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

WORK PACKAGE

FILLING KNOWLEDGE GAPS ABOUT GHG EMISSIONS FROM NUTRIENT-RICH ORGANIC SOILS (C1)

ACTIONS

Deliverable title	**Interim draft report on improved methodologies for GHG inventory reporting and related national reports**
Deliverable No	C1/3
Agreement No.	LIFE18 CCM/LV/001158
Report No.	2021- C1/3
Type of report	Interim
Elaborated by	LIFE OrgBalt team

2021

Report title	**Interim draft report on improved methodologies for GHG inventory reporting and related national reports**
Work package	Filling knowledge gaps about GHG emissions from nutrient-rich organic soils (C1)
Authors	Andis Lazdiņš, Guntis Saule, Kaido Soosaar, Ain Kull, Jauhiainen Jyrki, Laiho Raija, Dovilė Čiuldienė
Report No.	2021- C1/3
Type of report	Interim
Place	Salaspils
Organization	Latvia State Forest Research Institute "Silava"
Contact information	Riga street 111, Salaspils, LV-2169 Phone: +37129183320 E-mail: ieva.licite@silava.lv Web address: www.silava.lv
Date	2021
Number of pages	55

"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."

2021

SUMMARY

The main objective of the work package "Filling knowledge gaps about GHG emissions from nutrient-rich organic soils" (C1) is to provide knowledge and activity data for accounting of GHG emissions from nutrient-rich organic soils under conventional management scenarios and for evaluation of the long-term effect of the CCM measures.

In the first stage of the study, elaboration of climate-sensitive CS EFs using measurement data from 30 sampling sites in the Baltic States and Finland was initiated. Detailed information on progress of elaboration of EFs is available in the LIFE OrgBalt report 2021-C1/3 "Interim draft report on improved GHG emission factors for nutrient-rich managed organic soils in Baltic states". In addition, GHG EFs for drained organic soils in cropland, grassland and wetlands (peat extraction sites) developed within the EU LIFE program project "Sustainable and responsible management and re-use of degraded peatlands in Latvia" (LIFE REstore)[1] in Latvia have been implemented in the Latvia's National GHG Inventory.

Impacts of recalculations of on-site GHG emissions and removals from drained organic soils in cropland, grassland and in peat extraction sites in wetlands **in Latvia** due to implementation of CS EFs obtained within LIFE REstore project were evaluated. **In cropland**, use of CS EFs for CO_2, CH_4 and N_2O (4.80 t CO_2-C ha^{-1} yr^{-1}, -0.79 kg CH_4 ha^{-1} yr^{-1} and 7.1 kg N_2O-N ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in Latvia (78.1 – 135.1 kha depending from year in period of 1990-2019) by 1432.8 kt CO_2 eq. yr^{-1} or by 40.4% in average during 1990-2019. **In grassland**, use of CS EFs for CO_2, CH_4 and N_2O (4.40 t CO_2-C ha^{-1} yr^{-1}, 77.2 kg CH_4 ha^{-1} yr^{-1} and 0.3 kg N_2O-N ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in Latvia (57.4 – 80.8 kha depending from year in period of 1990-2019) by 584.9 kt CO_2 eq. yr^{-1} or by 31.6% in average during 1990-2019. **In wetlands (peat extraction sites)**, use of CS EFs for CO_2, CH_4 and N_2O (1.21 t CO_2-C ha^{-1} yr^{-1}, 10.83 kg CH_4 ha^{-1} yr^{-1} and 0.44 kg N_2O-N ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in peat extraction sites in Latvia (32.7 – 47.6 kha depending from year in period of 1990-2019) by 226.6 kt CO_2 eq. yr^{-1} or by 53.5% in average during 1990-2019**Figure 6**. Currently, for cropland only CS EFs for CO_2 and N_2O are implemented in the National GHG Inventory, but for grassland and wetlands (peat extraction sites) all CS EFs are implemented in the National GHG Inventory. The CS CO_2 EFs contributed the most to the reduction of total GHG emissions from drained organic soils in Latvia.

In addition, **we modelled and estimated potential impacts of recalculations of on-site GHG emissions and removals** from drained organic soils in cropland, grassland and in peat extraction sites in wetlands **in Lithuania and Estonia** due to implementation of EFs obtained within the LIFE REstore project in Latvia. Results of modelling and estimation confirm that recalculations of GHG emissions due to implementation of country- or region-specific GHG EFs for drained organic soils can significantlly impact total GHG emissions and removals from LULUCF and Agriculture (as N_2O emissions from drained organic soils in cropland and grassland are reported under Agriculture sector) sectors.

[1] Available at: https://restore.daba.gov.lv/public/eng/about_the_project/

In the following stages of the study, we will shift used methodology (used for National GHG Inventory) to a higher level (Tier) methods, which will be based on the results of the LIFE OrgBalt project (including improved activity data sets related to peat properties and water regime) and other studies. Evaluation of potential impact of recalculations due to implementation of EFs obtained within the LIFE OrgBalt project will be provided in the final version of this deliverable.

ABBREVIATIONS

BS = the Baltic States

C = carbon

CH_4 = methane

CO_2 = carbon dioxide

CS = country-specific

EF = emission factor

EU = the European Union

GHG = greenhouse gas

IPCC = the Intergovernmental Panel on Climate Change

IPCC Wetlands Supplement = 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands

N_2O = nitrous oxide

LIFE REstore = EU LIFE program project "Sustainable and responsible management and re-use of degraded peatlands in Latvia"

2006 IPCC Guidelines = 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use

2014 IPCC Guidelines = 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands

TABLE OF CONTENTS

Figures

Tables

1 GENERAL METHODOLOGY FOR CALCULATION OF GHG EMISSIONS FROM ORGANIC SOILS ACCORDING TO THE IPCC GUIDANCES

The Intergovernmental Panel on Climate Change (IPCC) guidelines, specifically 2006 IPCC Guidelines for National Greenhouse Gas Inventories[2] (2006 IPCC Guidelines) and 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC Wetlands Supplement), provide general methodology (three-level approaches or Tiers) for calculation of GHG emissions and removals from organic soils.

1.1 CO_2 emissions and removals from drained inland organic soils

Total carbon (C) losses from drained organic soils (CO_2-$C_{organic,drained}$) consists of on-site CO_2 emissions/removals of the organic soil from mineralisation and sequestration processes (CO_2-$C_{on\text{-}site}$), off-site CO_2 emissions from leached C from the organic soil (CO_2-C_{DOC}) and anthropogenic peat fires (L_{fire}) as presented in Equation (1) (IPCC Wetlands Supplement, Equation 2.2).

$$CO_2 - C_{organic,drained} = CO_2 - C_{on-site} + CO_2 - C_{DOC} + L_{fire} - CO_2 - C \quad (1)$$

Where:
CO_2-$C_{organic,drained}$ = CO_2-C emissions/removals by drained organic soils, tonnes C yr^{-1};
CO_2-$C_{on\text{-}site}$ = on-site CO_2 emissions/removals by drained organic soils, tonnes C yr^{-1};
CO_2-C_{DOC} = CO_2-C emissions from dissolved organic C exported from drained organic soils, tonnes C yr^{-1};
L_{fire}-CO_2-C = CO_2-C emissions from burning of drained organic soils, tonnes C yr^{-1}.

1.1.1 On-site CO_2 emissions

The most important factors considered for estimating on-site CO_2 emissions and removals from drained organic soils are land use and climate. Other factors such as nutrient status (or fertility) of the soil and drainage level (shallow or deep) affect emissions and can be considered where appropriate and with higher Tier methods. The basic methodology (Tier 1) for estimating annual C loss from drained organic soils is specified in Equation (2) (IPCC Wetlands Supplement, Equation 2.3). At Tier 1, there is no differentiation between CO_2 emissions from long-term drained organic soils and organic soils after initial drainage or where drainage is deepened. All Tier 1 default values including EFs are provided by the IPCC Guidelines (Table 1 based on Table 2.1 of the IPCC Wetlands Supplement). Classification of land area with organic soils according to the nutrient status in the BS and Finland is shown in Table 2.

$$CO_2 - C_{on-site} = \sum_{c,n,d} (A * EF)_{c,n,d} \quad (2)$$

Where:
CO_2-$C_{on\text{-}site}$ = annual on-site CO_2-C emissions/removals from drained organic soils in a land-use category, tonnes C yr^{-1};
A = land area of drained organic soils in a land-use category in climate domain c, nutrient status n and drainage class d, ha;
EF = emission factors for drained organic soils, by climate domain c, nutrient status n and drainage class d, tonnes C $ha^{-1}yr^{-1}$.

[2] Volume 4 (Agriculture, Forestry and Other Land Use, AFOLU)

Table 1. Default CO_2 emission/removal factors from drained organic soils in all land-use categories in temperate and boreal climate/vegetation zone

Land-use category	Nutrient status	Climate/vegetation zone	Emissions factor, tonnes CO_2-C ha^{-1} yr^{-1}	95% Confidence interval	
Forest Land, drained, including shrubland and drained land that may not be classified as forest	nutrient-poor	boreal	0.37	-0.11	0.84
Forest Land, drained	nutrient-poor	boreal	0.25	-0.23	0.73
	nutrient-rich	boreal	0.93	0.54	1.3
Forest Land, drained	all	temperate	2.6	2.0	3.3
Cropland, drained	all	boreal and temperate	7.9	6.5	9.4
Grassland, drained	all	boreal	5.7	2.9	8.6
Grassland, drained	nutrient-poor	temperate	5.3	3.7	6.9
Grassland, deep-drained	nutrient-rich	temperate	6.1	5.0	7.3
Grassland, shallow-drained	nutrient-rich	temperate	3.6	1.8	5.4
Peatland Managed for Extraction	all	boreal and temperate	2.8	1.1	4.2

Table 2. Classification of land area with organic soils according to the nutrient status (fertility) in the Baltic States and Finland

Country	Nutrient status or organic soils	Justification for classification	
		Type of area fit to the relevant nutrient status	Justification
Latvia	nutrient-poor	Raised bog – a rain-fed (ombrotrophic) peatland type; transition mire – a type of minerotrophic (groundwater-fed) mire, where the impact of the groundwater recedes, but the role of precipitation increases.	Soil fertility is determined by the origin of the peat.
	nutrient-rich	Fen – a type of wetland that mainly receives nutrients from groundwater.	
Lithuania	nutrient-poor	Classification is similar to Latvia: Raised bog – water is only from precipitation (ombrotrophic) peatland type; peat is poorly decomposed (peat moss present).	Nutrient poor and nutrient rich division is applicable for forest land category (forest site information obtained) and peat extraction sites, data from literature (proportion of nutrient poor and rich peat areas) applied.
	nutrient-rich	Classification is similar to Latvia: Fen – a type of wetland that mainly receives nutrients from groundwater; peat is well decomposed (peat moss not distinguishable).	
Estonia	nutrient-poor	Forest land was divided into nutrient-rich and nutrient-poor areas based on site quality class (SQC). Sites with SQC III–V are categorised as nutrient-poor.	
	nutrient-rich	SQC I and II are categorised as nutrient-rich.	
Finland	nutrient-poor	Ombrotrophic mires receive nutrient supply only from the atmosphere and are nutrient-poor.	Soil fertility is determined by the origin of the peat.
	nutrient-rich	Minerotrophic mires are supplied by minerogenic water flow from the surrounding mineral soils or by ground-water from springs and as seepage through peat, which carries additional nutrients to the mire. Minerotrophic mires can be divided into oligotrophic, mesotrophic, and eutrophic subtypes according to increasing trophic levels (Ruuhijärvi 1983; Laine & Vasander 1998).	

According to the IPCC Guidelines, the Tier 2 approach for CO_2 emissions/removals from drained organic soils incorporates country-specific information into Equations 1 and 2 to estimate CO_2 emissions/removals. Improvements to the Tier 1 approach may include: 1) a derivation of country-specific EFs; 2) specification of climate sub-domains considered suitable for refinement of EFs; 3) a finer, more detailed classification of management systems with a differentiation of land-use intensity classes; 4) a differentiation by drainage classes; 5) differentiation of EFs by time since drainage or the time since changes in drainage class, e.g. between EFs reflecting additional emissions after deepening of drainage or new drainage and long-term stable water tables, or 6) a finer, more detailed classification of nutrient status, e.g. by nitrogen, phosphorus or pH. Thus, it is good practice to derive country-specific EFs if measurements representing the national circumstances are available and to use a finer classification for climate and management systems, in particular for drainage classes, if there are significant differences in measured carbon loss rates among these classes.
CO_2 emissions/removals from drained organic soils can be estimated using modelling and/or measurement approaches (Tier 3 approach). Dynamic, mechanistic models will typically be used to simulate underlying processes while capturing the influence of land use and management, particularly the effect of seasonally variable levels of drainage on decomposition.

Note 1: Results of the LIFE OrgBalt project will provide transfer to a higher Tier method to calculate on-site CO_2 emissions from drained organic soils.

1.1.2 Off-site CO_2 emissions

The basic methodology (Tier 1) for estimating annual off-site CO_2 emissions associated with waterborne C loss from drained organic soils is specified in Equation (3) and (4) (IPCC Wetlands Supplement, Equation 2.4 and 2.5). All Tier 1 default values including EFs are provided by the IPCC Guidelines (Table 3 based on Table 2.2 of the IPCC Wetlands Supplement).

$$CO_2 - C_{DOC} = \sum_{c,n} (A * EF_{DOC})_{c,n} \tag{3}$$

Where:
CO_2-C_{DOC} = annual off-site CO_2-C emissions due to DOC loss from drained organic soils, tonnes C yr^{-1};
$A_{c,n}$ = land area of drained organic soils in a land-use category in climate zone c and nutrient status n, ha;
$EF_{DOCc,n}$ = emission factors for annual CO_2 emissions due to DOC loss from drained organic soils, by climate zone c and nutrient status n, tonnes C ha^{-1} yr^{-1} (see Equation (4)).

$$EF_{DOC} = DOC_{FLUX\_NATURAL} * (1 + \Delta DOC_{DRAINAGE}) * Frac_{DOC-CO2} \tag{4}$$

Where:
EF_{DOC} = emission factor for DOC from a drained site, tonnes C ha^{-1} yr^{-1};
$DOC_{FLUX\_NATURAL}$ = flux of DOC from natural (undrained) organic soil, tonnes C ha^{-1} yr^{-1};
$\Delta DOC_{DRAINAGE}$ = proportional increase in DOC flux from drained sites relative to undrained sites;
$Frac_{DOC-CO2}$ = conversion factor for proportion of DOC converted to CO_2 following export from site.

Table 3. Default DOC emission factors for drained organic soils

Climate zone	$DOC_{FLUX\_NATURAL}$, t C ha^{-1} yr^{-1}	$\Delta DOC_{DRAINAGE}$	$Frac_{DOC-CO2}$	$EF_{DOC\_DRAINED}$, t C ha^{-1} yr^{-1}
Boreal	0.08 (0.06-0.11)	0.60 (0.43-0.78)	0.9 (±0.1)	0.12 (0.07-0.19)
Temperate	0.21 (0.17-0.26)			0.31 (0.19-0.46)

According to the IPCC Guidelines, a Tier 2 approach for estimation of DOC may follow the Tier 1 methodology, but should use country-specific information where possible to refine the EFs used. Possible refinements where supporting data are available could include:

- use of country-level measurements from natural (undrained) organic soils to obtain accurate values of $DOC_{FLUX-NATURAL}$ for that country, for example by developing specific values for raised bogs versus fens, or for blanket bogs;
- use of country-level data on the impacts of organic soil drainage on DOC flux to derive specific values of $DOC_{DRAINAGE}$ that reflect local organic soil types, and the nature of drainage practices and subsequent land use - if sufficient, robust, direct measurements are available from representative drained sites, these may be used to estimate DOC fluxes from drained sites, replacing $DOC_{FLUX\_NATURAL}$ in Equation 4; specific DOC flux estimates from drained organic soils in different land-use categories could also be considered where data support this level of stratification; and
- use of alternative values for $Frac_{DOC-CO2}$ where evidence is available to estimate the proportion of DOC exported from drained organic soils that is transferred to stable long-term C stores, such as lake or marine sediments.

A Tier 3 approach might include the use of more detailed data to develop and apply process models that describe DOC release as a function of vegetation composition, nutrient levels, land-use category, water table level and hydrology, as well as temporal variability in DOC release in the years following land-use change and ongoing management activities (e.g. drain maintenance, forest management).

Note 2: In the recent study by Tiemeyer et al. (2020) in Germany, it is mentioned that DOC losses of drained sites constitute only a minor part of the total C budget even at sites with high DOC concentrations (Tiemeyer and Kahle, 2014; Frank et al., 2017). Frank (2016) and Frank et al. (2017) report mean DOC losses of 430 kg ha^{-1} yr^{-1} at a deeply drained grassland on bog peat (corresponding to 9% of the C budget of the respective site), and of ~200 kg ha^{-1} yr^{-1} at a shallow drained grassland (corresponding to 3% of the C budget of the respective site). In contrast to these relatively high values, Tiemeyer and Kahle (2014) measured DOC losses of 53 kg ha^{-1} yr^{-1} from a catchment with fen peat and other organic soils, which equals only around 1% of the C budget within this catchment. The relatively large variation in DOC losses indicates the need for additional country-specific measurements. Also the results of the recent study by Butlers et al. (2021) in forest land with drained and wet soils in Latvia showed that on-site emissions are are similar or higher (in case of CH_4) in wet areas indirectly highlighting the need for further research at regional level where DOC loss measurements would be included in estimates of total GHG removal/emission budget and C stock changes.

Note 3: Results of the LIFE OrgBalt project will not provide country-specific information on DOC losses from drained organic soils, but additional measurements would be useful as justified in the Note 2 above.

1.2 CO_2 emissions and removals from rewetted organic soils

The net C stock change of rewetted organic soils results from net gains or losses of C resulting from the balance between CO_2 and CH_4 emissions and removals.

1.2.1 CO_2 emissions and removals from rewetted organic soils

Components of CO_2-C emissions/removals from rewetted organic soils are specified in Equation (5) (IPCC Wetlands Supplement, Equation 3.3).

$$CO_2 - C_{rewetted\ org\ soil} = CO_2 - C_{composite} + CO_2 - C_{DOC} + L_{fire} - CO_2 - C \quad (5)$$

Where:

CO_2-$C_{rewetted\ org\ soil}$ = CO_2-C emissions/removals from rewetted organic soils, tonnes C yr^{-1};
CO_2-$C_{composite}$ = CO_2-C emissions/removals from the soil and non-tree vegetation, tonnes C yr^{-1};
CO_2-C_{DOC} = off-site CO_2-C emissions from dissolved organic C exported from rewetted organic soils, tonnes C yr^{-1};
L_{fire}-CO_2-C = CO_2-C emissions from burning of rewetted organic soils, tonnes C yr^{-1}.

