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)

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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. Within the LIFE OrgBalt project improved GHG emission factors (EFs) for nutrient-rich managed organic soils in Baltic States are elaborated (LIFE OrgBalt Report No. C1/5). It provides an opportunity to improve the Tier 2 method for GHG emission and removal calculations under the National GHG Inventories. Additional data to support implementation of higher Tier level methodology aiming at Tier 3 are available, as well.

Currently, country-specific (CS) and 2014 IPCC default (temperate zone) EFs are used for GHG emission reporting from drained nutrient-rich organic soils in forest land, cropland and grassland under the National GHG Inventory in Latvia. In Lithuania, 2006 IPCC default (temperate zone) EFs are used for GHG emission reporting, while, in Estonia, both 2006 and 2014 IPCC default (both temperate and boreal zone) EFs are used for GHG emission reporting from drained nutrient-rich organic soils in forest land, cropland and grassland. Thus, reporting approaches and used EFs differ among the Baltic States.

We modelled and estimated potential impacts of recalculations of on-site GHG emissions and removals from drained nutrient-rich organic soils in forest land, cropland and grassland in Latvia, Lithuania and Estonia due to implementation of EFs obtained within the LIFE OrgBalt project. Results of modelling and estimation confirm that recalculations of GHG emissions due to implementation of region-specific GHG EFs for drained nutrient-rich organic soils can significantly impact total GHG emissions and removals from the Land Use, Land-Use Change, and Forestry (LULUCF) and Agriculture sectors.

In Latvia, use of LIFE OrgBalt EFs (region-specific) of CO_2, CH_4 and N_2O for forest land, cropland and grassland leads to decrease total reported net GHG emissions from drained nutrient-rich organic soils (average during 1990-2022 if compare to the currently reported GHG emissions under the National GHG Inventory):

- decrease by 3050.6 kt CO_2 eq. yr^{-1} (by 103.7%) according to the Approach A for CO_2 and by 574.0 kt CO_2 eq. yr^{-1} (by 19.5%) according to the Approach B for CO_2 in forest land;
- decrease by 325.9 kt CO_2 eq. yr^{-1} (by 15.7%) in cropland;
- decrease by 347.4 kt CO_2 eq. yr^{-1} (by 26.9%) in grassland.

In Lithuania and Estonia, use of LIFE OrgBalt EFs (region-specific) of CO_2, CH_4 and N_2O for forest land, cropland and grassland leads to decrease or increase total reported net GHG emissions from drained nutrient-rich organic soils (average during 1990-2021 if compare to the currently reported GHG emissions under the National GHG Inventory) depending on land use type and used approach for CO_2 EF for forest land:

- In Lithuania:

  - decrease by 308.9 kt CO_2 eq. yr^{-1} (by 112.3%) according to the Approach A for CO_2 in forest land;
  - increase by 467.0 kt CO_2 eq. yr^{-1} (by 169.7%) according to the Approach B for CO_2 in forest land;
  - decrease by 251.5 kt CO_2 eq. yr^{-1} (by 19.9%) in cropland;
  - increase by 598.1 kt CO_2 eq. yr^{-1} (by 216.0%) in grassland.
- In Estonia:
  - decrease by 724.2 kt CO_2 eq. yr^{-1} (by 108.7%) according to the Approach A for CO_2 in forest land;
  - increase by 606.2 kt CO_2 eq. yr^{-1} (by 91.0%) according to the Approach B for CO_2 in forest land;
  - decrease by 133.0 kt CO_2 eq. yr^{-1} (by 19.9%) in cropland;
  - increase by 98.0 kt CO_2 eq. yr^{-1} (by 216.0%) in grassland.

This report reviews the currently applied EFs for organic soils in Finland, Estonia, Latvia and Lithuania and presents the EFs calculated for organic nutrient-rich soils during the OrgBalt project that could be applied by the states in following National GHG inventory submissions.

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"

LIFE OrgBalt = EU LIFE program project "Demostration of climate change mitigation measures in nutrient rich drained organic soils in Baltic states and Finland"

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[1] (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 $ha^{-1}yr^{-1}$.

[1] 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.

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).

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

Where:

$CO_2\text{-}C_{DOC}$ = 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)).

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

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).

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.

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.

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 1: Results of the LIFE OrgBalt project provide additional information to support implementation of 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:

$\Delta C_{SO-CONVERSION}$ = 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.

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

Where:

$CO_{2\ SO-RE}$ = 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).

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

Where:
$CO_{2\text{-}SO\text{-}DR}$ = 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 2: 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 3: Results of the LIFE OrgBalt project provide data to support implementation of a 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).

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

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 4: Results of the LIFE OrgBalt project provide data to support implementation of a 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.

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

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).

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

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 5: Results of the LIFE OrgBalt project provide data to support implementation of 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 6: Results of the LIFE OrgBalt project provide data to support implementation of 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:
$CH_{4\text{-}SO\text{-}REWET}$ = 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 7: 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 8: Results of the LIFE OrgBalt project provide country-specific GHG emission estimates 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 9: Results of the LIFE OrgBalt project do 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[2]

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[3] CO_2	Tier 2	CS	0.52 t C ha^{-1} yr^{-1}	Lupiķis and Lazdiņš, 2017[4]
			CH_4	Tier 1	D	2.5 kg CH_4 ha^{-1} yr^{-1} (organic soil)	Table 2.3 of the IPCC Wetlands Supplement
			CH_4	Tier 2	D	10.3 kg CH_4 ha^{-1} yr^{-1} (drainage ditches)	Vanags-Duka et al., 2022
			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	EF_{CO2} is 0.50 t CO_2-C ha^{-1} yr^{-1}; $EF_{DOC\_REWETTED}$ 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
Cropland	Cropland remaining Cropland, Land Converted to Cropland	drained organic soils	on-site[3] 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[3] 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

[2] Based on Latvia's National Inventory Report 1990-2021

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

[4] CO_2 EF (0.52 t CO_2-C ha^{-1} yr^{-1}, Lupikis and Lazdins, 2017) already includes proportion of both nutrient-rich and nutrient-poor drained organic soils. It was assumed that no CO_2 emissions from nutrient-poor drained organic soils (*Callunosa turf. mel.*, *Vacciniosa turf. mel.*, *Myrtillosa turf. mel.* forest site types) occurring. Taking into account the proportional distribution of forest site types with drained organic soil in Latvia according to the results of the 3rd cycle of the National Forest Inventory, CO_2 EF for nutrient-rich drained organic soils is 2.17 t CO_2-C ha^{-1} yr^{-1}.

Land use		Soil type	Gas	Method	Emission factor		
Category	Sub-category				Type	Value, unit	Source
							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 Remaining Peat Extraction	drained organic soils	on-site[3] 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} (organic soil)	LIFE REestore project, Lazdiņš and Lupiķis 2019
			CH_4	Tier 2	CS	122.5 kg CH_4 ha^{-1} yr^{-1} (drainage ditches)	Vanags-Duka et al., 2022
			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}; $EF_{DOC\_REWETTED}$ 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}; $EF_{DOC\_REWETTED}$ is 0.24 t CO_2-C ha^{-1} yr^{-1}	Table 3.1 and table 3.2 of the IPCC Wetlands Supplement
Settlements	Settlements Remaining Settlement, Land Converted to Settlement	drained organic soils	on-site[3] 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 the 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 of the 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

[5] Based on Lithuania’s National Inventory Report 1990-2021

							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	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 of the 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 of the 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 of the 2006 IPCC GL
			CH_4	NA	-	-	CH_4 emissions are assumed to be insignificant
			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 of the 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	Country-specific reference C stocks: 166.4 t C ha^{-1} yr^{-1} (FL rem FL); 266.8 t C ha^{-1} yr^{-1} (L conv to FL)	NIR 2023
			on-site CO_2, CL-SL	Tier 1	D	5 t CO_2-C ha^{-1} yr^{-1}	Table 5.6, p. 5.19 of the 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 of the 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 1	D	0.68 t C ha^{-1} yr^{-1}	Table 4.6, p. 4.53 of the 2006 IPCC GL (temperate)
			CH_4	Tier 1	D	2 kg CH_4 ha^{-1} yr^{-1} (organic soil, nutrient-rich);	Table 2.3 and Table 2.4 of the IPCC Wetlands Supplement (boreal)
						7 kg CH4 ha^{-1} yr^{-1} (organic soil, nutrient-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} (nutrient-rich)	Table 2.5 of the IPCC Wetlands Supplement (boreal)
						0.22 kg N_2O-N ha^{-1} yr^{-1} (nutrient-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

[6] Based on Estonia’s National Inventory Report 1990-2021

							according to the IPCC 2006 Guidelines.
Cropland	Cropand remaining Cropand, Land Converted to Cropand	drained organic soils	on-site CO_2	Tier 1	D	5.0 t CO_2-C ha^{-1} yr^{-1}	Table 5.6, p. 5.19 of the 2006 IPCC GL (boreal/cool temperate)
			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 Converted to Grassland	drained organic soils	on-site CO_2	Tier 2	D	0.25 t CO_2-C ha^{-1} yr^{-1}	Table 6.3, p. 6.17 of the 2006 IPCC GL
			CH_4	NA	–	–	–
			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-C 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	Tier 4	D	5.0 t CO_2-C ha^{-1} yr^{-1}	Table 5.6, p. 5.19 of the 2006 IPCC GL (boreal/cool temperate)
			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	drained organic	carbon/ CO_2	Tier 2, Tier 3	CS	Value is site-specific accounting change in	Chapter 6.4.2 in NIR-FI

[7] Based on Finnish National Inventory Report 1990-2021

Land use		Soil type	Gas	Method	Emission factor		
Category	Sub-category				Type	Value, unit	Source
	Land, Land Converted to Forest Land	soils				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 values.	2023 (Table 6.4-4), Minkkinen et al. 2007
			CH_4	Tier 1	CS	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	Chapter 6.10.2.2 / Table 6.10-4 in NIR-FI 2023. Values from Ojanen et al. (2010, 2018)
			N_2O	Tier 2	D	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))	Chapter 6.10.2.2 / Table 6.10-4 in NIR-FI 2023. Values from Ojanen et al. (2010, 2018), site types from Laine (1989)
Cropland	Cropland remaining Cropland, Land Converted to Cropland	drained organic soils	On-site CO_2	Tier 2	D	5.7 t CO_2-C ha^{-1} yr^{-1} (grass); 7.9 t CO_2-C ha^{-1} yr^{-1} (annual crops)	Table 2.1, p. 2.13 of the IPCC Wetlands Supplement (boreal)
			N_2O	Tier 2	D	13.0 kg N_2O-N ha^{-1} a^{-1} (cereals)	IPCC Wetlands Supplement (2013; table 2.5): Augustin et al., 1998; Drösler et al., 2013; Elsgaard et al., 2012; Flessa et al., 1998; Kasimir-Klemedtsson et al., 2009; Maljanen et al., 2003a,b, 2004, 2007; Petersen et al., 2012; Regina et al., 2004; Taft et al., 2013
				Tier 2	D	9.5 kg N_2O-N ha^{-1} a^{-1} (perennials)	IPCC Wetlands Supplement (2013; table 2.5): Grønlund et al., 2006; Hyvönen et al., 2009; Jaakkola, 1985; Maljanen et al., 2001, 2003a, 2004, 2009, 2010a; Nykänen et al., 1995; Regina et al., 1996, 2004

