stock changes from above-ground biomass C stock changes. Annual growing stock volume (GSV) changes starting with 2003 for category Forest land remaining forest land was estimated based on NFI data using the following steps:

1. Annual GSV changes in all forest areas (total forest management and afforested/reforested area) are estimated using sampling method. This estimation is based on the change in GSV on the same area (re-measured permanent sample plots data Vremt2 – Vremt1) and adding GSV increment (ΔVnew) of the first measurement of permanent sample plots i.e. new afforested areas or other plots which have no re-measurement data;
2. Annual GSV changes of afforested/reforested areas are estimated combining wall-to-wall and sampling methods. Area estimation is based on assessment by wall-to-wall method and mean GSV changes assessment is done using results from sampling method; average annual GSV changes are derived using relationship between mean GSV and age of forest in permanent plots of afforested/reforested areas (Lithuania's Greenhouse Gas Inventory Report 2019, Figure 11-14);
3. Estimation of annual GSV change in Forest Management area is based on the difference between all forests annual GSV changes (step 1) and annual GSV change of areas with natural forest expansion (step 2).

The equations presenting calculations on growing stock volume change in Forest land remaining Forest land are shown below:

$$\Delta FF_t = \left(\left(V_{rem_{t2}} - V_{rem_{t1}}\right) + \Delta V_{new}\right) - \Delta F_2 \tag{9}$$

where:

ΔFF_t – growing stock volume change for Forest land remaining Forest land for the defined year, m^3;
V_{remt1} – growing stock volume calculated at time t1, m^3;
V_{remt2} – growing stock volume calculated at time t2, m^3;
ΔF_2 – growing stock volume change of new forest (land converted to forest land) areas, m^3.

For the GHG inventory Lithuania defines DOM as it is described in IPCC (2006) Guidelines (Ch. 4.2.2), which provides two types of dead organic matter pools: dead wood and litter.

Annual change in C stocks in DOM in Forest Land remaining Forest Land is calculated following the summarizing equation for calculation of changes in DOM C pools which is equal to the sum of C stock in dead wood (measured available dead wood) and C stock in dead wood that is left on site after fellings (BGB). Dead wood that is left on site after fellings is assumed to be below-ground biomass which is roots. After a tree is felled, its volume is removed from total living trees volume in forest land and, if its stump is left on site, its below ground biomass is included as input to the total dead wood mass. Afterwards, for each of the subsequent 5 years, 1/5 of this belowground biomass is reported as emissions due to the decay process and therefore it is assumed that BGB decays in equal parts in 5 years.

Lithuania is applying Tier 1 assumption from the IPCC (2006) Guidelines (p. 4.36, Ch. 4, Vol. 4), which states that C stocks in dead wood and litter pools in non-forest land are zero (except for grassland), and that C in dead organic matter pools increases linearly to the value of mature forests over a specified time period. Due to the applied Tier1 assumption, Lithuania is also using a default 20 years period for litter accumulation in land converted to forest land category and afforestation/reforestation activity. Annual C stock changes in litter in land converted to forest land were estimated using national values of litter C stock, evaluated during the study conducted by Lithuanian Research Centre for Agriculture and Forestry, Institute of Forestry under the GHG inventory partnership project between Lithuania and Norway. The average value of C stock in litter is 1.2 t ha^{-1} in 10 years (after the conversion from agricultural land, where no litter C stock was measured in cropland and in grassland litter C stock is estimated to be 0.4 t C ha^{-1} in litter) and 2.5 t C ha^{-1} in 20 years). Annual C stock change in litter in land converted to forest land was estimated for two time periods: 0 – 10 years - (1.2 – 0.4 t C ha^{-1} (for grassland converted to forest land)/10 years; 11 – 20 years - (2.5 – 1.2 t C ha^{-1})/ 10 years. Change in C stock in litter in land converted to Forest land was calculated using area from annual land use conversion to forest land matrix.

3.4 Finland

GHG emissions from organic soils in Finland are reported in the sector LULUCF. The land area is divided into six land-use categories and into the subcategories "lands remaining in the same land use category for the last 20 years" and "lands converted to present land use during the past 20 years", except for peat extraction where a five-years conversion period is used (IPCC 2006 Guidelines' default). In this report we concentrate to subcategory "lands remaining in the same land use category" in more detail.

The organic soil land-use categories reported in the LULUCF sector include Forestland, Cropland, Grassland, Wetlands, Settlements and Other Land (Eggleston et al., 2006) and are listed in Table 17. Land-use areas in different categories are calculated from NFI data. NFI covers the whole country regardless of land ownership and all land use types and NFI data cover the whole time span needed for the GHG inventory's time series. The NFI is a sampling-based forest inventory system where sample plots are located in systematic clusters and the ratio of temporary and permanent clusters is 3:1. Areas for each land-use category are calculated by multiplying the number of the sample plot centres belonging to a particular land use category with the area representativeness of a sampling density region.

Table 17: Reported emissions, calculation methods and type of GHG EFs[3]

4. Land use, land-use change and forestry (organic soils)	Source 1)	Stock change reported	Emissions reported	Method	Emission factor
4.A Forest land (remaining, converted)	DOM, SOM	C/ CO_2		Tier 2, Tier 3	CS
4.B Cropland (remaining, converted)	DOM, SOM	C/ CO_2		Tier 1, Tier 2, Tier 3	CS, D
4.C Grassland (remaining, converted)	DOM, SOM	C/ CO_2		Tier 1, Tier 2, Tier 3	CS, D
4.D Wetlands (remaining,	Peat extraction areas:	C/ CO_2		Tier 2	CS

3 CS = country-specific, D = default used for organic soils in the Finnish inventory in 2017 (source: Statistics Finland, 2019 tables 1.4-1 and 5.4-1).

4. Land use, land-use change and forestry (organic soils)	Source 1)	Stock change reported	Emissions reported	Method	Emission factor
converted)	DOM, SOM				
	Flooded land: DOM, SOM	C/ CO_2		Tier 1	CS, D
	Other wetlands: SOM	C/ CO_2		Tier 2	CS
4.(II) Non-CO_2 emissions from drainage and rewetting and other management of organic and mineral soils (2	Wetlands: Peat extraction areas		CH_4, N_2O	Tier 2	CS
	Wetlands: Flooded land		CH_4	Tier 1	D
	Other Wetlands		CH_4, N_2O	Tier 2	CS
	Forest land: Drained organic forest soils		CH_4, N_2O	Tier 1, Tier 2	CS, D
3.D.a Direct Soil EFs for the subcategory Agricultural Soils in the Finnish inventory	Agricultural organic soils2)		N_2O	Tier 1	D
3.D.b Indirect Soil EFs for the subcategory Agricultural Soils in the Finnish inventory	Agricultural organic soils3)		N_2O	Tier 1	D

- DOM = dead organic matter, SOM = soil organic matter
- N_2O emission from synthetic fertilizers, animal manure applied to soils and from crops residue are based on default values in Tier 1 method.
- Atmospheric deposition

The GHG emission estimation of forests (remaining as forests) on organic land follows the estimation principles where EFs by fertility are applied with the modelled below-ground litter input (the method corresponds to the Tier 2 method of the Eggleston et al. (2006). Organic soils are divided into undrained and drained soils and the drained soils further into five site types based on the fertility of the soil (Table 3.4FI2, Statistics Finland, 2019 Table 6.4-1, Laine, 1989). NFI data are used to estimate the proportional distribution of site types.

The NFI provides tree-level increments and increment of growing stock data to employ tree species-specific biomass functions for direct estimation of biomass growth. The below-ground litter input of the trees is derived from the biomass estimates of the corresponding NFI data; for ground vegetation, average estimates of below-ground litter from ground vegetation are used. Carbon stock changes in living tree biomass are reported as an aggregated estimate for above-ground and below-ground biomass. The employed method is a Tier 3 Biomass Gain-Loss method (Eggleston et al. (2006), Vol. 4, Equation 2.7). Volume and biomass increments are predicted for sample trees using the NFI-derived tree volumes, biomass models and sample tree measurements.

Below-ground litter input based on the modelling of NFI data. The modelling of the below-ground litter input is based on biomass estimates and on litter turnover rates. Below-ground litter inputs consists of the annual litter production from the roots of trees, shrubs and graminoids and the roots of trees subjected to cuttings or natural losses. The below-ground litter production from trees is estimated as a product of the biomass estimate and turnover rate. The decomposition of SOM (peat) is estimated by multiplying the site-type-specific emission values (Table 18) by the corresponding area estimates based on the NFI data (Table 6).

Table 18: Carbon emissions (g C m^{-2} yr^{-1}) due to heterotrophic soil respiration from drained organic forest soils (peatlands) (source: Statistics Finland, 2019 Table 6.4-4, based emissions from Minkkinen et al. (2007) and site types from Laine (1989))

Name of site type group	Average emission	stdev
Herb-rich site	425.7	25.7
Vaccinium myrtillus type	312.1	20.2
Vaccinium vitis-idaea type	242.3	15.6
Dwarf shrub type	218.9	15.4
Cladina type	185.2	9.1

EFs of non-CO_2 emissions from drained organic forest soils are based on Ojanen et al. (2013) for N_2O emissions, and are provided for different soil fertility categories (Table 19). The CH_4 emissions consist of emissions from drained land (97.5% of the area, country-specific EFs) and from ditches (2.5% of the area, default fraction and EF 217 kg CH_4 ha^{-1} for boreal & temperate zones given the IPCC 2014. Country-specific EFs for CH_4 from drained organic land by drainage class are net emission of 11.6 kg CH_4 ha^{-1} (poorly drained) and net uptake of -2.8 kg CH_4 ha^{-1} (well drained, Table 19). Emissions were estimated with Tier 2 (land) and with Tier 1 (ditches) methods by multiplying land areas of drained organic forest soils with EFs.