Under Tier 1, the basic methodology for estimating annual C emissions/removals from rewetted organic soils was presented in Equation (5) and can be compiled using Equations (6), (7) and (8) (IPCC Wetlands Supplement, Equations 3.4, 3.5 and 3.6) where the nationally derived area of rewetted organic soils is multiplied by an EF, which is disaggregated by climate zone and where applicable by nutrient status (nutrient poor and nutrient rich). Tier 1 methodology is applicable from the year of rewetting. All Tier 1 default values including EFs are provided by the IPCC Guidelines (Table 4 and Table 5 based on Table 3.1 and Table 3.2 of the IPCC Wetlands Supplement).

$$CO_2 - C_{composite} = \sum_{c,n} (A * EF_{CO2}) \quad (6)$$

Where:
CO_2-$C_{composite}$ = CO_2-C emissions/removals from the soil and non-tree vegetation, tonnes C yr^{-1};
$A_{c,n}$ = area of rewetted organic soils in climate zone c and nutrient status n, ha;
$EF_{CO2\ c,n}$ = CO_2-C emission factor for rewetted organic soils in climate zone c, nutrient status n, tonnes C ha^{-1} yr^{-1}.

$$CO_2 - C_{DOC} = \sum_{c,n} \left(A * EF_{DOC\_REWETTED}\right) \quad (7)$$

Where:
CO_2-C_{DOC} = off-site CO_2-C emissions from dissolved organic C exported from rewetted organic soils, tonnes C yr^{-1};
A_c = area of rewetted organic soils in climate zone c, ha;
$EF_{DOC\_REWETTED\ c}$ = CO_2-C emission factor from DOC export from rewetted organic soils in climate zone c, tonnes C ha^{-1} yr^{-1}.

$$EF_{DOC\_REWETTED} = DOC_{FLUX} * Frac_{DOC-CO2} \quad (8)$$

Where:
$EF_{DOC\_REWETTED\ c}$ = emission factor for DOC from rewetted organic soils, tonnes C ha^{-1} yr^{-1};
DOC_{FLUX} = net flux of DOC from natural (undrained) and rewetted organic soils, tonnes C ha^{-1} yr^{-1};
$Frac_{DOC\_CO2}$ = conversion factor for proportion of DOC converted to CO_2 following export from site and equates to 0.9.

Table 4. Default emission factor (EF_{CO2}) and associated uncertainty, for CO_2-C from rewetted organic soils

Climate zone	Nutrient status	EF_{CO2}, tonnes CO_2-C ha^{-1} yr^{-1}	95% range
Boreal	poor	-0.34	-0.59 – -0.09
	rich	-0.55	-0.77 – -0.34
Temperate	poor	-0.23	-0.64 – +0.18
	rich	+0.50	-0.71 – +1.71

Table 5. Default DOC emission factors ($EF_{DOC\_REWETTED}$) from rewetted organic soils

Climate zone	DOC_{FLUX}, t C ha^{-1} yr^{-1}	$EF_{DOC\_REWETTED}$, tonnes CO_2-C ha^{-1} yr^{-1}
Boreal	0.08 (0.06 – 0.11)	0.08 (0.05 – 0.11)
Temperate	0.26 (0.17 – 0.36)	0.24 (0.14 – 0.36)

According to the IPCC Guidelines, a Tier 2 methodology uses country-specific EFs and parameters, spatially disaggregated to reflect regionally important practices and dominant ecological dynamics. It may be appropriate to sub-divide activity data and EFs according to the present vegetation composition which is a representation of the water table depth and soil properties or by land use prior to rewetting. A Tier 3 methodology involves a comprehensive understanding and representation of the dynamics of CO_2-C emissions and removals on rewetted organic soils, including the effect of site characteristics, soil characteristics, vegetation composition, soil temperature and mean water table depth. These could be integrated into a dynamic, mechanistic-based model or through a measurement-based approach.

Note 4: In the recent study by Tiemeyer et al. (2020) in Germany, it is mentioned that at wet sites with lower net ecosystem exchange (or even a slight uptake) DOC might be a relevant component of the total C budget (e.g., Evans et al., 2016). Frank (2016) measured average DOC losses of 120 kg ha^{-1} yr^{-1} from a bog rewetted after peat cutting in temperate climate zone, which is clearly lower than the IPCC Wetlands Supplement default value (mean 260 kg ha^{-1} yr^{-1}, Table 5) for rewetted organic soils. Therefore, additional measurements might be useful.

Note 5: Results of the LIFE OrgBalt project will provide higher Tier level methodology aiming at Tier 3 for all GHGs. Various land use changes due to different rewetting scenarios are included in the study (Table 6).

Table 6. Land use changes due to different rewetting scenarios included in the LIFE OrgBalt project

Country	Land use before rewetting	Land use after rewetting (depending on local conditions)
Latvia	Forest land	Forest land with wet soils
	Cropland	Forest land with wet soils
		Fen (wetland that mainly receives nutrients from groundwater)
		Grassland with wet (saturated) soils
Lithuania*	-	-
Estonia*	-	-
Finland	Forestry drained peatland where even aged forestry (including clear-felling at the end of rotation and dich cleaning) are practiced before growing the follow-up tree generation.	Continuous cover forestry with periodic selective tree harvesting as management where water level in soil is maintained by evaporation of the tree stand, and cyclic lowering of water level by ditch cleaning is avoided.
* Only reference sites in Lithuania and Estonia		

1.3 CO_2 emissions and removals from coastal wetlands

1.3.1 CO_2 emissions and removals from coastal wetlands (mangroves) with organic soils due to forest management practices

The Tier 1 default assumption is that soil CO_2 emissions and removals are zero (EF = 0) for forest management practices in mangroves. This assumption can be modified at higher tiers. At higher tiers, it is recommended to consider CO_2 emissions from soils due to forest clearing in carbon stock estimations.

1.3.2 CO_2 emissions and removals from coastal wetlands with organic soils due to extraction

Extraction refers collectively to the following activities: (A) excavation (associated with dredging used to provide soil for raising the elevation of land, or excavation to enable port, harbour and marina construction and filling), (B) construction of aquaculture ponds and (C) construction of salt production ponds (where soil is excavated to build berms where water is held in ponds). Each of these extraction activities is associated with the removal of biomass, dead organic matter and soil, which results in significant emissions when their removal is from saturated (water-logged) to unsaturated (aerobic) conditions. The Tier 1 methodology assumes that the biomass, dead organic matter and soil are all removed and disposed of under aerobic conditions where all carbon in these pools is emitted as CO_2 during the year of the extraction with no subsequent changes.

Regardless of the land-use category, the loss in soil carbon associated with extraction activities is estimated as $\Delta C_{conversion}$ and specified as Equation (9) (Equation 4.6. of the IPCC Wetlands Supplement).

$$\Delta C_{SO-CONVERSION} = \sum_{V,S} (SO_{AFTER} - SO_{BEFORE})_{V,S} * A_{CONVERTED\ V,S} \quad (9)$$

Where:

$\Delta C_{SO\text{-}CONVERSION}$ = initial changes in soil carbon stock from conversion due to extraction activities by vegetation type (v) and soil type (s), tonnes C;

SO_{AFTER}= soil carbon stock per unit of area, immediately after the conversion, by vegetation type (v) and soil type (s), tonnes C ha^{-1}, default value = 0;

SO_{BEFORE}= soil carbon stock per unit of area, immediately before the conversion, by vegetation type (v) and soil type (s), tonnes C ha^{-1};

A = area of conversion by vegetation type (v) and soil type (s), ha.

The Tier 1 methodology assumes that the soil is removed and disposed of under aerobic conditions where the C stock is emitted as CO_2 (oxidised) during the year of the extraction. The C stock is taken as all soil C except any refractory (unoxidisable) C. In mangrove soils, 4% of the C stock is refractory and this is taken to be representative of the refractory C in tidal marshes and seagrass meadows as well. Therefore, after the initial conversion of the soil pool in the year in which the activity occurs, CO_2 emissions are reported as zero. Default Tier 1 soil C stocks (to 1 m depth) for mangrove, tidal marsh and seagrass meadows for the calculation of CO_2 emissions are given in Table 7 (Table 4.11 of the IPCC Wetlands Supplement).

Table 7. Soil carbon stocks for mangroves, tidal marshes and seagrass meadows with organic soils for extraction activities

Organic soils			
Vegetation type	**SO_{BEFORE}, t C ha^{-1}**	**95% CI**	**Range**
Mangrove	471	436, 510	216-935
Tidal marsh	340	315, 366	221-579
Seagrass meadow	NA (seagrass meadows are assumed to be on mineral soils.)		

According to the IPCC Guidelines, at Tier 2, methodology can be applied to disaggregate by vegetation type and soil type. For the specific extraction activity, countries may use national data to determine their particular extraction processes and the volume of soil removed, if sufficient data are available. Because tidal marshes can occur in a range of climates, disaggregating by climate may also be applied to improve estimates if those country-specific data are available. Tier 2 may also refine the estimate for the soil C stock that is excavated to construct the aquaculture or salt production ponds by including country-specific information on the depth excavated during the construction phase. Tier 3 methods can employ models to estimate CO_2 emissions based on the effect of temperature and salinity on soil oxidation both seasonally and with climate and vegetation type. At Tier 3, it is good practice for countries to validate models with field measurements. Tier 3 methods may also include site-specific measurements of, for example, carbon content, bulk density, clay content, salinity, redox potential, etc., to determine the underlying processes of emissions.

1.3.3 CO_2 emissions and removals from organic soils due to rewetting, revegetation and creation of mangroves, tidal marshes and seagrass meadows

The rewetting and revegetation activity refers collectively to the following (1) rewetting, which saturates the soil of drained sites previously colonised by mangrove and tidal marshes and is a prerequisite for, and thus facilitates, reestablishment of the original vegetation by natural recolonisation, direct seeding and/or purposeful planting, (2) raising or lowering the soil elevation to facilitate reestablishment of the original vegetation by natural recolonisation, direct seeding and/or purposeful planting, (3) creation of coastal wetlands where it may be difficult to identify where they previously occurred and are in proximity to the coastal margin, and (4) reestablishment of seagrass on undrained soils by natural recolonisation, direct seeding and/or purposeful planting.

At Tier 1, the default method, EF_{RE} values are to be used in conjunction with Equation (10) (Equation 4.7 of the IPCC Wetlands Supplement) to estimate CO_2 emissions.

$$CO_{2SO-RE} = \sum_{V,S,C} (A_{RE} * EF_{RE})_{V,S,C} \qquad (10)$$

Where:

$CO_{2\,SO\text{-}RE}$ = CO_2 emissions associated with rewetting, revegetation and creation activities by vegetation type (v), soil type (s) and climate (c), tonnes C yr^{-1};

A_{RE} = area of soil that has been influenced by rewetting, revegetation and creation activities by vegetation type (v), soil type (s) and climate (c), ha;

EF_{RE}= CO_2 emissions from aggregated mineral and organic soils that have been influenced by rewetting and revegetation activities by vegetation type (v), soil type (s) and climate (c), tonnes C ha^{-1} yr-1.

EF_{RE} = 0 for rewetted and naturally saturated soils where no vegetation has been re-estabished or where re-establishment is expected to occur by recolonization. At Tier 1, EF_{RE} is applied (Table 8 based on Table 4.12 of the IPCC Wetlands Supplement) when vegetation has been established through replanting or reseeding. If, however, re-establishment of vegetation is expected to occur by recolonization, EF_{RE} = 0 is applied at Tier 1. When vegetation has been established the EFRE is disaggregated with respect to vegetation type. Organic and mineral soils are not differentiated at Tier 1 within any particular vegetation type, as the organic C inputs mainly derive from the production of above-ground and below-ground biomass under similar conditions of soil saturation. Land area estimates should be based on land classification within the new land-use category (if applicable) to apply Tier 1 EF_{RE}.

Table 8. Annual emission factors associated with rewetting (EF_{RE}) on aggregated organic and mineral soils at initiation of vegetation reestablishment

Ecosystem	EF_{REWET}, tonnes C ha^{-1} yr^{-1}	95% CI	Range
Mangrove	-1.62	1.3, 2.0	0.10 – 10.2
Tidal marsh	-0.91	0.7, 1.1	0.05 – 4.65
Seagrass meadow	-0.43	0.2, 0.7	0.09 – 1.12

According to the IPCC Guidelines, under the Tier 2 method, country-specific C accumulation rates could be dissagregated with respect to area of organic and mineral soils. Where such country-specific data can be acquired and used to improve estimations, disaggregation by climate zone could also be applied. Under the Tier 3 method, the land use prior to rewetting, its climate and vegetation type could be taken into account. A comprehensive understanding and representation of the dynamics of CO_2 gas EFs, based on field measurements of, for example, carbon content, bulk density, clay content, salinity, redox potential, etc., could be employed at Tier 3. A Tier 3 approach could also use empirical measurements and models that take into account the time-dependent nature of the CO_2 fluxes over a range of timescales, location relative to the low to high intertidal zone or other dynamics.

1.3.4 CO_2 emissions and removals from organic soils due to drainage in mangroves and tidal marshes

Annual C losses from drained organic soils are applied similarly for mangroves and tidal marshes (but not applicable to seagrass meadows) at Tier 1 level of estimation.
Guidance for inventories on drainage in coastal wetlands follows the assumptions at Tier 1 level of estimation that:

- emissions persist as long as the soil remains drained or as long as it takes for soil C stocks equivalent to those in natural/undrained settings with vegetation (Table 7) to be oxidised and
- the drainage condition is characterized by full drainage (i.e. the water table has been changed to 1 m below the soil surface).

Emissions from drained coastal wetland soils are estimated at Tier 1 for mangrove forests and tidal marshes using Equation (11) (Equation 4.8. of the IPCC Wetlands Supplement).

$$CO_{2-SO-DR} = (A_{DR} * EF_{DR}) \tag{11}$$

Where:
$CO_{2\text{-SO-DR}}$ = CO_2 emissions from aggregated organic and mineral soil C associated with drainage, tonnes C yr^{-1};
A_{RE} = land area under drainage, ha;
EF_{DR}= CO_2 emissions from organic or mineral soil C associated with drainage; tonnes C ha^{-1} yr^{-1}.

As described above, the Tier 1 EF is applied until the soil C stock (Table 7) is depleted and determines the time frame for emissions due to drainage regardless of whether a land-use change occurs. At Tier 1, a generic default EF is applied for drainage, regardless of vegetation or soil type (Table 9 based on Table 4.13 of the IPCC Wetlands Supplement). That is, the same EF is applied regardless of the management activity involving soil drainage.

Table 9. Annual emission factors associated with drainage (EF_{DR}) on aggregated organic and mineral soils

Ecosystem	EF_{DR}, tonnes C ha^{-1} yr^{-1}	95% CI	Range
Tidal marshes and mangroves	7.9	5.2, 11.8	1.2-43.9

According to the IPCC Guidelines, the Tier 2 estimation method is the same as the Tier 1 method, but national data can be used to additionally disaggregate by vegetation, soil type and regional climatic factors, if such data are available at reasonable cost. Tier 3 methods could take account of differences in the management of the drained wetland. Empirical measurements of gas flux based on site-specific measurements of, for example, carbon content, bulk density, clay content, salinity, redox potential, etc., to determine the underlying processes of emissions could be included. Site differences in frequency of drainage activity could also be considered at Tier 3 methods. Other factors that could be used to apply disaggregated data include salinity and tidal export of DOC and POC.

Note 6: The LIFE OrgBalt project does not include coastal wetlands and further investigations are required *(for instance, in areas with alluvial soils).*

1.4 Non-CO_2 emissions and removals from organic soils

1.4.1 CH_4 emissions and removals from drained inland organic soils

According to the Tier 1 methodology CH_4 emissions from the land surface are estimated using a simple EF approach (see Equation (12) based on Equation 2.6 of the IPCC Wetlands Supplement), depending on climate (boreal, temperate or tropical), type of land use and soil fertility (nutrient-rich/nutrient-poor organic soils). Different land uses imply drainage to different depths. Ditch CH_4 emissions are quantified for any area of drained organic soil where there are ditches or drainage canals. Estimation of ditch CH_4 emissions requires information on the land-use class and on the area of the landscape occupied by the drainage ditch network. All Tier 1 default values including EFs are provided in the IPCC Wetlands Supplement.

$$CH_{4\_organic} = \sum_{c,n,p} \left(A_{c,n,p} * \left((1 - Frac_{ditch}) * EF_{CH_{4}land_{c,n}} + Frac_{ditch} * EF_{CH_{4}ditch_{c,p}} \right) \right) \quad (12)$$

Where:

$CH_{4\_organic}$ = annual CH_4 loss from drained organic soils, kg CH_4 yr^{-1};

$A_{c,n,p}$ = land area of drained organic soils in a land-use category in climate zone c, nutrient status n and soil type p, ha;

$EF_{CH4\_landc,n}$ = emission factors for direct CH_4 emissions from drained organic soils, by climate zone c and nutrient status n, kg CH_4 ha^{-1} yr^{-1};

$Frac_{ditch}$ = fraction of the total area of drained organic soil which is occupied by ditches (where "ditches" are considered to be any area of manmade channel cut into the peatland). The ditch area may be calculated as the width of ditches multiplied by their total length. Where ditches are cut vertically, ditch width can be calculated as the average distance from bank to bank. Where ditch banks are sloping, ditch width should be calculated as the average width of open water plus any saturated fringing vegetation.

Default EFs for the Tier 1 method are provided in Table 10 (Table 2.3 of the IPCC Wetlands Supplement) for EF_{CH4_land} and Table 11 (Table 2.4 of the IPCC Wetlands Supplement) for EF_{CH4_ditch}.

Table 10. CH_4 emission/removal factors for drained organic soils (EF_{CH4_LAND}) in all land-use categories

Land-use category	**Nutrient status**	**Climate/vegetation zone**	**Emissions factor, kg CH_4 ha^{-1} yr^{-1}**	**95% confidence interval (centred on mean)**	
Forest land, drained	nutrient-poor	boreal	7.0	2.9	11
	nutrient-rich	boreal	2.0	-1.6	5.5
Forest land, drained	all	temperate	2.5	-0.60	5.7
Cropland, drained	all	boreal and temperate	0	-2.8	2.8
Grassland, drained	all	boreal	1.4	-1.6	4.5
Grassland, drained	nutrient-poor	temperate	1.8	0.72	2.9
Grassland, deep-drained	nutrient-rich	temperate	16	2.4	29
Grassland, shallow-drained	nutrient-rich	temperate	39	-2.9	81
Peat extraction	all	boreal and temperate	6.1	1.6	11

Settlements	all	all	There is no fixed default emission/removal factor for Settlements. For this category, it is good practice to take the default emission/removal factor of the land-use category that is closest to national conditions of drained organic soils under Settlements.

Table 11. Default CH_4 emission factors from drainage ditches

Climate zone	Land use	$EF_{CH4\text{-}ditch}$, kg CH_4 ha^{-1} yr^{-1}	Uncertainty range, kg CH_4 ha^{-1} yr^{-1}	$Frac_{ditch}$ (indicative value)
Boreal/temperate	drained forest land, drained wetlands	217	41-393	0.025
	shallow-drained grassland	527	285-769	0.05
	deep-drained grassland, cropland	1165	335-1995	0.05
	peat extraction	542	102-981	0.05

According to the IPCC Guidelines, the Tier 2 approach for estimating CH_4 emissions from drained organic soils incorporates country-specific information into Equation (12). Under Tier 2, the EFs for CH_4 from the surface of drained organic soils can be further differentiated by drainage depth, land-use subcategories or vegetation type (such as presence or absence of plant species that act as transporters of CH_4 from the soil to the atmosphere). Tier 2 approaches for CH_4 emissions from drainage ditches generally follow the Tier 1 approach, with country-specific measurements or estimates of annual mean ditch CH_4 emissions, and national or regional estimates of fractional ditch area that reflect local drainage practices. Tier 3 methods for estimating CH_4 emissions from drained organic soils involve a comprehensive understanding and representation of the dynamics of CH_4 emissions and removals on managed peatlands and organic soils, including the effect of site characteristics, peat/soil type, peat degradation and depth, land-use intensity, drainage depth, management systems, and the level and kinds of fresh organic matter inputs. Emission spikes may also occur, for example during spring thaw or strong rains or when debris from ditch dredging is deposited on adjacent land. For CH_4 emissions from drainage ditches, development of a Tier 3 approach could take account of the influence of land-management activities (e.g. organic matter additions to agricultural land) on substrate supply for methane production in ditches, of possible short-term pulses of ditch CH_4 emissions associated with land-use change, and of the legacy effects of past land use (e.g. nutrient-enriched soils). Information on drainage ditch characteristics and maintenance may be used to refine ditch CH_4 emission estimates.