Land use		Soil type	Gas	Method	Emission factor		
Category	Sub-category				Type	Value, unit	Source
Grassland	Grassland remaining Grassland, Land Converted to Grassland	drained organic soils	carbon/ CO_2	Tier 1, Tier 2, Tier 3	CS, D	3.5 t CO_2-C ha^{-1} yr^{-1}	Maljanen et al. 2010
			N_2O	Tier 2	D	5.7 kg N_2O-N ha^{-1} a^{-1}	Maljanen et al. 2010
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 2.19 t C ha^{-1} a^{-1} (Dwarf shrub type) for peat extraction areas converted to other wetlands, and emission of 1.85 t C ha^{-1} a^{-1} (Cladina type) for forest land converted to other wetlands	Chapter 6.4.2 in NIR-FI 2023 (Table 6.4-4), Minkkinen et al. 2007
	Flooded land Remaining Flooded Land	flooded organic soils	diffusive CO_2	Tier 1	D	11.8 kg CO_2 ha^{-1} day^{-1}	2006 IPCC Guidelines, Table 2A.2, p. Ap2.6
			diffusive CH_4	Tier 1	D	0.086 kg CH_4 ha^{-1} day^{-1}	2006 IPCC Guidelines, Vol. 4, Table 3A.2, p. Ap3.5
	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 2023. Emission values from Alm et al. (2007)
			CH_4	Tier 2	CS	Emission is site specific and varies based on proportion of stockpiles, ditches and production field	Chapter 6.10.2.2 / Table 6.10-3 in NIR-FI 2023. Emission values from Nykänen et al. (1996), Alm et al. (2007)
			N_2O	Tier 2	CS	Emission is site specific and varies based on proportion of stockpiles, ditches and production field	Chapter 6.10.2.2 / Table 6.10-3 in NIR-FI 2023. Emission values from Nykänen et al. (1996), Alm et al. (2007)
	Regressed wetlands	organic soils	CH_4	T2	CS	1.16 g CH_4 m^{-2} yr^{-1} (poor drainage ditch condition)	Chapter 6.10.2.2 / Table 6.10-4 in NIR-FI 2023. Values from Ojanen et al. (2010, 2018)
			N_2O	T2	CS	0.043 g N_2O m^{-2} yr^{-1} (Dwarf shrub type (Vatkg))	Chapter 6.10.2.2 / Table 6.10-4 in NIR-FI 2023. Values from Ojanen et al. (2010, 2018), site types from Laine (1989)

3 IMPACT OF LIFE ORGBALT EMISSION FACTORS' APPLICATION IN GHG INVENTORY REPORTING AND RELATED NATIONAL REPORTS IN LATVIA, LITHUANIA AND ESTONIA

3.1 Improved methodologies of estimation of GHG emissions and removals within national GHG inventory reporting

LIFE OrgBalt provides information to improve Latvia's, Lithuania's and Estonia's National GHG Inventories; both region-specific GHG EFs are elaborated (provide an opportunity to improve the Tier 2 method) and additional data to support implementation of higher Tier level methodology aiming at Tier 3 are available. In this chapter, we present approximate evaluation of possible impact of application of LIFE OrgBalt EFs in GHG inventory reporting in Latvia, Lithuania and Estonia. GHG EFs for different types of land use (forest land, cropland and grassland) elaborated within the project are summarized in **Error! Reference source n ot found.**. To provide a wider insight, comparison of elaborated EFs with 2014 IPCC default EFs (the 2014 IPCC Wetlands Supplement) and results from other studies conducted in the Baltic States is provided. In addition, for forest land, LIFE OrgBalt provides stratified EFs by the type of dominant tree species or even specific tree species (deciduous, coniferous; alder, birch, spruce, pine), which can be additionally implemented into the National GHG Inventories. Detailed description of the elaborated EFs is provided in the LIFE OrgBalt deliverable "Report on improved GHG emission factors for nutrient-rich managed organic soils in Baltic states".

Note 10: Elaborated GHG EFs for different types of land use (Table 22) will be summarized in scientific manuscripts and, thus, could be corrected/improved during the peer review process.

Table 22. EFs for on-site GHG emissions for drained organic soils (nutrient-rich) in forest land, cropland and grassland in the Baltic states elaborated within the LIFE OrgBalt project; comparison with 2014 IPCC default EFs and results from other studies conducted in the Baltic States is provided.

Type of land use	Gas[8]	EF elaborated within LIFE OrgBalt project[9] (value and unit)	2014 IPCC default EFs		Other studies conducted in the Baltic States	
			Value and unit	Reference	Value and unit	Reference
Forest land	CO_2	Approach A[10]: -3.89 t CO_2 (-1.06 t CO_2-C) ha^{-1} yr^{-1}	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 (both nutrient-rich and poor soils)[11]

[8] CH_4 emissions only from drained soils are included, CH_4 emissions from drainage ditches are excluded.

[9] Elaborated GHG EFs for different types of land use will be summarized in scientific manuscripts and, thus, could be corrected/improved during the peer review process.

[10] Approach A – CO_2 EF calculated as difference between CO_2 emissions from soil (4.30 t C ha^{-1} yr^{-1}) and carbon supply to soil by woody plant litter (1.69 t C ha^{-1} yr^{-1}; foliar fine litter) and understorey plant residue including above- and belowground vegetation of herbaceous plants and tree fine roots (3.67 t C ha^{-1} yr^{-1}). CO_2 emissions from soil were calculated by multiplying estimated soil total respiration by empirical factor (mean 0.65) characterising share of soil respiration in total respiration.

[11] CO_2 EF (0.52 t CO_2-C ha^{-1} yr^{-1}, Lupikis and Lazdins, 2017) already includes proportion of both nutrient-rich and nutrient-poor drained organic soils. It was assumed that no CO_2 emissions from nutrient-poor drained organic soils (*Callunosa turf.*

Type of land use	Gas[8]	EF elaborated within LIFE OrgBalt project[9] (value and unit)	2014 IPCC default EFs		Other studies conducted in the Baltic States	
			Value and unit	Reference	Value and unit	Reference
		Approach B[12]: 3.85 t CO_2 (1.05 t CO_2-C) ha^{-1} yr^{-1}	3.41 t CO_2 (or 0.93 t CO_2-C) ha^{-1} yr^{-1}	Table 2.1 of the IPCC Wetlands Supplement (boreal, nutrient-rich)	Within a 240-year forest management cycle: 0.1 t C ha^{-1} yr^{-1} (deciduous-dominant species); −0.6 t C ha^{-1} yr^{-1} (coniferous-dominant species)	Butlers et al., 2022 (nutrient rich soils)
					3.96 t CO_2 (or 1.08 t CO_2-C) ha^{-1} yr^{-1}	Lazdiņš et al., 2024 (include both nutrient rich and poor soils)
	CH_4	-4.78 kg CH_4 (or -3.58 kg CH_4-C) ha^{-1} yr^{-1}	2.5 kg CH_4 (or 1.87 kg CH_4-C) ha^{-1} yr^{-1}	Table 2.3 of the IPCC Wetlands Supplement (temperate)	-4.6 kg CH_4 (or -3.4 kg CH_4-C) ha^{-1} yr^{-1}	Butlers et al., 2023 (nutrient rich soils)
			2.0 kg CH_4 (or 1.50 kg CH_4-C) ha^{-1} yr^{-1}	Table 2.3 of the IPCC Wetlands Supplement (boreal, nutrient-rich)		
	N_2O	13.9 kg N_2O (or 8.8 kg N_2O-N) ha^{-1} yr^{-1}	4.4 kg N_2O (or 2.8 kg N_2O-N) ha^{-1} yr^{-1}	Table 2.5 of the IPCC Wetlands Supplement (temperate)	1.7 kg N_2O (or 1.1 kg N_2O-N) ha^{-1} yr^{-1}	Butlers et al., 2023 (nutrient rich soils)
			5.0 kg N_2O (or 3.2 kg N_2O-N) ha^{-1} yr^{-1}	Table 2.5 of the IPCC Wetlands Supplement (boreal, nutrient-rich)		
Cropland	CO_2	15.0 t CO_2 (or 4.1 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)	17.6 t CO_2 (or 4.80 t CO_2-C) ha^{-1} yr^{-1}	Licite and Lupikis, 2020
	CH_4	-0.61 kg CH_4 (or -0.46 kg CH_4-C) ha^{-1} yr^{-1}	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)	-0.79 kg CH_4 (or -0.59 kg CH_4-C) ha^{-1} yr^{-1}	Licite and Lupikis, 2020
	N_2O	8.86 kg N_2O (or 5.6 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)	11.3 kg N_2O (or 7.2 kg N_2O-N) ha^{-1} yr^{-1}	Licite and Lupikis, 2020
Grassland	CO_2	12.8 t CO_2 (or 3.5 t CO_2-C) ha^{-1} yr^{-1} (no statistically significant difference between deep-drained and shallow-drained soils was found)	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)	16.1 t CO_2 (or 4.39 t CO_2-C) ha^{-1} yr^{-1}	Licite and Lupikis, 2020
			13.2 t CO_2 (or 3.6 t CO_2-C) ha^{-1} yr^{-1}	Table 2.1 of the IPCC Wetlands Supplement (temperate, shallow-drained, nutrient-rich)	12.8 t CO_2 (or 3.48 t CO_2-C) ha^{-1} yr^{-1}	Purviņa el al., 2024
			20.9 t CO_2 (or 5.7 t CO_2-C) ha^{-1} yr^{-1}	Table 2.1 of the IPCC Wetlands Supplement (boreal)		
	CH_4	4.94 kg CH_4 (or 3.70 kg CH_4-C) ha^{-1} yr^{-1}	16 kg CH_4 (or 12.0 kg CH_4-C) ha^{-1} yr^{-1}	Table 2.3 of the IPCC Wetlands Supplement (temperate, deep-drained, nutrient-rich)	77.2 kg CH_4 (or 57.8 kg CH_4-C) ha^{-1} yr^{-1}	Licite and Lupikis, 2020

mel., *Vacciniosa turf. mel.*, *Myrtillosa turf. mel.* forest site types) occurring. Taking into account the proportional distribution of forest site types with drained organic soil in Latvia according to the results of the 3rd cycle of the National Forest Inventory, CO_2 EF for nutrient-rich drained organic soils is 2.17 t CO_2-C ha^{-1} yr^{-1}.

[12] Approach B – CO_2 EF calculated as difference between CO_2 emissions from forest floor (6.41 t C ha^{-1} yr^{-1}) and carbon supply to soil by woody plant litter (1.69 t C ha^{-1} yr^{-1}; foliar fine litter) and understorey plant residue including above- and belowground vegetation of herbaceous plants and tree fine roots (3.67 t C ha^{-1} yr^{-1}). Thus, approach B may overestimate net CO_2 emissions from drained organic soil because elaborated net CO_2 EF (specifically C output flow) includes autotrophic respiration in addition to soil heterotrophic respiration.

Type of land use	Gas[8]	EF elaborated within LIFE OrgBalt project[9] (value and unit)	2014 IPCC default EFs		Other studies conducted in the Baltic States	
			Value and unit	Reference	Value and unit	Reference
			39 kg CH_4 (or 29.2 kg CH_4-C) ha^{-1} yr^{-1}	Table 2.3 of the IPCC Wetlands Supplement (temperate, shallow-drained, nutrient-rich)	-1.56 kg CH_4 (or -1.17 kg CH_4-C) ha^{-1} yr^{-1}	Purviņa et al., 2024
			1.4 kg CH_4 (or 1.0 kg CH_4-C) ha^{-1} yr^{-1}	Table 2.3 of the IPCC Wetlands Supplement (boreal)		
	N_2O	1.84 kg N_2O (or 1.2 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)	0.41 kg N_2O (or 0.26 kg N_2O-N) ha^{-1} yr^{-1}	Licite and Lupikis, 2020
			2.5 kg N_2O (or 1.6 kg N_2O-N) ha^{-1} yr^{-1}	Table 2.5 of the IPCC Wetlands Supplement (temperate, shallow-drained, nutrient-rich)	3.76 kg N_2O (or 2.39 kg N_2O-N) ha^{-1} yr^{-1}	Purviņa et al., 2024
			14.9 kg N_2O (or 9.5 kg N_2O-N) ha^{-1} yr^{-1}	Table 2.5 of the IPCC Wetlands Supplement (boreal)		

Mean soil C stock change estimated during the study period is indicative as soil C balance in the study sites and study period. However, the results obtained from the LIFE OrgBalt are applicable for compiling them with other existing research measurement raw data, thereby obtaining a broader data set for conducting meta-analysis. Such analysis and synthesis would allow for even more effective use of information on soil GHG emissions and C input in soil to investigate variances in mutual relations, as well as searching, characterizing, and quantifying the overall relation of individual GHG emissions or soil carbon input and influencing factors. This would enable the results obtained in individual research sample plots to be scaled up to the country level in accordance with the IPCC Tier 3 methodological level.

