ORGANIC SOILS IN NATIONAL INVENTORY SUBMISSIONS OF EU COUNTRIES

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cover picture: Maize on peat soil in Northwest Germany (Photo: John Couwenberg)

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Preface

This publication is a revised version of the master thesis of Nina Martin at the University of Greifswald titled "Organic soils in national inventory submissions of EU countries ", which was completed in May 2021. It presents a comprehensive analysis of UNFCCC greenhouse gas reporting on emissions from agriculturally used organic soils for all EU countries (plus the UK). It refers to inventory data of the countries published in 2020. Where shortcomings in reporting were identified, suggestions to improve were made.

The Greifswald Mire Centre has published basic considerations and recommendations on reporting organic soil emissions by EU countries before in Barthelmes (2018). The current report presents similar findings but adds much detail. Unless otherwise stated, assessments of peatland areas refer to the data of the Global Peatland Database published for Europe in Joosten et al. (2017) and Tanneberger et al. (2017).

With this publication we would like to provide a critical look at the inventory data on organic soil emissions in the EU and constructively provide approaches as well as concrete data for improvement.

A set of tables with all the numbers can be found online here (xlsx file).

Content

List of abbreviations and acronyms

AFOLU	-	Agriculture, forestry and other land use
AR4	-	IPCC 4th Assessment Report
AR5	-	IPCC 5th Assessment Report
CF	-	Conversion Factor
CLC	-	Corine Land Cover
CO_2-eq	-	Carbon dioxide equivalent
CRF	-	Common Reporting Format
DOC	-	Dissolved Organic Carbon
EF	-	Emission Factor
Eq	-	Equation
EU	-	European Union
FAO	-	Food and Agriculture Organization of the United Nations
GHG	-	Greenhouse gas
GPD	-	Global Peatland Database
GWP	-	Global Warming Potential
IEF	-	Implied Emission Factor
IPCC	-	Intergovernmental Panel on Climate Change
LPIS	-	Land Parcel Information System
LULUCF	-	Land Use, Land-Use Change and Forestry
NFI	-	National Forest Inventory
NIR	-	National Inventory Report
NIS	-	National Inventory Submission
OC	-	Organic Carbon
SOC	-	Soil Organic Carbon
UK	-	United Kingdom
UNFCCC	-	United Nations Framework Convention on Climate Change
WT	-	Water table
WTD	-	Water table depth
WTt	-	Transformed water table

List of chemical formulae and units

C	-	Carbon
CH_4	-	Methane
CO_2	-	Carbon dioxide
ha	-	Hectare
kg	-	Kilogram
kt	-	Thousand tonnes
Mt	-	Million tonnes
N	-	Nitrogen
N_2O	-	Nitrous oxide
O	-	Oxygen
t	-	Ton
y	-	Year

1. Summary

European peatlands are among the most degraded peatlands of the world, mostly due to intensive agricultural use over the past centuries. Agriculture on organic soils commonly requires drainage, which results in peat decomposition and thereby causes large amounts of GHG emissions.

In their National Inventory Submissions (NISs), EU member states are obligated to report areas of agriculture on organic soils and associated emissions, to the UNFCCC. Agriculture on organic soils is split into two sectors in the UNFCCC reporting format.

N_2O emissions are reported in the 'Agriculture' sector under 'Cultivation of organic soils (i.e. histosols)'. CO_2 and CH_4 emissions are reported in the 'Cropland' and 'Grassland' categories of the 'LULUCF' sector. As of 2014, the IPCC Wetlands Supplement offers revised emission factors (EFs) and more detailed guidelines for reporting of emissions from organic soils. Most EU countries, however, still use the 2006 IPCC Guidelines in their NISs and thereby ignore scientific advances. Within this study, we were able to show that consequent implementation of the IPCC Wetlands Supplement does not require a lot of effort, but increases EU wide emissions from agriculture on organic soils from 92.3 Mt to 166.7 Mt CO_2-equivalents per year. Roughly 40 Mt of increase are caused by corrections in the area assessment and the remainder 30 Mt are the result of updated emission factors and global warming potential.

A detailed set of tables accompanies this report and is available online here (xlsx file).

2. Introduction

2.1. Relevance of European organic soils

Intact peatlands, also called mires, are a net carbon sink. They sequester carbon from the atmosphere in the form of peat. Peat consists of incompletely decomposed plant remains and forms under water saturated, anoxic conditions. The carbon that is initially fixed by peat forming plants can in this way be stored for millennia as long as the peat remains waterlogged. Consequently, the mires of the world have attenuated the greenhouse effect and have had a cooling effect on the climate (Frolking et al. 2011).

The maximum extent of peatlands in Europe during the Holocene is estimated to have been some 650,000 km^2 (Joosten and Tanneberger 2017, p. 151). The highest peatland density occurs in northern latitudes, where peatlands cover from about 5 % (Denmark, Iceland) up to about 20 % (Finland, Estonia) of the country area (Joosten et al. 2017a).

Peatland use has a century-long history in Europe and is ongoing on a large scale. As long as drainage and other exploitation is the rule and conservation efforts are the exception, peatlands will degrade and be lost. About 10 % of the original peatland area has been lost completely with no trace of peat left. Another half of the remaining peatlands is no longer peat accumulating, making Europe the continent with the largest loss of accumulating peatlands (Joosten and Tanneberger 2017, pp. 151).

Since the 20th century, drainage for agriculture, peat extraction and forestry has been the main cause for peatland degradation (IPCC 2019, p. 397). Some 25-44 % of European peat soils are used for agriculture (the Leppelt et al.2014). Drainage is necessary for intensive agricultural use to be able to grow crops that are normally not adapted to water saturated conditions and also to make fields accessible for heavy machinery (Joosten et al. 2017a). Countries with the highest share of the total peatland area used for agriculture are Hungary (98 %), Greece (90 %), the Netherlands and Germany (85 %), Denmark, Poland and Switzerland (70 %) where high population densities required use of wetlands for food production. The given percentages refer to areas around the year 2000 (Joosten and Clarke 2002). In recent years the area of organic soils under agricultural use is slightly decreasing for economic reasons, due to increasing nature protection efforts or disappearance of the organic soil layers (Joosten and Tanneberger 2017).

With drainage, peatlands turn into a strong source of CO_2 (IPCC 2014). The drained peat becomes aerated, decomposes and the stored carbon is lost to the atmosphere. In addition, drainage favors production of N_2O, a much more potent greenhouse gas than CO_2 (Maljanen et al. 2007; Myhre et al. 2013). Drainage water contains dissolved organic carbon (DOC) that is lost from the peatland and ultimately returns to the atmosphere as CO_2 (IPCC 2020, p. 397). Whereas intact mires are a source of CH_4, drained peatlands emit next to no CH_4 (Maljanen et al. 2007, Couwenberg 2011, IPCC 2014). Drainage ditches, however, emit a considerable amount of CH_4 (IPCC 2014). The climate effect of CH_4 is stronger than that of CO_2 but not as strong as that of N_2O (Myhre et al. 2013).

So, human interventions do not only lead to loss of peat accumulating mires as functioning ecosystems with severe threats to biodiversity (Minayeva et al. 2016), but also have a considerable impact on the global climate. Even though 80-85 % of the global peatlands are in a natural or near-natural state, drained peatlands emit approximately 2 Gt of CO_2 each year (Joosten et al. 2016), which is about 5 % of total anthropogenic greenhouse gas (GHG) emissions (IPCC 2020, p. 397; Günther et al. 2020). Worldwide, organic soils contain roughly one third of all soil carbon and twice as much as all forest biomass while covering only 3 % of the terrestrial land surface (Joosten et al. 2016, FAO 2020), about 4 million km^2. Without a major rewetting offensive, a lot of this soil carbon would be released to the atmosphere and take up 12-41 % of the remaining emission budget that would keep global warming below 1.5-2 °C (Leifeld et al. 2019).