Note 7: Results of the LIFE OrgBalt project will provide higher Tier level methodology aiming at Tier 3.

1.4.2 N_2O emissions and removals from drained inland organic soils

According to the Tier 1 methodology direct N_2O emissions from managed (drained) organic soils are estimated using Equation (13) (based on Equation 2.7 of the IPCC Wetlands Supplement). This Equation is used to estimate N_2O for specific land-use categories, but there are not enough data available to develop coefficients to modify EFs by condition-specific variables (e.g. variations in drainage depths).

$$\begin{aligned} N_2O - N_{OS} = [&(F_{OS,CG,Bor} * EF_{2CG,Bor}) + (F_{OS,CG,Temp} * EF_{2CG,Temp}) \\ &+ (F_{OS,CG,Trop} * EF_{2CG,Trop}) + (F_{OS,F,Bor,NR} * EF_{2F,Bor,NR}) \\ &+ (F_{OS,F,Temp,NR} * EF_{2CG,Temp,NR}) + (F_{OS,F,Bor,NP} * EF_{2F,Bor,NP}) \\ &+ (F_{OS,F,Temp,NP} * EF_{2F,Temp,NP}) + (F_{OS,F,Trop} * EF_{2F,Trop})] \end{aligned} \quad (13)$$

Where:

$N_2O\text{-}N_{OS}$ = annual direct N_2O–N emissions from managed/drained organic soils, kg N_2O–N yr^{-1};

F_{OS} = annual area of managed/drained organic soils (the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient-Rich and Nutrient-Poor, respectively), ha;
EF_2 = emission factor for N_2O emissions from drained/managed organic soils, (the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient-Rich and Nutrient-Poor, respectively), kg N_2O–N $ha^{-1}yr^{-1}$.

Default EFs were derived from the mean of all data within each land-use class, typically from chamber measurements (Table 12 based on Table 2.5 of the IPCC Wetlands Supplement).

Table 12. Direct N_2O emission/removal factors from drained organic soils in all land-use categories

Land-use category	Nutrient status	Climate/vegetation zone	Emission factor, kg N_2O-N ha^{-1} yr^{-1}	95% confidence interval	
Forest land, drained	nutrient-poor	boreal	0.22	0.15	0.28
	nutrient-rich	boreal	3.2	1.9	4.5
Forest land, drained	all	temperate	2.8	-0.57	6.1
Cropland, drained	all	boreal and temperate	13	8.2	18
Grassland, drained	all	boreal	9.5	4.6	14
Grassland, drained	nutrient-poor	temperate	4.3	1.9	6.8
Grassland, deep-drained	nutrient-rich	temperate	8.2	4.9	11
Grassland, shallow-drained	nutrient-rich	temperate	1.6	0.56	2.7
Peatland managed for extraction	all	boreal and temperate	0.30	-0.03	0.64
Settlements	all	all	There is no fixed default emission/removal factor for Settlements. For this category, it is good practice to take the default emission/removal factor of the land-use category that is closest to national conditions of drained organic soils under Settlements.		

According to the IPCC Guidelines, Tier 2 estimates are to be based on the Tier 1 (Equation (13)), but use country- or region-specific EFs. These can be further stratified by drainage class, nutrient status of organic soils or other criteria used for stratifying organic soils for direct N_2O emissions. The corresponding EFs are country- or region-specific and take into account the land-management systems. Tier 2 EFs can follow the Tier 1 assumption that N mineralisation from degrading organic matter exceeds the amount of N input so that measured N_2O emissions are attributed in their entirety to the drained organic soil. Tier 3 methods are based on modelling or measurement approaches. Tier 3 approaches can attribute N_2O emissions from drained organic soils separately to the mineralisation of peat or organic matter versus N input by fertiliser, crop residues and organic amendments. Attribution could rely on the fraction of N_2O released by N_2O emissions peaks after N fertilisation, or by subtracting a fertiliser EF from total N_2O emissions. Nitrogen mineralisation from the drained organic soil can be estimated by CO_2-C emissions from the drained organic soil and the C/N ratio of the topsoil; this value could be used to predict N_2O emissions.

Note 8: Results of the LIFE OrgBalt project will provide higher Tier level methodology aiming at Tier 3.

1.4.3 CH_4 emissions and removals from rewetted organic soils

CH_4 emissions and removals from the soils of rewetted organic soils result from 1) the balance between CH_4 production and oxidation and 2) emission of CH_4 produced by the combustion of soil organic matter during fire (Equation (14) based on Equation 3.7 of the IPCC Wetlands Supplement). The default EFs provided in IPCC Guidelines only cover CH_4-C_{soil} (Table 13). These CH_4 emissions result from the decomposition of the organic soil by microbes under anaerobic conditions and are strongly controlled by oxygen availability within the soil and by soil temperature. Methane emissions also originate from the decay of non-tree vegetation, since these pools cannot be easily separated on organic soils they are combined here as CH_4-C_{soil}. The probability of fire occurrence in rewetted organic soils is likely small if water table position is near the surface, but possible soil emissions from fires are included here for completeness.

$$CH_4 - C_{rewetted\ org\ soil} = CH_4 - C_{soil} + L_{fire} - CH_4 - C \qquad (14)$$

Where:

CH_4-$C_{rewetted\ org\ soil}$ = CH_4-C emissions/removals from rewetted organic soils, tonnes C yr^{-1};
CH_4-C_{soil} = emissions/removals of CH_4-C from rewetted organic soils, tonnes C yr^{-1};
L_{fire}-CH_4-C = emissions of CH_4-C from burning of rewetted organic soils, tonnes C yr^{-1} (see section 1.5).

The default methodology (Tier 1) covers CH_4 emissions from rewetted organic soils (Equation (15) based on Equation 3.8 of the IPCC Wetlands Supplement).

$$CH_4 - C_{soil} = \frac{\sum_{c,n}(A * EF_{CH4\ soil})_{c,n}}{1000} \qquad (15)$$

Where:

CH_4-C_{soil} = emissions/removals of CH_4-C from rewetted organic soils, tonnes C yr^{-1};
$A_{c,n}$ = area of rewetted organic soils in climate zone c and nutrient status n, ha;
$EF_{CH4\ soil}$ = emission factor from rewetted organic soils in climate zone c and nutrient status n, kg CH_4-C ha^{-1} yr^{-1}.

Table 13. Default emission factors for CH_4 from rewetted organic soils

Climate zone	Nutrient status	EF_{CH4}	95% range
Boreal	poor	41	0.5-246
	rich	137	0-493
Temperate	poor	92	3-445
	rich	216	0-856

According to the IPCC Guidelines, Tier 2 calculations use country-specific EFs and parameters, spatially disaggregated to reflect regionally important ecosystems or practices. In general, CH_4-C fluxes from wet organic soils are extremely skewed, approaching a log-normal (right-tailed) distribution. A Tier 3 approach involves a comprehensive understanding and representation of the dynamics of CH_4 emissions on rewetted organic soils, including the representation of interactions between the dominant drivers of CH_4 dynamics and potentially addressing different flux pathways, including ebullition.

Note 9: Results of the LIFE OrgBalt project will provide a higher Tier level methodology aiming at Tier 3. Various land use changes due to different rewetting scenarios are included in the study (Table 7).

1.4.4 N_2O emissions and removals from rewetted organic soils

The emissions of N_2O from rewetted organic soils are controlled by the quantity of N available for nitrification and denitrification, and the availability of the oxygen required for these chemical reactions.

Oxygen availability is in turn controlled by the depth of the water table. Raising the depth of the water table will cause N_2O emissions to decrease rapidly, and fall practically to zero if the depth of the water table is less than 20 cm below the surface. Saturated conditions may promote denitrification and the consumption of N_2O, but in practice this effect is very small and considered negligible. This is because anoxic conditions and low NH_4^+ availability reduce the rates of mineralisation and nitrification, two processes that are prerequisites for denitrification. Equation (16) (Equation 3.9 of the IPCC Wetlands Supplement) includes the essential elements for estimating N_2O emissions from rewetted organic soils.

$$N_2O_{rewetted\ org\ soil} - N = N_2O_{soil} - N + L_{fire} - N_2O - N \quad (16)$$

here:

$N_2O_{rewetted\ org\ soil}$-N = N_2O-N emissions from rewetted organic soils, kg N_2O-N yr^{-1};
N_2O_{soil}-N = N_2O-N emissions from the soil pool of rewetted organic soils, kg N_2O-N yr^{-1};
L_{fire}-N_2O-N = N_2O-N emissions from burning of rewetted organic soils, kg N_2O-N yr^{-1}.

Under Tier 1, emissions of N_2O from rewetted soils are assumed to be negligible. Countries where rewetted organic soils are a significant component of a key category should take into account patterns of N_2O emissions from these sites, particularly where the nitrogen budget of the watershed is potentially influenced by significant local or regional N inputs such as in large-scale farmland development. Country-specific EFs should take into account fluctuations of the water table depth, which controls oxygen availability for nitrification, and previous land use, which may have resulted in top soil enrichment. The development of country-specific EFs should take into consideration that significant N inputs into rewetted ecosystems may originate from allochtonous (external) sources, such as fertilizer use in the surrounding watershed.

Note 10: Results of the LIFE OrgBalt project will provide a higher Tier level methodology aiming at Tier 3. Various land use changes due to different rewetting scenarios are included in the study (Table 7).

1.4.5 CH_4 emissions and removals from organic soils in coastal wetlands (rewetted mangroves and tidal

In the case of rewetting of lands that had been previously in an agricultural (or any other drained) land-use category, the Tier 1 method estimates CH_4 emissions without considering the land-use prior to rewetting (Equation (17) based on Equation 4.9 of the IPCC Wetlands Supplement).

$$CH_{4-SO-REWET} = \sum_V (A_{REWET} * EF_{REWET})_V \quad (17)$$

Where:

$CH_{4-SO-REWET}$ = CH_4 emissions associated with rewetted and created coastal wetland by vegetation type (v), kg CH_4 yr^{-1};
A_{REWET} = area of soil that has been rewetted (including tidal marsh or mangrove wetland creation), by vegetation type (v), ha;
EF_{REWET} = CH_4 emissions from mineral and organic soils that have been rewetted by vegetation type (v), kg CH_4 ha^{-1} yr^{-1}.

Tier 1 CH_4 EFs are found in Table 14 (Table 4.14 of the IPCC Wetlands Supplement) and should be used in conjunction with Equation (17) to estimate emissions taking into account vegetation type (and associated salinity level).

Table 14. Emission factors for CH_4 (EF_{REWET}) for Tier 1 estimation of rewetted land previously vegetated by tidal marshes and mangroves

Vegetation type	Salinity, ppt	EF_{REWET}, kg CH_4 ha^{-1} yr^{-1}	95% CI	Range
Tidal freshwater and brackish marsh and mangrove	< 18	193.7	99.8, 358	10.95-5392
Tidal saline water marsh and mangrove1	> 18	0 (marshes and mangroves with salinities >1 ppt approximate an order of magnitude lower rates than from tidal freshwater and brackish marsh (as defined here, salinity <18ppt), so a Tier 1 assumption is to apply 0)		0-40

According to the IPCC Guidelines, at Tier 2, country-specific data can be applied. Improved estimates can be produced if country-specific data could include more disaggregation by salinity and vegetation type. At Tier 3, country-specific values can be used and developed to model possible time-dependent changes in CH_4 emissions. Tier 3 methods may also consider vegetation composition and density, as plants can act as a conduit for gas exchange between the soil and atmosphere.

Note 11: The LIFE OrgBalt project does not include coastal wetlands and further investigations are required (for instance, in areas with alluvial soils).

1.4.6 CH_4 emissions and removals from organic soils in pristine wetlands

Neither 2006 IPCC Guidelines nor IPCC Wetlands Supplement provide guidelines for calculation of CH_4 emissions and removals from organic soils in pristine wetlands including wet grassland, forest land and wetlands.

Note 12: Results of the LIFE OrgBalt project will provide country-specific GHG emission factors for pristine wetlands.

1.5 GHG emissions from burning of organic soils

1.5.1 CO_2 and non-CO_2 emissions from fires on drained inland organic soils

It is good practice to report GHG emissions from fires on all managed lands with organic soils, including all fire-related emissions both from natural fires and from those that have a human-induced cause (e.g. soil drainage) even if the initiation of the fire is non-anthropogenic in nature (e.g. lightning strike). Emissions from fires on organic soils critically depend on extent and depth of organic soil, fuel moisture, water table depth and hence thickness of the drained layer, and resulting depth of consumed organics, all of which are affected by site characteristics, weather, land management, fire type and climate. At Tier 1, differentiation by land-management category and fire type is possible, but reporting at higher tiers will enable a greater level of differentiation between land use, site characteristics and fire types. The parameters required to calculate the CO_2 and non-CO_2 emissions from burning organic soils are area burnt, mass of fuel available for consumption, combustion factor (also known as burning efficiency and can be used to characterise smouldering vs. flaming fires), and EF.

The mass of fuel that can potentially burn in a fire event on organic soils will be determined by measuring the depth of burn, along with soil bulk density and C content; the former is strongly controlled by soil water content (influenced by position of the water table or permafrost depth) while the latter variables are ideally measured in the field. While default values can be used for Tier 1 reporting (Equation (18) based on the Equation 2.8 of the IPCC Wetlands Supplement), data on the depth of burn and soil C density need to be determined in the case of higher tiers. The combustion factor describes how much of the fuel mass available is actually consumed during a fire event, i.e. converted into CO_2 or non-CO_2 gases. The EF (G_{ef}) determines the mass of CO_2 or non-CO_2 gas emitted per unit mass of fuel consumed by the fire. Total emissions of CO_2 or non-CO_2 gases are calculated from the product of area burnt and the corresponding biomass loading, combustion factor and EF.

$$L_{fire} = A * M_B * C_f * G_{ef} * 10^{-3} \quad (18)$$

Where:

L_{fire} = amount of CO_2 or non-CO_2 emissions, e.g. CH_4 from fire, tonnes;
A = total area burnt annually, ha;
M_B = mass of fuel available for combustion, tonnes ha^{-1} (i.e. mass of dry organic soil fuel) (default values in Table 18, units differ by gas species);
C_f = combustion factor, dimensionless;
G_{ef} = emission factor for each gas, g kg^{-1} dry matter burnt (default values in Table 19).

The Tier 1 method uses default values for M_B, C_f and G_{ef} along with default EFs provided in Table 18 and Table 19 (Tables 2.6 and 2.7 of the IPCC Wetlands Supplement). Gas species in Table 19 are given as CO_2-C, CO and CH_4. Due to limited data available in the scientific literature, organic soils have been very broadly stratified according to climate domain (boreal/temperate and tropical) and fire type (wild vs. prescribed). Values are derived from the literature for all categories with the exception of prescribed fires. For higher tiers, data on the variation in the mass of fuel available (based on site- or region-specific data, including area of organic soil burnt, depth of organic soil, depth of burn and/or depth of water table/soil moisture content values and soil bulk density) are incorporated.

Table 15. Organic soil fuel consumption values (mass of fry matter for a range of organic soil and fire types, to be used conjunction with Equation (18), to estimate the product of quantities M_b and C_f)

Climate/vegetation zone	Sub-category	Mean, t d.m. ha^{-1}	95% confidence interval, t d.m. ha^{-1}	
Boreal/temperate	Wildfire (undrained peat)	66	46	86
	Wildfire (drained peat)	336	4 (Standard error)	
	Prescribed fire (land management	-	-	

Table 16. Emission factors for organic soil fires (means ±95% CI, to be used as quantity G_{ef} in Equation (18))

Climate/vegetation zone	CO_2-C, g kg^{-1} dry matter burnt	CO, g kg^{-1} dry matter burnt	CH_4, g kg^{-1} dry matter burnt
Boreal/temperate	362 ± 41	207 ± 70	9 ± 4

At higher tiers, the approach for estimating GHG emissions from fires on organic soils incorporates country-specific information into Equation (18). When deriving higher tier EFs, country-specific combustion factors need to be developed. Regional factors for stratification could include:

- stratification by drainage class - position of the soil water table is a proxy for soil moisture, which determines depth of burn;
- stratification by depth of burn - this can be measured in the field post-fire or using remote sensing approaches;
- stratification by fire type (wild vs. prescribed fires) - GIS techniques of interpolation may be

helpful in this analysis; under Tier 3, one might consider annual sampling of a number of control sites;

- stratification by organic soil type taking into account general hydrology (e.g. bog vs. fen) and vegetation structure (open, shrubby, forested) whenever possible;
- use of regionally specific values for organic soil bulk density and carbon concentration; and
- stratification by land-use and management types, including differences in drainage layout and intensity, land-use intensity and practices, all of which will influence the mass of fuel available for combustion.

EFs can be derived from measurements (field or laboratory-based) or calculations validated against country-specific measurements. A higher tier approach might also use process-based models, adequately validated using observation data that take into account temporal and spatial variations in the differences between fires on different types of organic soils and conditions and fuel combustion efficiencies. This approach will involve a comprehensive mechanistic understanding of combustion of organic soils, including the effects of site characteristics, drainage intensity, vegetation cover, soil type and depth, management practices, depth of water table and soil moisture, among others. Models ideally also take into account the fire return interval.

1.5.2 CO_2 and non-CO_2 emissions from fires on rewetted organic soils

While the likelihood of fires on rewetted organic soils is considered low (particularly in comparison to drained organic soils), fire risk may still be real. Emissions from the burning of organic soils can be estimated following the methodologies in Equation (18) using the fuel consumption values estimated for undrained organic soils given in Table 18 (same value for all climates) as well as EFs from Table 19.

Note 13: Results of the LIFE OrgBalt project will not provide country-specific GHG emission factors for organic soil burning. Reporting status of GHG emissions from organic soil burning in Latvia, Lithuania, Estonia and Finland is shown in Table 20.

Table 17. Reporting status of GHG emissions from organic soil burning in Latvia, Lithuania, Estonia and Finland

Country	Soil type	Reporting status
Latvia	drained	Latvia does not report GHG emissions from organic soil burning so far.
	rewetted	
Lithuania	all	Lithuania does not report GHG emissions from organic soil burning so far. Areas of peat extraction sites burnt (small areas, non-annual) present, lack of data of peat layer thickness burnt during wildfire.
Estonia		Estonia does not report GHG emissions from organic soil burning.
Finland	drained	Wildfire emissions on forest lands are reported only for CO_2 emissions. It is assumed that losses due to fires are mainly captured in the NFI tree measurements, and for the remining cases default emission factors from the 2006 IPCC guidelines (Table 2.5, p. 2.47) are applied. Controlled burning of post-logging burning of harvest residues (prescribed burning) is assumed to be carried out only on forest land on mineral soils (it refers to harvest residues, not soil). All wildfires on croplands and grasslands are reported under one class in national fire statistics. CO_2 from biomass burning is not reported as it is assumed that carbon is reabsorbed by the biomass during the growing season. CO and NO emissions from burning residue biomass are reported separately and not included in the total amount of GHG emissions. According to Decree 189/2009 of the Ministry of Agriculture and Forestry, field burning of crop residues has to be avoided and is allowed only if it is necessary in order to succeed in

		sowing or to prevent weeds or pests (it refers to biomass residues, not soil). GHG emissions from organic soil burning (peat extraction fields) are off-site and reported under energy sector emissions (Chapter 3.2.4 Energy industries in NIR-FI, 2021) .