3.2 Possible impact of application of LIFE OrgBalt EFs in GHG inventory reporting in Latvia

It is assumed that all drained organic soils in cropland and grassland in Latvia correspond to nutrient-rich status, while in forest land 78.7% of all drained organic soils correspond to nutrient-rich status (forest site types: *Myrtillosa turf. mel.*, *Oxalodosa turf. mel.*) according to the results of the National Forest Inventory (4th cycle, first four years[13]) (Figure 1). Soils are considered organic as defined in the National Forest Inventory: soil is classified as organic if the organic layer (H horizon) is at least 20 cm deep.

[13] National Forest Inventory: https://www.silava.lv/petnieciba/nacionalais-meza-monitorings

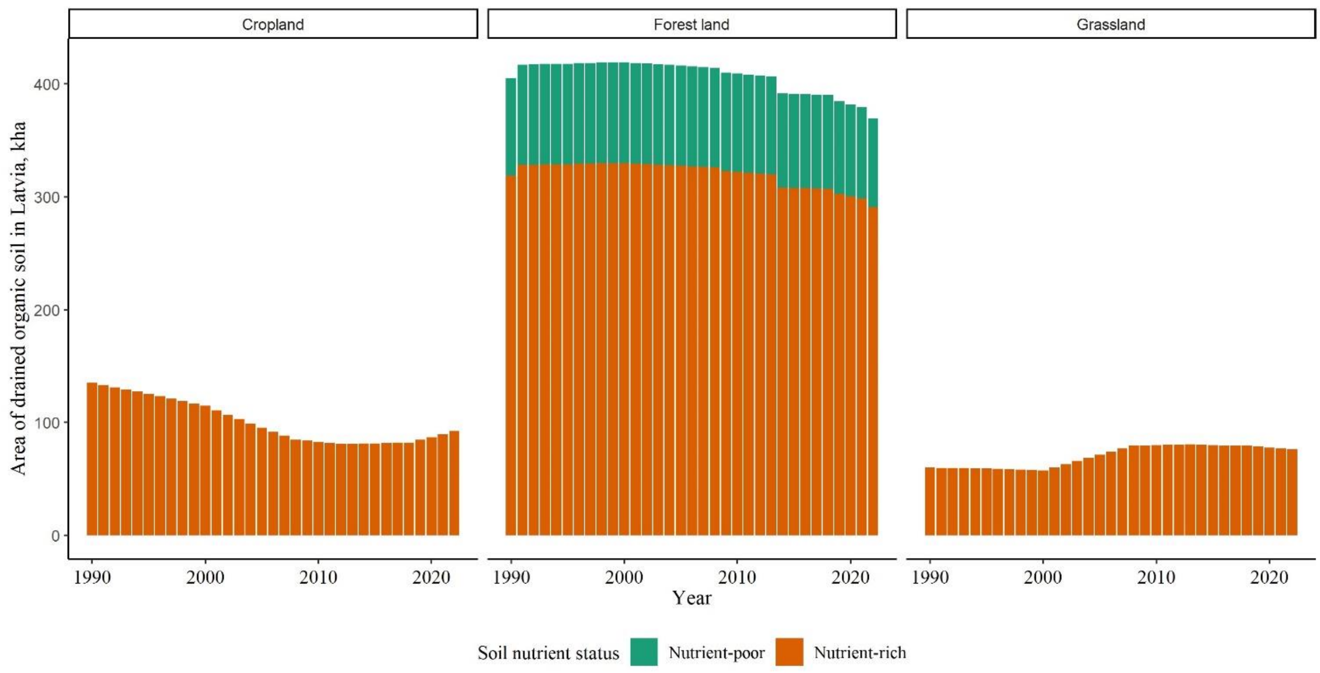

Figure 1. Area of drained organic soil in cropland, grassland and forest land in Latvia[14].

3.2.1 Forest land

Impact of recalculation of on-site GHG emissions and removals from drained nutrient-rich organic soils in forest land in Latvia due to implementation of LIFE OrgBalt EFs is shown in Figure 2. GHG emissions from nutrient-poor organic soils and CH_4 emissions from drainage ditches are excluded from this estimation. LIFE OrgBalt CO_2 EF (approach A[15], indicating the CO_2 removals) are lower compared to currently used CS EF (Lupikis and Lazdins, 2017) as well as lower than the 2014 IPCC default EFs for temperate and boreal zone (Table 22). Also LIFE OrgBalt CO_2 EF (approach B[16], indicating the CO_2 emissions) are lower than currently used CS EF (Lupikis and Lazdins, 2017)[17] and the 2014 IPCC default EFs for temperate zone, while higher than the 2014 IPCC default EFs for boreal zone (Table 22). However, approach B may overestimate net CO_2 emissions from drained organic soil because elaborated net CO_2 EF (specifically C output flow) includes autotrophic respiration in addition to soil heterotrophic respiration. LIFE OrgBalt CH_4 EF is lower compared to currently used EF (2014 IPCC default EF for temperate zone) as well as lower than the 2014 IPCC default EF for boreal zone, while LIFE OrgBalt N_2O EF is higher compared to both currently used EF

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[14] Latvia's Greenhouse Gas Inventory Report 2024

[15] Approach A – CO_2 EF calculated as difference between CO_2 emissions from soil (4.30 t C ha^{-1} yr^{-1}) and carbon supply to soil by woody plant litter (1.69 t C ha^{-1} yr^{-1}; foliar fine litter) and understorey plant residue including above- and belowground vegetation of herbaceous plants and tree fine roots (3.67 t C ha^{-1} yr^{-1}). CO_2 emissions from soil were calculated by multiplying estimated soil total respiration by empirical factor (mean 0.65) characterising share of soil respiration in total respiration.

[16] Approach B – CO_2 EF calculated as difference between CO_2 emissions from forest floor (6.41 t C ha^{-1} yr^{-1}) and carbon supply to soil by woody plant litter (1.69 t C ha^{-1} yr^{-1}; foliar fine litter) and understorey plant residue including above- and belowground vegetation of herbaceous plants and tree fine roots (3.67 t C ha^{-1} yr^{-1}).

[17] CO_2 EF (0.52 t CO_2-C ha^{-1} yr^{-1}, Lupikis and Lazdins, 2017) already includes proportion of both nutrient-rich and nutrient-poor drained organic soils. It was assumed that no CO_2 emissions from nutrient-poor drained organic soils (*Callunosa turf. mel.*, *Vacciniosa turf. mel.*, *Myrtillosa turf. mel.* forest site types) occurring. Taking into account the proportional distribution of forest site types with drained organic soil in Latvia according to the results of the 3rd cycle of the National Forest Inventory, CO_2 EF for nutrient-rich drained organic soils is 2.17 t CO_2-C ha^{-1} yr^{-1}.

(2014 IPCC default EF for temperate zone) and the 2014 IPCC default EF for boreal zone (Table 22).

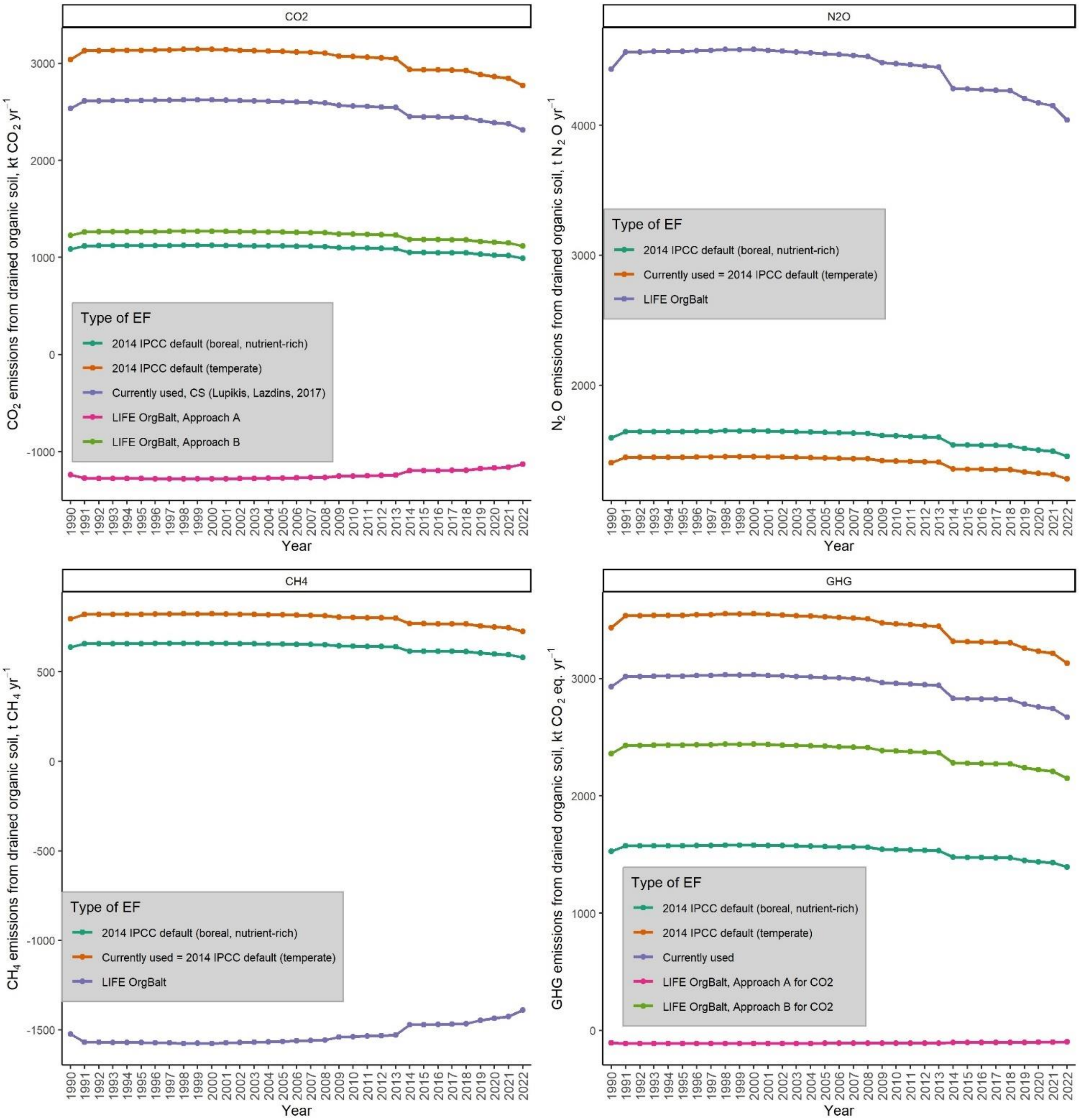

Figure 2. On-site CO_2, CH_4, N_2O and total GHG[18] emissions and removals from drained nutrient-rich organic soils in forest land in Latvia (forest site types: *Myrtillosa turf. mel.*, *Oxalodosa turf. mel.*) according to the different EFs summarized in Table 22.