2.2. International Inventory Reporting

2.2.1. The National Inventory Submissions

According to UNFCCC Decision 24/CP.19[1], Annex I parties to the UNFCCC (United Nations Framework Convention on Climate Change) are obligated to generate annual National Inventory Submissions (NIS). These submissions contain complete Greenhouse Gas (GHG) inventories as well as all information about the underlying methods. The GHG inventory data are submitted in the form of Common Reporting Format (CRF) tables, while all supplemental information has to be documented in the National Inventory Report (NIR). In this way, it is assured that transparency of emission sources and sinks and data acquisition methods remain transparent, and that data remain consistent in time and space, and comparable between countries. The NISs should be prepared in accordance with the revision of the UNFCCC guidelines on annual inventories[1] and the 2006 IPCC (Intergovernmental Panel on Climate Change) Guidelines for national Greenhouse Gas Inventories (IPCC 2006). Organic soil emission reporting should in addition take into account the supplementary guidelines of the IPCC Wetlands Supplement (IPCC 2014). Each year, emissions are estimated for the reference year 1990 and for each of the following years up to two years prior to the year of submission. For the NISs from 2020 that were analysed in this study, this is the year 2018.

Organic soil emissions are reported in both the 'Agriculture' and the 'LULUCF' (Land Use, Land-Use Change and Forestry) sector. Whereas all land-use related GHG emissions are part of AFOLU (Agriculture, forestry and other land use) in the IPCC reporting guidelines, they are disaggregated in the two sectors 'Agriculture' and 'LULUCF' under the UNFCCC reporting. In principle, the 'Agriculture' sector includes N2O emissions from cropland and grassland land-use, while CO_2 and CH4 emissions from all land-use categories are reported

[1] FCCC/CP/2013/10/Add.3, https://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf

in the 'LULUCF' sector. The area reported in the 'Agriculture' sector should thus equal the area under 'Cropland' and 'Grassland' in the 'LULUCF' sector. In general, the 'LULUCF' and 'Agriculture' land-use categories used by UNFCCC do not line up with the AFOLU categories of the IPCC.

2.2.2. The IPCC reporting Guidelines

As mentioned above, Annex I countries are obligated to report all GHG emissions transparently, consistently and comparably. In order to do so, the IPCC offers detailed guidelines.

An important concept of the guidelines is *good practice*. Countries which *follow good practice* submit inventories which '*contain neither over- nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable*.' (IPCC 2006, Vol 1, Ch 1, p. 1.6). As IPCC cannot be prescriptive, but only advise, the phrase '*it is good practice*' is the strongest possible wording the IPCC can use. It basically means that parties *should* follow the advice.

Good practice determines which tier of methodological complexity should be used according to a country-specific key category analysis. If a source category is key –which means that if it belongs to the categories which summed up in descending order of magnitude emit 95 % per cent of all emissions – it is *good practice* to use a tier 2 (intermediate) or 3 (most complex and accurate) method. Otherwise the tier 1 (basic) method is sufficient. For tier 1, the IPCC guidance offers default methods and emission factors (EFs) to allow for countries to estimate emissions with very low effort.

The tier 2 approach uses the same calculation steps as tier 1. Country-specific information is incorporated to improve the tier 1 approach. There are several options to use country-specific data. It is *good practice* to derive country-specific EFs and to use a finer classification of management systems and climate sub-domains, if measurements representing the national circumstances are available. The applied methods for derivation of country-specific EFs need to be compatible with the standards behind the default EFs from Annex 2A.1 of the 2006 IPCC Guidelines (IPCC 2006, IPCC 2014).

The tier 3 approach requires modelling of the underlying processes that captures the influence of different variables. It is good practice to document all steps transparently and to provide evidence that the national circumstances are well represented according to Section 2.5, Chapter 2, Volume 4 of the 2006 IPCC Guidelines (IPCC 2006, IPCC 2014).

The IPCC 2006 Guidelines (IPCC 2006) are the standard guidelines for GHG inventory reporting. In 2014, the IPCC has published the IPCC Wetlands Supplement (IPCC 2014) which fills several gaps in reporting. It addresses not only drained, but also rewetted and managed, but undrained soils. Furthermore, it provides guidance on off-site CO_2 emissions and CH_4 emissions from drained organic soils and drainage ditches. Tier 1 EFs for the different land-use categories are also updated according to new scientific findings.

The IPCC Wetlands Supplement fills gaps in the 2006 IPCC Guidelines based on updated scientific knowledge. According to the IPCC, it is *good practice* to follow the guidance of the IPCC Wetlands Supplement for estimation of GHG emissions from managed organic soils in national GHG inventories (IPCC 2014, p. 15). This study will assess in how far EU member states (and the UK) indeed follow the updated methodology.

The IPCC Wetlands Supplement further stratifies organic soils within land-use categories and offers default EFs for all subcategories. It is stated, that it is

good practice to stratify land-use categories by

- climate domain (Table 4.1, Chapter 4, Volume 4 of the *2006 IPCC Guidelines*)
- nutrient status (Section 7.2.1.1, Chapter 7, Volume 4 of the *2006 IPCC Guidelines*)
    - Generally, ombrogenic organic soils are characterised as nutrient-poor, while minerogenic organic soils are characterised as nutrient-rich. This broad characterisation may vary by peatland type or national circumstances.
- drainage class (shallow or deep) according to the stratification given in Table 2.1.
    - Drainage class is defined as the mean annual water table averaged over a period of several years; the shallow-drained class is defined as the mean annual water table depth of less than 30 cm below the surface; the deepdrained class is defined as the mean annual water table depth of 30 cm and deeper below the surface.
    - For Tier 1 methods, if the typical range of mean annual water table levels of drained organic soils for each land-use category is unknown - water table depth is specific for land-use categories and climate domains - the default assumption is that the organic soil is deep-drained because deepdrained conditions are the most widespread and suitable for a wide range of management intensities. Higher tier methods could further differentiate the drainage intensity within land-use categories if there are significant areas that differ from the default deep-drained conditions.'

(IPCC 2014)

2.2.3. Global Warming Potential

Global Warming Potential (GWP) is a default metric that has been developed to allow comparison of the radiative forcing (RF) of emissions of different GHGs. The emissions are transferred to a common scale of 'CO_2-equivalents' (Myhre et al.2013, p. 711). Pulse emissions of CH_4 or N_2O can in this way be related with a pulse emission of CO_2 over a specific time horizon, which is not an ideal approach (Myhre et al. 2013, Günther et al. 2020), but one that has been generally accepted within the UNFCCC. The time horizon implemented for GHG inventory reporting to the UNFCCC is 100 years. The choice of a particular time horizon is not a scientific one but a value judgement of effects over different time periods (Myhre et al. 2013, pp. 711). While the GWP conversion factors (CFs) from the 4th Assessment Report of the IPCC (AR4, Forster et al. 2007) – 25 CO_2-equivalents for CH_4

and 298 CO_2-equivalents for N_2O – are still used by EU member states for their national GHG inventories, GWP CFs were revised on the basis of additional scientific data and made available with the 5th Assessment Report of the IPCC (AR5, Myhre et al. 2013) - 28 CO_2-equivalents for CH_4 and 265 CO_2-equivalents for N_2O.