2 CURRENTLY USED METHODOLOGY FOR CALCULATION OF GHG EMISSION FROM ORGANIC SOILS WITHIN NATIONAL GHG INVENTORY IN BALTIC STATES AND FINLAND

All Baltic States and Finland follow the 2006 IPCC Guidelines and IPCC Wetlands Supplement to calculate GHG emissions from organic soils within their national GHG inventories. For accounting GHG emissions, EF's based on Tier levels (1, 2 and 3) differ by country and land use type.

2.1 Latvia

Summary of currently used methodology for the calculation of GHG emissions from organic soils in Latvia is provided in Table 18.

Table 18. Currently used methodology for calculation of GHG emission from organic soils within the National GHG inventory in Latvia[3]

Land use		Soil type	Gas	Method	Emission factor		
Category	**Sub-category**				**Type**	**Value, unit**	**Source**
Forest Land	Forest Land remaining Forest Land, Land Converted to Forest Land	drained organic soils	on-site[4] CO_2	Tier 2	CS	0.52 t C ha^{-1} yr^{-1}	Lupiķis and Lazdiņš, 2017
			CH_4	Tier 1	D	2.5 kg CH_4 ha^{-1} yr^{-1} (organic soil); 217 kg CH_4 ha^{-1} yr^{-1} (drainage ditches)	Table 2.3 and Table 2.4 of the IPCC Wetlands Supplement
			N_2O	Tier 1	D	2.8 kg N_2O-N ha^{-1} yr^{-1}	Table 2.5 of the IPCC Wetlands Supplement
		rewetted organic soils	CO_2	Tier 1	D	0.5 t CO_2-C ha^{-1} yr^{-1}	Table 3.1 of the IPCC Wetlands Supplement
			CH_4	Tier 1	D	216 kg CH_4-C ha^{-1} yr^{-1}	Table 3.3 of IPCC Wetlands Supplement
Cropland	Cropland remaining Cropland, Land Converted to Cropland	drained organic soils	on-site[4] CO_2	Tier 2	CS	4.80 t CO_2-C ha^{-1} yr^{-1}	LIFE REestore project, Licite and Lupikis, 2020
			CH_4	Tier 1	D	0 kg CH_4 ha^{-1} yr^{-1} (organic soil); 1165 kg CH_4 ha^{-1} yr^{-1} (drainage ditches)	Table 2.3 and Table 2.4 of the IPCC Wetlands Supplement
			N_2O	Tier 2	CS	7.1 kg N_2O-N ha^{-1} yr^{-1}	LIFE REestore project, Licite and Lupikis, 2020
Grassland	Grassland remaining Grassland, Land Converted to Grassland	drained organic soils	on-site[4] CO_2	Tier 2	CS	4.40 t CO_2-C ha^{-1} yr^{-1}	LIFE REestore project, Licite and Lupikis, 2020
			CH_4	Tier 2	CS	57.80 kg CH_4-C ha^{-1} yr^{-1} (organic soil); 1165 kg CH_4 ha^{-1} yr^{-1} (drainage ditches)	LIFE REestore project, Licite and Lupikis, 2020 (organic soil); Table 2.4 of the IPCC Wetlands Supplement (drainage ditches)
			N_2O	Tier 2	CS	0.3 kg N_2O-N ha^{-1} yr^{-1}	LIFE REestore project, Licite and Lupikis, 2020
Wetlands	Wetlands Remaining Wetlands, Peat Extraction	drained organic soils	on-site[4] CO_2	Tier 2	CS	1.21 t CO_2-C ha^{-1} yr^{-1}	LIFE REestore project, Lazdiņš and Lupiķis 2019
			CH_4	Tier 2	CS	10.83 kg CH_4 ha^{-1} yr-1	LIFE REestore project, Lazdiņš and Lupiķis 2019

[3] Based on Latvia's National Inventory Report 1990-2019

[4] Only on-site CO_2 emissions from drained organic soils are reported, off-site CO_2 emissions are not reported in Latvia so far.

Land use		Soil type	Gas	Method	Emission factor		
Category	Sub-category				Type	Value, unit	Source
	Remaining Peat Extraction		N_2O	Tier 2	CS	0.44 kg N_2O-N ha^{-1} yr^{-1}	LIFE REestore project, Lazdiņš and Lupiķis 2019
		rewetted organic soils	CO_2	Tier 1	D	EF_{CO2} is 0.50 t CO_2-C ha^{-1} yr^{-1},but $EF_{DOC\_REWETTED}$ is 0.24 t CO_2-C ha^{-1} yr^{-1}	Table 3.1 and Table 3.2 of the IPCC Wetlands Supplement
			CH_4	Tier 1	D	216 kg CH_4-C ha^{-1} yr^{-1}	Table 3.3 of the IPCC Wetlands Supplement
	Land Converted to Wetlands, Land Converted to Other Wetlands	rewetted organic soils	CO_2	Tier 1	D	EF_{CO2} is 0.50 t CO_2-C ha^{-1} yr^{-1},but $EFD_{OC\_REWETTED}$ is 0.24 t CO_2-C ha^{-1} yr^{-1}	Table 3.1 and table 3.2 of the IPCC Wetlands Supplement
Settlements	Settlements Remaining Settlement, Land Converted to Settlement	drained organic soils	on-site[4] CO_2	Tier 1	D	7.9 t C ha^{-1} yr^{-1}	Table 2.1 of the IPCC Wetlands Supplement
			N_2O	Tier 1	D	13 kg N_2O-N ha^{-1} yr^{-1}	Table 2.5 of the IPCC Wetlands Supplement

2.2 Lithuania

Summary of currently used methodology for the calculation of GHG emissions from organic soils in Lithuania is provided in Table 19.

Table 19. Currently used methodology for calculation of GHG emission from organic soils within the National GHG inventory in Lithuania[5]

Land use		Soil type	Gas	Method	Emission factor		
Category	Sub-category				Type	Value, unit	Source
Forest Land	Forest Land remaining Forest Land, Land Converted to Forest Land	drained organic soils	CO_2	Tier 1	D	0.68 t C ha^{-1} yr^{-1}	Table 4.6, p. 4.53 of 2006 IPCC GL
			CH_4	NA	-	-	Under Tier1 2006 IPCC assumed insignificant
			N_2O	Tier 1	D	0.6 kg N_2O-N ha^{-1} yr^{-1} (N-rich) 0.1 kg N_2O-N ha^{-1} yr^{-1} (N-poor)	Table 11.1 , p. 11.11 2006 IPCC GL
		rewetted organic soils	CO_2	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory according to the IPCC 2006 Guidelines.
			CH_4	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory

[5] Based on Lithuania's National Inventory Report 1990-2019

							according to the IPCC 2006 Guidelines.
Cropland	Cropland remaining Cropland, Land Converted to Cropland	drained organic soils	CO_2	Tier 1	D	5 t CO_2-C ha^{-1} yr^{-1}	Table 5.6, p. 5.19 2006 IPCC GL
			CH_4	NA	–	–	–
			N_2O (reported under Agriculture sector)	Tier 1	D	8 kg N_2O-N ha^{-1} yr^{-1}	Table 11.1, p.11.11 2006 IPCC GL
Grassland	Grassland remaining Grassland, Land Converted to Grassland	drained organic soils	CO_2	Tier 1	D	0.25 t CO_2-C ha^{-1} yr^{-1}	Table 6.3, p. 6.17 2006 IPCC GL
			CH_4	NA	–	–	–
			N_2O (reported under Agriculture sector)	Tier 1	D	8 kg N_2O-N ha^{-1} yr^{-1}	Table 11.1, p.11.11 2006 IPCC GL
Wetlands	Wetlands Remaining Wetlands, Peat Extraction Remaining Peat Extraction	drained organic soils	on-site CO_2	Tier 1	D	1.1 t CO_2-C ha^{-1} yr^{-1} (peat rich) 0.2 t CO_2-C ha^{-1} yr^{-1} (peat poor)	Table 7.4, p. 7.13 2006 IPCC GL
			CH_4	NA	-	-	-
			N_2O	Tier 1	D	1.8 kg N_2O-N ha^{-1} yr^{-1} (N rich) Tier 1 considers only N rich	Table 7.6, p. 7.14 2006 IPCC GL
		rewetted organic soils	CO_2	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory according to the IPCC 2006 Guidelines.
			CH_4	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory according to the IPCC 2006 Guidelines.
	Land Converted to Wetlands, Land Converted to Other Wetlands	rewetted organic soils	CO_2	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory according to the IPCC 2006 Guidelines.
Settlements	Land Converted to Settlement	drained organic soils	on-site CO_2, FL-SL	Tier 2	CS	166.4 t C ha^{-1} yr^{-1} (FL rem FL) 266.8 t C ha^{-1} yr^{-1} (L conv to FL)	NIR 2021

			on-site CO_2, CL-SL	Tier 1	D	5 t CO_2-C ha^{-1} yr^{-1}	Table 5.6, p. 5.19 2006 IPCC GL
			on-site CO_2, GL-SL	Tier 1	D	0.25 t CO_2-C ha^{-1} yr^{-1}	Table 6.3, p. 6.17 2006 IPCC GL

2.3 Estonia

Summary of currently used methodology for the calculation of GHG emissions from organic soils in Estonia is provided in Table 20.

Table 20. Currently used methodology for calculation of GHG emission from organic soils within the National GHG inventory in Estonia[6]

Land use		Soil type	Gas	Method	Emission factor		
Category	Sub-category				Type	Value, unit	Source
Forest Land	Forest Land remaining Forest Land, Land Converted to Forest Land	drained organic soils	on-site CO_2	Tier 2	OTH	0.329 t C ha^{-1} yr^{-1}	NIS (National Inventory Submission) Sweden 2021
			CH_4	Tier 1	D	2 kg CH_4 ha^{-1} yr^{-1} (organic soil, N-rich);	Table 2.3 and Table 2.4 of the IPCC Wetlands Supplement
						7 kg CH4 ha-1 yr-1 (organic soil, N-poor);	
						217 kg CH_4 ha^{-1} yr^{-1} (drainage ditches)	
			N_2O	Tier 1	D	3.2 kg N_2O-N ha^{-1} yr^{-1} (N-rich)	Table 2.5 of the IPCC Wetlands Supplement
						0.22 kg N_2O-N ha^{-1} yr^{-1} (N-poor)	
		rewetted organic soils	CO_2	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory according to the IPCC 2006 Guidelines.
			CH_4	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory according to the IPCC 2006 Guidelines.
Cropland	Cropand remaining Cropand, Land Converted to Cropand	drained organic soils	on-site CO_2	Tier 2	OTH	6.1 t CO_2-C ha^{-1} yr^{-1}	NIS Sweden 2021
			CH_4	NA	–	–	–
			N_2O	Tier 1	D	8 kg N_2O-N ha^{-1} yr^{-1}	Table 11.1 of the IPCC 2006
Grassland	Grassland remaining Grassland, Land	drained organic soils	on-site CO_2	Tier 2	OTH	1.495 t CO_2-C ha^{-1} yr^{-1}	NIS Sweden 2021
			CH_4	NA	–	–	–

[6] Based on Estonia's National Inventory Report 1990-2019

	Converted to Grassland		N_2O	Tier 1	D	8 kg N_2O-N ha^{-1} yr^{-1}	Table 11.1 of the IPCC 2006
Wetlands	Wetlands Remaining Wetlands, Peat Extraction Remaining Peat Extraction	drained organic soils	on-site CO_2	Tier 2	CS	1.741 t CO_2-C ha^{-1} yr^{-1}	Salm et al 2012
			CH_4	Tier 2	CS	0.12 kg CH_4 ha^{-1} yr-1	Salm et al 2012
			N_2O	Tier 2	CS	0.19 kg N_2O-N ha^{-1} yr^{-1}	Salm et al 2012
		rewetted organic soils	CO_2	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory according to the IPCC 2006 Guidelines.
			CH_4	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory according to the IPCC 2006 Guidelines.
	Land Converted to Wetlands, Land Converted to Other Wetlands	rewetted organic soils	CO_2	NA	–	–	Emissions from rewetted organic soils are not reported, since it is not mandatory according to the IPCC 2006 Guidelines.
Settlements	Land Converted to Settlement	drained organic soils	on-site CO_2, FL-SL	Tier 2	OTH	2.25 t C ha^{-1} yr^{-1}	NIS Sweden 2021
			on-site CO_2, CL-SL	Tier 2	OTH	6.1 t C ha^{-1} yr^{-1}	NIS Sweden 2021
			on-site CO_2, WL-SL	Tier 2	OTH	2.25 t C ha^{-1} yr^{-1}	NIS Sweden 2021
			N_2O	NA	–	–	–

2.4 Finland

Summary of currently used methodology for the calculation of GHG emissions from organic soils in Finland is provided in Table 21.

Table 21. Currently used methodology for calculation of GHG emission from organic soils within the National GHG inventory in Finland[7]

Land use		Soil type	Gas	Method	Emission factor		
Category	Sub-category				Type	Value, unit	Source
Forest Land	Forest Land remaining Forest Land, Land Converted to Forest Land	drained organic soils	carbon/ CO_2	Tier 2, Tier 3	CS	No single value. Value is site-specific accounting change in dead wood mass + below-ground litter input – heterotrophic emission from soil. Data from NFI, meteorological data, scientific studies are used for modelling and producing site-specific	Chapter 6.4.2 in NIR-FI 2020

[7] Based on Finnish National Inventory Report 1990-2019

Land use		Soil type	Gas	Method	Emission factor		
Category	Sub-category				Type	Value, unit	Source
						values.	
			CH_4	Tier 1	CS	No single EF value. Value is site-specific; 1.16 g CH_4 m^{-2} yr^{-1} at sites with poor drainage ditch condition, and value is -0.28 g at sites with good drainage ditch condition (Ditch condition	Values from Ojanen et al. (2010, 2018)
			N_2O	Tier 2	D	No single EF value. Value is site-specific. 0.331 g N_2O m^{-2} yr^{-1} (Herb-rich type (Rhtkg)); 0.177 g (Vaccinium myrtillus type I (MtkgI)); 0.323 g (Vaccinium myrtillus type II (MtkgII)); 0.064 g (Vaccinium vitis-idaea type I (PtkgI)); 0.098 g (Vaccinium vitis-idaea type II (PtkgII)); 0.043 g (Dwarf shrub type (Vatkg)); 0.029 g (Cladina type (Jätkg))	Values from Ojanen et al. (2010, 2018), site types from Laine (1989)
Cropland	Cropland remaining Cropland, Land Converted to Cropland	drained organic soils	carbon/ CO_2	Tier 2	CS, D	No single EF value. Value is site-specific, and is based on modelling explained in NIR	Chapter 5.4.2.2 in NIR-FI 2020
Grassland	Grassland remaining Grassland, Land Converted to Grassland	drained organic soils	carbon/ CO_2	Tier 1, Tier 2, Tier 3	CS, D	No single EF value. Value is site-specific, and is based on modelling explained in NIR	Chapter 5.4.2.2 in NIR-FI 2020
Wetlands	Other Wetlands Remaining Other Wetlands (peat extraction areas converted to other wetlands)	drained organic soils	carbon/ CO_2	Tier 2	CS	Carbon emission of 218.9 g C m-2 a-1 (Dwarf shrub type emission) for peat extraction areas converted to other wetlands, and emission of 185.2 g C m^{-2} a^{-1}, (Cladina type emission) for forest land converted to other wetlands	Chapter 6.7.2.1 in NIR-FI 2020. Minkkinen et al. 2007
	Peat Extraction areas	drained organic soils	carbon/ CO_2	Tier 3	CS	No single EF value. Different value applied boreal, middle boreal and south boreal vegetation zones, and site-spesific emission varies based on proportion of stockpiles, ditches and production field.	Chapter 6.7.2.1 / Table 6.7-2 in NIR-FI 2020. Emission values from Nykänen et al. (1996), Alm et al. (2007)
			CH_4	Tier 2	CS	No single EF value. Emission is site specific and varies based on proportion of stockpiles, ditches and	Chapter 6.7.2.1 in NIR-FI 2020. Emission values from Nykänen et al. (1996), Alm et al. (2007)

Land use		Soil type	Gas	Method	Emission factor		
Category	Sub-category				Type	Value, unit	Source
						production field	
			N_2O	Tier 2	CS	No single EF value. Emission is site specific and varies based on proportion of stockpiles, ditches and production field	Chapter 6.7.2.1 in NIR-FI 2020. Emission values from Nykänen et al. (1996), Alm et al. (2007)

3 LATVIA'S EXPERIENCE IN IMPLEMENTATION OF PREVIOUS LIFE PROJECT' (LIFE RESTORE) RESULTS IN NATIONAL GHG INVENTORY METHODOLOGY – CASE STUDY

3.1 Improved methodologies in GHG inventory reporting

Latvia's National GHG Inventory was improved based on implementation of results of EU LIFE program project "Sustainable and responsible management and re-use of degraded peatlands in Latvia"[8] (LIFE REstore). One of the objectives of LIFE REstore project was to approbate a field measurement based methodology for accounting of the GHG emissions from managed wetlands in Latvia in accordance with the supplement to the IPCC guidelines.

A study was conducted to improve EFs of GHG from managed organic soils, in order to replace the default EFs set by the IPCC Guidelines for National GHG Inventories with scientifically proven EFs, suitable for application in Latvia. In total, measurements have been carried out in 41 objects, and data from 36 sites have been used for elaboration of the EFs:

- Peat extraction field, where peat is extracted with milling method with an effective drainage system in the area;
- Abandoned peat extraction field – raised bog (*Sphagnum*) peat has been extracted, and the dominant peat type on the top is fen or transitional mire peat; area is not covered with vegetation; groundwater table is not controlled and is close to the peat surface throughout the year;
- Abandoned peat extraction field – raised bog peat has been extracted and the dominant peat type in the upper layer is fen or transitional mire peat; the area is covered with herbs and dwarf shrubs, groundwater table is not regulated and is close to the peat surface the whole year;
- Perennial grassland on former peat extraction site, where the grass is mown, groundwater table is lowered, fen or transitional mire peat is highly decomposed;
- Cropland on former peat extraction site, where cultivated grassland or crops are established, groundwater table is lowered, fen or transitional mire peat is highly decomposed;
- Cropland that has replaced an abandoned peat extraction site, where legumes are grow groundwater table is lowered; fen or transitional mire peat is highly decomposed;
- Highbush blueberry plantations on former peat extraction fields, groundwater table is lowered or close to the surface, raised bog or mixed peat;
- Large cranberry plantations on former peat extraction fields on raised bog peat; groundwater table is slightly lowered or close to the surface;
- At least 20 years old pine stands corresponding to the *Myrtillosa mel* . forest type; groundwater table is lowered; raised bog or transitional mire peat;
- At least 20 years old birch stands, that correspond to the *Myrtillosa mel*. forest type; groundwater table is lowered; raised or transitional mire peat;
- Relatively intact raised bog; groundwater table is not regulated; the area does not correspond to the definition of a forest according to the Forest Law (trees do not exceed the height of 5 m, the projective cover in mature stands does not exceed 20%, the area continuously covered with trees does not exceed 0.1 ha);
- Relatively intact transitional mire; groundwater table is not regulated; the area does not

[8] Available at: https://restore.daba.gov.lv/public/eng/about_the_project/

correspond to the definition of a forest in the Forest Law.