In general, use of LIFE OrgBalt EFs for CO_2 (approach A), CH_4 and N_2O (-1.06 t CO_2-C ha^{-1} yr^{-1}, -4.78 kg CH_4 ha^{-1} yr^{-1} and 13.9 kg N_2O ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained

[18] Global Warming Potential values for 100-year time horizon: 28 for CH_4 and 265 for N_2O (AR5).

nutrient-rich organic soils in forest land in Latvia (290.7 – 329.8 kha depending from year in period of 1990-2022) by 3050.6 kt CO_2 eq. yr^{-1} or by 103.7% in average during 1990-2022 if compare to currently reported GHG emissions under the National GHG Inventory. Although to a lesser extent, also use of LIFE OrgBalt EFs for CO_2 (approach B, 1.05 t CO_2-C ha^{-1} yr^{-1}), CH_4 and N_2O leads to decrease total net GHG emissions from drained nutrient-rich organic soils in forest land in Latvia by 574.0 kt CO_2 eq. yr^{-1} or by 19.5% in average during 1990-2022 if compare to currently reported GHG emissions under the National GHG Inventory (Figure 2).

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 LIFE OrgBalt EFs is shown in Figure 3. CH_4 emissions from drainage ditches are excluded from this estimation.

All LIFE OrgBalt EFs for cropland are lower compared to currently used EFs as well as lower than the IPCC default EFs for temperate and boreal zone (Table 22). Use of LIFE OrgBalt EFs for CO_2, CH_4 and N_2O (4.1 t CO_2-C ha^{-1} yr^{-1}, -0.61 kg CH_4 ha^{-1} yr^{-1} and 8.86 kg N_2O ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in cropland in Latvia (81.0 – 135.1 kha depending from year in period of 1990-2022, Figure 1) by 325.9 kt CO_2 eq. yr^{-1} or by 15.7% in average during 1990-2022 if compare to the currently reported GHG emissions under the National GHG Inventory. The LIFE OrgBalt CO_2 EF contributed the most to the reduction of total GHG emissions from drained organic soils in cropland in Latvia (Figure 3).

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 LIFE OrgBalt EFs is shown in Figure 4. CH_4 emissions from drainage ditches are excluded from this estimation.

LIFE OrgBalt CO_2 EF is lower compared to currently used CS CO_2 EF (Licite and Lupikis, 2020) as well as lower than the 2014 IPCC default EFs for temperate and boreal zone (Table 22). LIFE OrgBalt CH_4 EF is lower compared to currently used CS CH_4 EF (Licite and Lupikis, 2020) as well as lower than the 2014 IPCC default EFs for temperate zone, while higher than 2014 IPCC default EF for boreal zone. LIFE OrgBalt N_2O EF is lower compared to 2014 IPCC default EFs for temperate and boreal zone, while higher than currently used CS N_2O EF (Licite and Lupikis, 2020). In total, use of LIFE OrgBalt EFs for CO_2, CH_4 and N_2O (3.5 t CO_2-C ha^{-1} yr^{-1}, 4.94 kg CH_4 ha^{-1} yr^{-1} and 1.84 kg N_2O 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 1990-2022, Figure 1) by 347.4 kt CO_2 eq. yr^{-1} or by 26.9% in average during 1990-2022 if compare to currently reported GHG emissions under the National GHG Inventory. The LIFE OrgBalt CO_2 and CH_4 EFs contributed the most to the reduction of total GHG emissions from drained organic soils in grassland in Latvia (Figure 4).

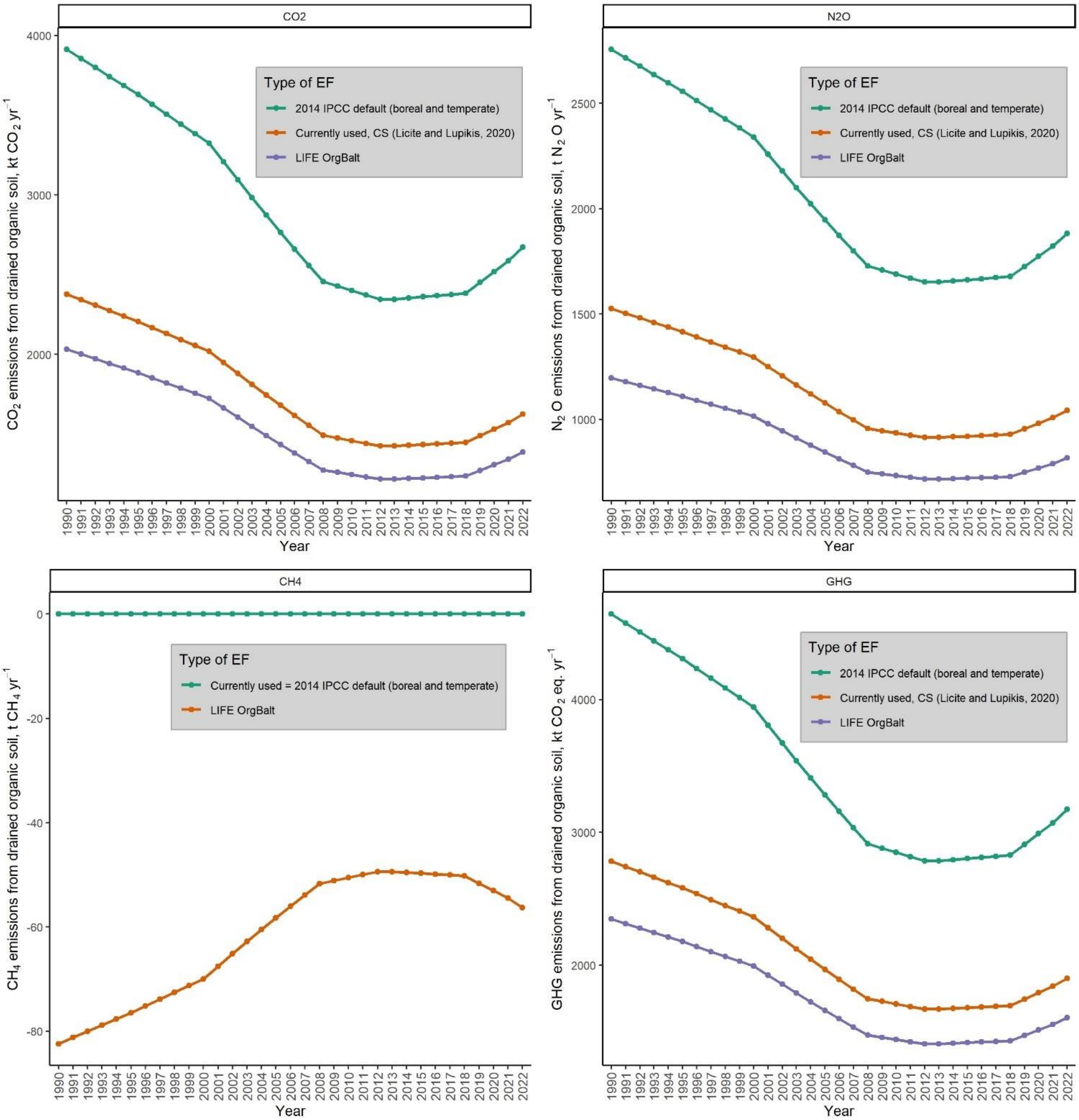

Figure 3. On-site CO_2, CH_4, N_2O and total GHG[19] emissions and removals from drained nutrient-rich organic soils in cropland in Latvia[20] according to the different EFs summarized in Table 22.

[19] Global Warming Potential values for 100-year time horizon: 28 for CH_4 and 265 for N_2O (AR5).

[20] It is assumed that all drained organic soils in cropland in Latvia correspond to nutrient-rich organic soils.

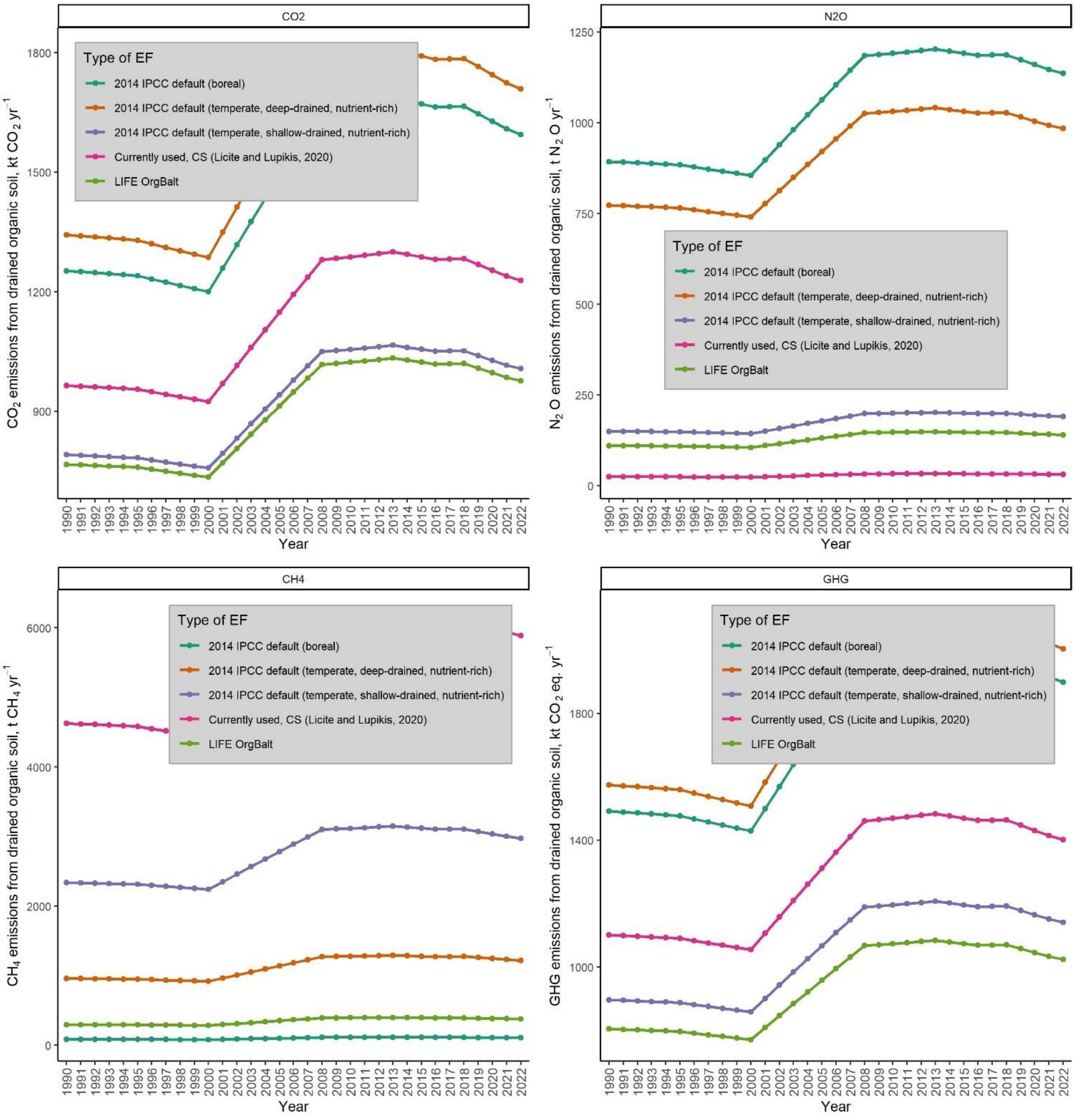

Figure 4. On-site CO_2, CH_4, N_2O and total GHG[21] emissions and removals from drained nutrient-rich organic soils in grassland in Latvia[22] according to the different EFs summarized in Table 22.