Table 19: EFs and their uncertainty for N_2O emissions from drained forestland (by fertility class) and for CH_4 emissions (by drainage condition) (source: Table 6.10-4 in Statistics Finland, 2019)

Site type	N_2O emissions, g N_2O		Ditch conditions	CH_4 emissions, g CH_4	
	EF	SE		EF	SE
Herb-rich type (Rhtkg)	0.331	0.101	Poor	1.16	0.48
Vaccinium myrtillus type (Mtkgl)	0.177	0.052	Good	-0.28	0.04
Vaccinium myrtillus type (Mtkgll)	0.323	0.123			
Vaccinium vitis-idaea type (Ptkgl)	0.064	0.004			
Vaccinium vitis-idaea type (PtkgII)	0.098	0.022			
Dwarf shrub type (Vatkg)	0.043	0.009			
Cladina type (Jätkg)	0.029	0.007			

The aggregated annual EFs for SOM and DOM for forest land remaining forest land in Southern Finland (SF) and Northern Finland (NF) are provided in Table 20.

Table 20: The aggregated annual emission factors (tonnes C ha^{-1}) (SOM + DOM) for forestland in Southern Finland (SF) and Northern Finland (NF) and by fertility type for drained peatlands 2007-2017, (negative numbers represent a loss of C) (source: Table 1_App_6f in Statistics Finland, 2019)

Year	Mineral	Mineral	Rhtkg	Mtkg	Ptkg	Vatkg	Jatkg	Rhtkg	Mtkg	Ptkg
	soilsSF	soilsNF	SF	SF	SF	SF	SF	NE	NF.	NE
2007	0.05	0.12	1.76	-0.63	0.07	0.31	0.64	-2.07	-0.93	-0.23
2008	0.06	0.12	1.76	-0.62	0.08	0.31	0.65	-2.03	-0.89	-0.19

Year	Mineral	Mineral	Rhtkg	Mtkg	Ptkg	Vatkg	Jatkg	Rhtkg	Mtkg	Ptkg
	soilsSF	soilsNF	SF	SF	SF	SF	SF	NE	NF.	NE
2009	0.07	0.12	1.80	-0.67	0.03	0.27	0.60	-2.03	-0.9	-0.20
2010	0.06	0.11	1.76	-0.63	0.07	0.31	0.64	-1.99	-0.85	-0.15
2011	0.08	0.11	1.76	-0.63	0.07	0.30	0.64	-1.96	-0.82	-0.12
2012	0.11	0.12	1.76	-0.62	0.07	0.64	0.64	-1.94	-0.8	-0.11
2013	0.12	0.12	1.71	-0.57	0.13	0.36	0.70	-1.91	-0.77	-0.07
2014	0.14	0.13	1.68	-0.55	0.15	0.38	0.72	-1.88	-0.74	-0.05
2015	0.16	0.15	1.64	-0.51	0.19	0.43	0.76	-1.86	-0.72	-0.02
2016	0.17	0.16	1.61	-0.47	0.23	0.46	0.80	-1.84	-0.7	0.00
2017	0.18	0.16	1.60	-0.46	0.24	0.47	0.81	-1.81	-0.68	0.02

In croplands, above-ground and below-ground biomasses are currently calculated based on the national yield statistics (yield ha^{-1}) of main crop plants divided into 16 regions in Finland. Yield statistics are converted to biomass. Yield losses are assumed to take place after harvesting, and, therefore, yield biomass (BMY) is calculated from the harvested yield. Fallow and perennial crops are assumed to have the same constant below-ground biomass per hectare (Table 1_App_6j in Statistics Finland, 2019). Above-ground biomass of fallow is assumed to be 5375 kg ha^{-1} in the South Finland and 4845 kg ha^{-1} in the North Finland. Hectare-based biomasses are weighted with the area of each cultivated crop plants taken. Since grasslands are mainly abandoned fields, the above and below-ground biomasses of fallow are used for grassland vegetation as well.

Soil C input on croplands consists of plant residues and manure. Carbon input through plant residues are estimated on the basis of plant biomass. Manure-derived C is calculated based on the regional numbers of livestock and livestock-specific rates of volatile solids in manure and assuming that 50% of the volatile solids is carbon. Total soil C input is obtained as a sum of above- and below-ground plant residues and C from manure. The C input is divided into fractions based on its chemical quality. Nitrogen content of crop residues for estimating the N_2O emissions are calculated based on the crop plant biomasses. Nitrogen in above-ground residues (NAG) and below-ground biomass are taken into account. The emissions from manure management, agricultural soils and field burning of agricultural residues are calculated according to Tier 1 and Tier 2 methods following common reporting formats (CRF 3.B, -D and -F) as explained in details in the publication Grönroos et al. (2017). The EFs are derived from the model simulation. For cropland remaining cropland, EFs can be loss of C (negative) or gain of C (positive) depending on the C input rate of each year (Table 21).

Table 21: Emission factors (negative is loss of C and positive gain of C) for cropland remaining cropland (t C ha^{-1}) (source: Table 3_App_6j in Statistics Finland, 2019)

Year	South	North
2007	-0.050	-0.098
2008	-0.094	-0.110
2009	-0.063	-0.088
2010	-0.076	-0.095
2011	-0.060	-0.047

Year	South	North
2012	-0.073	-0.060
2013	-0.039	-0.089
2014	-0.043	-0.107
2015	-0.031	-0.093
2016	-0.033	-0.104
2017	-0.039	-0.127

Emissions from organic soils in Finland. The LULUCF sector in Finland has been a net sink during the whole reporting period from 1990 to 2017 as the removals in the sector exceeded the emissions (Table 6.1-2 in Statistics Finland, 2019). However, the largest emissions in the LULUCF sector have come from changes in SOC in forest and agricultural soils (Table 22).

The 'Cropland' category in LULUCF in Finland is a source because emissions from organic soils exceed the small removals by mineral soils and living biomass (Table 6.1-2 in Statistics Finland, 2019). The main reason for increase in GHG emissions from croplands in Finland from 1990 to 2017 is because increase in the proportion of organic soils in agriculture in comparison to mineral soils in agriculture as the farms quitting production are located in the southern regions and the enlarging farms are in the peat-rich regions of western and northern Finland (Regina et al., 2019). GHG emissions on organic soils growing annual crops (6.35 Mt CO_2 eq.) are several times higher compared to grasslands (0.85 Mt CO_2 eq., Table 22). Comparison of studies suggest almost double emission rates from annual compared to perennial grasslands on organic soils (Table 22), which indicates that less frequent soil disturbance slows down peat decomposition (Regina et al., 2019).

Only part of agricultural non-CO_2 soil emissions is included in reported total GHG emissions of Finland (Table 23). The N_2O emissions from cultivated organic soils have increased as a result of the increased area of these soils in cultivation (Statistics Finland 2019). CH_4 fluxes from soils are not reported as they are of minor significance and not a mandatory category (Regina et al., 2019).

Table 22: Annual greenhouse gas fluxes of cultivated organic soils (from Regina et al., 2019)

	Mean (g m² yr⁻¹)	Min	Max	*n*	*GWP (t CO_2 eq. ha^{-1} yr^{-1})*	Ref.
Annual crop						
Net CO_2 exchange	2080±1150	770	3040	*4*	*20.8*	1,2,3
C loss as yield (CO_2)	600±180	460	855	*4*	*6.0*	1,2,3
CH_4 flux	-0.06±0.24	-0.49	0.51	*10*	*-0.02*	3,4,5
N_2O flux	1.74±0.92	0.84	3.79	*11*	*5.2*	3,6,7
Total					*32.0*	
Perennial crop						
Net CO_2 exchange	560±1210	-780	2750	*8*	*5.6*	1,2,3
C loss as yield (CO_2)	920±400	280	1570	*8*	*9.2*	1,2,3
CH_4 flux	0.15±0.34	-0.25	0.91	*14*	*0.05*	3,4,5,8
N_2O flux	1.14±1.47	0.04	5.47	*19*	*3.4*	3,6,7,8,9,10
Total					*18.3*	

n=number of annual flux estimates
GWP=global warming potential, where the net climatic impact can be estimated by converting the emissions of CH4 and N2O to carbon dioxide (Myhrel et al. 2013).
*negative value=carbon sequestration, positive value=carbon loss
References in table available in Regina et al. (2019: 1 (Maljanen, Martikainen et al. 2001); 2 (Lohila et al. 2004); 3 (Maljanen et al. 2004); 4 (Maljanen et al. 2003a); 5 (Regina et al. 2007); 6 (Maljanen et al. 2003b); 7 (Regina et al. 2004b); 8 (Maljanen et al. 2009); 9 (Maljanen et al. 2010); 10 (Shurpali et al. 2009)

'Forestland' SOM and the dead organic matter (DOM) pools in organic soils act as a source because of CO_2, CH_4 and N_2O emissions from drained soils (Table 3.4FI7). In LULUCF, 'Wetlands' category includes a diverse group of organic soils (e.g peat mining areas) without biomass cover or with low biomass cover, and hence constitute a source of CO_2, CH_4 and N_2O emissions (Table 23).

Table 23: Summary of GHG emissions and removals (Mt CO_2 eq.) from organic soils in the LULUCF sector where positive figures indicate emissions and negative removals (source of summary: Statistics Finland, 2019, Table 6.1-2).