Within the study the CO_2 balance of the ecosystem was measured directly, using transparent chambers and measuring changes in CO_2 concentrations, including both photosynthetic CO_2 uptake and CO_2 emissions. Measurements can be taken only at temperatures above 0 °C. Therefore, in parallel with the measurements using the transparent chambers, CO_2 emissions of the ecosystem are measured with opaque chambers throughout the year. Since photosynthesis stops at temperatures below 0 °C, during this period the ecosystem balance equals to the ecosystem emissions. Ecosystem CH_4 and N_2O balance is independent from photosynthesis, therefore, to measure these gases, transparent chambers are not required and only opaque chambers can be use. Collars both for opaque chambers and transparent chambers are installed in five repetitions at each site.

To determine ecosystem emissions – concentrations of GHG (CO_2, CH_4 and N_2O), the collected gas samples from the opaque chambers were transported to the Climate Change laboratory of the Department of Geography of University of Tartu. Analyses were done with the Shimadzu GC-2014 gas chromatograph, equipped with an electron capture detector, flame ionisation detector and Loftfield autosampler. Changes in CO_2 concentration in transparent chambers were measured using the EGM-5 portable CO_2 gas analyser.

In parallel with the gas exchange measurements, a comprehensive characterization of soil and groundwater was done, determining those parameters, which can significantly influence GHG emissions from soil. The primary focus is on the factors that can be measured or modelled relatively easy, for example, groundwater table and the C/N ratio. In forest land C input in soil was determined from tree litter and living tree biomass.

It was concluded that use of default EFs provided by the IPCC Wetlands Supplement leads to overestimate total net GHG emissions from drained organic soils in Latvia. Emissions factors for different types of land use obtained within LIFE REstore project (Lazdiņš and Lupiķis, 2019; Licite and Lupikis, 2020) and incorporated into Latvia's National GHG Inventory are summarized in Table 22.

Table 22. EFs for on-site GHG emissions for drained organic soils in different types of land use in Latvia obtained within LIFE REstore project; comparison with IPCC default EFs and results from other studies conducted in Latvia (values currently used for GHG calculations within the GHG inventory are in bold)

Type of land use	Gas[9]	EF obtained within LIFE REstore project (value and unit)	IPCC default EFs		Other studies conducted in Latvia	
			Value and unit	Reference	Value and unit	Reference
Forest land	CO_2	Results of the LIFE REstore project represent only nutrient-poor soils (developed on raised bog and transition mire, Table 2), thus not included in the GHG Inventory so far.	9.53 t CO_2 (or 2.6 t CO_2-C) ha^{-1} yr^{-1}	Table 2.1 of the IPCC Wetlands Supplement (temperate)	**1.91 t CO_2 (or 0.52 t CO_2-C) ha^{-1} yr^{-1}**	Lupikis and Lazdins, 2017
	CH_4		**2.50 kg CH_4 (or 1.87 kg CH_4-C) ha^{-1} yr^{-1}**	Table 2.3 of the IPCC Wetlands Supplement (temperate)	-4.63 kg CH_4 (or -3.47 kg CH_4-C) ha^{-1} yr^{-1}	Butlers et al., 2021
	N_2O		**4.40 kg N_2O (or 2.8 kg N_2O-N) ha^{-1} yr^{-1}**	Table 2.5 of the IPCC Wetlands Supplement (temperate)	1.73 kg N_2O (or 1.1 kg N_2O-N) ha^{-1} yr^{-1}	Butlers et al., 2021
Cropland	CO_2	**17.6 t CO_2 (or 4.80 t CO_2-C) ha^{-1} yr^{-1}**	29.0 t CO_2 (or 7.9 t CO_2-C) ha^{-1} yr^{-1}	Table 2.1 of the IPCC Wetlands Supplement (boreal and temperate)	-	-
	CH_4	-0.79 kg CH_4 (or -0.59 kg CH_4-C) ha^{-1} yr^{-1} (not included	**0 kg CH_4 (or 0 kg CH_4-C) ha^{-1} yr^{-1}**	Table 2.3 of the IPCC Wetlands Supplement (boreal and temperate)	-	-

9 CH_4 emissions only from drained soils are included, CH_4 emissions from drainage ditches are excluded.

		in the GHG Inventory so far)				
	N_2O	**11.2 kg N_2O (or 7.1 kg N_2O-N) ha^{-1} yr^{-1}**	20.4 kg N_2O (or 13 kg N_2O-N) ha^{-1} yr^{-1}	Table 2.5 of the IPCC Wetlands Supplement (boreal and temperate)	-	-
Grassland	CO_2	**16.1 t CO_2 (or 4.40 t CO_2-C) ha^{-1} yr^{-1}**	22.4 t CO_2 (or 6.1 t CO_2-C) ha^{-1} yr^{-1}	Table 2.1 of the IPCC Wetlands Supplement (temperate, deep-drained, nutrient-rich)	-	-
	CH_4	**77.2 kg CH_4 (or 57.8 kg CH_4-C) ha^{-1} yr^{-1}**	16.0 kg CH_4 (or 11.98 kg CH_4-C) ha^{-1} yr^{-1}	Table 2.3 of the IPCC Wetlands Supplement (temperate, deep-drained, nutrient-rich)	-	-
	N_2O	**0.47 kg N_2O (or 0.3 kg N_2O-N) ha^{-1} yr^{-1}**	12.9 kg N_2O (or 8.2 kg N_2O-N) ha^{-1} yr^{-1}	Table 2.5 of the IPCC Wetlands Supplement (temperate, deep-drained, nutrient-rich)	-	-
Wetlands, Peat Extraction Remaining Peat Extraction	CO_2	**4.44 t CO_2 (or 1.21 t CO_2-C) ha^{-1} yr^{-1}**	10.27 t CO_2 (or 2.8 t CO_2-C) ha^{-1} yr^{-1}	Table 2.1 of the IPCC Wetlands Supplement (boreal and temperate)	-	-
	CH_4	**10.83 kg CH_4 (or 8.11 kg CH_4-C) ha^{-1} yr-1**	6.1 kg CH_4 (or 4.57 kg CH_4-C) ha^{-1} yr^{-1}	Table 2.3 of the IPCC Wetlands Supplement (boreal and temperate)	-	-
	N_2O	**0.69 kg N_2O (or 0.44 kg N_2O-N) ha^{-1} yr^{-1}**	0.47 kg N_2O (or 0.3 kg N_2O-N) ha^{-1} yr^{-1}	Table 2.5 of the IPCC Wetlands Supplement (boreal and temperate)	-	-

3.2 Impact of improved methodologies on GHG inventory and related national reports

3.2.1 Forest land

Impact of recalculation of on-site GHG emissions and removals from drained organic soils in forest land in Latvia due to implementation of CS EFs (Lupikis and Lazdins, 2017; Butlers et al., 2021) is shown in **Figure 1** and **Figure 2**. CH_4 emissions from drainage ditches are excluded from this estimation. All CS EFs are lower compared to the IPCC default EFs (Table 22). Use of CS EFs for CO_2, CH_4 and N_2O (0.52 t CO_2-C ha^{-1} yr^{-1}, -4.63 kg CH_4 ha^{-1} yr^{-1} and 1.1 kg N_2O-N ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in forest land in Latvia (384.8 – 419.1 kha depending from year in period of 1990-2019) by 3850.6 kt CO_2 eq. yr^{-1} or by 78.9% in average during 1990-2019. The CS CO_2 EF contributed the most to the reduction of total GHG emissions from drained organic soils in forest land in Latvia (Figure 2). Currently, only CS CO_2 EF is implemented in the National GHG Inventory. Results of the LIFE REstore project represent only nutrient-poor soils (developed on raised bog and transition mire, Table 2), thus not included in the National GHG Inventory so far.

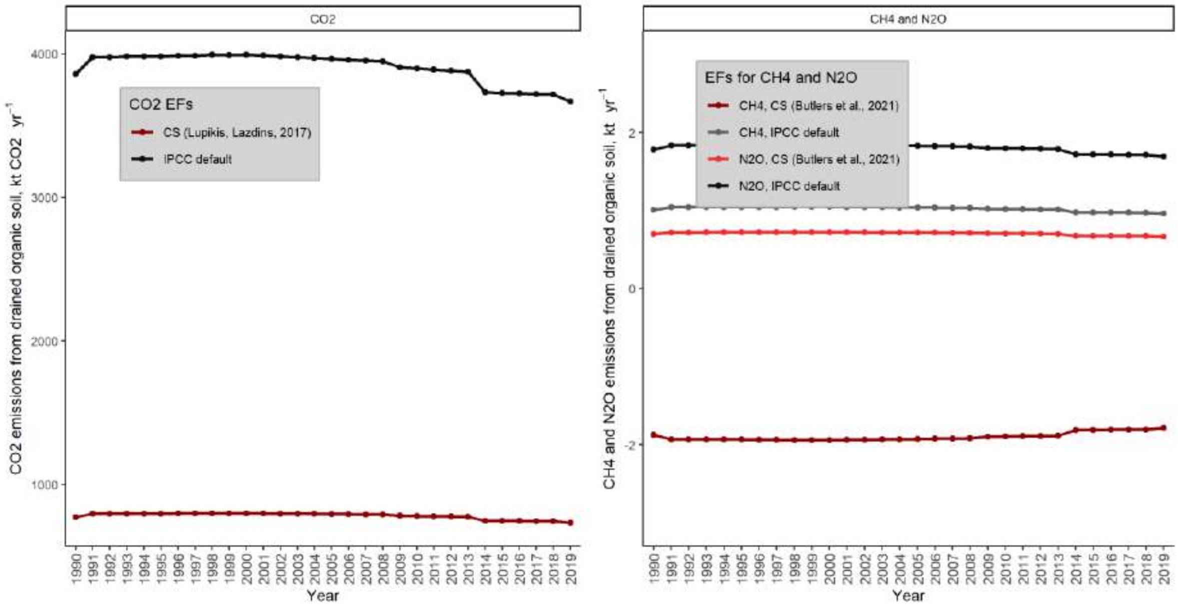

Figure 1. Impact of recalculation of on-site CO_2, CH_4 and N_2O emissions and removals from drained organic soils in forest land in Latvia due to implementation of country-specific EFs

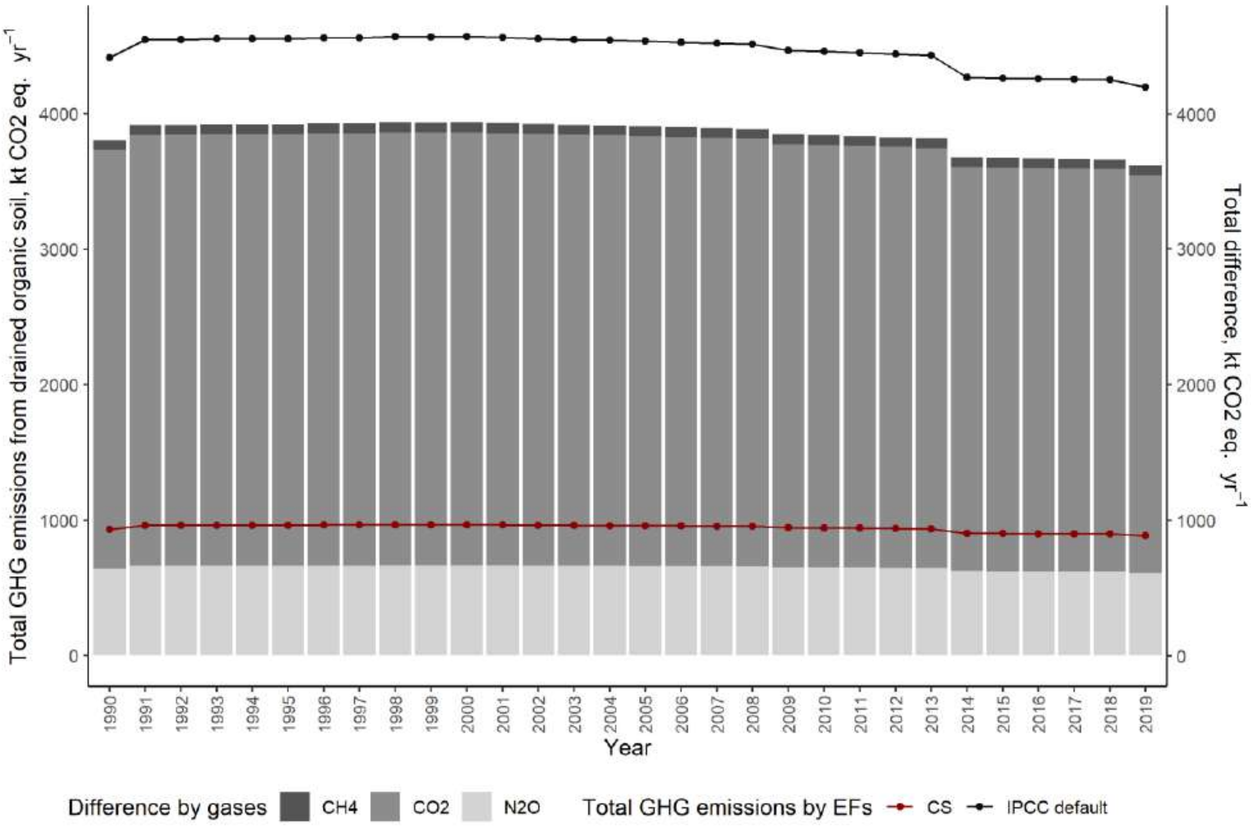

Figure 2. Total impact of recalculation of on-site GHG emissions and removals from drained organic soils in forest land in Latvia due to implementation of country-specific EFs

3.2.2 Cropland

Impact of recalculation of on-site GHG emissions and removals from drained organic soils in cropland in Latvia due to implementation of CS EFs obtained within LIFE REstore project is shown in Figure 3 and Figure 4. CH_4 emissions from drainage ditches are excluded from this estimation. All CS EFs are lower compared to the IPCC default EFs (Table 22). Use of CS EFs for CO_2, CH_4 and N_2O (4.80 t CO_2-C ha^{-1} yr^{-1}, -0.79 kg CH_4 ha^{-1} yr^{-1} and 7.1 kg N_2O-N ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in cropland in Latvia (78.1 – 135.1 kha depending from year in period of 1990-2019) by 1432.8 kt CO_2 eq. yr^{-1} or by 40.4% in average during 1990-2019. The CS CO_2 EF contributed the most to the reduction of total GHG emissions from drained organic soils in cropland in Latvia (Figure 4). Currently, only CS EFs for CO_2 and N_2O are implemented in the National GHG Inventory. Furthermore, on-site N_2O emissions from drained organic soils are reported under the Agriculture sector.

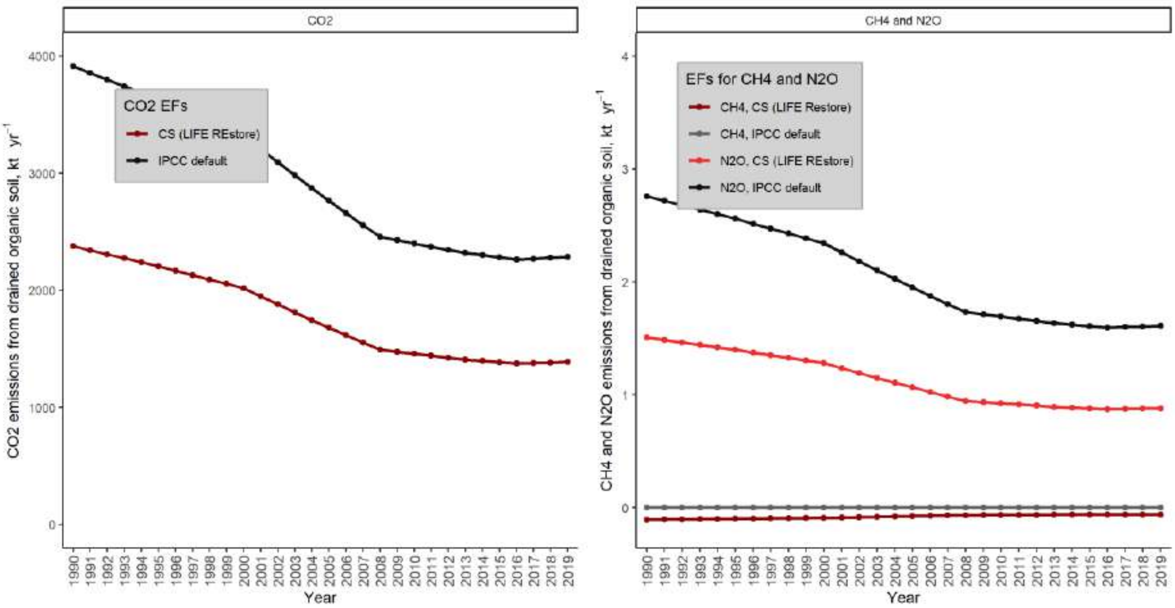

Figure 3. Impact of recalculation of on-site CO_2, CH_4 and N_2O emissions and removals from drained organic soils in cropland in Latvia due to implementation of country-specific EFs obtained within the LIFE REstore project

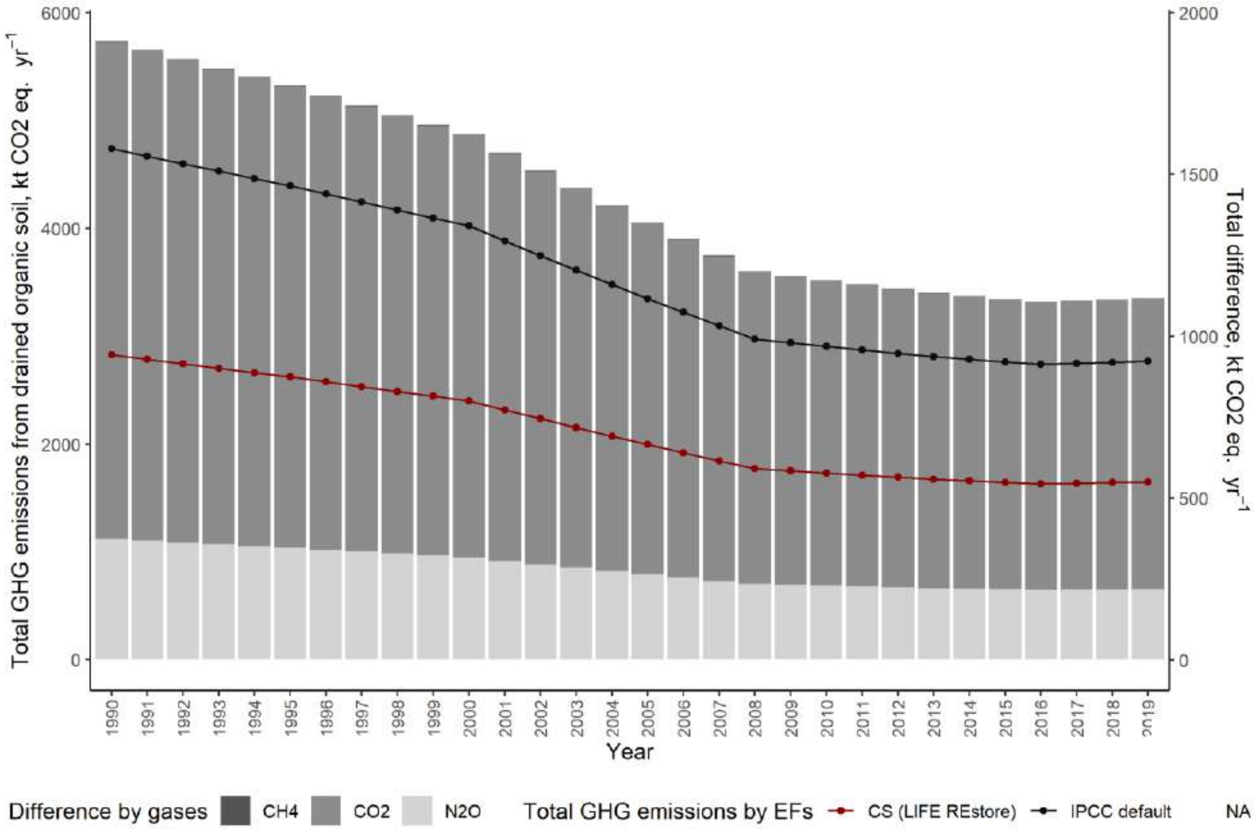

Figure 4. Total impact of recalculation of on-site GHG emissions and removals from drained organic soils in cropland in Latvia due to implementation of country-specific EFs obtained within the LIFE REstore project