[21] Global Warming Potential values for 100-year time horizon: 28 for CH_4 and 265 for N_2O (AR5).

[22] It is assumed that all drained organic soils in grassland in Latvia correspond to nutrient-rich organic soils.

3.3 Possible impact of application of LIFE OrgBalt EFs in GHG inventory reporting in Lithuania

Organic soils in Lithuania are determined by using national definition of organic soils, provided in the book of Lithuanian soil classification: soil is classified as organic if it has peat layer not thinner than 40 cm or 60 cm of poorly decomposed peat (mainly moss fibres) in bogs. In addition to this, histic horizon must contain not less than 70-75 percent of organic matter by volume. In forest land, 68.1% of all drained organic soils (or 4.7 % of total forest area) correspond to nutrient-rich (fertile) status according to the Lithuania's Greenhouse Gas Inventory Report 2023 based on the most recent NFI data (NFI 2014 - 2018) (Figure 5). In cropland, organic soils constitute 1.1 % of the total cropland area (all organic soils are inventoried as drained in cropland). In grassland, organic soils constitute 6.6% from the total grasslands area, while drained organic soils in grassland category constitute 6.2% of total grassland area. We assumed that all drained organic soils in cropland and grassland in Lithuania correspond to nutrient-rich status.

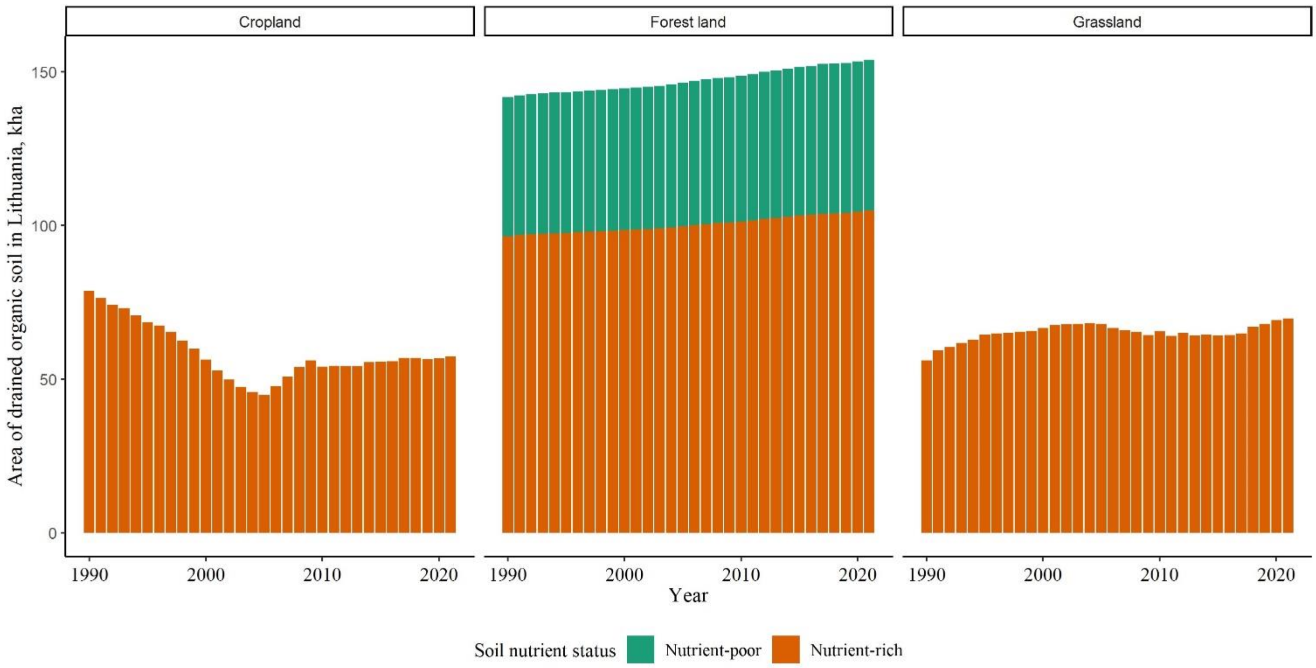

Figure 5. Area of drained organic soil in cropland, grassland and forest land in Lithuania[23].

3.3.1 Forest land

Impact of recalculation of on-site GHG emissions and removals from drained nutrient-rich organic soils in forest land in Lithuania due to implementation of LIFE OrgBalt EFs is shown in Figure 6. GHG emissions from nutrient-poor organic soils and CH_4 emissions from drainage ditches are excluded from this estimation.

[23] Lithuania's Greenhouse Gas Inventory Report 2023

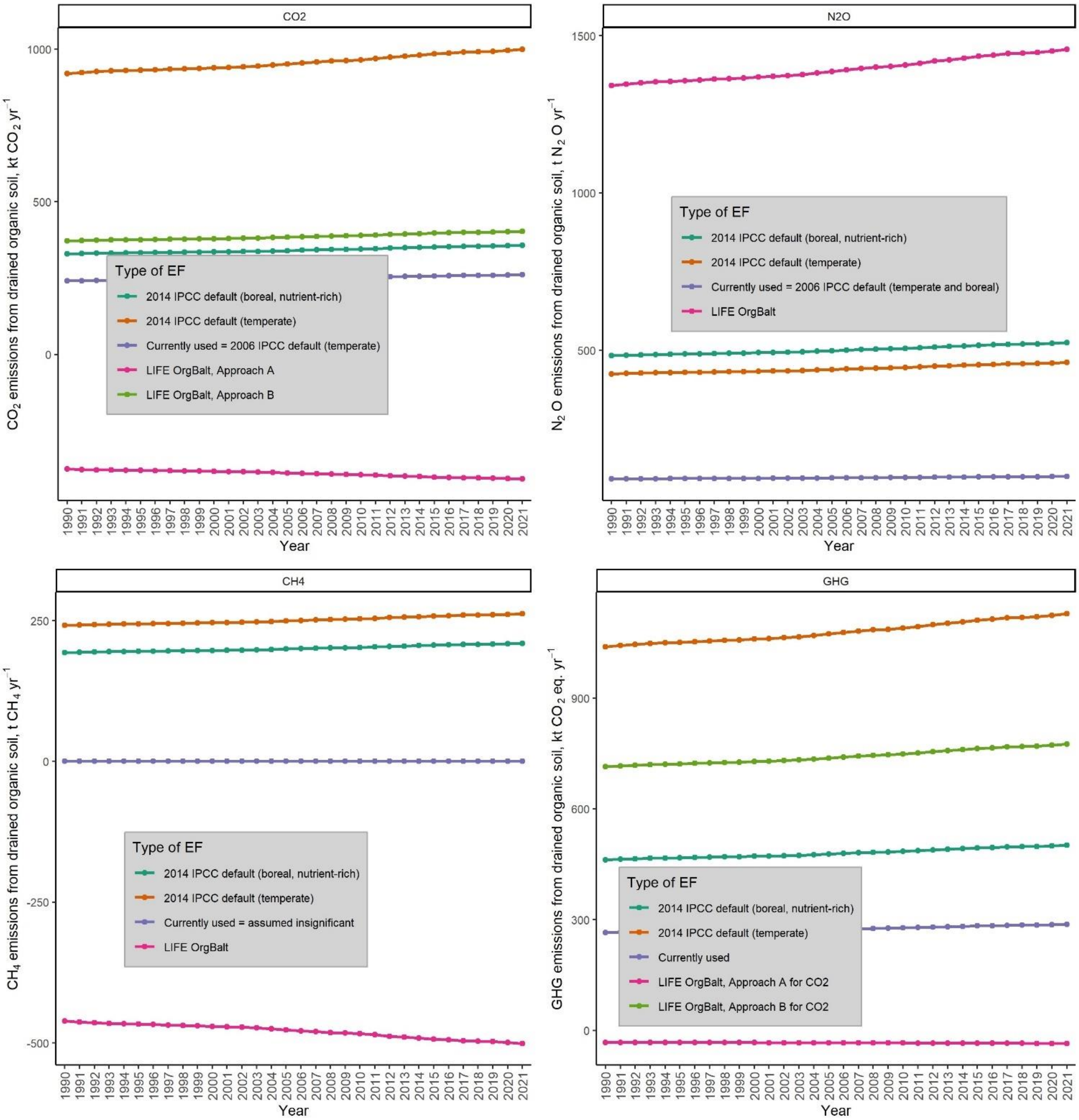

Figure 6. On-site CO_2, CH_4, N_2O and total GHG[24] emissions and removals from drained nutrient-rich organic soils in forest land in Lithuania according to the different EFs summarized in Table 22.

LIFE OrgBalt CO_2 EF (Approach A[25], indicating the CO_2 removals) are lower compared to currently used EF

[24] Global Warming Potential values for 100-year time horizon: 28 for CH_4 and 265 for N_2O (AR5).

[25] Approach A – CO_2 EF calculated as difference between CO_2 emissions from soil (4.30 t C ha^{-1} yr^{-1}) and carbon supply to soil by woody plant litter (1.69 t C ha^{-1} yr^{-1}; foliar fine litter) and understorey plant residue including above- and belowground vegetation of herbaceous plants and tree fine roots (3.67 t C ha^{-1} yr^{-1}). CO_2 emissions from soil were

(2006 IPCC default EF for temperate zone, Table 19), while LIFE OrgBalt CO_2 EF (Approach B[26]) is higher than currently used EF in Lithuania. No CH_4 emissions or removals are reported in Lithuania currently (considered insignificant), while LIFE OrgBalt CH_4 EF indicates CH_4 removals (Table 22). LIFE OrgBalt N_2O EF is higher compared to currently used EF (2006 IPCC default EF for temperate zone) for drained nutrient-rich organic soil in Lithuania.

In general, use of LIFE OrgBalt EFs for CO_2 (approach A), CH_4 and N_2O (-1.06 t CO_2-C ha^{-1} yr^{-1}, -4.78 kg CH_4 ha^{-1} yr^{-1} and 13.9 kg N_2O ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained nutrient-rich organic soils in forest land in Lithuania (96.5 – 104.8 kha depending from year in period of 1990-2021, Figure 5) by 308.9 kt CO_2 eq. yr^{-1} or by 112.3% in average during 1990-2021 if compare to currently reported GHG emissions under the National GHG Inventory. Contrary, use of LIFE OrgBalt EFs for CO_2 (approach B, 1.05 t CO_2-C ha^{-1} yr^{-1}), CH_4 and N_2O leads to increase total net GHG emissions from drained organic soils in forest land in Lithuania by 467.0 kt CO_2 eq. yr^{-1} or by 169.7% in average during 1990-2021 if compare to currently reported GHG emissions under the National GHG Inventory.

3.3.2 Cropland

Impact of recalculation of on-site GHG emissions and removals from drained nutrient-rich organic soils in cropland in Lithuania due to implementation of LIFE OrgBalt EFs is shown in Figure 7. CH_4 emissions from drainage ditches are excluded from this estimation.

All LIFE OrgBalt EFs for cropland are lower compared to currently used EFs (Table 19). Use of LIFE OrgBalt EFs for CO_2, CH_4 and N_2O (4.1 t CO_2-C ha^{-1} yr^{-1}, -0.61 kg CH_4 ha^{-1} yr^{-1} and 8.86 kg N_2O ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in cropland in Lithuania (45.0 – 78.7 kha depending from year in period of 1990-2021, Figure 5) by 251.5 kt CO_2 eq. yr^{-1} or by 19.9% in average during 1990-2021 if compare to the currently reported GHG emissions under the National GHG Inventory.