	Source	Year / Mt CO_2 eq.				
4. LULUCF (organic soils only)		**1990**	**2000**	**2010**	**2015**	**2017**
4.A Forest land (remaining, converted)	DOM[1)] + SOM	12.8	9.10	7.30	5.10	4.30
4.B Cropland (remaining, converted)	DOM[2)] + SOM	5.17	5.28	6.03	6.27	6.35
4.C Grassland (remaining, converted)	DOM[2)] + SOM	1.10	0.89	0.87	0.86	0.85
4.D Wetlands (remaining, converted)	SOM	1.20	1.65	1.75	2.00	1.82
4.(II) Non-CO_2 emissions from drainage and rewetting and other management of organic and mineral soils	SOM	1.20	1.65	1.75	2.00	1.82

[1)] Dead organic matter in dead wood and litter, [2)] Dead organic matter in litter

4. GHG MONITORING METHODOLOGIES ELABORATED

4.1 Status of anthropogenic GHG emission data – experiences based on data from drained organic forest soils

Peatlands and other C-rich organic soils have been widely converted into agricultural and forestry land or used for peat extraction (Joosten, 2010). These land uses typically involve drainage by ditching. Draining of organic soils enhances aerobic decomposition and thus the mobilization of their C and N stores (e.g., Abdalla et al., 2016; Ernfors et al., 2008; Pärn et al., 2018a, 2018b; Petrescu et al., 2015; Post et al., 1985). Forestry is an extensive land-use type on peatlands in northern Europe, especially in the Nordic and Baltic countries (e.g., Barthelmes et al., 2015).

Currently, both the IPCC (2006) AFOLU guidelines and the IPCC (2014) Wetlands Supplement may be used for reporting the annual GHG emissions and removals for soils under anthropogenic land uses, such as drained organic forest soils. Area-based EFs, describing the net annual soil GHG emissions/removals, have been developed to reflect the impacts of ecosystem type, land management and environmental conditions.

Countries may opt for different methodological levels in their GHG reporting by applying default IPCC EFs (Tier 1), country-specific data for national EF's (Tier 2) or repeated national inventories and/or advanced modelling (Tier 3). Tier 2 and Tier 3 for drained organic forest soils should make the national estimates more accurate because the Tier 1 EFs are basically average values from peer reviewed published data that cover a wide range of different situations categorized under world climatic zones (Table 24), (Takahiro Hiraishi et al., 2013). In practice, most countries currently use the Tier 1 EFs for soil emissions/removals by drained organic forest soils. This is largely because of a lack of useful GHG data and other national inventory data.

Table 24: IPCC (2014) Tier 1 level GHG emission (EF) averages (Ave) and respective uncertainties (95% confidence interval, CI) for CO_2, CH_4 and N_2O gases in the boreal and temperate drained organic forest soils

Climate zone	Forest site type	EF CO_2-C (kg ha^{-1} yr^{-1})			EF CH_4 (kg ha^{-1} yr^{-1})			EF N_2O-N (kg ha^{-1} yr^{-1})		
		Ave	95% Cl	N	Ave	95% Cl	N	Ave	95% Cl	N
Boreal	Very poor[4] and Nutrient-poor combined	0,37	-0,11-0,84	63	-	-	-	-	-	-
	Nutrient-rich	0,93	0,54-1,30	62	2	-1,6-5,5	83	3,2	1,9-4,5	75
	Nutrient-poor	0,25	-0,23-0,73	59	7	2,9-11	47	0,22	0,15-0,28	43
Temperate	-	2,6	2,00-3,30	8	2,5	-0,6-5,7	13	2,8	-0,57-6,1	13

Uncertainty of the GHG EFs is still generally high. For instance, the 95% confidence interval for the Tier 1 CO_2-C EF for boreal nutrient-poor soils ranges from -0.23 tonnes c ha^{-1} yr^{-1} removal to 0.73 tonnes CO_2-C ha^{-1} yr^{-1} emission, and that for the

[4] 'Very poor' refers to sites with poor tree growth (due to extremely low nutrient availability, nutrient imbalance or wetness, but still fulfilling the minimum criteria as in FAO's Forest Resources Assessment (FRA, 2015).

corresponding CH_4 EF from 2.9 to 11 tonnes CH_4 ha^{-1} yr^{-1} emissions (IPCC, 2014). Even in Finland where a Tier 2 method is used, the relative uncertainty of CO_2 emissions from organic soils in the reporting category 'forest remaining forest' is as high as 150% (Statistics Finland, 2019). This means that those soils can be either sinks or sources of CO_2, though the latter is more likely due to the estimated 1.1 Mt C decrease annually in the soil C stock of those lands.

4.1.1 Tier 1 EFs and potential ways to develop data use in drained organic forest soils

The IPCC Tier 1 EF categories (i.e. nutrient-rich vs. nutrient-poor) in the boreal climate zone forests lumps together several differing soil- and vegetation community types and soils with differing management history (Table 24). Uncertainty of Tier 1 EFs in the can be expected to decrease both by increase in the number of soil GHG balance estimates in the present categories and also by use of more site-type specific categories with sufficient data. Such category based improvements could take into account at least following aspects;

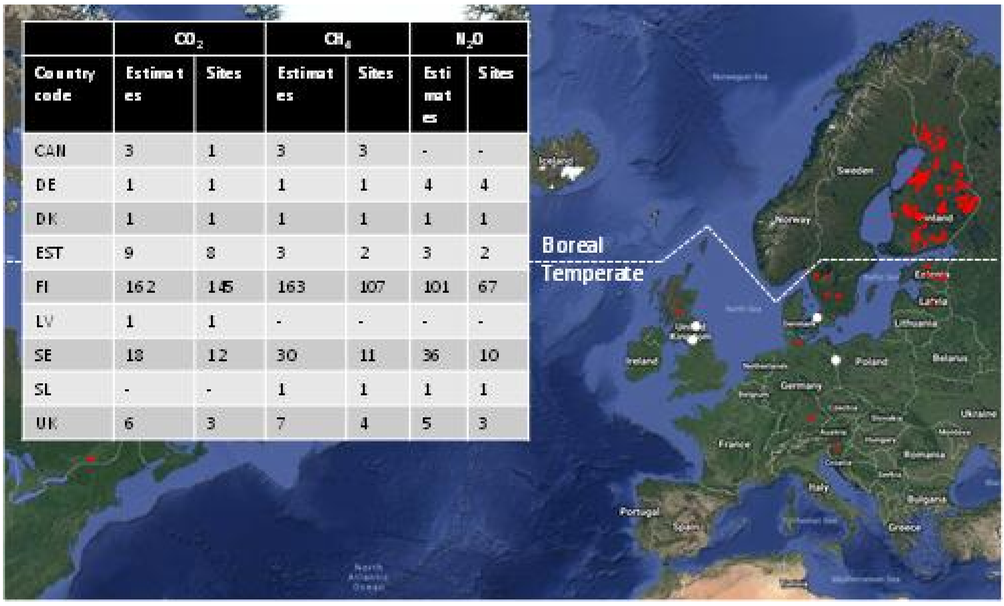
- There is large amount of drained organic forest soil data from boreal zone including specific identifiable nutrient-poor and nutrient richer site types (with specific vegetation types, and peat composition and nutrient characteristics), and these have acknowledged potential for tree growth/ biomass production (e.g. Kari Minkkinen & Laine, 1998, 2006; Ojanen et al., 2010, 2013; Simola et al., 2012). Current Tier 1 EFs pool all data into maximum three categories, i.e. 'very poor together with nutrient poor', 'nutrient poor' and 'nutrient rich'. Low and typical forest growth potential on a site may not be limited into site nutrient status only.
- Site management history in afforested land may bear legacy effects of past land use in the present soil characteristics. Such are, for example, impacts of former tilling and added fertilization and other soil amendment (e.g. sand or lime) on nutrient-rich soils used previously in agriculture, or consequences of previous peat harvesting that removed major part of the peat deposit from the top soil layer in nutrient-poor soils in peat extraction. Thus, specific attention may be required in data from afforested soils that may have differing soil properties compared to land simply drained for forest growing.
- GHG emissions from different organic C-rich soil types (e.g, histosols (peat), muck, gyttja) may differ due to formed physical or chemical soil properties, such as, SOM origin, organic and mineral substrate composition. Therefore, categories should (if data is sufficiently available) identify specific soil types.

Part of uncertainty in the IPCC CO_2 EFs for drained organic forest soils may be formed due to differences in data originated from studies using different data collection methods and data composition approaches within the methods. These questions, and further GHG data needs for upgrading EFs to Tier 2 and Tier 3, are studied based on literature review materials in the following sections.

4.1.2 GHG data availability for drained forest soils

The most recent analysis on 52 peer-reviewed publications presenting GHG data and data collection methods applied for drained organic forest soils in boreal and temperate climate zones, i.e. Jauhiainen et al. (2019), was funded by Nordic Forest Research (SNS). This analysis focused on data that have been used, or have the potential to be used, for the measured sites. It evaluated the methods used in data collection for estimating the net annual soil GHG emissions/removals, identified major gaps in background/environmental data, and formulated recommendations for future research. In the next paragraphs we summarize the main findings from this analysis.

The analysis showed that most (over 100 annual soil GHG estimates for CO_2, CH_4 and N_2O gases) of the GHG data originates from boreal climate zone and more specifically from Finland (Figure 7). The highest number GHG estimates for the temperate climate zone are from Sweden (18 CO_2, 30 CH_4, and 36 N_2O estimates) and Estonia (9 CO_2, 3 CH_4, and 3 N_2O estimates). Lack of data availability from temperate climate region is obvious. Even in Finland, richest in monitored sites and provided estimates, there is no possibility to inspect this GHG data by category level including forest management options. The accuracy of EFs can be improved as more peer-reviewed data become available and quantify a wider set of specific management options and ecological conditions for a given country or region.