2.3. Organic soil classification

In order to be able to estimate organic soil GHG emissions from managed land, organic soils have to be identified. Many definitions of organic soils exist in the scientific community (Joosten et al. 2017b). Ideally, a consistent classification would assure conformity in the GHG inventories of different countries. The definition by IPCC (2006, Annex 3A.5) reads as follows:

Organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below (FAO 1998):

1. Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm.
2. Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter).
3. Soils are subject to water saturation episodes and has either:
    a. At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or
    b. At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or
    c. An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

This definition fails to provide consistency across countries as it omits a criterion of minimum thickness of the organic layer. This omission is on purpose, it allows for country-specific, often historically determined organic soil definitions (IPCC 2014, Joosten et al. 2017b, p. 67). A common criterion in Europe is a minimum thickness of 30 cm (Joosten and Clarke 2002, p. 33), but many other thresholds are used as well (Joosten et al. 2017b, p. 66).

One important differentiation that is often not adequately recognized is between organic soils (also called 'histosols') and peat soils. While some countries use both terms equivalently, others understand peat soils as a subset of organic soils and stratify 'peat soils' and 'peaty soils' within the 'organic soils' category. Peaty soils contain either less organic carbon (OC) by weight or have an only shallow peat layer (that does not fulfil the country-specific thickness criterion of peat soils). Many terms for peaty soils exist in different countries and different languages and it is important to keep in mind that they do not all describe the same concept. Even restricted to the English language, several terms exist, including ‘peaty soils’, ‘peat-like soils’ and ‘shallow peat soils’. Denmark, for example, accounts for peaty soils with an OC content (by weight) of 6−12 % (NIR, p. 400; see also chapter 4.2.7.). The Dutch term ‘moerige gronden’ applies to peat layers of 5-40 cm within the first 80 cm of the upper soil, whereas peat soils are defined as containing a peat layer of at least 40 cm within the first 120 cm (Arets et al. 2020, p. 63). Peaty soils are not covered specifically in the IPCC Guidelines (see above), although they can be substantial emitters of GHGs (Tiemeyer et al. 2016).

2.4. Aims

This study aims to assess GHG emissions of organic soils under agricultural use in EU countries (and the UK) on European ground (i.e. excluding overseas territories). This study thus includes organic soils in the ‘Agriculture’ sector and the ‘Cropland’ and ‘Grassland’ categories of the ‘LULUCF’ sector of the annual National Inventory Submissions (NIS). Data from the NISs of 2020 are used, which describe the situation for the year 2018.

3. Methods

3.1. CRF Data Import

To analyse GHG emissions as reported by each of the EU member states, data from CRF tables for the year 2018 from the 2020 submission of the NIS were imported into an Excel file (Microsoft Excel Version 2013) with sheets for each individual country (Table 3.1). Data were imported using in-cell commands.

Area data and GHG emissions from organic soils under agricultural use are listed in CRF tables 3.D.a (Agriculture, Direct N_2O emissions from managed soils), 4.B (LULUCF, Cropland), 4.C (LULUCF, Grassland) and 4(II) (LULUCF, Emissions and removals from drainage and rewetting and other management of organic and mineral soils).

Table 3.1. Sheets of the CRF tables used to source data on areas of organic soils under agricultural use and associated GHG emissions.

CRF table code	CRF sector	Source and sink category	Source and sink sub-category	Reported GHG
3.D.a	Agriculture	Direct N_2O emissions from managed soils	Cultivation of organic soils (i.e. histosols)	N_2O
4.B	LULUCF	Cropland	Total organic soils	CO_2
4.C	LULUCF	Grassland	Total organic soils	CO_2
4(II).B	LULUCF	Cropland	Total organic soils	CO_2, CH_4
4(II).C	LULUCF	Grassland	Total organic soils	CO_2, CH_4

To be able to discuss emissions from agriculturally used organic soils in the context of other national and agricultural GHG emission sources, further data on areas and emissions were imported (Table 3.2.).

In the following chapters, the CRF categories are referred to as ‘Cultivation of organic soils (i.e. histosols)’ as part of the sector ‘Agriculture’, and as ‘Cropland’ and ‘Grassland’. It is important to clearly distinguish the CRF categories from the homonymous but not necessarily identical categories in the IPCC nomenclature (IPCC 2006; 2014) as well as from the ‘Agriculture undiff.’ and other agricultural use categories established within this study.

Table 3.2. Sheets of the CRF tables used to source data on further areas and associated GHG emissions.

CRF table code	CRF sector	Source and sink category	Source and sink sub-category	Reported GHG
Summary1	-	Total national emissions and removals	-	CO_2, CH_4, N_2O
Summary1.3	Agriculture	Agriculture	-	CO_2, CH_4, N_2O
Summary1.3	Agriculture	Enteric fermentation	-	CH_4
Summary1.3	Agriculture	Manure management	-	CH_4, N_2O
Summary1.3	Agriculture	Rice cultivation	-	CH_4
Summary1.3	Agriculture	Agricultural soils	-	CH_4, N_2O
Summary1.3	Agriculture	Prescribed burning of savannas	-	CH_4, N_2O
Summary1.3	Agriculture	Field burning of agricultural residues	-	CH_4, N_2O
Summary1.3	Agriculture	Liming	-	CO_2
Summary1.3	Agriculture	Urea application	-	CO_2
Summary1.3	Agriculture	Other carbon-containing fertilizers	-	CO_2
Summary1.3	Agriculture	Other	-	CO_2, CH_4, N_2O
Summary1.4	LULUCF	LULUCF	-	CO_2, CH_4, N_2O
Summary1.4	LULUCF	Cropland	-	CH_4, N_2O
Summary1.4	LULUCF	Grassland	-	CH_4, N_2O
Summary2	-	Total (net emissions)	-	CH_4, N_2O, all
Summary2.3	Agriculture	Agriculture	-	CH_4, N_2O, all
Summary2.3	Agriculture	Enteric fermentation	-	CH_4, all
Summary2.3	Agriculture	Manure management	-	CH_4, N_2O, all
Summary2.3	Agriculture	Rice cultivation	-	CH_4
Summary2.3	Agriculture	Agricultural soils	-	CH_4, N_2O, all
Summary2.4	LULUCF	LULUCF	-	CH_4, N_2O, all
Summary2.4	LULUCF	Cropland	-	CH_4, N_2O, all
Summary2.4	LULUCF	Grassland	-	CH_4, N_2O, all
4	LULUCF	Cropland	-	CO_2
4	LULUCF	Grassland	-	CO_2
4.B	LULUCF	Total Cropland	-	CO_2
4.C	LULUCF	Total Grassland	-	CO_2
4(II).B	LULUCF	Cropland	Total mineral soils	CO_2, CH_4, N_2O
4(II).C	LULUCF	Grassland	Total mineral soils	CO_2, CH_4, N_2O
4(III).B	LULUCF	Cropland	-	N_2O
4(III).C	LULUCF	Grassland	-	N_2O

3.2. Data set completion

Information about the IPCC guidelines used for the national GHG inventory was taken from the NIR of each EU member state (References listed in Annex 1). Methodology and EFs were scrutinized.

If countries follow

- the 2006 IPCC Guidelines and apply the attendant EFs, the gaps in GHG emission reporting were filled using tier 1 methodologies and default EFs from the IPCC Wetlands Supplement (IPCC 2014). The gap-filling notably concerns inclusion of DOC and CH_4 fluxes.
- the IPCC Wetlands Supplement methodology, the reported emissions were monitored for completeness and missing data were substituted using tier 1 EFs (IPCC 2014).