3.3.3 Grassland

Impact of recalculation of on-site GHG emissions and removals from drained nutrient-rich organic soils in grassland in Lithuania due to implementation of LIFE OrgBalt EFs is shown in Figure 8. CH_4 emissions from drainage ditches are excluded from this estimation.

LIFE OrgBalt CO_2 EF is higher compared to currently used CO_2 EF (Table 19), while LIFE OrgBalt N_2O EF is lower compared to currently used EF for drained nutrient-rich organic soil in Lithuania. No CH_4 emissions or removals are reported in Lithuania currently (considered insignificant), while LIFE OrgBalt CH_4 EF indicates CH_4 emissions (Table 22). In total, use of LIFE OrgBalt EFs for CO_2, CH_4 and N_2O (3.5 t CO_2-C ha^{-1} yr^{-1}, 4.94 kg CH_4 ha^{-1} yr^{-1} and 1.84 kg N_2O ha^{-1} yr^{-1}, respectively) leads to increase total net GHG emissions from drained organic soils in grassland in Lithuania (56.1 – 69.7 kha depending from year in period of 1990-2021, Figure 5) by 598.1 kt CO_2 eq. yr^{-1} or by 216.0% in average during 1990-2021 if compare to currently reported GHG emissions under the National GHG Inventory.

calculated by multiplying estimated soil total respiration by empirical factor (mean 0.65) characterising share of soil respiration in total respiration.

[26] Approach B – CO_2 EF calculated as difference between CO_2 emissions from forest floor (6.41 t C ha^{-1} yr^{-1}) and carbon supply to soil by woody plant litter (1.69 t C ha^{-1} yr^{-1}; foliar fine litter) and understorey plant residue including above- and belowground vegetation of herbaceous plants and tree fine roots (3.67 t C ha^{-1} yr^{-1}). Thus, approach B may overestimate net CO_2 emissions from drained organic soil because elaborated net CO_2 EF (specifically C output flow) includes autotrophic respiration in addition to soil heterotrophic respiration.

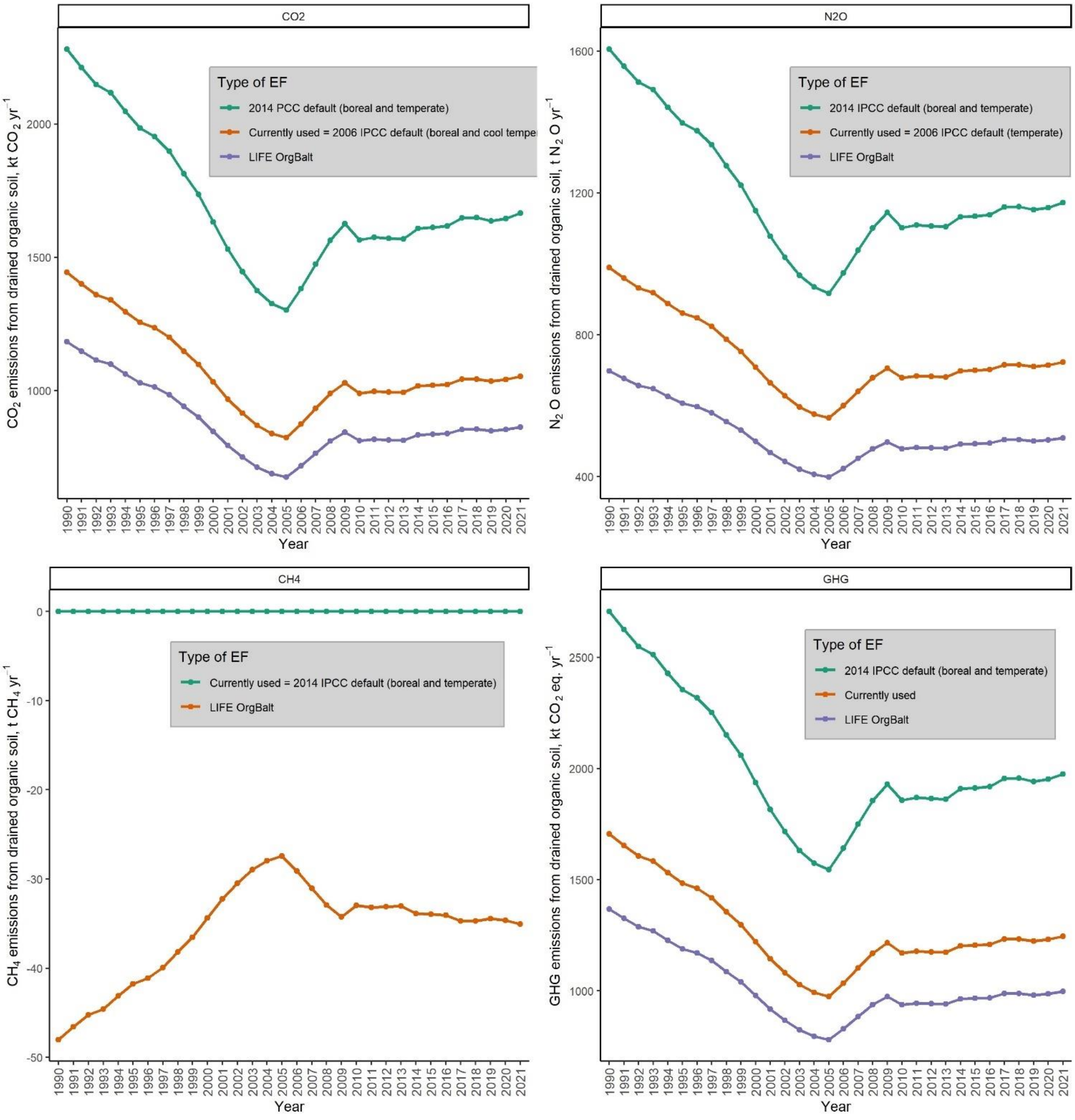

Figure 7. On-site CO_2, CH_4, N_2O and total GHG[27] emissions and removals from drained nutrient-rich organic soils in cropland in Lithuania according to the different EFs summarized in Table 22.

[27] Global Warming Potential values for 100-year time horizon: 28 for CH_4 and 265 for N_2O (AR5).

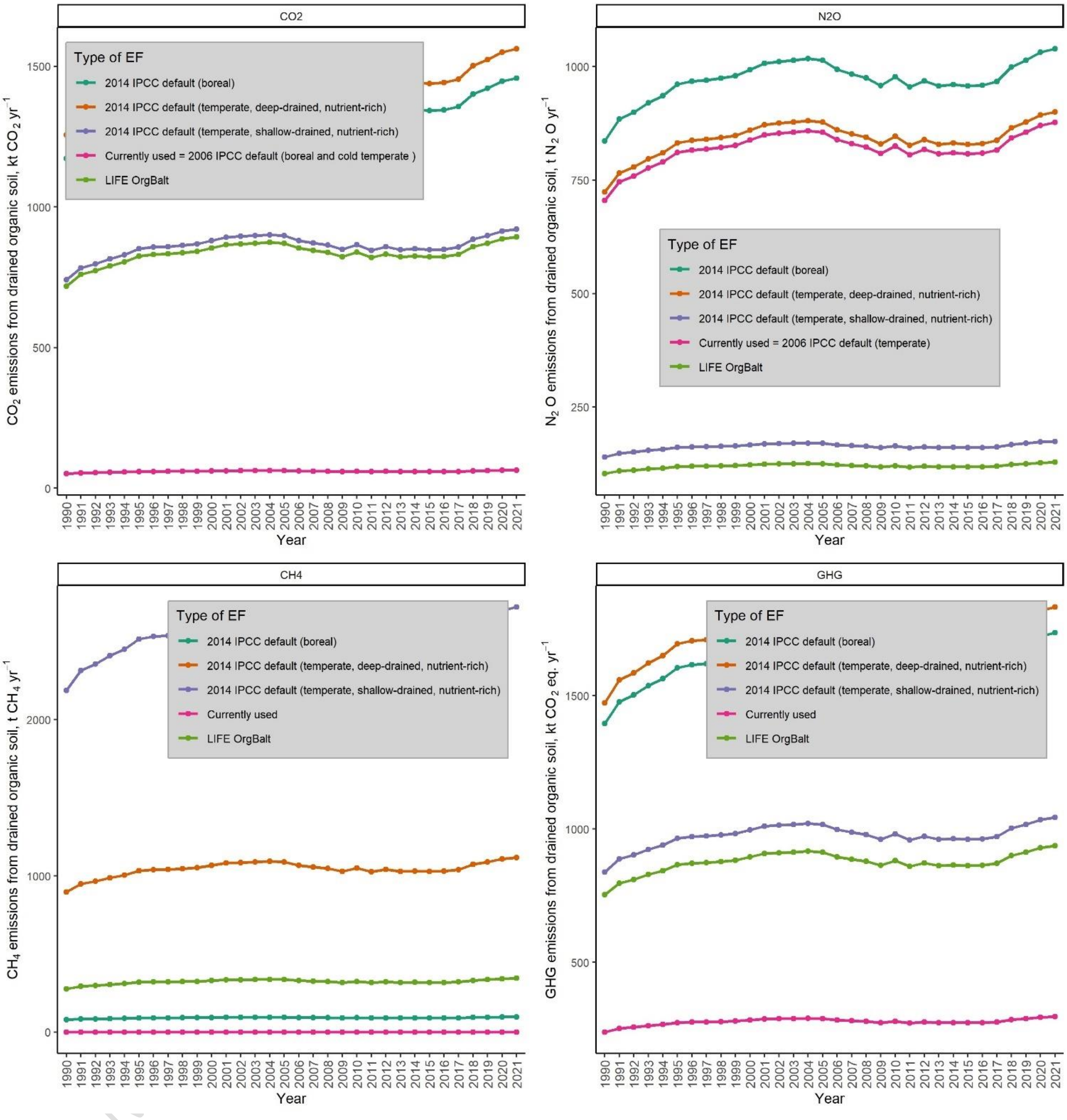

Figure 8. On-site CO_2, CH_4, N_2O and total GHG[28] emissions and removals from drained nutrient-rich organic soils in grassland in Lithuania according to the different EFs summarized in Table 22.

[28] Global Warming Potential values for 100-year time horizon: 28 for CH_4 and 265 for N_2O (AR5).

3.4 Possible impact of application of LIFE OrgBalt EFs in GHG inventory reporting in Estonia

According to the Estonia's Greenhouse Gas Inventory Report 2023, for undrained soils the 'organic' soil type is defined with an organic layer of more than 30 cm in depth and for drained soils more than 25 cm in depth. The soil is drained when the distance from the functioning drainage ditch is up to 100 m. In forest land, 60.5% from total areas of drained organic forest soils is considered nutrient-rich, while 39.5% - nutrient-poor (according to the Estonia's Greenhouse Gas Inventory Report 2023, Table 6.11). We assumed that all drained organic soils in cropland and grassland in Estonia correspond to nutrient-rich status (Figure 9).