3.2.3 Grassland

Impact of recalculation of on-site GHG emissions and removals from drained organic soils in grassland in Latvia due to implementation of CS EFs obtained within LIFE REstore project is shown in

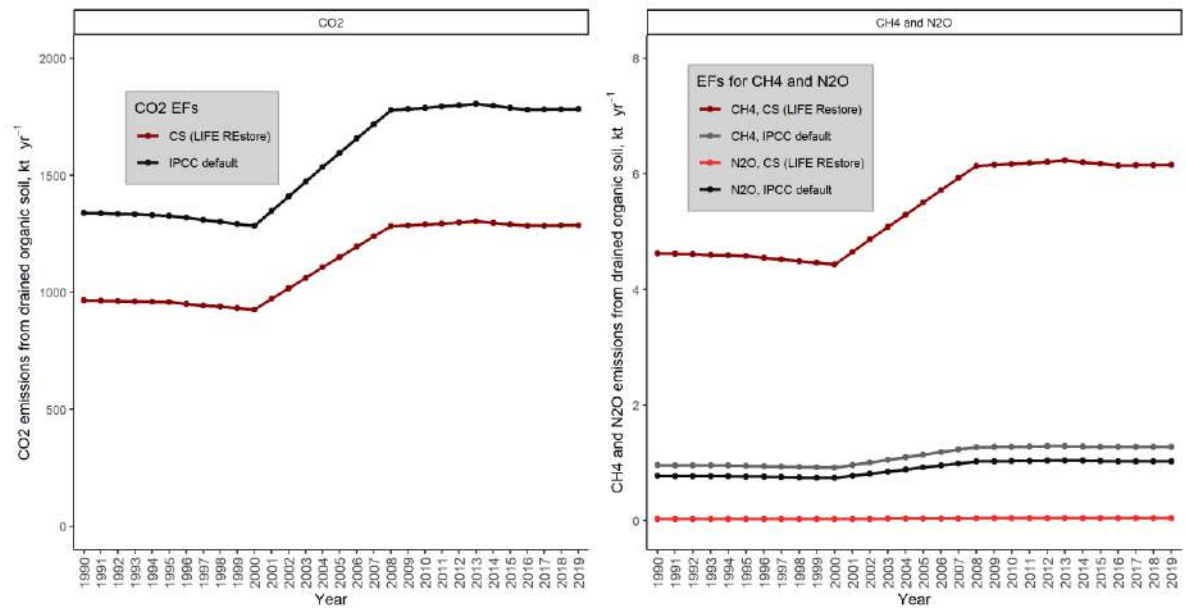

Figure **5** and Figure 6. CH_4 emissions from drainage ditches are excluded from this estimation. CS EFs for

CO_2 and N_2O are lower compared to the IPCC default EFs, but CS CH_4 EF is higher compared to the IPCC default EF (Table 22). Use of CS EFs for CO_2, CH_4 and N_2O (4.40 t CO_2-C ha^{-1} yr^{-1}, 77.2 kg CH_4 ha^{-1} yr^{-1} and 0.3 kg N_2O-N ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in grassland in Latvia (57.4 – 80.8 kha depending from year in period of 1990-2019) by 584.9 kt CO_2 eq. yr^{-1} or by 31.6% in average during 1990-2019 (Figure 6). Currently, all CS EFs are implemented in the National GHG Inventory. On-site N_2O emissions from drained organic soils are reported under the Agriculture sector.

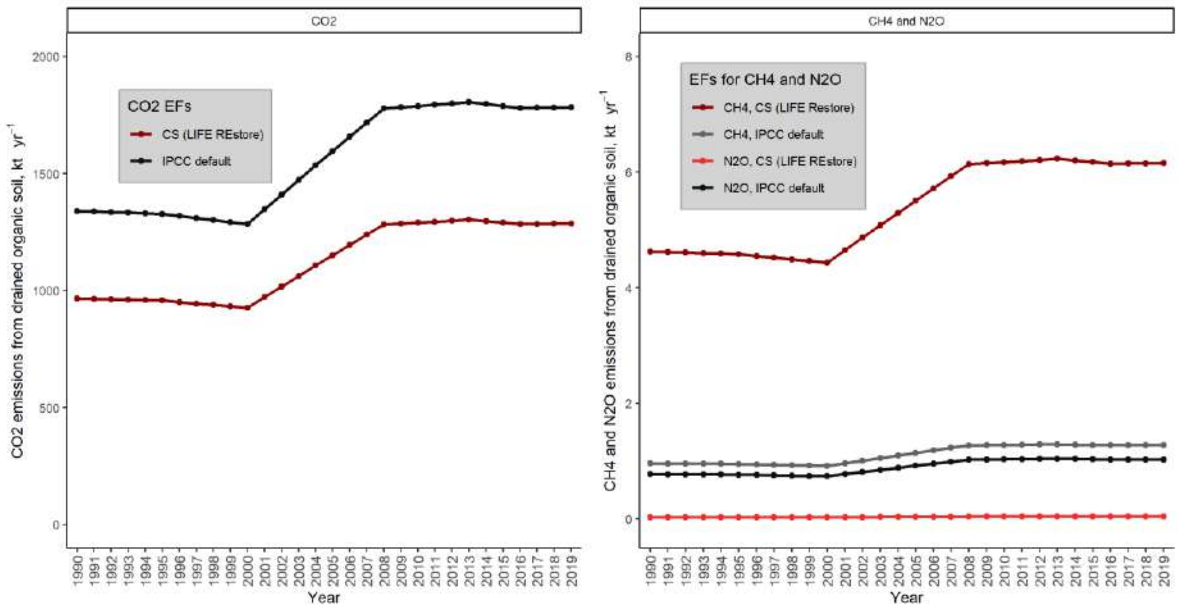

Figure 5. Impact of recalculation of on-site CO_2, CH_4 and N_2O emissions and removals from drained organic soils in grassland in Latvia due to implementation of country-specific EFs obtained within the LIFE REstore project

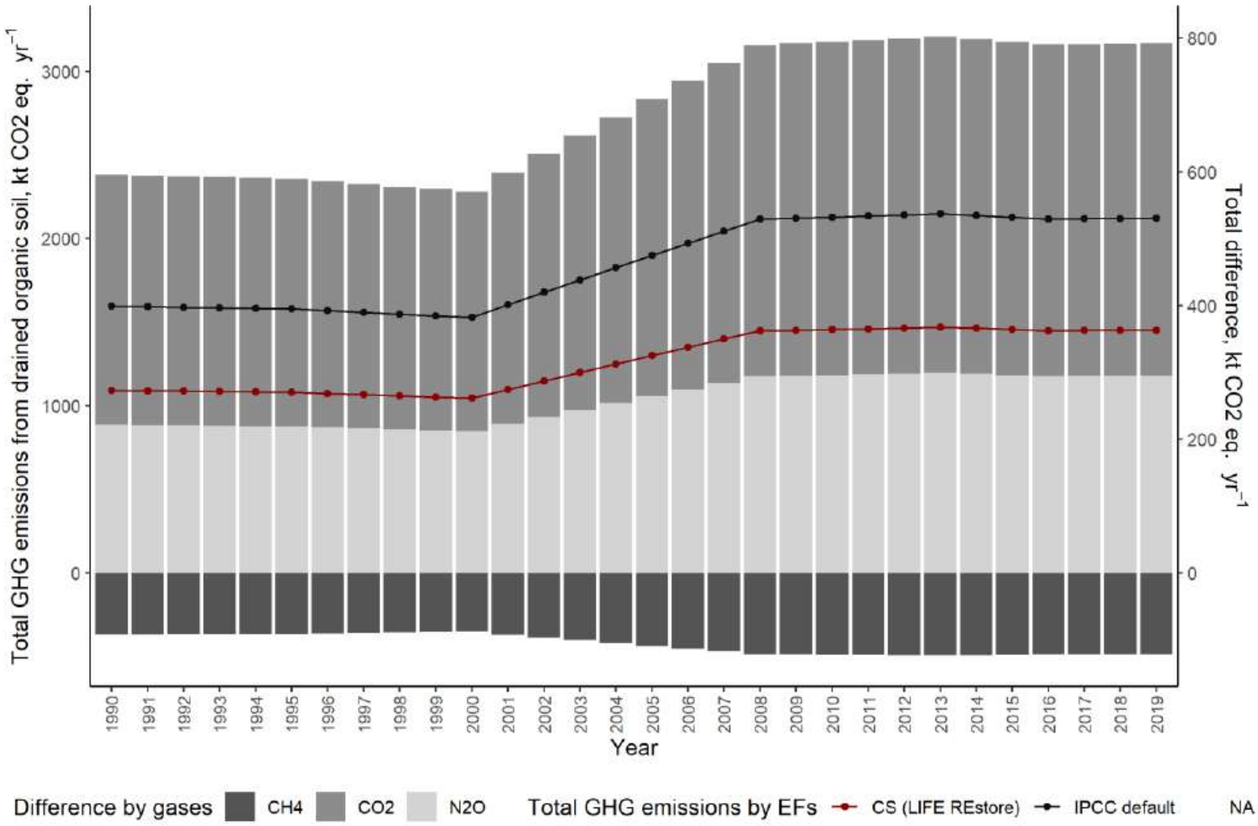

Figure 6. Total impact of recalculation of on-site GHG emissions and removals from drained organic soils in grassland in Latvia due to implementation of country-specific EFs obtained within the LIFE REstore project

3.2.4 Wetlands (Peat Extraction Sites)

Impact of recalculation of on-site GHG emissions and removals from drained organic soils in wetlands (peat (peat extraction sites) in Latvia due to implementation of CS EFs obtained within LIFE REstore project is shown shown in Figure 7

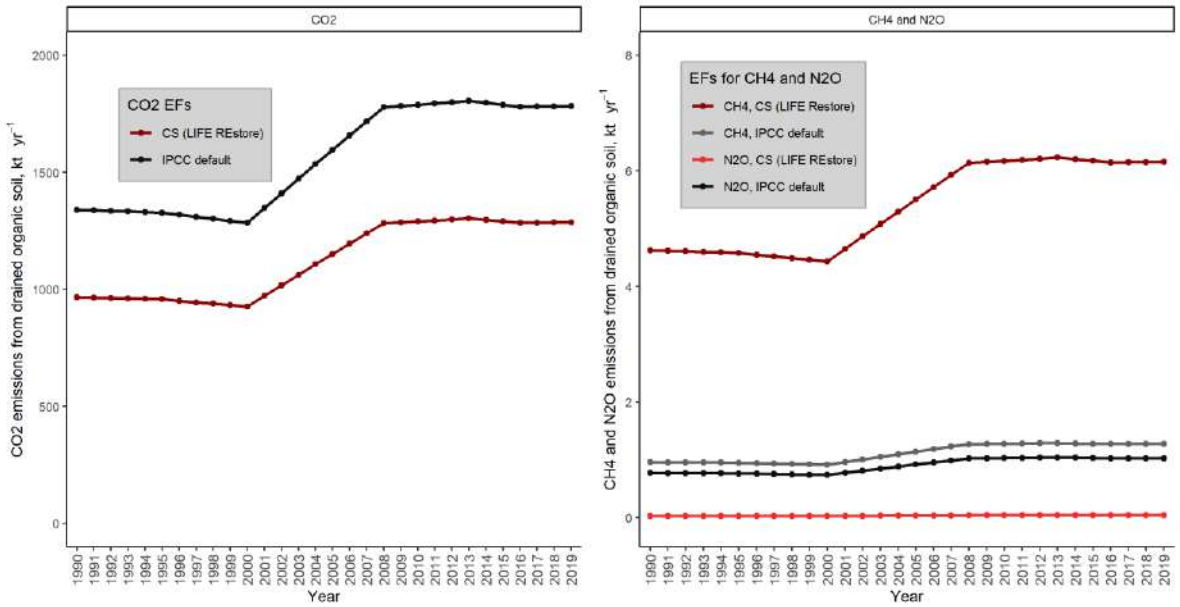

Figure 5 and Figure 8. CH_4 emissions from drainage ditches are excluded from this estimation. CS CO_2 EF is lower compared to the IPCC default EFs, but CS EFs for CH_4 and N_2O are higher compared to the IPCC default EF (Table 22). Nevertheless, use of CS EFs for CO_2, CH_4 and N_2O (1.21 t CO_2-C ha^{-1} yr^{-1}, 10.83 kg CH_4 ha^{-1} yr^{-1} and 0.44 kg N_2O-N ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in peat extraction sites in Latvia (32.7 – 47.6 kha depending from year in period of 1990-2019) by 226.6 kt CO_2 eq. yr^{-1} or by 53.5% in average during 1990-2019**Figure 6**. The CS CO_2 EF contributed the most to the reduction of total GHG emissions from drained peat extraction sites in Latvia (Figure 8**Figure 6**). Currently, all CS EFs are implemented in the National GHG Inventory.

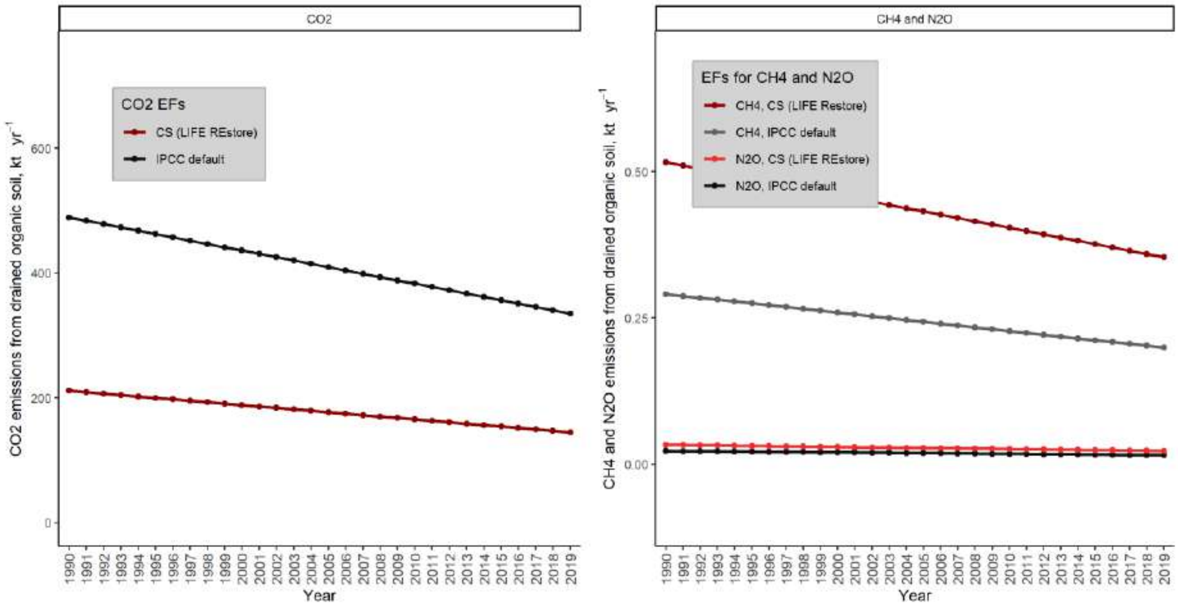

Figure 7. Impact of recalculation of on-site CO_2, CH_4 and N_2O emissions and removals from drained organic soils in wetland (peat extraction sites) in Latvia due to implementation of country-specific EFs obtained within the LIFE REstore project

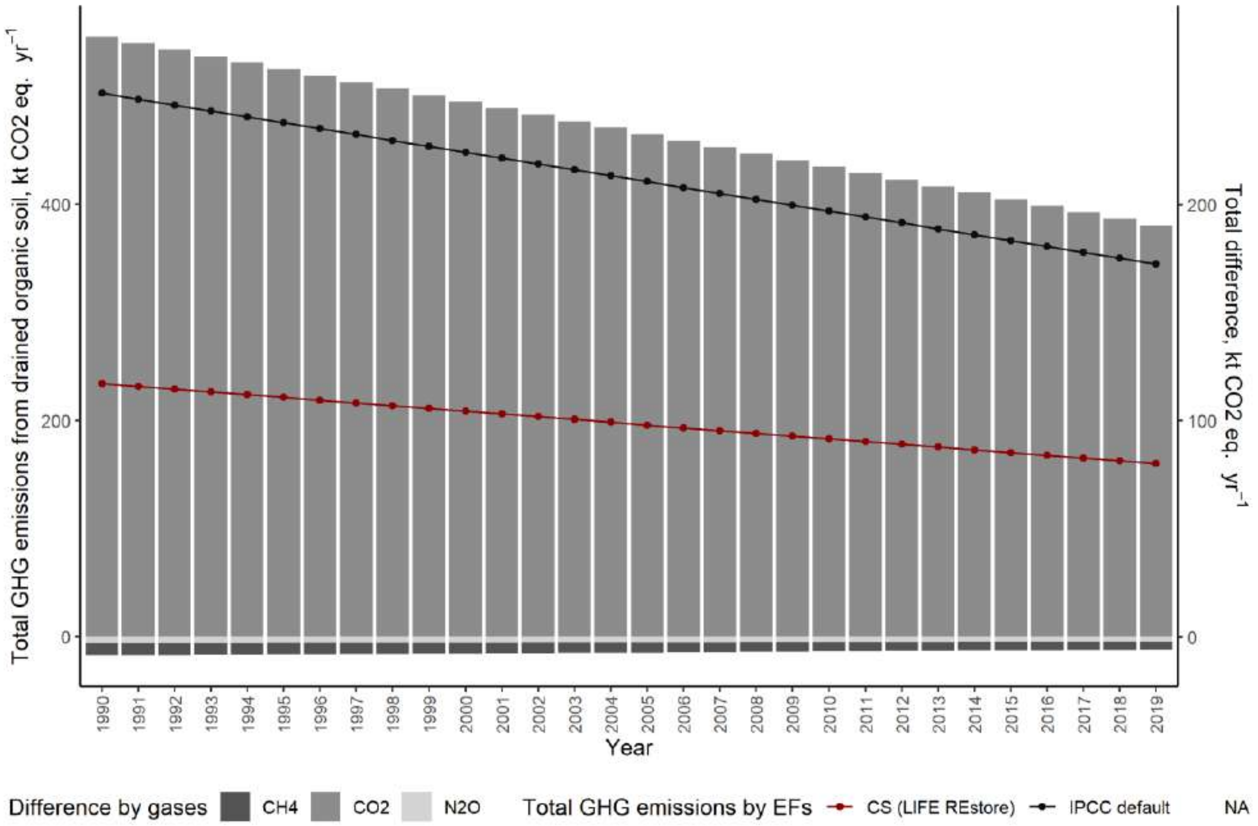

Figure 8. Total impact of recalculation of on-site GHG emissions and removals from drained organic soils in wetland (peat extraction sites) in Latvia due to implementation of country-specific EFs obtained within the LIFE REstore project

4 Approximate evaluation of possible impact of LIFE REstore emission factors` application in GHG inventory reporting and related national reports in Lithuania and Estonia

In this chapter, we present approximate evaluation of possible impact of application of LIFE REstore EFs in GHG inventory reporting in Lithuania and Estonia. To provide wider insight into impacts of recalculations we also included the IPCC default values in the comparison.