Some EU member states have derived country-specific EFs, corresponding to a tier 2 or tier 3 method of either the 2006 IPCC Guidelines (IPCC 2006) or the IPCC Wetlands Supplement (IPCC 2014). The methods and the scientific literature underlying such country-specific EFs were evaluated. For that purpose, the relevant chapters of the NIR were analysed. The data provided need to reflect the country-specific conditions better than the default values from the IPCC Wetlands Supplement (IPCC 2014). If this is the case, the country-specific EFs were adopted. Otherwise default EFs from the IPCC Wetlands Supplement were used.

For some countries inventories of organic soil area and/or country-specific emissions factors exist that have not (yet) been implemented in the respective national submissions. The alternative EFs are adopted if they indeed reflect the country-specific conditions better than the default values from the IPCC Wetlands Supplement. This is for example the case for the UK, for which a detailed organic soil inventory in line with the IPCC Wetlands Supplement is available (Evans et al. 2017). See the respective country chapters in section 4.1. for details.

The categorization of emissions in the ‘Cultivation of organic soils (i.e. histosols)’ category for N_2O and the ‘Cropland’ and ‘Grassland’ categories for CO_2 and CH_4 (see table 3.1.) was adopted from the NIS format in order to enable a clear comparison with the reported emissions.

If reported emissions were not adopted according to the criteria explained in this chapter, emissions were recalculated. The basic equation 1 for the calculation of annual emissions is in line with the IPCC Wetlands Supplement (IPCC 2014):

$$E(CO_2, CH_4, N_2O) = A_{\,c,n,d} \times EF_{(CO_2,CH_4,N_2O)_{c,n,d}} \times CF_{(CO_2,CH_4,N_2O)} \quad \text{(Eq. 1)}$$

Where:

$E(CO_2, CH_4, N_2O)$ = CO_2, CH_4, N_2O emissions from organic soils in a land-use category, in t CO_2 y^{-1}, t CH_4 y^{-1}, t N_2O y^{-1}

$A_{c,n,d}$= land area of organic soils in a land-use category, by climate domain c, nutrient status n and drainage class d, in ha

$EF_{(CO2,CH4,N2O)c,n,d}$= emission factor for organic soils in a land-use category, by climate domain c, nutrient status n and drainage class d, in t C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}, kgN_2O-N ha^{-1} y^{-1}

$CF_{CO2,CH4,N2O}$ = conversion factor, 44/12 for CO_2 emissions, 1/1000 for CH_4 emissions, 44/28000 for N_2O emissions

Calculations are made with the disaggregated EFs as far as applicable. From the disaggregated EFs an area-weighted, mean 'implied' EF (IEF) can be calculated. Countries include such IEFs in their CRF tables to sum up organic soil emissions of all climate domains, nutrient status and drainage classes in a land-use category. We recalculated IEFs as well (Eq 2) to enable a quick comparison with the reported IEFs.

$$IEF_{os} = \sum_{c,n,d}(A \times EF)_{c,n,d} \div A_{total} \quad \text{(Eq. 2)}$$

Where:

IEF_{os} = area-weighted, implied emission factor for organic soils in a land-use category, in t C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}, kg N_2O-N ha^{-1} y^{-1}

$A_{c,,}$ = land area of organic soils in a land-use category, by climate domain c, nutrient status n and drainage class d, in ha

$EF_{c,n,d}$ = emission factors for organic soils in a land-use category, by climate domain c, nutrient status n and drainage class d, in t C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}, kg N_2O-N ha^{-1} y^{-1}

A_{total} = total land area of organic soils in a land-use category, in ha

The IPCC default EFs differ depending on climate domain, nutrient status and drainage class. Most of the EU member states are entirely in the temperate climate zone, except for Finland and Sweden (Fig. 3.1.). Regarding drainage class and nutrient status, if no country-specific data are available, organic soils in the grassland category are assumed to be 75 % deep-drained, nutrient-rich, 12.5 % shallow-drained, nutrient-rich and 12.5 % drained, nutrient-poor (based on expert judgement).

We modified the default EF for shallow-drained grassland by excluding measurements from intensively used grassland sites with deep water table in summer (four measurements from the 'Freisinger Moos', Drösler 2013), as intensive use hardly occurs on shallow-drained organic soils in the EU. The resulting EFs for temperate climate are 2.36 t C ha^{-1} y^{-1}, 48.7 kg CH_4 ha^{-1} y^{-1} and 1.5 kg N_2O-N ha^{-1} y^{-1} instead of 3.6 t C ha^{-1} y^{-1}, 39 kg CH4 ha^{-1} y^{-1} and 1.6 kg N2O-N ha^{-1} y^{-1}.

For some countries the areal extent of organic soils drained for agriculture was corrected using the European peatland inventory (Joosten et al. 2017a) and the Global Peatland Database (GPD, see chapter 3.3.3.). These corrections did not always provide detailed data on the extent of croplands and grasslands, but rather refer to 'peatlands drained for agriculture'. In such case, the EF used is the mean value between the default factor of cropland and the unspecific value for grassland explained above. The respective areas are classified as a third land-use category 'Agriculture undiff.'.

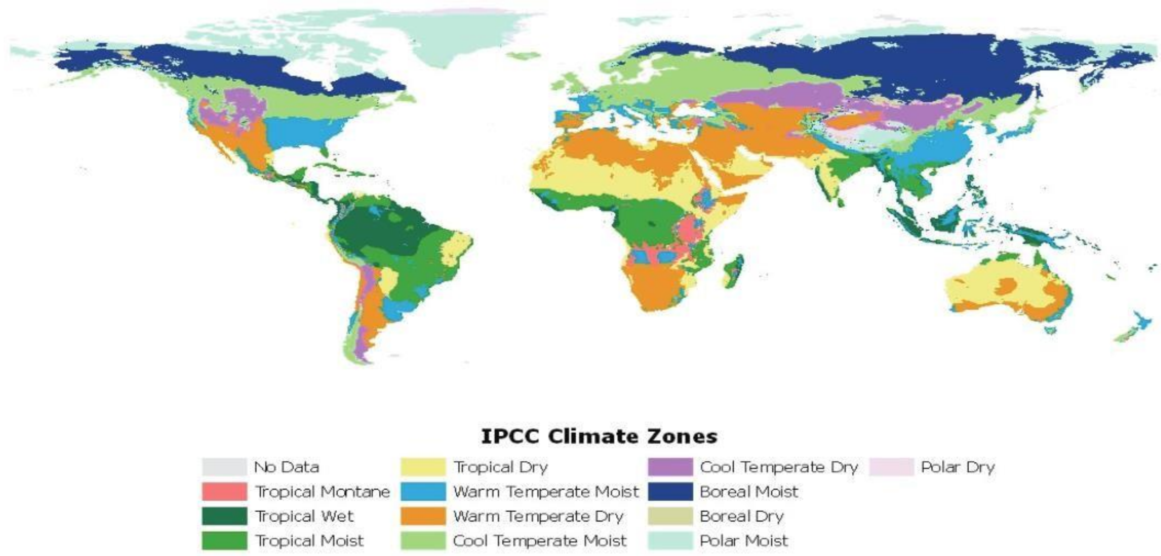

Fig. 3.1.: Delineation of major climate zones, updated from the 1996 IPCC Guidelines (from IPCC 2006).

The Wetlands Supplement to the 2006 IPCC Guidelines introduces EFs for rewetted organic soils. As this study refers to the total area of organic soils in the relevant categories, rewetted organic soils are technically included. Yet, rewetting takes place only very scarcely in the EU. There is hardly any agriculture that takes place on rewetted soils except for some experimental sites (Geurts et al. 2019). This fraction is assumed to be negligible and EFs for drained organic soils are applied on the total organic soil area.

The acquisition of organic soil area data used for the recalculation of GHG emissions is explained in chapter 3.3.

The calculations of emissions which are not adopted from the CRF table of each country follow equation 1 for CO_2, CH_4 and N_2O respectively. Specific aspects are mentioned in the next two sections.