	CO_2		CH_4		N_2O	
Country code	Estimates	Sites	Estimates	Sites	Estimates	Sites
CAN	3	1	3	3	-	-
DE	1	1	1	1	4	4
DK	1	1	1	1	1	1
EST	9	8	3	2	3	2
FI	162	145	163	107	101	67
LV	1	1	-	-	-	-
SE	18	12	30	11	36	10
SL	-	-	1	1	1	1
UK	6	3	7	4	5	3

Figure 7: Monitoring sites providing seasonal and annual soil GHG balance estimates for organic drained forest soils (red=peat, white=other organic soils) in boreal and temperate zones (based on Jauhiainen et al., 2019).

4.1.3 Method considerations on CO_2 data collection on organic soils

Methods in GHG monitoring have specific characteristics, which may impact the emission estimate quality. The methods used to quantify soil CO_2 balance can be classified into gaseous flux monitoring methods and soil inventory methods. The two method groups differ profoundly in the way they quantify the components of the soil C balance. The flux methods include i) EC flux monitoring by sensors located above the canopy, and ii) chamber techniques involving chambers enclosing a known gas space over soil with or without ground vegetation, litter and roots. Data processing in flux-based methods usually requires additional data on mass-based C stock changes, such as C inputs as litter, or change in vegetation C stock.

Flux data monitored by dark chambers forms the largest data set for forests on drained organic soils (Jauhiainen et al., 2019). Ideally, complete soil CO_2 balance estimate is based primarily on data (i) collected on-site, (ii) includes quantified heterotrophic emission sources (litter and soil) without autotrophic emissions from live plants, and (iii) include spatially and temporally large monitoring work. However such complete CO_2 data sets are rare (Meyer et al., 2013; Ojanen et al., 2010, 2013; Uri et al., 2017).

More usual in published CO_2 flux data is one or multiple deficiencies in data collection. Diurnally, cooler night-time temperatures result in lower emissions (Brændholt et al., 2017). Not accounting for this pattern by collecting flux data also during night-periods or by modelling results in overestimated emissions. In manual chamber data, the diurnal temperature differences have been taken into account mostly by applying temperature modelling into fluxes monitored during day-time in the boreal zone studies, but, only 36% of the temperate zone studies account for diurnal temperature differences (Jauhiainen et al., 2019). Consideration given to soil temperature impacts on GHG fluxes should be a requirement in data collection, processing and reporting in studies using manual GHG flux data collection by the chamber method.

Soil C balance is the balance between C added in litter inputs and C lost as CO_2 in emissions from litter and SOM decomposition. The most typical data lacking for completion of the soil CO_2 balance estimate in chamber method in the reviewed publications was the annual rate of litterfall (Jauhiainen et al., 2019). In studies where the monitored surfaces are kept clean from litter, the above-ground litter CO_2 emission must be estimated separately, which may be laborious and result in bias or error. 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., 2014, 2013). Comparable integrated assessments for the temperate region, and for afforested sites, formerly used for peat mining or as cropland, are still lacking. Emissions from decomposing litter are included in CO_2 flux monitoring by having the deposited litter on the soil surface intact, but even then the rate of litter inputs need to be measured, or estimated, to complement the balance.

Work towards reduced uncertainty in the inputs and decomposition rates of different litter types under different conditions is needed. Species-specific aboveground litter production estimates are available for birch, pine and spruce, if measures quantifying the tree biomass are known (e.g., Repola, 2008, 2009). Considerably less specific data are available on understory litter production (Petra Straková et al., 2010), litter decomposition (Domisch et al., 2000; Petra Straková et al., 2012; Tuomi et al., 2011; Tupek et al., 2015), and, especially, on belowground (fine root) litter production and decomposition rates (Bhuiyan et al., 2017; Finér et al., 2011; Jagodzinski et al., 2016; Laiho et al., 2003). Use of generic values for litterfall and litter decomposition cannot be recommended because these rates are site-type specific, typically differing between nutrient-poor and rich sites, and also depend on growing season length (Lehtonen et al., 2016; Ojanen et al., 2013; P. Straková et al., 2011; Petra Straková et al., 2010, 2012).

Above- and belowground autotrophic respiration of vegetation remaining inside the chamber is a CO_2 flux source that was often acknowledged but not always quantified in the dark chamber studies. Living roots of both ground vegetation and trees extending to the monitoring plot may still add autotrophic CO_2 emission unless specifically excluded by trenching (Subke et al., 2006). Although c. 0.5 proportion between total and autotrophic respiration is a fairly common outcome in studies conducted on both organic and mineral soils (e.g., Bond-Lamberty et al., 2004; Comstedt et al., 2011), use of a literature-based fixed coefficient induces a source of uncertainty with a potentially high impact on the soil CO_2 balance estimate.

Eddy covariance (EC) method has been applied in three studies in drained organic forest soils Alm et al., 2007; Lohila et al., 2011; Meyer et al., 2013). EC data typically combine high temporal flux sampling intensity with a large areal coverage, i.e. the data has good representativeness for the studied area. For estimating soil CO_2 balance as ‘NEE minus change in vegetation biomass’, the greatest biomass change in forested sites is naturally in the tree stand. Although the EC method produces continuous GHG data, gaps in the data are unavoidable in long data series and gap-filling is needed. Syntheses on flux data in various ecosystems worldwide (Wang et al., 2017) find EC monitoring sensitivity to differ by ecosystems, where forest systems in northern areas appear to form challenging environments for integrating diurnal and seasonal fluxes generally due to footprint related issues, below-canopy horizontal advection, and issues arising from correlation between temperature and respiration.

Inventory methods integrate the outcome from all processes affecting the soil C stock over time. C in mass based C-stock change is converted to CO_2 by multiplying with 3.67 (the mass ratio between CO_2 and C, 44/12). In this method, soil C stocks are estimated at least twice. Volumetric soil samples are taken from the peat surface down to the bottom of the peat deposit or, alternatively, sampling may be down to a clearly definable reference layer. The C-stock is calculated from the soil bulk densities and C concentrations, and the C stock change is then simply the difference in the C-stock estimates between the time points. Soil CO_2-C balance estimates based on inventory data integrate the outcome from all C-stock contributing processes over long (decadal) periods. The drawback is the difficulty in determining a small temporal change in a very large soil C stock (e.g. Minkkinen & Laine, 1998Minkkinen and Laine, 1998). Year-to-year differences in soil C stock or specific forms of C or GHGs cannot be studied, which limit the use of the method only for Tier 1 EFs. Reliable estimates may be obtained only if the bottom of the peat deposit /reference layer is defined accurately and in a similar manner in the repeated sampling (see, Jauhiainen et al., 2019).

4.1.4 CH_4 and N_2O monitoring – ground vegetation considerations

Current CH_4 and N_2O data for forming EFs is based on flux monitoring by dark chambers. N_2O and CH_4 fluxes have been studied specifically, but also from the same soil surfaces together with CO_2 flux monitoring. In such combined CO_2, CH_4 and N_2O monitoring surfaces, where ground vegetation and litter is removed and/or soil is trenched for studying the heterotrophic CO_2 flux, the caused disturbances in vegetation and soil conditions may influence the CH_4 and N_2O fluxes. For forming the EFs for CH_4 and N_2O there is no guidance on how living vegetation presence or litter dynamics should be taken into account in flux measurements, except that vegetation presence can be reported for CH_4 monitoring locations (Takahiro Hiraishi et al., 2013). However, wetland plants that have roots with aerenchymatous tissue are known to pipe out CH_4 from waterlogged peat layers (Askaer et al., 2011), but in drained sites sedges may also attenuate the emissions (Strack & Waddington, 2008). Excluding these plant types may lead to severe underestimation of the CH_4 flux. Belowground biomass disturbance, e.g. rhizosphere and mycorrhizal mycelia removal by trenching, has been shown to result in increased N_2O flux in drained organic forest soils (Ernfors et al., 2011). For constructing Tier 2 factors it should be recommended in any case that ground vegetation should be kept intact in CH_4 and N_2O monitoring.

4.1.5 Importance of reporting key drivers influencing soil GHG balance

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 GWT regime (K. V. Arnold et al., 2005; Ojanen et al., 2014, 2010, 2013; K. von Arnold et al., 2005). These parameters are not, however, routinely reported in studies quantifying GHG fluxes (Table 2 in Jauhiainen et al., 2019). Different tree species produce litters of different quality (e.g., Straková et al., 2010), which decompose at different rates (e.g., Straková et al., 2012) and have been found to result in differing soil GHG fluxes on mineral soils (e.g., Butterbach-Bahl et al., 2002; Papen & Butterbach-Bahl, 1999). Further, tree stand information may be needed for estimating tree litter inputs if those have not been measured. Average annual or seasonal GWT were provided in less than half (44%) of the publications (Table 2 in Jauhiainen et al., 2019). The volume of increasingly oxic soil above the GWT is important for aerobic decomposition processes producing CO_2. Also for the balance in processes producing and consuming CH_4 in soil, i.e. methanogenesis and methanotrophy, the GWT depth influence on oxic and anoxic soil environment is critical. Less than a third of the publications reported physical (e.g., bulk density) or chemical characteristics (e.g., C, N, and P concentrations, pH) of the soil (Table 2 in Jauhiainen et al., 2019). Chemical quality of the organic matter is known to constrain its decomposition rate (e.g. Straková et al., 2012) and the resulting GHG fluxes. Sampling depth for determining soil characteristics in drained forest soils should be within the vegetation rooting zone and above the GWT.