4.1 Lithuania

Currently Lithuania reports CO_2 emissions from drained organic soils in cropland and grassland using IPCC 2006 provided default CO_2 EFs. Notation key "NA" is reported for CH_4 emissions from drained organic soils in cropland and grassland, N_2O emissions from cropland and grassland are reported under Agriculture sector as emissions from cultivation of organic soils. Comparison of evaluation of GHG emissions from drained organic soils in cropland and grassland using different types of EFs is presented in Figure 9 and Figure 10. If LIFE REstore EF for the estimation of CO_2 emissions from drained organic soils in cropland would be applied in Lithuania, the amount of calculated CO_2 emissions would decrease by 596.6 kt CO_2 yr^{-1}, on average, compared to currently reported amount of CO_2 emissions. On the contrary, use of LIFE REstore EF for the estimation of CO_2 emissions from drained organic soils in grassland would increase calculated CO_2 emissions by 549.5 kt CO_2 yr^{-1}, on average, compared to currently reported amount of CO_2 emissions.

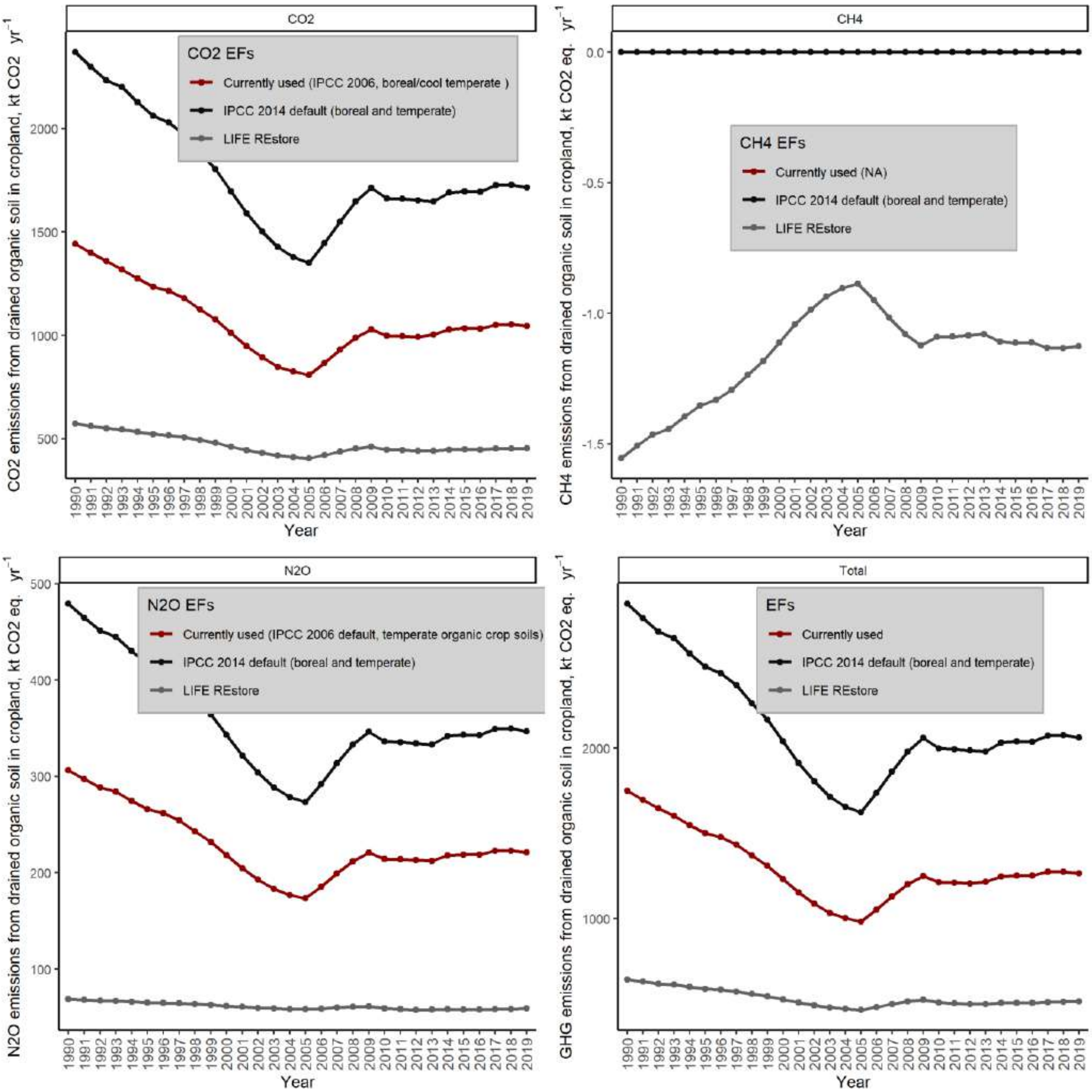

Figure 9. Evaluation of GHG emissions from drained organic soils in cropland in Lithuania using different type of EFs: IPCC 2014 default EFs; EF obtained within the LIFE REstore project in Latvia; currently used EFs for GHG reporting within Lithuania's National Inventory

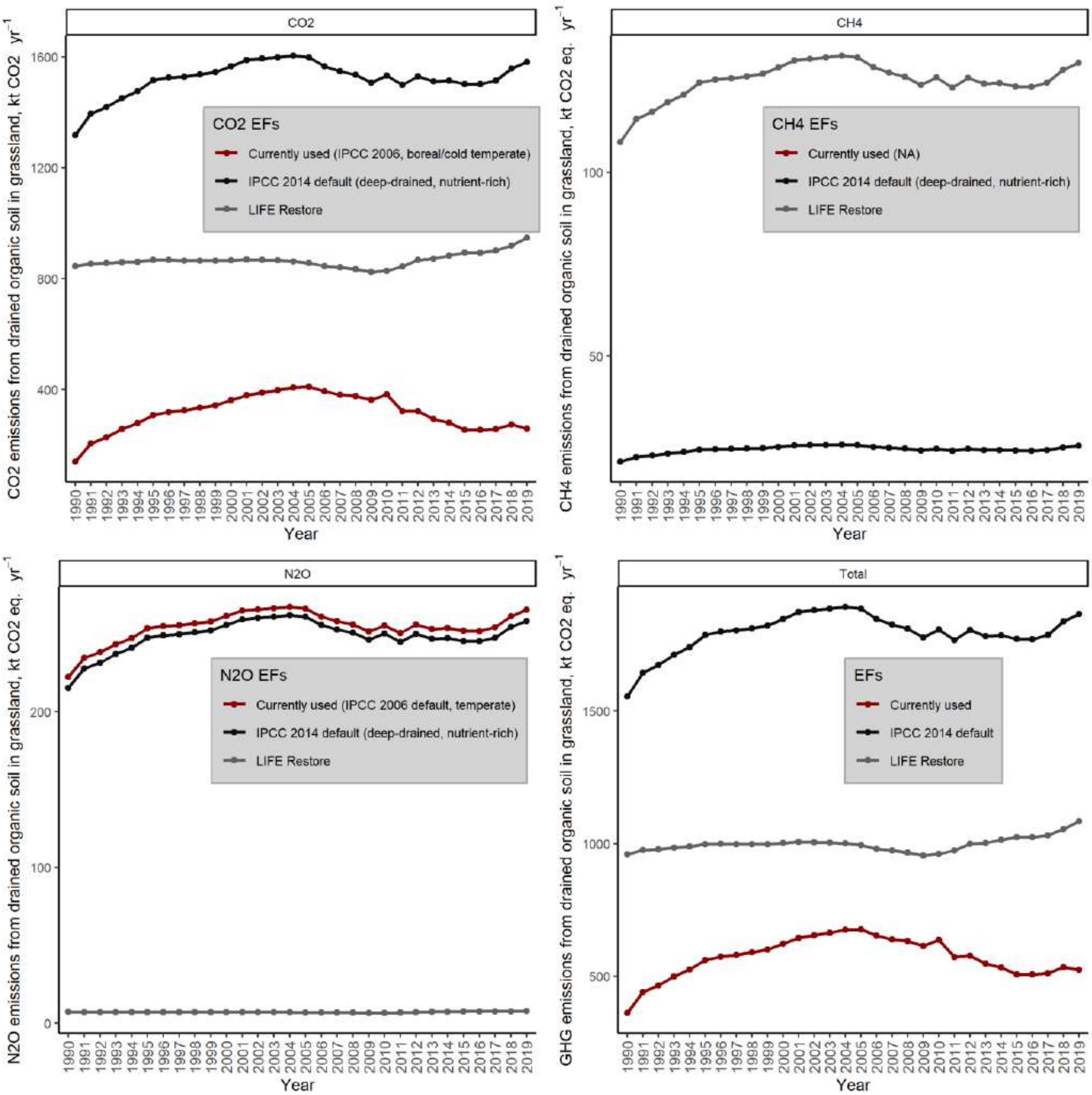

Figure 10. Evaluation of GHG emissions from drained organic soils in grassland in Lithuania using different type of EFs: IPCC 2014 default EFs; EF obtained within the LIFE REstore project in Latvia; currently used EFs for GHG reporting within Lithuania's National Inventory

For wetlands (peat extraction sites) Lithuania reports both CO_2 and N_2O emissions using default EFs provided by the IPCC 2006. Notation key "NA" is reported for CH_4 emissions from drained organic soils in peat extraction sites. Use of LIFE REstore CO_2 EF would lead to increase amount of CO_2 emissions from peat extraction sites by 36.8 kt CO_2 yr^{-1}, on average, compared to currently reported amount of CO_2 emissions. On the contrary, use of LIFE REstore EFs for the estimation of N_2O emissions from peat extraction sites would decrease calculated N_2O emissions by 2.0 kt CO_2 eq. yr^{-1}, on average, compared to currently reported amount of emissions. Nevertheless, total amount of GHG emissions from drained organic soils in peat extraction sites would increase by 39.0 kt CO_2 eq. yr^{-1}, on average, if LIFE REstore CO_2,

CH_4 and N_2O EFs would be implemented in calculations (Figure 11).

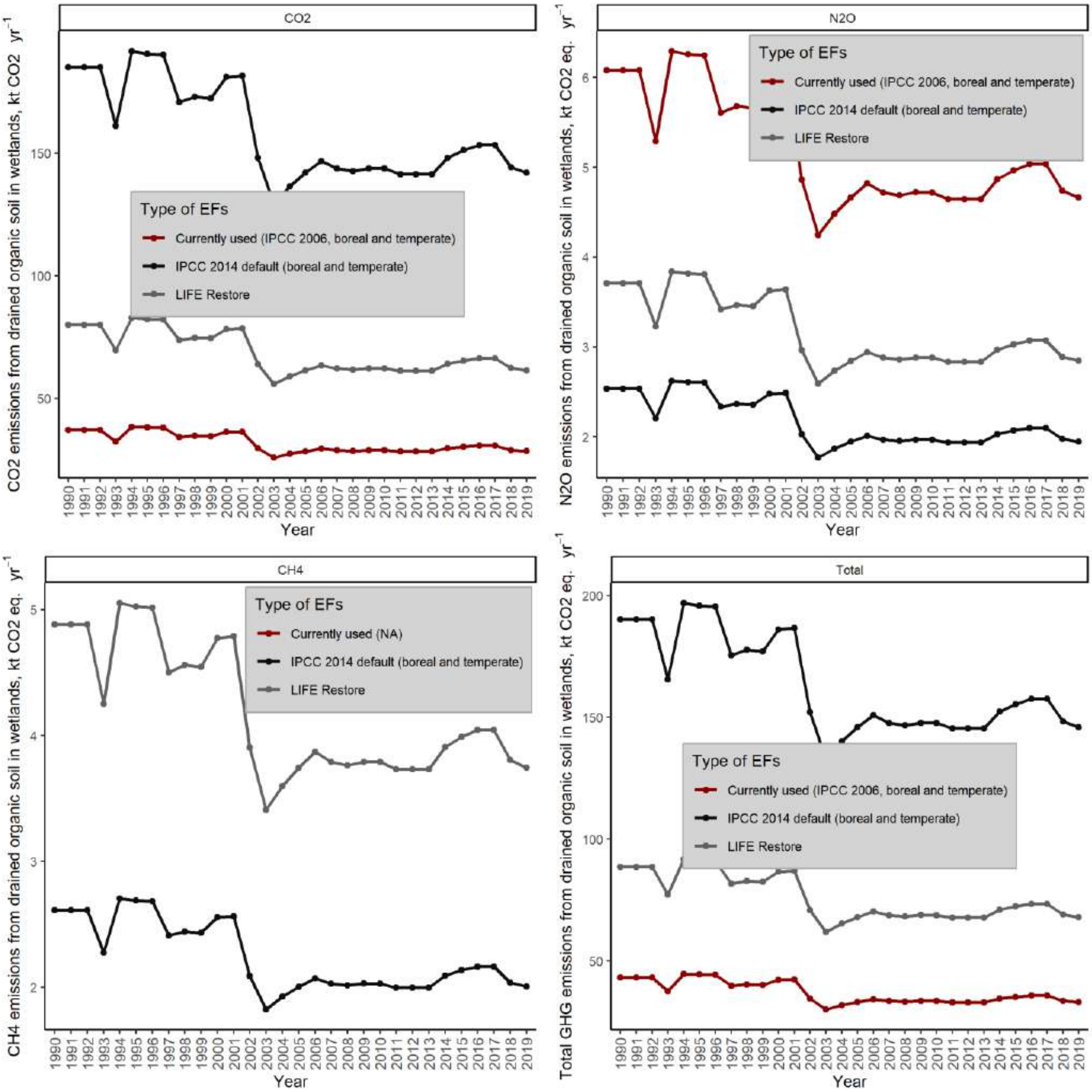

Figure 11. Evaluation of GHG emissions from drained organic soils in wetlands (peat extraction sites) in Lithuania using different type of EFs: IPCC default EFs; EFs obtained within the LIFE REstore project in Latvia; currently used EFs for GHG reporting within Lithuania's National Inventory

4.2 Estonia

Currently Estonia reports CO_2 and N_2O emissions from drained organic soils in cropland and grassland using CO_2 EFs developed in Sweden (NIS Sweden 2021) and IPCC 2006 provided default N_2O EFs. Notation key "NA" is reported for CH_4 emissions from drained organic soils in cropland and grassland. Comparison of evaluation of GHG emissions from drained organic soils in cropland and grassland using different types of EFs is presented in Figure 12 and Figure 13. If LIFE REstore EF for the estimation of CO_2 emissions from drained organic soils in cropland would be applied in Estonia, the amount of calculated CO_2 emissions would decrease by 131.9 kt CO_2 yr^{-1}, on average, compared to currently reported amount of CO_2 emissions. On the contrary, use of LIFE REstore EF for the estimation of CO_2 emissions from drained organic soils in grassland would increase calculated CO_2 emissions by 122.2 kt CO_2 yr^{-1}, on average, compared to currently reported amount of CO_2 emissions.

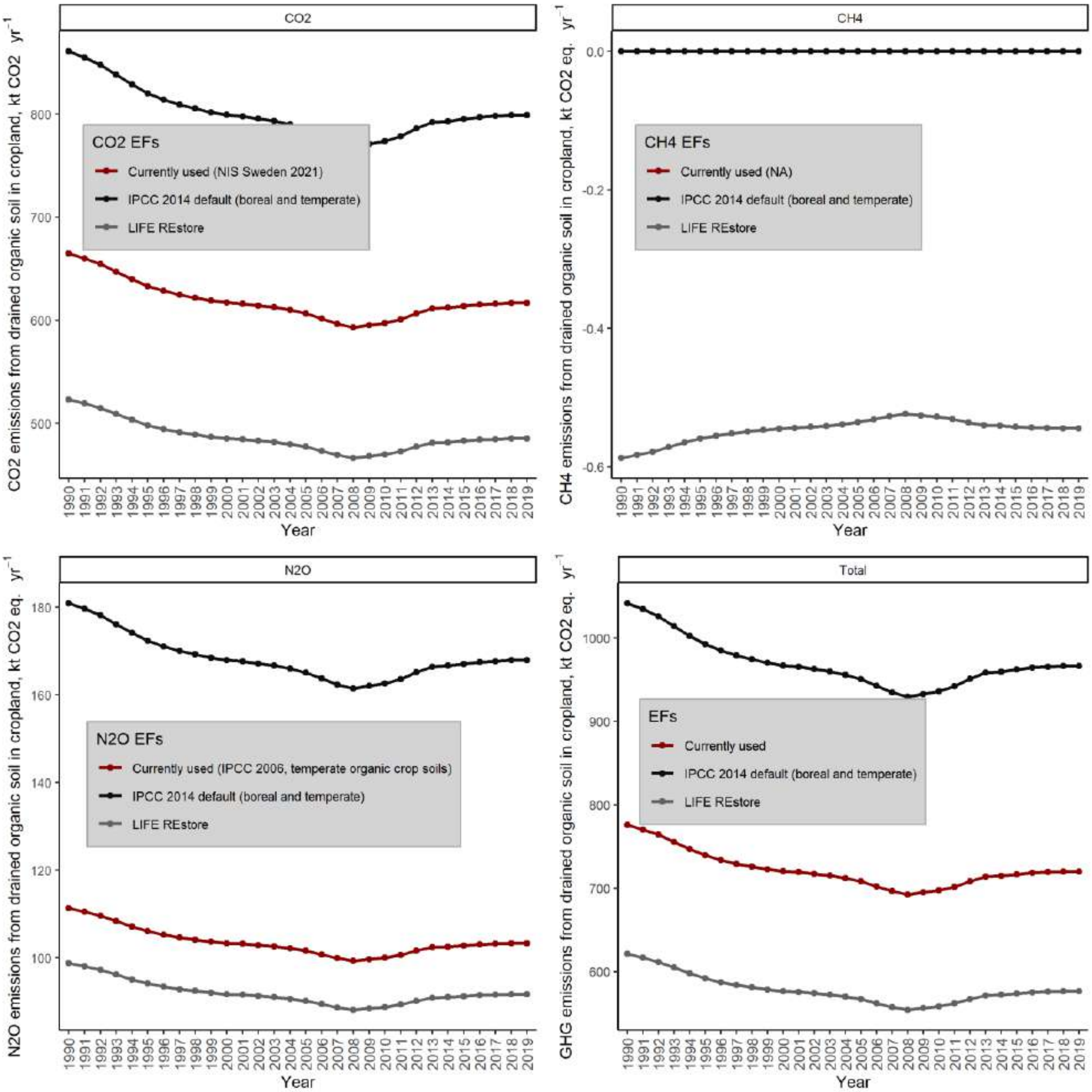

Figure 12. Evaluation of GHG emissions from drained organic soils in cropland in Estonia using different type of EFs: IPCC 2014 default EFs; EF obtained within the LIFE REstore project in Latvia; currently used EFs for GHG reporting within Estonia's National Inventory