3.2.1. Carbon dioxide emissions from 'Cropland' and 'Grassland'

Emissions are calculated separately for each of the three land-use categories according to equation 1, the IEFs combine on-site emissions and emissions from DOC (equation 3).

$$IEF_{os} = \sum_{c,n,d}((A \times EF_{on-site})_{c,n,d} + (A \times EF_{DOC})_{c,n}) \div 2A_{total} \qquad \text{(Eq. 3)}$$

Where:

IEF_{os} = area-weighted, implied emission factor for organic soils in a land-use category, in t C ha^{-1} y^{-1}

$A_{c,,}$ = land area of organic soils in a land-use category, by climate domain c, nutrient status n and drainage class d, in ha

A_{total} = total land area of organic soils in a land-use category, in ha

$EF_{on-site_{c,n,d}}$ = emission factors for on-site emissions from a land-use category, by climate domain c, nutrient status n and drainage class d, in t CO_2-C ha^{-1} y^{-1}

$EF_{DOC_{c,n}}$ = emission factors for DOC emissions from a land-use category, by climate domain c and nutrient status n, in t CO_2-C ha^{-1} y^{-1}

3.2.2. Methane emissions from 'Cropland' and 'Grassland'

Emissions are calculated separately for each of the three land-use categories according to equation 1, the IEF combines on-site ('land') emissions and emissions from ditches (equation 4). The default ditch fraction is 0.05 (IPCC 2014).

$$IEF_{os} = \sum_{c,n,d}((1 - frac_{ditch}) \times EF_{land_{c,n,d}} + frac_{ditch} \times EF_{ditch_{c,d}}) \qquad \text{(Eq. 4)}$$

Where:

IEF_{os} = area-weighted, implied emission factor for organic soils in a land-use category, in kg CH_4 ha^{-1} y^{-1}

$EF_{land_{c,n,d}}$ = emission factors for emissions from a land-use category, by climate domain c, nutrient status n and drainage class d, in kg CH_4 ha^{-1} y^{-1}

$EF_{ditch_{c,d}}$ = emission factors for emissions from a land-use category, by climate domain c and drainage class d, in kg CH_4 ha^{-1} y^{-1}

$frac_{ditch}$ = fraction of the total area of drained organic soil which is occupied by ditches

3.2.3. Calculation of CO_2-equivalents

CH_4 and N_2O emissions are converted to CO_2 equivalents in order to be able to compare emissions of the different GHGs as well as to sum up total emissions of all relevant gases. All EU countries use GWP CFs from AR4 (Forster et al. 2007) for a 100-year time horizon. Within the scope of AR5 (Myhre et al. 2013), scientific advances were taken into account and revised GWP CFs were derived. The GWP CFs from AR5 are therefore used in this study (Table 3.3.).

Table 3.3. Global Warming Potential for different time horizons according to AR4 and AR5 respectively. (Forster et al. 2007, Myhre et al. 2013)

	AR4 20-y	AR4 100-y	AR5 20-y	AR5 100-y
CO_2	1	1	1	1
CH_4	72	25	84	28
N_2O	289	298	264	265

3.3. Spatial data assessment

3.3.1. Organic soils definition

The IPCC offers a broad and general definition of organic soils that allows for country-specific approaches (IPCC 2006, Annex 3A.5, see 2.2). Definitions vary between the different country submissions and also between additional organic soils inventories used in this study. Organic soil mapping has a long history in Europe and has evolved long before aims of unified GHG emission reporting were started. As high resolution mapping approaches are still scarce over the past few years, GHG inventories rely on older organic soil maps and the corresponding organic soil definitions. As a result, the different EU countries use organic soil maps based on different definitions of what constitutes an organic soil. These different mapping approaches will affect emission estimates.

3.3.2. Coverage

Aim of this study is to assess GHG emissions from organic soils under agricultural use of EU member states on European ground. Overseas territories of Denmark, France and the UK are thus not subject of interest. However, exclusion of these overseas areas and emissions from the CRF data is not always obvious and would exceed the scope of this study. As GHG emissions from organic soils in overseas territories are very low ($\ll$ 1 % of the total emissions in the relevant categories), these emissions are included but can be regarded as negligible. More details are provided in the relevant country chapters.

3.3.3. Spatial data acquisition

For quality assessment of the reported organic soil areas in the ‘Cropland, ‘Grassland’ and ‘Cultivation of organic soils (i.e. histosols)’ categories, we analysed the spatial data acquisition methods in the 2020 NIS of each country and the resulting areas imported from the CRF table of each country. The reported areas were compared with data from Joosten et al. (2017a, see Tanneberger et al. 2017 for GIS cources), who present a peatland inventory for all European countries as well as with the Global Peatland Database (GPD). The spatial data from Nordic-Baltic countries were furthermore compared with data from Barthelmes et al. (2015). For the UK, a more recent organic soil inventory exists which was considered as well (Evans et al. 2017). The reported organic soil areas are as a consequence either adopted or corrected for the calculation of GHG emissions in this study, following the rules below.

Spatial data from the NIS were assessed by the following questions:

- are the reported areas comparable with those in the above-mentioned publications?
- does the method used for spatial data acquisition offer a better estimate than the above-mentioned publications?
- is the area of 'Cultivation of organic soils (i.e. histosols)' identical with the sum of organic soils in the 'Cropland' and 'Grassland' categories?

Spatial data were corrected, if

- organic soils are reported as 'not occuring' in either of the relevant categories but exist according to the above-mentioned publications. In this case, spatial data from the respective publications were adopted. Details are provided in the country chapters (see 4.1.).
- the reported areas differ substantially from the above-mentioned publications. In this case, data from the publication with the most detailed and therefore likely most accurate method were adopted. Details are provided in the country chapters (see 4.1.).
- the reported areas differ substantially from the above-mentioned publications. Yet, although the respective publication is deemed more reliable, it does not differentiate between cropland and grassland. In this case, the reported areas of 'Cropland' and 'Grassland' are adopted and the additional area is classified as 'Agriculture undiff'. Details are provided in the country chapters (see 4.1.).
- the sum of the organic soil areas in the 'Cropland' and 'Grassland' categories (reporting categories 4.B and 4.C) do not match the organic soil area in the 'Cultivation of organic soils (i.e. histosols)' category (reporting category 3.D). In this case – unless otherwise noted - the higher value is used. Details are provided in the country chapters (see 4.1.).

3.4. NIR references

In the country chapters (see 4.1.) there are many references to the respective National Inventory Reports. These references are included as (NIR). The full reference for the NIR of each country is given in Annex 1.

4. Results and Discussion

The methodologies used in the National Inventory Submissions of the EU countries differ substantially. Some countries use the IPCC 2006 Guidelines (IPCC 2006) and thus their report on emissions is incomplete, others follow the IPCC 2013 Wetlands Supplement with some using tier 2 methodologies (see table 4.1.).

Emissions in the relevant categories of each country and the corrections we made are presented in detail in the country chapters below. Each of the country chapters starts with a table that summarizes reported and corrected numbers. The order of the country chapters follows the alphabetical order of the ISO Alpha-3 country codes in Table 4.1.

Table 4.1. Methodologies used by individual EU countries to report organic soil emissions from agricultural land in the sectors 'Agriculture' ('Cultivation of organic soils (histosols)' and 'LULUCF' ('Cropland' and 'Grassland'). The years indicate the IPCC Guidelines used in the NIS, T1 and T2 indicate the tier level of reporting. Dashes indicate that no emissions are reported.