4.1.6 Spatial and temporal scale considerations in GHG flux monitoring

In studies utilizing chamber techniques, on an average previous studies include 8 replicate flux monitoring points per site for CO_2 (range 2 to 48), 5 for CH_4 (2 to 16) and 5 for N_2O (2 to 16) (Jauhiainen et al., 2019). In the reviewed soil inventory studies, multiple-site surveys included 1–5 sampling points at each site and 1–3 replicate cores at each sampling point. It can be reasoned that one EC tower gives an integrated flux for the whole footprint area. It is understood that sampling procedures are strongly constrained by resources and are often trade-offs between spatial and temporal representativeness. An increase in the number of spatial replicates, i.e. the number of monitoring points, increases the spatial representativeness in both inventory and gaseous flux monitoring by chambers. The representativeness in flux estimates based on chambers can be limited if common site vegetation, soil, or topography characteristics are not covered by the monitoring points, and/or if the areal proportions of these properties are unknown. In soil inventory methods as well, attention to representative sampling at the study site is important.

The temporal scale of GHG flux sampling ranges from continuous sampling with EC, to automated chamber monitoring at varying frequencies, and non-continuous manually performed (day-time) sampling from chambers in intervals of several days to weeks. If GHG flux data collection is continued over several years, the multiple annual soil GHG balance estimates obtained yield a valuable description of the dynamics of the GHG fluxes in varying environmental conditions. In about half (53%) of the flux studies GHG monitoring lasted for at least 2 years, and thus nearly half of the publications included data from one-year or shorter monitoring (Jauhiainen et al., 2019). Most studies (77%) included also at least some flux monitoring events during cold (winter/frosted soil/snow cover) periods. The IPCC (2014) applied an annualization coefficient of 1.15 for the few 'seasonal' GHG flux estimates that excluded the cold period. Use of such a fixed coefficient is a source of uncertainty, since i) the length of the (un)monitored period may vary from study to study, and ii) 'seasonal' flux data and data used for forming the coefficient may not come from comparable climatic or site conditions. Although winter-time fluxes form a relatively small proportion of the annual flux (15% as applied in IPCC, 2014), more year-round field data from a larger number of sites in drained conditions would be beneficial for further modelling of cold season GHG fluxes.

4.2 Lessons learned on data collection, reporting and further data needs

Basic definitions and guidelines for forming EFs for GHG inventories on organic soils are provided by IPCC (2006, 2014). Consistent data increases the applicability of the data for forming more specific Tier 2 EFs. Each data collection method and data type has its strengths and weaknesses that contribute to the final outcome when converted to soil GHG balance estimates. It would be highly beneficial to consider post-publication data use already during reporting by providing details on site characteristics and conditions, relatively easily acquirable measurements that have potential to correlate with GHG fluxes. For organic soils generally applicable gaps and data collection ideas as identified by Jauhiainen et al. (2019) include:

- Lack of applicable data, mostly due to a lack of environmental data, hampers developing more dynamic EFs than mere averages that currently provide the most basic Tier 1 level for GHG inventories.

- Details on the characteristics and conditions at the monitoring sites are necessary to better analyse and synthesize the general dependencies between the GHG fluxes and environmental parameters.
- Consideration given to diurnal and longer term soil temperature impacts on monitored GHG fluxes should be a requirement for manual GHG flux data collection by chambers.
- More empirical cold season GHG flux data is needed for modelling.
- There is a lack of studies relating GHG fluxes and long-term GWT regimes (e.g., shallow drained vs. deep drained conditions) and of unambiguous GWT summaries in GHG flux reporting in general.
- Work toward reduced uncertainty in production and decomposition rates of belowground litter types, e.g., fine roots, in different conditions is needed because these data are still only sparsely available and typically not quantified in flux studies.
- There is a need for integrated studies on annual aboveground litter production and decomposition with impact assessment to soil CO_2 balance for the temperate region and for afforested sites, formerly used for peat mining or as cropland.
- In future studies of CH_4 and N_2O fluxes, vegetation and litter should be kept intact in the flux measurement points.

5. WAYS FORWARD IN GHG DATA COLLECTION AND MANAGEMENT

In Latvia study on improvement of emission factors of greenhouse gasses (CO_2, CH_4 and N_2O) form managed nutrient-poor organic soils has ended in 2019 within the scope of LIFE REstore project. Study included peat extraction sites, deciduous and coniferous forests stands on extracted peat fields, agricultural lands, including cropland, grassland, cranberry and highbush blueberry plantations and also relatively intact parts of raised bogs and transitional mires. Measurements have been carried out in 41 objects and 36 sites for 2 years, continuation of monitoring work would be necessary as well as further studies and measurements for nutrient-rich organic soils in different land use categories.

Major issues in GHG reporting due to the management of organic soils:

- High uncertainty of activity data characterizing land use and management;
- Insufficient modelling capabilities to link activity data and calculation of GHG emissions with sufficient accuracy;
- Limited knowledge on the impact of climate change mitigation measures on GHG emissions organic soils.

Priorities in research and development for the improvement of inventories and projections GHG emissions from organic soils:

- Development and implementation of LiDAR, Copernicus and land parcel information system based activity data gathering tools;
- Reduction of uncertainties by closer integration of activity data, management approaches, climate data and emission factors;
- Elaboration of modelling tools for evaluation of impact of climate change mitigation measures on GHG emissions from organic soils.

Ongoing activities in relation to climate change mitigation in LULUCF sector in Latvia, particularly, in relation to the management of organic soils is provided in further paragraphs.

Sustainable use of soil resources in the changing climate (SUCC), duration 01.01.2020-31.12.2023, partnership – Estonia, Norway, Latvia, Lithuania. Objectives:

- To develop novel molecular methods for rapid abundance assessment of various microbial groups and their potential of organic degradation and carbon release;
- To determine shifts in carbon allocation in plants and carbon sequestration in soil along the latitudinal gradient in response to climate change;
- To evaluate the economic costs and benefits of changing climate on various aspects of forestry and soil carbon balance;

- To determine ecological sustainability of afforestation of former agricultural land;
- To develop sustainable forestry and other land use practices to mitigate the negative effects of climate change on the one hand and securing forest productivity on the other hand.

Reduction of CO_2 emissions by restoring degraded peatlands in Northern European Lowland (LIFE PeatRestore), duration 15.06.2019-31.12.2020, LIFE program (LSFRI Silava ensures external GHG measurement services in Latvia and Lithuania), partnership – Latvia, Estonia, Germany, Lithuania. Objectives:

- To restore degraded peatland sites;
- To measure the change in greenhouse gas emissions from peatlands before and after restoration and model fluxes using the Greenhouse Gas Emission Site Types (GEST) approach;
- To produce a handbook on how to carry out restoration and best manage the restored peatlands;
- To create guidelines with best practice scenarios for peatland use in relation to the EU climate policy and legislation.

Elaboration of guidelines and modelling tool for GHG emission reduction in forests on nutrient-rich organic soils, duration 03.2019-12.2021, Forest sector competence centre research program, national project. Objectives:

- Research sites for validation of GHG emission factors and further research on the impact of management on GHG emissions;
- GHG emission factors for soil, depending on carbon uptake, groundwater level, dominant tree species, temperature and other factors;
- Model for estimating the mitigation effect of under various forest management scenarios integrated in the long-term forest resource forecasting model;
- Economic impact of GHG mitigation measures and the required state support;
- Sociological survey of the main target groups, including the identification of preconditions for the implementation of climate change mitigation measures in forests on fertile organic soils;
- Recommendations for the management of forests on fertile organic soils to maximize the climate change mitigation effect.

Interaction of microbial diversity with methane turnover and mercury methylation in organic soils, duration 2018-2021, National academic research grant, national project. Objectives:

- Apply and develop standardised procedures for sample collection and processing, in order to ensure long-term continuity and comparability of the obtained data and results;

- Determine and compare microbial profiles obtained from samples collected in various environmental and management conditions;
- Correlate microbial profiles and functional analyses with soil properties, CH_4 emissions and Hg and MeHg levels.

Improvement of GHG and CO_2 reporting system and development of appropriate methodological solutions, duration 2018-2020, Grant of Ministry of Agriculture of Republic of Latvia, national project. Objectives:

- To improve the system for accounting and reporting GHG emissions and CO_2 sequestration from cropland and grassland management in line with IPCC 2019 guidelines;
- To characterize the impact of minimal soil treatment on GHG emissions at the demo site of Latvia University of Life Sciences and Technologies.
- To elaborate biomass expansion factors for major farm crops and to develop carbon input data for farm crops in organic and conventional farming systems;
- To elaborate remote sensing technologies for improvement of accounting systems for GHG emissions and CO_2 removals in cropland and grassland management.

Areas for knowledge exchange and gap closing. Even though Lithuania has implemented several studies related to organic soils / peatlands, systematic and actual information of GHG emissions occurring due to the certain management practice in different land use categories is still lacking. Generalized study of mean GHG emissions due to the drainage and rewetting of organic soils in order to have a basis for management decisions in order to reduce GHG emissions from LULUCF.

In Estonia increasing number of manual chamber-based studies (over 50 sites) over last decade have been performed in mires, drained bogs (gradient perpendicular to the drainage ditch), abandoned peat extraction and rewetted sites and in forests with organic soil. Most of these measurements cover ecosystem respiration CO_2, CH_4 and N_2O measurements of in-tact vegetation while only limited number of long-term high frequency (automatic) transparent chamber or eddy-covarience measurements in ecosystems on organic soils are available.

Cross-validation of eddy-covarience and chamber-based measurements in similar ecosystems of same climate could give better understanding of spatial variation of GHG emissions and improve quality of input parameters for models.