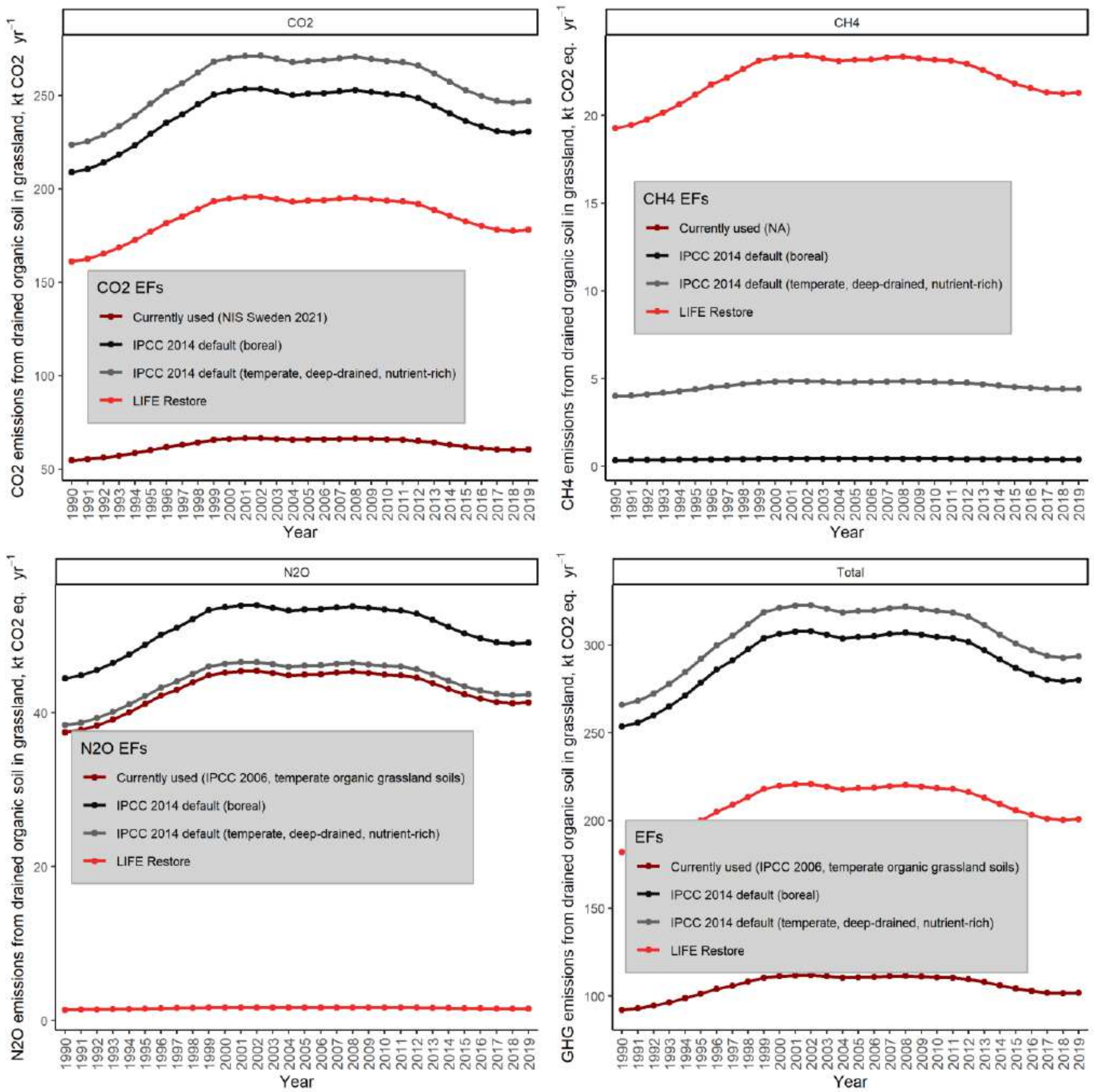

Figure 13. Evaluation of GHG emissions from drained organic soils in grassland in Estonia using different type of EFs: IPCC 2014 default EFs; EF obtained within the LIFE REstore project in Latvia; currently used EFs for GHG reporting within Estonia's National Inventory

For wetlands (peat extraction sites) Estonia reports both CO_2 and CH_4 as well as N_2O emissions using country specific EFs based on Salm et al. (2012). Use of LIFE REstore CO_2 EF would lead to decrease amount of CO_2 emissions from peat extraction sites by 40.7 kt CO_2 yr^{-1}, on average, compared to currently reported amount of CO_2 emissions. On the contrary, use of LIFE REstore EFs for the estimation of CH_4 and N_2O emissions from peat extraction sites would increase calculated CH_4 and N_2O emissions by 5.6 and 2.4 kt CO_2 eq. yr^{-1}, on average, compared to currently reported amount of emissions. Nevertheless, total amount of GHG emissions from drained organic soils in peat extraction sites would decrease by 32.7 kt CO_2 eq. yr^{-1}, on average, if LIFE REstore GHG EFs would be implemented in calculations (Figure 14).

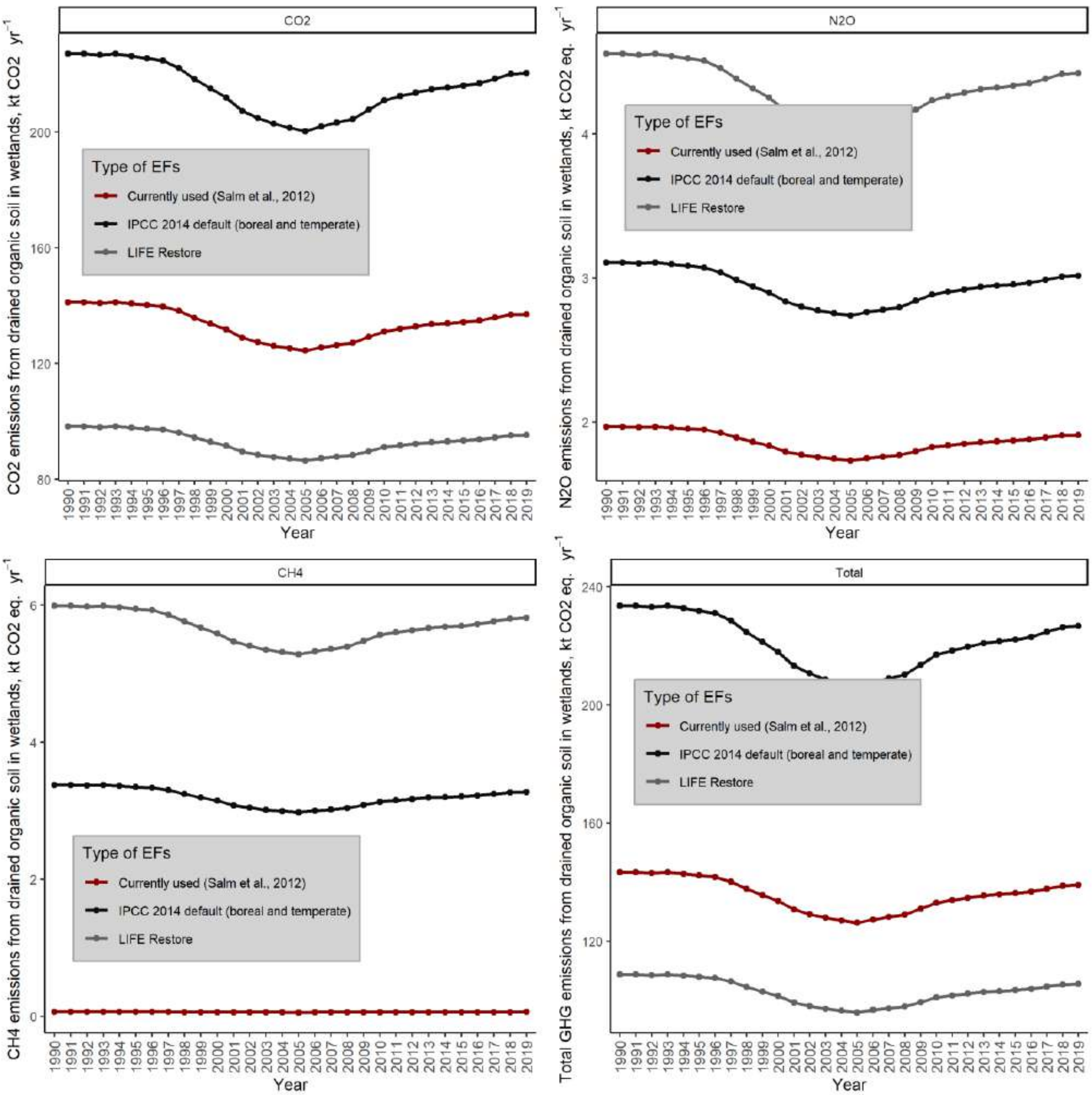

Figure 14. Evaluation of GHG emissions from drained organic soils in wetlands (peat extraction sites) in Estonia using different type of EFs: IPCC default EFs; EFs obtained within the LIFE REstore project in Latvia; currently used EFs for GHG reporting within Estonia's National Inventory

5 POTENTIAL IMPACT OF FUTURE RECALCULATIONS

We will provide evaluation of potential impact of recalculations due to implementation of EFs obtained within the LIFE OrgBalt project in final version of deliverable "Improved methodologies for GHG inventory reporting and related national reports" in the final stage of the project.

6 CONCLUSIONS

GHG EFs for drained organic soils in cropland, grassland and wetlands (peat extraction sites) developed within the EU LIFE program project "Sustainable and responsible management and re-use of degraded peatlands in Latvia" (LIFE REstore) in Latvia have been implemented in the Latvia's National GHG Inventory. In cropland, use of CS EFs for CO_2, CH_4 and leads to decrease total net GHG emissions from drained organic soils in Latvia by 1432.8 kt CO_2 eq. yr^{-1} or by 40.4% in average during 1990-2019. In grassland, use of CS EFs for CO_2, CH_4 and N_2O leads to decrease total net GHG emissions from drained organic soils in Latvia by 584.9 kt CO_2 eq. yr^{-1} or by 31.6% in average during 1990-2019. In wetlands (peat extraction sites), use of CS EFs for CO_2, CH_4 and N_2O leads to decrease total net GHG emissions from drained organic soils in peat extraction sites in Latvia by 226.6 kt CO_2 eq. yr^{-1} or by 53.5% in average during 1990-2019**Figure 6**. Currently, for cropland only CS EFs for CO_2 and N_2O are implemented in the National GHG Inventory, but for grassland and wetlands (peat extraction sites) all CS EFs are implemented in the National GHG Inventory. The CS CO_2 EFs contributed the most to the reduction of total GHG emissions from drained organic soils in Latvia.

We modelled and estimated potential impacts of recalculations of on-site GHG emissions and removals from drained organic soils in cropland, grassland and in peat extraction sites in wetlands in Lithuania and Estonia due to implementation of EFs obtained within the LIFE REstore project in Latvia. Results of modelling and estimation confirm that recalculations of GHG emissions due to implementation of country- or region-specific GHG EFs for drained organic soils can significantlly impact total GHG emissions and removals from LULUCF and Agriculture sectors.

In the following stages of the study, we will shift used methodology (used for National GHG Inventory) to a higher level (Tier) methods, which will be based on the results of the LIFE OrgBalt project (including improved activity data sets related to peat properties and water regime) and other studies. Evaluation of potential impact of recalculations due to implementation of EFs obtained within the LIFE OrgBalt project will be provided in the final version of this deliverable.

7 FURTHER WORK TO BE DONE

Some points to look out for in further work are:

1) GHG fluxes from naturally wet soils, particularly more attention to improvement of activity data sets (soil moisture, temperature and groundwater level) and modelling of GHG fluxes. Preliminary results of PhD theses (A. Butlers, Latvian State Forest Research Institute "Silava") highlighted that GHG emissions from wet organic soils (nutrient-rich) can reach the same level as it is in drained organic soils or even exceed, for instance, in case of CH_4 if groundwater level is above 20-30 cm (Butlers at al., 2021). Detected factors that most significantly influence amount of GHG emissions from organic soils are air and soil temperature (refers to CO_2), soil moisture and groundwater level (refers to CH_4), nitrogen content in soil solution (refers to N_2O). Studies on impact of tree species and land cover (stand or clearcut) on GHG emissions from naturally wet soils needs to be expanded (by increase number of sample plots) to reduce uncertainties and to quantify the impact.

2) Stem fluxes in deciduous forests, particularly in areas with naturally wet organic and wet soils. The recent studies in neighbouring countries proves that trees can be significant source of CH_4 emissions, especially in areas with seasonally fluctuating or high groundwater level. Increase of CH_4 emissions during seasonal floods and periodic increase of groundwater level can contribute to more than 70% of the net CH_4 emissions in forests with water saturated soils (Schindler et al., 2021). This and earlier studies (Schindler et al., 2020; Vargas, Barba, 2019) have significantly clarified the processes affecting GHG fluxes in organic soils and pointed to underestimated sources of GHG emissions – pristine, naturally wet organic soils and tree stems; however, demonstration of GHG fluxes in rather extreme and specific conditions are hardly applicable in average conditions and cannot be directly transferred to GHG inventory. Comprehensive studies are necessary also to prove the effect of certain climate change mitigation measures, e.g. seasonal adjustment of groundwater level in deciduous tree stands and use of selective thinning instead of regenerative clear-felling. Limited and controversial knowledge about GHG fluxes in organic soils in combination with high uncertainty hampers implementation of climate change mitigation measures aimed at reduction of the largest source of GHG emissions in Latvia and abroad. It should be emphasized that, for example, in Latvia we are not using Eddy covariance technique, thus emissions from tree stems are not accounted/estimated.

3) Wet and drained mineral soils in forest lands. Lack of scientifically based data, concerns about continuation of peat mineralization and CH_4 emissions.

4) Lack of scientifically based data on emissions from alluvial soils with high organic matter (carbon) content in cropland and grassland (including CH_4 emissions in case of rewetting).

5) Lack of scientifically based data on DOC emissions (dissolved organic C exported from organic soils), which are currently likely to be significantly overestimated.

6) Lack of scientifically based data on emissions from drainage ditches in organic soils, which are currently likely to be significantly overestimated.

7) Lack of scientifically based data on emissions from flooded land, which are currently likely to be underestimated according to the preliminary results.

8 REFERENCES

Alm, J., Shurpali, N. J., Minkkinen, K., Aro, L., Hytönen, J., Laurila, T. et al. 2007. Emission factors and their uncertainty for the exchange of CO_2, CH_4 and N_2O in Finnish managed peatlands. Boreal Environment Research 12, 191-209.

Butlers, A., Bārdule, A., Spalva, G., Muižnieks, E. 2021. N_2O and CH_4 emissions from naturally wet and drained nutrient-rich organic forest soils. Proceeding of International Scientific Conference "Rural Development 2021" (under review process).

Evans, C.D., Renou-Wilson, F., Strack, M. 2016. The role of waterborne carbon in the greenhouse gas balance of drained and re-wetted peatlands. Aquat. Sci., 78: 573-590.

Frank, S. 2016. Factors controlling concentrations and losses of dissolved carbon and nitrogen from disturbed bogs in Lower Saxony (Germany). PhD thesis, Leibniz-Universität Hannover, Hannover, Germany.

Frank, S., Tiemeyer, B., Bechtold, M., Lücke, A., Bol, R. 2017. Effect of past peat cultivation practices on present dynamics of dissolved organic carbon. Sci. Total Environ., 574: 1243-1253.

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

IPCC. 2014. 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland.

Laine, J., Vasander, H. 1998. Ecology and vegetation gradients of peatlands. In Vasander H (ed). Mires of Finland, 10–19. Finnish Peatland Society, Helsinki.

Laine, J. 1989. Metsäojitettujen soiden luokittelu. [Classification of peatlands drained for forestry, Summary in English]. Suo 40: 37–51. http://www.suo.fi/pdf/article9651.pdf

Lazdiņš A., Lupiķis A. 2019. LIFE REstore project contribution to the greenhouse gas emission accounts in Latvia. In: A. Priede, A. Gancone (Eds.), Sustainable and responsible after-use of peat extraction areas (pp. 21–52). Baltijas Krasti.

Licite I., Lupikis, A. 2020. Impact of land use practices on greenhouse gas emissions from agriculture land on organic soils. Proceedings of 19th International Scientific Conference Engineering for Rural Development, 1823–1830. DOI: 10.22616/ERDev.2020.19.TF492

Lupikis A., Lazdins A. 2017. Soil carbon stock changes in transitional mire drained for forestry in Latvia: A case study. Proceedings of 23rd Annual International Scientific Conference "Research for Rural Development 2017".

Minkkinen, K., Laine, J., Shurpali, N., Mäkiranta, P., Alm, J. & Penttilä, T. 2007. Heterotrophic soil respiration in forestry-drained peatlands. Boreal Environment Research 12: 115-126.

NIR-FI 2020. Finland's National Inventory Report (NIR) under the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the European Union (EU). Available at https://unfccc.int/documents/219060

NIR Sweden (2020). National Inventory Report Sweden 2020. Greenhouse Gas Emission Inventories 1990–2018. Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Swedish Environmental Protection Agency

Nykänen, H., Silvola, J., Alm, J. and Martikainen, P. 1996. Fluxes of greenhouse gases CH_4, CO_2 and N_2O on some peat mining areas in Finland. In: Laiho, R., Laine, J. and Vasander, H. (eds.) (1996). Northern Peatland in global climate change. (Proceedings of the International Workshop held in Hyytiälä, Finland, 8-12 October 1995, The Finnish Research Programme on Climate Change – SILMU). Publications of the Academy of Finland 1/96, 141-147.

Ojanen, P., Minkkinen, K., Alm, J. Penttilä, T. 2010. Soil-atmosphere CO_2, CH_4 and N_2O fluxes in boreal forestry-drained peatlands. Forest Ecology and Management 260: 411-421.

Ojanen, P., Minkkinen, K., Alm, J., Penttilä, T. 2018. Corrigendum to “Soil–atmosphere CO_2, CH_4 and N_2O fluxes in boreal forestry-drained peatlands“. Forest Ecology and Management 412: 95-96.

Ruuhijärvi, R. 1983. The Finnish mire types and their regional distribution. In Gore AP (ed). Mires: Swamp, bog, fen and moor, 47–67. Ecosystems of the world 4B. Elsevier, Amsterdam.

Salm, J-O., Maddison, M., Tammik, S., Soosaar, K., Truu, J., Mander, Ü. 2012. Emissions of CO_2, CH_4 and N_2O from undisturbed, drained and mined peatlands in Estonia. Hydrobiologia, 692, 41–55.

Schindler, T., Machacova, K., Mander, Ü., Escuer-Gatius, J., Soosaar, K. 2021. Diurnal Tree Stem CH_4 and N_2O Flux Dynamics from a Riparian Alder Forest. Forests, 12(7), 863. https://doi.org/10.3390/f12070863

Schindler, T., Mander, Ü., Machacova, K., Espenberg, M., Krasnov, D., Escuer-Gatius, J., Veber, G., Pärn, J., Soosaar, K. 2020. Short-term flooding increases CH_4 and N_2O emissions from trees in a riparian forest soil-stem continuum. *Scientific Reports*, *10*(1), 3204. https://doi.org/10.1038/s41598-020-60058-7

Tiemeyer, B., Kahle, P. 2014. Nitrogen and dissolved organic carbon (DOC) losses from an artificially drained grassland on organic soils. Biogeosciences, 11: 4123-4137.

Tiemeyer, B.; Freibauer, A.; Borraz, E.A.; Augustin, J.; Bechtold, M.; Beetz, S.; Beyer, C.; Ebli, M.; Eickenscheidt, T.; Fiedler, S.; et al. A new methodology for organic soils in national greenhouse gas inventories: Data synthesis, derivation and application. Ecol. Indic. 2020, 109, 105838.

Vargas, R., Barba, J. 2019. Greenhouse gas fluxes from tree stems. *Trends in Plant Science*, *24*(4), 296–299. https://doi.org/10.1016/j.tplants.2019.02.005