Code	Country	Cultivation of histosols	Cropland	Grassland
AUT	Austria	2013, T1	-	2013, T1
BEL	Belgium	2006, T1	2006, T1	2006, T1
BGR	Bulgaria	2006, T1	-	-
CYP	Cyprus	-	-	-
CZE	Czech Republic	-	-	-
DEU	Germany	2013, T2	2013,T1, T2	2013,T1, T2
DNK	Denmark	2013, T2	2013, T2	2013, T2
ESP	Spain	-	-	-
EST	Estonia	2006, T1	2006, T2	2006, T2
FIN	Finland	2006, T2	2006, T1, T2	2006, T2
FRA	France	2006, T1	2006, 2013, T1	2006, 2013, T1
GBR	The UK	2006, T1	2006, T1	2006, T1
GRC	Greece	2006, T1	2006, T1	-
HRV	Croatia	2006, T1	2006, T1	2006, T1
HUN	Hungary	-	-	-
IRL	Ireland	2013, T1	2013, T1	2013, T1
ITA	Italy	2006, T1	2006, T1	2006, T1
LTU	Lithuania	2006, T1	2006, T1	2006, T1
LUX	Luxembourg	-	-	-
LVA	Latvia	2013, T1	2013, T1	2013, T1
MLT	Malta	-	-	-
NLD	The Netherlands	2006, T2	2006, T2	2006, T2
POL	Poland	2006, T1	2006, T1	2006, T1
PRT	Portugal	-	-	-
ROU	Romania	2006, T1	2006, T1	2006, T1
SVK	Slovakia	-	-	-
SVN	Slovenia	2006, T1	2006, T1	2006, T1
SWE	Sweden	2013, T1	2013, T1, T2	2013, T1

The data presented in the country chapters are collected in an online table, available here (xlsx file). This table includes additional data imported from CRF tables to allow comparisons with total emissions from agriculture or the entire country. It furthermore provides a summary table with an overview of the corrections made and total numbers for the EU (+UK).

4.1. Country chapters

4.1.1. AUT – Austria

Table 4.2. Austrian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	12.95	100	8.2	11.1	0.17	1.74
Cropland	CO_2	-	60	-	8.21 (7.9 + 0.31 DOC)	-	1806.20
	CH_4_land	-	60	-	0	-	-
	CH_4_land+ditch	-	60	-	58.3	-	3.5
Grassland	CO_2	12.95	40	6.4	6.41 (6.1 + 0.31 DOC)	304.46	940.13
	CH_4_land	12.95	40	16	16	-	-
	CH_4_land+ditch	12.95	40	73.5	73.5	0.95	2.94
Subtotal CO_2						**304.10**	**2746.33**
Subtotal CH_4 [CO_2-eq]						**23.79**	**180.12**
Subtotal N_2O [CO_2-eq]						**49.74**	**461.40**
Total [CO_2-eq]		**12.95**	**100**			**377.63**	**3387.86**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Austria reports relevant emissions following the tier 1 approach of the IPCC Wetlands Supplement (IPCC 2014).

According to the Austrian NIR, organic soils occur only in the 'Grassland', not in the 'Cropland' category (NIR, p. 360). Areas are estimated from data of the Austrian Soil Information System[2]. SOC content of 200 grassland sites was determined. Those sites with more than 17 % SOC in the upper 30 cm were categorized as organic soils and their area was extrapolated to the whole country (NIR, p. 360). The resulting area of organic soils in the grassland category is 12.95 kha.

A detailed organic soil inventory does not exist for Austria. Essl and Steiner (2017, p. 260) estimate the area of organic soils under agricultural use at approximately 100 kha, with 60

[2] https://www.umweltbundemt.at/boris

kha cropland and 40 kha grassland, respectively (Grünig 2010). Although the spatial data presented by Grünig (2010) are only a rough estimate, they are adopted in this study.

In the NIS, Austria assumes all grassland organic soils to be deeply drained and uses the IPCC Wetlands Supplement (IPCC 2014) tier 1 EF for deep-drained, nutrient-rich grassland. Grünig (2010) considers the entire 100 kha of agriculturally used organic soils to be under intensive management. Correction of the emissions assessment therefore uses corresponding tier 1 EFs.

The recalculation results in a massive increase of relevant GHG emissions (Table 4.2.) caused by the much larger estimated organic soil area and the inclusion of croplands on organic soils. Austria needs to considerably improve its soil inventory in the different land-use categories in order to appropriately account for GHG emissions from organic soils.

4.1.2. BEL – Belgium

Table 4.3. Belgian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	**Reported emission**	**Area [kha]**		**IEF**		**GHG emission**	
		reported	**corrected**	**reported***	**corrected***	**reported****	**corrected****
Cultivation of histosols	N2O	2.52	6.4	8	4.9	0.03	0.05
Cropland	CO_2	1.9	1.9	10	8.21 (7.9 + 0.31 DOC)	69.63	57.2
	CH4_land	1.9	1.9	-	0	-	-
	CH4_land+ditch	1.9	1.9	-	58.3	-	0.11
Grassland	CO_2	0.82	4.5	1.9	2.67 (2.36 + 0.31 DOC)	5.69	44.06
	CH4_land	0.82	4.5	-	48.7	-	-
	CH4_land+ditch	0.82	4.5	-	72.6	-	0.33
Agriculture undiff.	N2O	-	9	-	10	-	0.14
	CO_2	-	9	-	8.11 (7.8 + 0.31 DOC)	-	234.63
	CH4_land+ ditch	-	9	-	62.3	-	0.56
Subtotal CO_2						**75.32**	**335.88**
Subtotal CH_4 [CO_2-eq]						**-**	**27.95**
Subtotal N_2O [CO_2-eq]						**9.44**	**50.39**
Total [CO_2-eq]		**2.52; 2.72**	**15.4**			**84.76**	**433.71**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Belgium reports emissions from organic soils under agricultural use following the tier 1 approach of the IPCC 2006 Guidelines.

The area of organic soils is determined by overlaying a land-use map (resolution: 0.5 ha) and a soil map. The results are presented disaggregated for the regions Flanders and Wallonia in the NIR (pp. 234). In Flanders, 1.9 kha of 'Cropland' and 0.62 kha of 'Grassland' are mapped. For Wallonia, one site with 0.2 kha of 'Grassland' is mentioned, but emissions are not reported as no drainage or tillage occurs in this nature conservation area. In the 'Cultivation of organic soils (i.e. histosols)' category, this site is not reported, as indicated by 0.2 kha area difference between this category and the sum of 'Cropland' and 'Grassland' areas (Table 4.3.). We use spatial data information from the GPD, which mentions a substantially larger total area of 15.4 kha of agriculturally used organic soils (see also Frankard et al. 2017). The 4.5 kha of grassland are shallow-drained. For 9 kha it is unclear how much of this area is used as cropland and how much as grassland. The EF used for correction is for 'Agriculture undiff.' (see methods section).

The recalculated emissions exceed the reported emissions by about four 4 times (Table 4.3.), caused mainly by the larger estimate of organic soil area. Belgium needs to considerably improve its soil inventory in the different land-use categories in order to appropriately account for GHG emissions from organic soils.

4.1.3. BGR – Bulgaria

Table 4.4. Bulgarian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N2O	41.27	41.27	8	11.9	0.52	0.72
Cropland	CO_2	-	31.77	-	8.21 (7.9 + 0.31 DOC)	-	956.38
	CH4_land	-	31.77	-	0	-	-
	CH4_land+ditch	-	31.77	-	58.3	-	1.85
Grassland	CO_2	-	6.88	-	6.01 (5.7 + 0.31 DOC)	-	151.61
	CH4_land	-	6.88	-	17	-	-
	CH4_land+ditch	-	6.88	-	66.5	-	0.46
Subtotal CO_2						**-**	**1108.00**
Subtotal CH_4 [CO_2-eq]						**-**	**64.63**
Subtotal N_2O [CO_2-eq]						**154.6**	**191.76**
Total [CO_2-eq]		**41.27**	**41.27; 38.65**			**154.6**	**1364.38**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Bulgaria reports emissions from organic soils under agricultural use following the tier 1 approach of the IPCC 2006 Guidelines.