Gap filling exercise to investigate how other participating countries are evaluating changes in drainage – if the drainage is no longer present during the field measurement / visit, if there is any reduction in the areas of drained organic soils due to the potential deterioration or malfunction of the drainage system – would be needed.

Development of models on site level factors influencing GHG flux. Data on site characteristics combined with data on soil GHG balance may help in identifying condition dependencies with GHG emissions. One potential way forward in development from default EF values towards higher Tier levels is by testing dependencies between net annual soil GHG balance estimates and the reported characteristics and environment conditions on the sites (Figure 8).

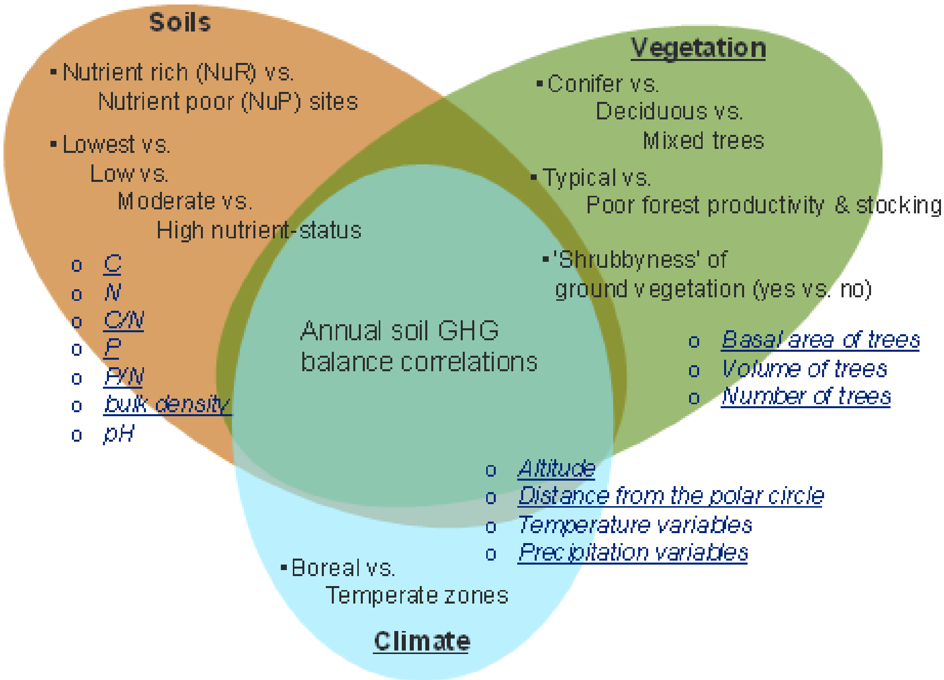


Figure 8: Some identified environment and site-specific characteristics on soils, vegetation and climate that may have potential as predictors of GHG emissions formed.

REFERENCES

1. Abdalla, M., Hastings, A., Truu, J., Espenberg, M., Mander, Ü., & Smith, P. (2016). Emissions of methane from northern peatlands: A review of management impacts and implications for future management options. *Ecology and Evolution*, *6*(19), 7080–7102. https://doi.org/10.1002/ece3.2469
2. Adermann, V. (2010). Estonia. In E. Tomppo, T. Gschwantner, M. Lawrence, & R. McRoberts (Eds.), *National forest inventories: Pathways for common reporting* (pp. 171–184). Springer.
3. Alm, J., Narasinha, J. S., Minkkinen, K., Lasse, A., Lasse, A., Hytönen, J., Laurila, T., Lohila, A., Maljanen, M., Martikainen, P. J., Penttilä, T., Mäkiranta, P., Saarnio, S., Silvan, N., Tuittila, E.-S., & Laine, J. (2007). Emission factors and their uncertainty for the exchange of CO2 , CH4 and N2O in Finnish managed peatlands. *Boreal Environment Research*, *12*, 191–206.
4. Arnold, K. V., Weslien, P., Nilsson, M., Svensson, B. H., & Klemedtsson, L. (2005). Fluxes of CO2, CH4 and N2O from drained coniferous forests on organic soils. *Forest Ecology and Management*, *210*(1–3), 239–254. https://doi.org/10.1016/j.foreco.2005.02.031
5. Askaer, L., Elberling, B., Friborg, T., Jørgensen, C. J., & Hansen, B. U. (2011). Plant-mediated CH4 transport and C gas dynamics quantified in-situ in a Phalaris arundinacea-dominant wetland. *Plant and Soil*, *343*(1–2), 287–301. https://doi.org/10.1007/s11104-011-0718-x
6. Bardule, A., Lupikis, A., Butlers, A., & Lazdins, A. (2017). Organic carbon stock in different types of mineral soils in cropland and grassland in Latvia. *Zemdirbyste-Agriculture*, *104*(1), 3–8. https://doi.org/10.13080/z-a.2017.104.001
7. Barthelmes, A., Couwenberg, J., & Risager, M. (2015). *Peatlands and Climate in a Ramsar context*. Nordic Council of Ministers. https://doi.org/10.6027/TN2015-544
8. Bhuiyan, R., Minkkinen, K., Helmisaari, H.-S., Ojanen, P., Penttilä, T., & Laiho, R. (2017). Estimating fine-root production by tree species and understorey functional groups in two contrasting peatland forests. *Plant and Soil*, *412*(1), 299–316. https://doi.org/10.1007/s11104-016-3070-3
9. Bond-Lamberty, B., Wang, C., & Gower, S. T. (2004). A global relationship between the heterotrophic and autotrophic components of soil respiration? *Global Change Biology*, *10*(10), 1756–1766. https://doi.org/10.1111/j.1365-2486.2004.00816.x
10. Brændholt, A., Steenberg Larsen, K., Ibrom, A., & Pilegaard, K. (2017). Overestimation of closed-chamber soil CO2 effluxes at low atmospheric turbulence. *Biogeosciences*, *14*(6), 1603–1616. https://doi.org/10.5194/bg-14-1603-2017
11. Buivydaitė, V., Vaičys, M., Juodis, J., & Motuzas, A. (2001). *Lietuvos dirvožemių klasifikacija (Classification of the Soils of Lithuania)*. Lietuvos mokslas.
12. Butterbach-Bahl, K., Rothe, A., & Papen, H. (2002). Effect of tree distance on N2O and CH4-fluxes from soils in temperate forest ecosystems. *Plant and Soil*, *240*(1), 91–103. https://doi.org/10.1023/A:1015828701885
13. Comstedt, D., Boström, B., & Ekblad, A. (2011). Autotrophic and heterotrophic soil respiration in a Norway spruce forest: Estimating the root decomposition and soil moisture effects in a trenching experiment. *Biogeochemistry*, *104*(1–3), 121–132. https://doi.org/10.1007/s10533-010-9491-9
14. Domisch, T., Finér, L., Laiho, R., Karsisto, M., & Laine, J. (2000). Decomposition of Scots pine litter

and the fate of released carbon in pristine and drained pine mires. *Soil Biology and Biochemistry*, *32*(11–12), 1571–1580. https://doi.org/10.1016/S0038-0717(00)00070-5

15. Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Kiyoto, T. (Eds.). (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Agriculture, Forestry and Other Land Use. In *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Vol. 4, p. 678). Institute for Global Environmental Strategies (IGES).
16. Ernfors, M., Rütting, T., & Klemedtsson, L. (2011). Increased nitrous oxide emissions from a drained organic forest soil after exclusion of ectomycorrhizal mycelia. *Plant and Soil*, *343*(1–2), 161–170. https://doi.org/10.1007/s11104-010-0667-9
17. Ernfors, M., von Arnold, K., Stendahl, J., Olsson, M., & Klemedtsson, L. (2008). Nitrous oxide emissions from drained organic forest soils—an up-scaling based on C:N ratios. *Biogeochemistry*, *89*(1), 29–41. https://doi.org/10.1007/s10533-008-9190-y
18. Finér, L., Ohashi, M., Noguchi, K., & Hirano, Y. (2011). Fine root production and turnover in forest ecosystems in relation to stand and environmental characteristics. *Forest Ecology and Management*, *262*(11), 2008–2023. https://doi.org/10.1016/j.foreco.2011.08.042
19. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., & Troxler, T. G. (Eds.). (2013). *Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol*. IPCC, Switzerland. http://www.ipcc-nggip.iges.or.jp/public/kpsg/pdf/KP_Supplement_Entire_Report.pdf
20. Hiraishi, Takahiro, Krug, T., Tanabe, K., Srivastava, N., Fukuda, M., Troxler, T., & Jamsranjav, B. (2013). *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (p. 354). IPCC. http://www.ipcc-nggip.iges.or.jp/public/wetlands/pdf/Wetlands_Supplement_Entire_Report.pdf
21. Jaagus, J. (2006). Trends in sea ice conditions on the Baltic Sea near the Estonian coast during the period 1949/50–2003/04 and their relationships to large-scale atmospheric circulation. *Boreal Environmental Research*, *11*, 169–183.
22. Jaagus, J., & Kull, A. (2011). Changes in surface wind directions in Estonia during 1966–2008 and their relationships with large-scale atmospheric circulation. *Estonian Journal of Earth Sciences*, *60*(4). https://doi.org/10.3176/earth.2011.4.03
23. Jaagus, Jaak. (1997). THE IMPACT OF CLIMATE CHANGE ON THE SNOW COVER PATTERN IN ESTONIA. *Climatic Change*, *36*(1), 65–77. https://doi.org/10.1023/A:1005304720412
24. Jagodzinski, A. M., Ziółkowski, J., Warnkowska, A., & Prais, H. (2016). Tree Age Effects on Fine Root Biomass and Morphology over Chronosequences of Fagus sylvatica, Quercus robur and Alnus glutinosa Stands. *PLOS ONE*, *11*(2), e0148668. https://doi.org/10.1371/journal.pone.0148668
25. Jauhiainen, J., Alm, J., Bjarnadottir, B., Callesen, I., Christiansen, J. R., Clarke, N., Dalsgaard, L., He, H., Jordan, S., Kazanavičiūtė, V., Klemedtsson, L., Lauren, A., Lazdins, A., Lehtonen, A., Lohila, A., Lupikis, A., Mander, Ü., Minkkinen, K., Kasimir, Å., … Laiho, R. (2019). Reviews and syntheses: Greenhouse gas exchange data from drained organic forest soils – a review of current approaches and recommendations for future research. *Biogeosciences*, *16*(23), 4687–4703. https://doi.org/10.5194/bg-16-4687-2019
26. Joosten, H. (2010). *The Global Peatland CO2 Picture: Peatland Status and Drainage Related*

Emissions in All Countries of the World (p. 36). Greifswald University.