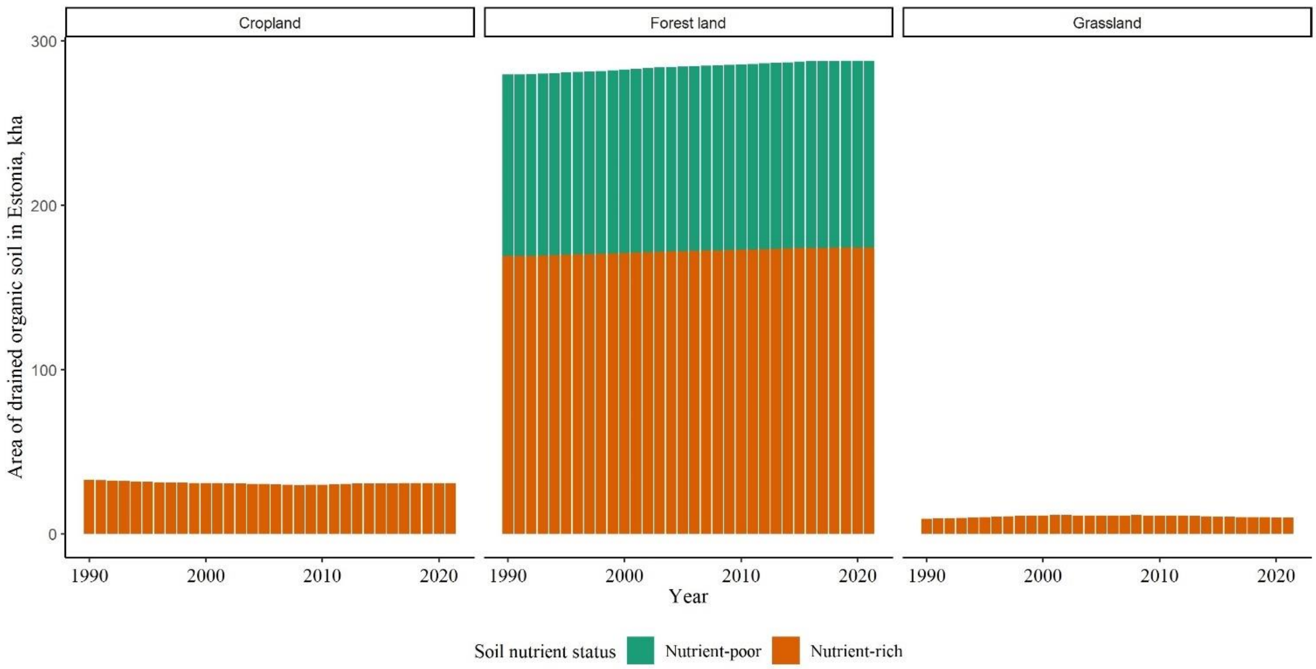

Figure 9. Area of drained organic soil in cropland, grassland and forest land in Estonia[29].

3.4.1 Forest land

Impact of recalculation of on-site GHG emissions and removals from drained nutrient-rich organic soils in forest land in Estonia due to implementation of LIFE OrgBalt EFs is shown in Figure 10. GHG emissions from nutrient-poor organic soils and CH_4 emissions from drainage ditches are excluded from this estimation.

LIFE OrgBalt CO_2 EF (Approach A[30], indicating the CO_2 removals) is lower compared to currently used EF

[29] Estonia's Greenhouse Gas Inventory Report 2023

[30] Approach A – CO_2 EF calculated as difference between CO_2 emissions from soil (4.30 t C ha^{-1} yr^{-1}) and carbon supply to soil by woody plant litter (1.69 t C ha^{-1} yr^{-1}; foliar fine litter) and understorey plant residue including above- and belowground vegetation of herbaceous plants and tree fine roots (3.67 t C ha^{-1} yr^{-1}). CO_2 emissions from soil were calculated by multiplying estimated soil total respiration by empirical factor (mean 0.65) characterising share of soil respiration in total respiration.

(2006 IPCC default EF for temperate zone), while LIFE OrgBalt CO_2 EF (Approach B[31]) is higher than currently used EF for drained nutrient-rich organic soil in Estonia (Table 20). LIFE OrgBalt CH_4 EF is lower (indicates CH_4 removals) compared to currently used EF (2014 IPCC default EF for boreal zone). LIFE OrgBalt N_2O EF is higher compared to currently used EF (2014 IPCC default EF for boreal zone) for drained nutrient-rich organic soil.

In general, use of LIFE OrgBalt EFs for CO_2 (approach A), CH_4 and N_2O (-1.06 t CO_2-C ha^{-1} yr^{-1}, -4.78 kg CH_4 ha^{-1} yr^{-1} and 13.9 kg N_2O ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained nutrient-rich organic soils in forest land in Estonia (169.1 – 174.3 kha depending from year in period of 1990-2021, Figure 9) by 724.2 kt CO_2 eq. yr^{-1} or by 108.7% in average during 1990-2021 if compare to currently reported GHG emissions under the National GHG Inventory. Contrary, use of LIFE OrgBalt EFs for CO_2 (approach B, 1.05 t CO_2-C ha^{-1} yr^{-1}), CH_4 and N_2O leads to increase total net GHG emissions from drained organic soils in forest land in Estonia by 606.2 kt CO_2 eq. yr^{-1} or by 91.0% in average during 1990-2021 if compare to currently reported GHG emissions under the National GHG Inventory.

[31] Approach B – CO_2 EF calculated as difference between CO_2 emissions from forest floor (6.41 t C ha^{-1} yr^{-1}) and carbon supply to soil by woody plant litter (1.69 t C ha^{-1} yr^{-1}; foliar fine litter) and understorey plant residue including above- and belowground vegetation of herbaceous plants and tree fine roots (3.67 t C ha^{-1} yr^{-1}). Thus, approach B may overestimate net CO_2 emissions from drained organic soil because elaborated net CO_2 EF (specifically C output flow) includes autotrophic respiration in addition to soil heterotrophic respiration.

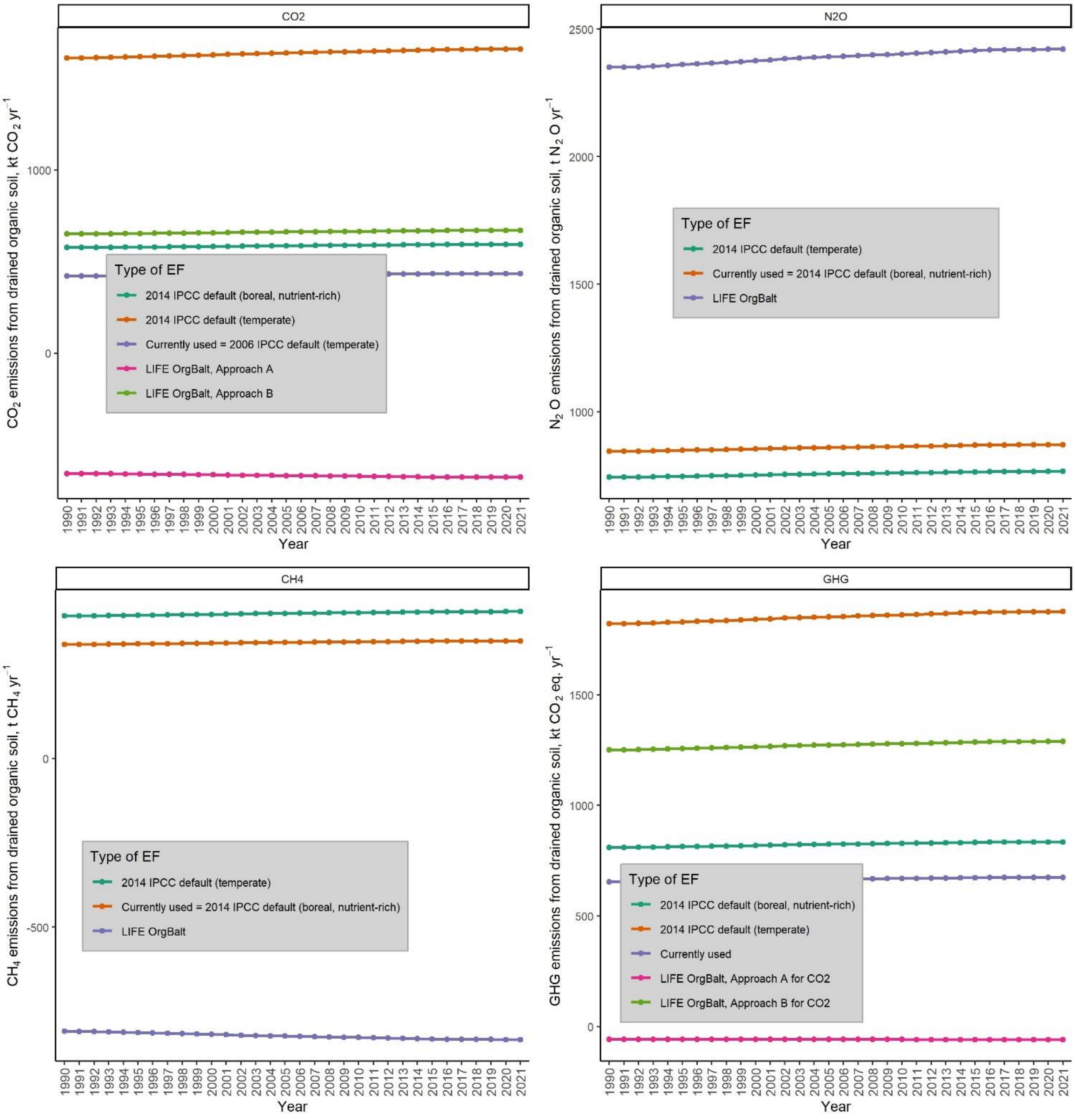

Figure 10. On-site CO_2, CH_4, N_2O and total GHG[32] emissions and removals from drained nutrient-rich organic soils in forest land in Estonia according to the different EFs summarized in Table 22.

3.4.2 Cropland

Impact of recalculation of on-site GHG emissions and removals from drained organic soils in cropland in Estonia due to implementation of LIFE OrgBalt EFs is shown in Figure 11. CH_4 emissions from drainage

[32] Global Warming Potential values for 100-year time horizon: 28 for CH_4 and 265 for N_2O (AR5).

ditches are excluded from this estimation.

All LIFE OrgBalt EFs for cropland are lower compared to currently used EFs for drained nutrient-rich organic soil in Estonia (Table 20). Use of LIFE OrgBalt EFs for CO_2, CH_4 and N_2O (4.1 t CO_2-C ha^{-1} yr^{-1}, -0.61 kg CH_4 ha^{-1} yr^{-1} and 8.86 kg N_2O ha^{-1} yr^{-1}, respectively) leads to decrease total net GHG emissions from drained organic soils in cropland in Estonia (29.8 – 33.0 kha depending from year in period of 1990-2021, Figure 5) by 133.0 kt CO_2 eq. yr^{-1} or by 19.9% in average during 1990-2021 if compare to the currently reported GHG emissions under the National GHG Inventory.