According to the Bulgarian NIS, the area of organic soils in the category 'cultivation of organic soils (i.e. histosols)' in the 'Agriculture' sector is adopted from the FAO database[3]. The FAO reports 31.77 kha of organic soils under cropland and 6.88 kha of organic soils under grassland, summing up to 38.65 kha. The Bulgarian CRF table reports 41.27 kha, however. Bulgaria's NIR does not offer an explanation for this discrepancy in spatial data. Referring to older inventory reporting, Ganeva et al. (2017) estimate a total peatland area as low as 6.6 and up to 35 kha. Another unmotivated conclusion in the NIR is, that no organic soils would occur in the 'LULUCF' sector. Spatial data from the FAO database, which Bulgaria itself refers to, clearly show that this is not the case. We use the area data from the FAO for the 'Cropland' and 'Grassland' categories and the IPCC Wetlands Supplement (IPCC 2014) tier 1 default methodology and EFs.

[3] http://www.fao.org/faostat/en/#data/GV

The recalculation of emissions results in a major increase of almost one order of magnitude. This increase is mainly because all three relevant gases are accounted for instead of N_2O only. Bulgaria needs to improve its soil inventory in the different land-use categories and follow the IPCC guidelines consistently in order to provide a realistic estimate of emissions from organic soils under agriculture.

4.1.4. CYP – Cyprus

Organic soils under agricultural use do not occur in Cyprus (NIR, p. 164; Ioannides et al. 2017, p. 338).

4.1.5. CZE – Czech Republic

Table 4.5. Czech emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source ad sink (sub-) category	Reported emission	Area [kha]		-	IEF	GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	-	4.25	-	6.9	-	0.05
Cropland	CO_2	-	-	-	-	-	-
	CH_4_land	-	-	-	-	-	-
	CH_4_land+ditch	-	-	-	-	-	-
Grassland	CO_2	-	4.25	-	6.01 (5.7 + 0.31 DOC)	-	93.66
	CH_4_land	-	4.25	-	17	-	-
	CH_4_land+ditch	-	4.25	-	66.5	-	0.28
Subtotal CO_2						**-**	**93.66**
Subtotal CH_4 [CO_2-eq]						**-**	**7.91**
Subtotal N_2O [CO_2-eq]						**-**	**12.21**
Total [CO_2-eq]			**4.25**			**-**	**113.78**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

According to the Czech NIS, organic soils do not occur in the 'Cropland' (NIR, p. 286) and 'Grassland' categories (NIR, p. 291). In the GPD, however, 4.25 kha of grassland on organic soils is documented. Emissions amount to 113.78 kt CO_2-equivalents following the IPCC Wetlands Supplement (IPCC 2014). Rybniček et al (2017) estimate a total peatland area of 28.5 kha, the majority of which remains undrained. Most of the drained sites are used for forestry.

4.1.6. DEU – Germany

Table 4.6. German emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected**	reported**	corrected**
Cultivation of histosols	N_2O	1218.88	1218.88	4.7	6.4	8.92	12.98
Cropland	CO_2	342.14	342.14	8.1	8.1	10161.47	10161.47
	CH_4_land	342.14	342.14	11.4	11.4	-	-
	CH_4_land+ditch	342.14	342.14	26	26	8.90	8.90
Grassland	CO_2	970.48	970.48	6.7	6.7	23999.73	23999.73
	CH_4_land	970.48	970.48	10.4	10.4	-	-
	CH_4_land+ditch	970.48	970.48	20.9	20.9	20.28	20.28
Subtotal CO_2						**34161.2**	**34161.2**
Subtotal CH_4 [CO_2-eq]						**729.49**	**817.00**
Subtotal N_2O [CO_2-eq]						**2658.64**	**3440.50**
Total [CO_2-eq]		**1218.88; 1312.62**	**1218.88; 1312.62**			**37549.33**	**38418.71**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Germany reports all relevant emissions following the IPCC Wetlands Supplement (IPCC 2014) methodology.

Following a tier 2 method, Germany has produced a high resolution 'Organic Soils Map' (grid width 25 m) in accordance with the IPCC definition of organic soils (Roßkopf et al. 2015, see also Tegetmeyer et al. 2021), for the first time covering also shallow peat soils and peats mixed with mineral soils (NIR, p. 543). This map is overlain with the constantly updated German Digital Landscape Model (ATKIS Basis-DLM; spatial resolution of at least 1:25,000), which depicts land-use. The area of organic soils under cultivation reported in the 'Agriculture' sector (1218.88 kha) differs from the aggregated area under grassland and cropland of the 'LULUCF' sector (1312.62 kha). This discrepancy arises, because undrained wet grassland areas (71.41 kha) and 'Woody Grassland' areas (22.33 kha) are accounted for in the 'LULUCF' sector only (NIR, p. 544, table 4.7.). Emissions of undrained wet grassland areas are assumed to be zero (NIR, p. 544); emissions from 'Woody Grassland' are assumed to be lower and are reported in CRF table 4(II).C under 'total mineral soils'. Organic soils are defined as drained if the mean annual water table is at least 0.1 m below the surface. Germany accounts not only for 'true' peat soils but also for 'other organic soils' as they are found to emit equal amounts of GHGs in drained condition (Tiemeyer et al. 2016). The reported area is regarded as appropriate.

Table 4.7. Organic soil areas, by land-use categories, along with the applicable drained-area fractions, adopted from NIR, p. 544.

	Organic soils area [kha]	Drained fraction [%]
Cropland	342.14	100.0
Grassland (in the strict sense)	948.15	92.3
Woody Grassland	22.33	98.3

To estimate N_2O emissions from cultivation of histosols, Germany has adopted country specific EFs for cropland (10.9 kg N_2O-N ha^{-1} y^{-1} from Leppelt et al. 2014, using data from Germany) and grassland (2.3 kg N_2O-N ha^{-1} y^{-1} from Tiemeyer et al. 2016). The EF used for grassland is notably low. To compare with default EFs, it should be noted that 34 % of German grasslands on organic soils are estimated to be shallow-drained (Tiemeyer et al. 2020, p. 9, table 4). An area-weighted average EF with 34 % nutrient-rich, shallow-drained grassland and 66 % nutrient-rich, deep-drained grassland using the default IPCC EFs amounts to 6.0 kg N_2O-N ha^{-1} y^{-1}, which is more than 2.5 times higher than the EF used in the German submission. The EF for nutrient-poor grassland is not included in this average EF, for reasons of simplicity, but also because of its small area. In Tiemeyer et al. (2016), the low value is explained with lower N-fertilization rates on German grasslands compared with the study areas used to derive the IPCC 2013 default EFs (Tiemeyer et al. 2016, p. 12). A new study by Tiemeyer et al. (2020) with an 'unprecedented large GHG data set' arrives at an EF of 4.6 kg N_2O-N ha^{-1} y^{-1} for drained grassland. This EF was calculated using mean site averages of N_2O measurements for each respective land-use type. Regarding the large number of measurements included in the new study and the more realistic value compared with the default EF, the revised EF of 4.6 kg N_2O-N ha^{-1} y^{-1} is adopted in this study. For the purpose of consistency, the EF of 11.1 kg N_2O-N ha^{-1} y^{-1} for cropland is taken from Tiemeyer et al. (2020) as well. The IPCC (2014) default EF of 13 kg N_2O-N ha^{-1} y^{-1} is only slightly higher. The 2021 submission of Germany uses these numbers as well.