27. Kalniņa, L. (2019). Studies by LIFE Restore in areas affected by peat extraction. In *Sustainable and responsible after-use of peat extraction areas* (pp. 21–54). Baltijas Krasti.
28. Karazija, S. (1988). *Lietuvos miškų tipai (Lithuanian forest types)*. "Mokslas".
29. Kārkliņš, A. (2016). Organic soils in the context of calculation of GHG emissions. *Proceedings Scientifically Practical Conference Balanced Agriculture*, 40–44.
30. Kekkonen, H., Ojanen, H., Haakana, M., Latukka, A., & Regina, K. (2019). Mapping of cultivated organic soils for targeting greenhouse gas mitigation. *Carbon Management*, *10*(2), 115–126. https://doi.org/10.1080/17583004.2018.1557990
31. Kõlli, R, Ellermäe, O., Köster, T., Lemetti, I., Asi, E., & Kauer, K. (2009). Stocks of organic carbon in Estonian soils. *Estonian Journal of Earth Sciences*, *58*(2), 95. https://doi.org/10.3176/earth.2009.2.01
32. Kõlli, R, Tamm, I., & Astover, A. (2011). Stocks and annual fluxes of organic carbon in the mineral soil cover of Estonia. *Estonian Journal of Ecology*, *60*(4), 251. https://doi.org/10.3176/eco.2011.4.01
33. Kõlli, Raimo, Köster, T., Kauer, K., & Lemetti, I. (2010). Pedoecological Regularities of Organic Carbon Retention in Estonian Mineral Soils. *International Journal of Geosciences*, *1*(3), 139–148. https://doi.org/10.4236/ijg.2010.13018
34. Köster, K., Metslaid, M., Engelhart, J., & Köster, E. (2015). Dead wood basic density, and the concentration of carbon and nitrogen for main tree species in managed hemiboreal forests. *Forest Ecology and Management*, *354*, 35–42. https://doi.org/10.1016/j.foreco.2015.06.039
35. Laiho, R., Vasander, H., Penttilä, T., & Laine, J. (2003). Dynamics of plant-mediated organic matter and nutrient cycling following water-level drawdown in boreal peatlands. *Global Biogeochemical Cycles*, *17*(2). https://doi.org/10/dtrdqr
36. Laine, J. (1989). Metsäojitettujen soiden luokittelu. [Classification of peatlands drained for forestry, Summary in English]. *SUO*, *40*(1), 37–51.
37. Lazdiņš, A., Bārdule, A., Butlers, A., Lupiķis, A., Okmanis, M., Bebre, I., Sarkanābols, T., & Petaja, G. (2016). *Aramzemes un ilggadīgo zālāju apsaimniekošanas radīto siltumnīcefekta gāzu (SEG) emisiju un oglekļa dioksīda (CO2) piesaistes uzskaites sistēmas pilnveidošana un atbilstošu metodisko risinājumu izstrādāšana (2016. Gada starpziņojums)* (101115/S109; p. 33). https://drive.google.com/open?id=0Bxv4jQ_04jXZRExSMWhPMWhDNDg
38. Lazdiņš, A., & Lupiķis, A. (2017). *Aramzemes un ilggadīgo zālāju apsaimniekošanas radīto siltumnīcefekta gāzu (SEG) emisiju un oglekļa dioksīda (CO2) piesaistes uzskaites sistēmas pilnveidošana un atbilstošu metodisko risinājumu izstrādāšana* (10.9.1-11/17/875; p. 51). Latvijas Valsts mežzinātnes institūts ''Silava''.
39. Lehtonen, A., Palviainen, M., Ojanen, P., Kalliokoski, T., Nöjd, P., Kukkola, M., Penttilä, T., Mäkipää, R., Leppälammi-Kujansuu, J., & Helmisaari, H.-S. (2016). Modelling fine root biomass of boreal tree stands using site and stand variables. *Forest Ecology and Management*, *359*, 361–369. https://doi.org/10/gfj54m
40. Lohila, A., Minkkinen, K., Aurela, M., Tuovinen, J.-P., Penttilä, T., Ojanen, P., & Laurila, T. (2011). Greenhouse gas flux measurements in a forestry-drained peatland indicate a large carbon sink. *Biogeosciences*, *8*(11), 3203–3218. https://doi.org/10.5194/bg-8-3203-2011
41. L.U. Consulting. (2010). *Augšņu un reljefa izejas datu sagatavošana un eiropas komisijas izstrādāto*

augsnes un reljefa kritēriju mazā labvēlīgo apvidu noteikšanai piemērošanas simulācija ((Elaboration of soil and terrain data and simulation of European Commission criteria for determination of less favourable rural areas: Summary of project report)) (p. 125). Latvijas Republikas Zemkopības Ministrija.

42. Lupiķis, A., & Lazdins, A. (2017). Soil carbon stock changes in transitional mire drained for forestry in Latvia: A case study. *Research for Rural Development*, *1*, 55–61.
43. MacDonald, G. M., Beilman, D. W., Kremenetski, K. V., Sheng, Y., Smith, L. C., & Velichko, A. A. (2006). Rapid Early Development of Circumarctic Peatlands and Atmospheric CH4 and CO2 Variations. *Science*, *314*(5797), 285–288. https://doi.org/10.1126/science.1131722
44. Männik, A., Zirk, M., Rõõm, R., & Luhamaa, A. (2015). Climate parameters of Estonia and the Baltic Sea region derived from the high-resolution reanalysis database BaltAn65+. *Theoretical and Applied Climatology*, *122*(1), 19–34. https://doi.org/10.1007/s00704-014-1271-3
45. Meyer, A., Tarvainen, L., Nousratpour, A., Björk, R. G., Ernfors, M., Grelle, A., Kasimir Klemedtsson, Å., Lindroth, A., Räntfors, M., Rütting, T., Wallin, G., Weslien, P., & Klemedtsson, L. (2013). A fertile peatland forest does not constitute a major greenhouse gas sink. *Biogeosciences*, *10*(11), 7739–7758. https://doi.org/10.5194/bg-10-7739-2013
46. Ministry of Environmental Protection and Regional Development. (2019). *Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990 – 2017* (p. 511). Ministry of Environmental Protection and Regional Development of the Republic of Latvia. https://unfccc.int/documents/194812
47. Ministry of the Environment. (2019). *Greenhouse gas emissions in Estonia 1990-2017. National inventory report. Submission to the UNFCCC Secretariat. Common Reporting Formats (CRF) 1990–2017* (p. 482). Ministry of the Environment. https://www.envir.ee/sites/default/files/content-editors/Kliima/nir_est_1990-2017_15.01.2019.pdf
48. Minkkinen, K., Laine, J., Shurpali, N. J., Maekiranta, P., Alm, J., & Penttilae, T. (2007). Heterotrophic soil respiration in forestry-drained peatlands. *Boreal Environment Research*, *12*(2), 115–126.
49. Minkkinen, Kari, & Laine, J. (1998). Long-term effect of forest drainage on the peat carbon stores of pine mires in Finland. *Canadian Journal of Forest Research*, *28*(9), 1267–1275. https://doi.org/10.1139/x98-104
50. Minkkinen, Kari, & Laine, J. (2006). Vegetation heterogeneity and ditches create spatial variability in methane fluxes from peatlands drained for forestry. *Plant and Soil*, *285*(1–2), 289–304. https://doi.org/10.1007/s11104-006-9016-4
51. MoE/EPA/SFS. (2019). *Lithuanian's National Inventory Report 2019: Greenhouse Gas Emissions 1991-2017* (p. 550). https://am.lrv.lt/uploads/am/documents/files/KLIMATO%20KAITA/Studijos%2C%20metodin%C4%97%20med%C5%BEiaga/NIR_2019_01_15_FINAL.pdf
52. Mokma, D. L. (2005). ORGANIC SOILS. In *Encyclopedia of Soils in the Environment* (pp. 118–129). Elsevier. https://doi.org/10.1016/B0-12-348530-4/00034-5
53. Ojanen, P., Lehtonen, A., Heikkinen, J., Penttilä, T., & Minkkinen, K. (2014). Soil CO2 balance and its uncertainty in forestry-drained peatlands in Finland. *Forest Ecology and Management*, *325*, 60–73. https://doi.org/10.1016/j.foreco.2014.03.049
54. Ojanen, P., Minkkinen, K., Alm, J., & Penttilä, T. (2010). Soil–atmosphere CO2, CH4 and N2O fluxes in boreal forestry-drained peatlands. *Forest Ecology and Management*, *260*(3), 411–421.