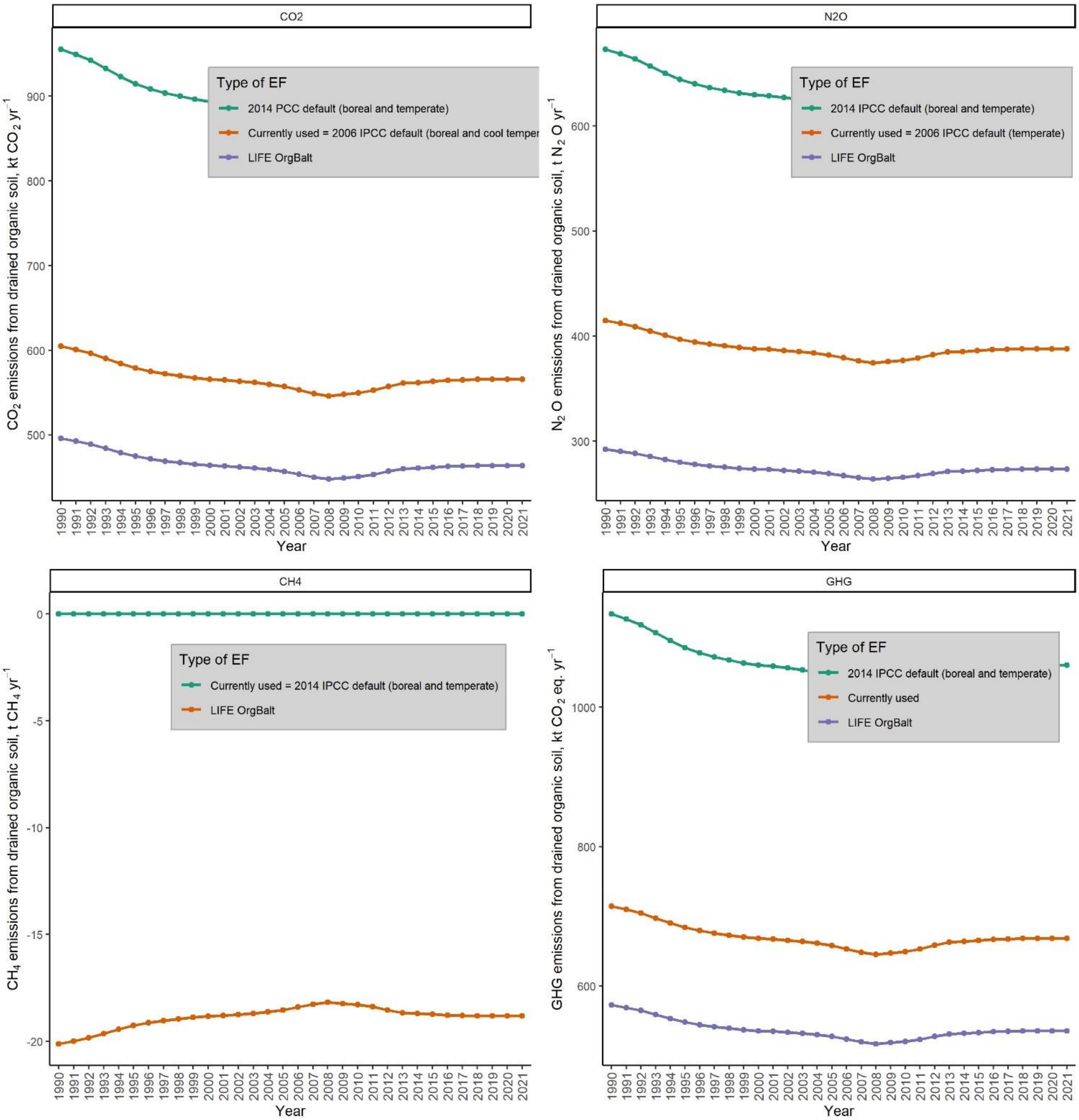

Figure 11. On-site CO_2, CH_4, N_2O and total GHG[33] emissions and removals from drained nutrient-rich organic soils in cropland in Estonia according to the different EFs summarized in Table 22.

3.4.3 Grassland

Impact of recalculation of on-site GHG emissions and removals from drained organic soils in grassland in Estonia due to implementation of LIFE OrgBalt EFs is shown in Figure 12. CH_4 emissions from drainage ditches are excluded from this estimation.
LIFE OrgBalt CO_2 EF is higher compared to currently used CO_2 EF (Table 20), while LIFE OrgBalt N_2O EF is lower compared to currently used EF for drained nutrient-rich organic soil in Estonia. No CH_4 emissions or removals are reported in Estonia currently (considered insignificant), while LIFE OrgBalt CH_4 EF indicates CH_4 emissions (Table 22). In total, use of LIFE OrgBalt EFs for CO_2, CH_4 and N_2O (3.5 t CO_2-C ha^{-1} yr^{-1}, 4.94 kg CH_4 ha^{-1} yr^{-1} and 1.84 kg N_2O ha^{-1} yr^{-1}, respectively) leads to increase total net GHG emissions from drained organic soils in grassland in Estonia (9.3 – 11.4 kha depending from year in period of 1990-2021, Figure 9) by 98.0 kt CO_2 eq. yr^{-1} or by 216.0% in average during 1990-2021 if compare to currently reported GHG emissions under the National GHG Inventory.

[33] Global Warming Potential values for 100-year time horizon: 28 for CH_4 and 265 for N_2O (AR5).

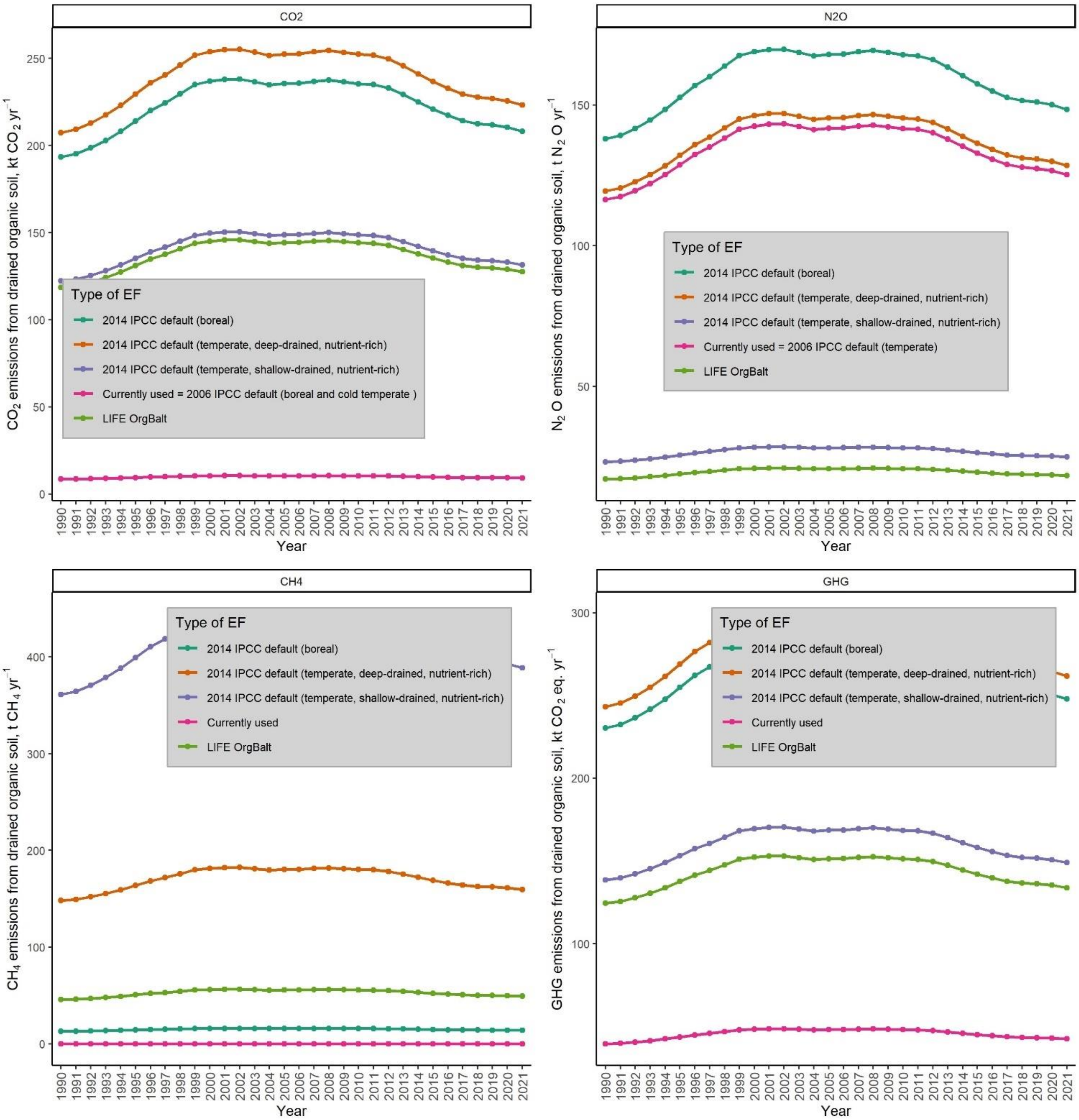

Figure 12. On-site CO_2, CH_4, N_2O and total GHG[34] emissions and removals from drained nutrient-rich organic soils in grassland in Estonia according to the different EFs summarized in Table 22.

[34] Global Warming Potential values for 100-year time horizon: 28 for CH_4 and 265 for N_2O (AR5).

4 CONCLUSIONS

LIFE OrgBalt provides information to improve Latvia's, Lithuania's and Estonia's National GHG Inventories. GHG (CO_2, CH_4 and N_2O) EFs for drained nutrient-rich organic soils in forest land, cropland and grassland developed within the EU LIFE program project "Demonstration of climate change mitigation measures in nutrients rich drained organic soils in Baltic States and Finland" (LIFE OrgBalt) provide an opportunity to improve the Tier 2 method for GHG emission and removal calculations. Additional data to support implementation of higher Tier level methodology aiming at Tier 3 are available.

Currently, country-specific and 2014 IPCC default (temperate zone) EFs are used for GHG emission reporting from drained nutrient-rich organic soils in forest land, cropland and grassland under the National GHG Inventory in Latvia. In Lithuania, 2006 IPCC default (temperate zone) EFs are used for GHG emission reporting, while, in Estonia, both 2006 and 2014 IPCC default (both temperate and boreal zone) EFs are used for GHG emission reporting from drained nutrient-rich organic soils in forest land, cropland and grassland. Thus, reporting approaches and used EFs differ among the Baltic States.

We modelled and estimated potential impacts of recalculations of on-site GHG emissions and removals from drained nutrient-rich organic soils in forest land, cropland and grassland in Latvia, Lithuania and Estonia due to implementation of EFs obtained within the LIFE OrgBalt project. Results of modelling and estimation confirm that recalculations of GHG emissions due to implementation of region-specific GHG EFs for drained nutrient-rich organic soils can significantly impact total GHG emissions and removals from LULUCF and Agriculture sectors.

In Latvia, use of LIFE OrgBalt EFs (region-specific) of CO_2, CH_4 and N_2O for forest land, cropland and grassland leads to decrease total reported net GHG emissions from drained nutrient-rich organic soils (average during 1990-2022 if compare to the currently reported GHG emissions under the National GHG Inventory):

- decrease by 3050.6 kt CO_2 eq. yr^{-1} (by 103.7%) according to the Approach A for CO_2 and by 574.0 kt CO_2 eq. yr^{-1} (by 19.5%) according to the Approach B for CO_2 in forst land;
- decrease by 325.9 kt CO_2 eq. yr^{-1} (by 15.7%) in cropland;
- decrease by 347.4 kt CO_2 eq. yr^{-1} (by 26.9%) in grassland.

In Lithuania and Estonia, use of LIFE OrgBalt EFs (region-specific) of CO_2, CH_4 and N_2O for forest land, cropland and grassland leads to decrease or increase total reported net GHG emissions from drained nutrient-rich organic soils (average during 1990-2021 if compare to the currently reported GHG emissions under the National GHG Inventory) depending on land use type and used approach for CO_2 EF for forest land:

- In Lithuania:
  - decrease by 308.9 kt CO_2 eq. yr^{-1} (by 112.3%) according to the Approach A for CO_2 in forest land;

- increase by 467.0 kt CO_2 eq. yr^{-1} (by 169.7%) according to the Approach B for CO_2 in forest land;
- decrease by 251.5 kt CO_2 eq. yr^{-1} (by 19.9%) in cropland;
- increase by 598.1 kt CO_2 eq. yr^{-1} (by 216.0%) in grassland.

- In Estonia:
  - decrease by 724.2 kt CO_2 eq. yr^{-1} (by 108.7%) according to the Approach A for CO_2 in forest land;
  - increase by 606.2 kt CO_2 eq. yr^{-1} (by 91.0%) according to the Approach B for CO_2 in forest land;
  - decrease by 133.0 kt CO_2 eq. yr^{-1} (by 19.9%) in cropland;
  - increase by 98.0 kt CO_2 eq. yr^{-1} (by 216.0%) in grassland.

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