https://doi.org/10.1016/j.foreco.2010.04.036

55. Ojanen, P., Minkkinen, K., & Penttilä, T. (2013). The current greenhouse gas impact of forestry-drained boreal peatlands. *Forest Ecology and Management*, *289*, 201–208. https://doi.org/10.1016/j.foreco.2012.10.008
56. Paal, J., & Leibak, E. (2011). *Estonian mires: Inventory of habitats*.
57. Papen, H., & Butterbach-Bahl, K. (1999). A 3-year continuous record of nitrogen trace gas fluxes from untreated and limed soil of a N-saturated spruce and beech forest ecosystem in Germany: 1. N2O emissions. *Journal of Geophysical Research: Atmospheres*, *104*(D15), 18487–18503. https://doi.org/10.1029/1999JD900293
58. Pärn, J., Verhoeven, J. T. A., Butterbach-Bahl, K., Dise, N. B., Ullah, S., Aasa, A., Egorov, S., Espenberg, M., Järveoja, J., Jauhiainen, J., Kasak, K., Klemedtsson, L., Kull, A., Laggoun-Défarge, F., Lapshina, E. D., Lohila, A., Lõhmus, K., Maddison, M., Mitsch, W. J., … Mander, Ü. (2018a). Author Correction: Nitrogen-rich organic soils under warm well-drained conditions are global nitrous oxide emission hotspots. *Nature Communications*, *9*. https://doi.org/10/gdcf44
59. Pärn, J., Verhoeven, J. T. A., Butterbach-Bahl, K., Dise, N. B., Ullah, S., Aasa, A., Egorov, S., Espenberg, M., Järveoja, J., Jauhiainen, J., Kasak, K., Klemedtsson, L., Kull, A., Laggoun-Défarge, F., Lapshina, E. D., Lohila, A., Lõhmus, K., Maddison, M., Mitsch, W. J., … Mander, Ü. (2018b). Nitrogen-rich organic soils under warm well-drained conditions are global nitrous oxide emission hotspots. *Nature Communications*, *9*(1), 1135. https://doi.org/10.1038/s41467-018-03540-1
60. Petaja, G., Okmanis, M., Polmanis, K., Stola, J., Spalva, G., & Jansons, J. (2018). Evaluation of greenhouse gas emissions and area of organic soils in cropland and grassland in Latvia – integrated National forest inventory data and soil maps approach. *Agronomy Research*, *16*(4), 1809–1823. https://doi.org/10.15159/ar.18.183
61. Petrescu, A. M. R., Lohila, A., Tuovinen, J.-P., Baldocchi, D. D., Desai, A. R., Roulet, N. T., Vesala, T., Dolman, A. J., Oechel, W. C., Marcolla, B., Friborg, T., Rinne, J., Matthes, J. H., Merbold, L., Meijide, A., Kiely, G., Sottocornola, M., Sachs, T., Zona, D., … Cescatti, A. (2015). The uncertain climate footprint of wetlands under human pressure. *Proceedings of the National Academy of Sciences*, *112*(15), 4594–4599. https://doi.org/10.1073/pnas.1416267112
62. Pilvere, I. (2016). *Organisko augšņu devuma novērtējums Latvijas lauksaimniecībā – daudzfaktoru ietekmes izvērtējums efektīvas zemes izmantošanas risinājumu piedāvājumā (Assessment of the contribution of organic soils to Latvian agriculture – multi-factor impact assessment in the supply of efficient land use solutions), research report of BIO4ECO project (INTERREG EUROPE)*. Latvia University of Fife Sciences and Technologies. https://www.zm.gov.lv/zemkopibas-ministrija/statiskas-lapas/interreg-europe-projekta-bio4eco-ietvaros-latvija-veikts-petijums-?id=15376#jump
63. Post, W. M., Pastor, J., Zinke, P. J., & Stangenberger, A. G. (1985). Global patterns of soil nitrogen storage. *Nature*, *317*(6038), 613–616. https://doi.org/10.1038/317613a0
64. Regina, K., Heikkinen, J., & Maljanen, M. (2019). Greenhouse Gas Fluxes of Agricultural Soils in Finland. In N. Shurpali, A. K. Agarwal, & V. Srivastava (Eds.), *Greenhouse Gas Emissions* (pp. 7–22). Springer Singapore. https://doi.org/10.1007/978-981-13-3272-2_2
65. Repola, J. (2008). Biomass equations for birch in Finland. *Silva Fennica*, *42*(4). https://doi.org/10.14214/sf.236

66. Repola, J. (2009). Biomass equations for Scots pine and Norway spruce in Finland. *Silva Fennica*, *43*(4). https://doi.org/10.14214/sf.184
67. Rieley, J. (2014). Utilization of peatlands and peat. In R. Biancalani & A. Avagyan (Eds.), *Towards climate-responsible peatlands management* (pp. 22–26). Food and Agriculture Organization of the United Nations (FAO).
68. Salm, J.-O., Maddison, M., Tammik, S., Soosaar, K., Truu, J., & Mander, Ü. (2012). Emissions of CO2, CH4 and N2O from undisturbed, drained and mined peatlands in Estonia. *Hydrobiologia*, *692*(1), 41–55. https://doi.org/10.1007/s10750-011-0934-7
69. Simola, H., Pitkänen, A., & Turunen, J. (2012). Carbon loss in drained forestry peatlands in Finland, estimated by re-sampling peatlands surveyed in the 1980s. *European Journal of Soil Science*, *63*(6), 798–807. https://doi.org/10.1111/j.1365-2389.2012.01499.x
70. Slepetiene, A., Amaleviciute-Volunge, K., Slepetys, J., Liaudanskiene, I., & Volungevicius, J. (2018). The status of Pachiterric Histosols as influence by different land use. In B. Topcuoğlu & M. Turan (Eds.), *Peat* (pp. 49–73).
71. Sooäär, J., & Jaagus, J. (2007). Long-term changes in the sea ice regime in the Baltic Sea near the Estonian coast. *Proceedings of the Estonian Academy of Sciences, Engineering*, *13*, 189–200.
72. State Ltd. "Latvian Environment, Geology and Meteorology Centre". (2017). *Climate Change Scenarios for Latvia* (p. 17). https://www4.meteo.lv/klimatariks/summary.pdf
73. Statistics Finland. (2019). *Greenhouse gas emissions in Finland 1990 to 2017. National Inventory Report under the UNFCCC and the Kyoto Protocol. Submission to the European Union*. Statistics Finland. https://www.stat.fi/static/media/uploads/tup/khkinv/fi_eu_nir_2017_2019-03-15.pdf
74. Strack, M., & Waddington, J. M. (2008). Spatiotemporal variability in peatland subsurface methane dynamics. *Journal of Geophysical Research: Biogeosciences*, *113*(G2), n/a–n/a. https://doi.org/10.1029/2007JG000472
75. Straková, P., Niemi, R. M., Freeman, C., Peltoniemi, K., Toberman, H., Heiskanen, I., Fritze, H., & Laiho, R. (2011). Litter type affects the activity of aerobic decomposers in a boreal peatland more than site nutrient and water table regimes. *Biogeosciences*, *8*(9), 2741–2755. https://doi.org/10.5194/bg-8-2741-2011
76. Straková, Petra, Anttila, J., Spetz, P., Kitunen, V., Tapanila, T., & Laiho, R. (2010). Litter quality and its response to water level drawdown in boreal peatlands at plant species and community level. *Plant and Soil*, *335*(1–2), 501–520. https://doi.org/10.1007/s11104-010-0447-6
77. Straková, Petra, Penttilä, T., Laine, J., & Laiho, R. (2012). Disentangling direct and indirect effects of water table drawdown on above- and belowground plant litter decomposition: Consequences for accumulation of organic matter in boreal peatlands. *Global Change Biology*, *18*(1), 322–335. https://doi.org/10.1111/j.1365-2486.2011.02503.x
78. Tuomi, M., Laiho, R., Repo, A., & Liski, J. (2011). Wood decomposition model for boreal forests. *Ecological Modelling*, *222*(3), 709–718. https://doi.org/10.1016/j.ecolmodel.2010.10.025
79. Tupek, B., Mäkipää, R., Heikkinen, J., Peltoniemi, M., Ukonmaanaho, L., Hokkanen, T., Nojd, P., Nevalainen, S., Lindgren, M., & Lehtonen, A. (2015). *Foliar turnover rates in Finland—Comparing estimates from needle-cohort and litterfall-biomass methods*. https://helda.helsinki.fi/handle/10138/165220
80. Turunen, J. (2008). Development of Finnish peatland area and carbon storage 1950–2000. *Boreal Environment Research*, *13*, 319–334.

81. Uri, V., Kukumägi, M., Aosaar, J., Varik, M., Becker, H., Morozov, G., & Karoles, K. (2017). Ecosystems carbon budgets of differently aged downy birch stands growing on well-drained peatlands. *Forest Ecology and Management*, *399*, 82–93. https://doi.org/10.1016/j.foreco.2017.05.023
82. Vaičys, M., Beniušis, R., Karazija, S., Kuliešis, A., Raguotis, A., & Rutkauskas, A. (2006). *Miško augaviečių tipai (Forest site types)*. Lututė.
83. Valatka, S., Stoškus, A., & Pileckis, M. (2018). *Lietuvos durpynai: Kiek jų turime, ar racionaliai naudojame? (Lithuanian peatlands: How many we have, the use is rational?)* (p. 91). Gamtos paveldo fondas.
84. von Arnold, K., Nilsson, M., Hånell, B., Weslien, P., & Klemedtsson, L. (2005). Fluxes of CO2, CH4 and N2O from drained organic soils in deciduous forests. *Soil Biology and Biochemistry*, *37*(6), 1059–1071. https://doi.org/10.1016/j.soilbio.2004.11.004

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