For estimation of CO_2 and CH_4 emissions from organic soils, Germany used a tier 2 country-specific method. Water tables are calculated for 25 x 25 m grid points (Bechtold et al. 2014) and mapped to CO_2-C on-site emissions. The relationship between emissions and water table is based on national annual flux measurement values. Emissions are assumed to increase with water table depth up to about 50 cm depth beyond which they remain at a single high value (NIR, p. 544; Tiemeyer et al. 2020). CH_4 on-site emissions from grassland soils (CH_{4_land}) are estimated similarly, but with an exponential function describing the non-linear relationship between CH_4 emissions and the water table. For cropland, the average of national annual measurements is used, because soils are too dry for CH_4 fluxes to show a meaningful correlation with water table (NIR, p. 545). DOC emissions and CH_4 emissions from ditches are calculated using the 2013 IPCC Wetlands Supplement (IPCC 2014) tier 1 EFs (NIR, p. 544), as data to derive country-specific EFs are not available (Tiemeyer et al. 2020).

The IEFs for CO_2 emissions are close to the IPCC Wetlands Supplement default values, with the country specific IEF for cropland (8.1 t CO_2-C ha^{-1} y^{-1} including DOC) differing by 0.1 t CO_2-C ha^{-1} y^{-1} from the default value (8.2 t CO_2-C ha^{-1} y^{-1} including DOC) and the country specific EF for grassland (7.4 t CO_2-C ha^{-1} y^{-1} including DOC) differing by 1 t CO_2C ha^{-1} y^{-1} from the default value (6.4 t CO_2-C ha^{-1} y^{-1} including DOC). For 'Woody Grassland', the tier 1 default value (2.9 t CO_2-C ha^{-1} y^{-1} including DOC) for drained forestland is used (NIR, p.

545). This IPCC default EF mixes only few measurements made in (cold) temperate deciduous forests with measurements made in (boreal) coniferous forests. It is likely that forest type and tree cover influence the CO_2 balance and that emissions from woody grasslands are underestimated.
The country specific EFs for CH_4 differ substantially from the IPCC tier 1 values. The onsite nationally derived IEF for cropland is remarkably high (11.4 kg CH_4 ha^{-1} y^{-1}) compared with the default EF (0 kg CH_4 ha^{-1} y^{-1}). Germany reports a ditch area fraction of 1.3 % (NIR, p. 510), which is four times lower than the IPCC default of 5 %. For ditch emissions, Germany uses the default EF from the IPCC Wetlands Supplement (IPCC 2014). Overall, CH_4 on-site emissions and ditches combined are less than half the IPCC default value (26 kg CH_4 ha^{-1} y^{-1} country-specific vs. 58.3 kg CH_4 ha^{-1} y^{-1} IPCC default). As the same ditch area fraction is used also for grassland the country specific IEF including ditches (23 kg CH_4 ha^{-1} y^{-1}) is much lower than the IPCC default EF (73.5 kg CH_4 ha^{-1} y^{-1}). Whereas the main difference is caused by the ditch area fraction, also the German onsite IEF (10.4 kg CH_4 ha^{-1} y^{-1}) is lower than the IPCC default value (16 kg CH_4 ha^{-1} y^{-1}).

Overall, the German methodology is in line with the IPCC Best Practice Guidelines and the 2014 IPCC Wetlands Supplement and therefore provides good estimates of annual GHG emissions from organic soils under agricultural use. However, accuracy of the German nationally-derived EFs should not be overrated. There are still large uncertainties in the underlying water table depth (WTD) map (Bechtold et al. 2014), which is generated by extrapolating WTD between measurements of 'only' 1094 dip wells across Germany to an area of 1.3 million hectares (i.e. 1 dip well represents $>$ 1000 ha). Bechtold et al. (2014) admit 'structural deficits' in the WTD regionalization model, resulting mainly from missing or weak predictor variables (Bechtold et al. 2014). For improvement, for example the mapping of tile drains and soil moisture observations are suggested, as well as more data acquisition from grassland and arable land to eliminate overrepresentation of nature conservation sites (Bechtold et al. 2014). Furthermore, results are presented in reference to a transformed water table (WTt), which is supposed to be linearly correlated with GHG emissions, but consequently is non-linearly correlated with the real WT. Deviations and biases between observed and predicted values of the WTt therefore have a limited explanatory power regarding the real WT. The presented results show slight biases in the predicted WTt of forest on organic soils and organic soils in the southern geographical region (c.f. Bechtold et al. 2014). This could or could not indicate large actual errors in terms of true WT.

The recalculation in this study results in a minor increase of CO_2-equivalents of about 2 % (Table 4.6.), caused by the higher corrected IEF for N_2O emissions and application of the revised GWP CFs of AR5 (Myhre et al. 2013).

4.1.7. DNK – Denmark

Table 4.8. Danish emissions from organic soils under agricultural use (including emissions from Greenland) as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	179.02	179.02	7.8[2]	11.2	2.19	3.16
Cropland	CO_2	127.43	127.43	7.6[2]	8.21 (7.9 + 0.31 DOC)	3552.60	3835.92
	CH_4_land	127.43	127.43	0	0	-	-
	CH_4_land+ditch	127.43	127.43	44.3[3]	58.3	5.64	7.42
Grassland	CO_2	51.62	51.62	6.5[2]	6.01 (5.7 + 0.31 DOC)	1232.78	1137.43
	CH_4_land	51.62	51.62	-	17	-	-
	CH_4_land+ditch	51.62	51.62	57[3]	66.5	2.94	3.43
Subtotal CO_2						**4785.38**	**4973.35**
Subtotal CH_4 [CO_2-eq]						**214.53**	**303.94**
Subtotal N_2O [CO_2-eq]						**652.11**	**838.13**
Total [CO_2-eq]		**179.02; 179.04**	**179.02; 179.04**			**5652.01**	**6115.42**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Data reported in the Danish CRF tables include emissions from overseas territories, namely Greenland. These data are included in this study as well – unless otherwise noted – in order to guarantee consistency in the generated tables. Methods and data of these areas are separately listed in the Danish NIR, but are only in part disaggregated from the Danish emissions in the CRF tables. Based on the data provided, overseas emissions can be regarded as negligible.

Denmark reports all relevant emissions following the methodology of the IPCC Wetlands Supplement (IPCC 2014). Nonetheless there are some inconsistencies in spatial data between CRF tables and also between CRF tables and the NIR (Table 4.9.). In CRF table 4(II), the total organic soil area of 'Cropland' (127.43kha) and 'Grassland' (51.62 kha) amounts to 179.04 kha. In CRF tables 4.B and 4.C, Denmark reports different numbers, 126.88 kha in 'Cropland' and 58.84 kha in 'Grassland', with a total of 185.72 kha. The difference in 'Grassland' area results from 7.23 kha of 'unmanaged' land on Greenland, which are included in CRF table 4.C without organic soil emissions, but are missing in CRF table 4(II).C. As land listed in the 'LULUCF' sector is defined as managed, mention of this 'unmanaged' area in the 'LULUCF' sector is confusing and leads to inconsistencies. The NIR does not offer further information about this ‘unmanaged’ land and consequently does not allow any conclusions regarding the actual state of this land and potential soil GHG emissions. The source of the discrepancy in ‘Cropland’ area could not be identified.

The area data from CRF table 4(II).B and 4(II).C are used in this study, as they are in line with the area referred to for ‘Cultivation of organic soils (i.e. histosols)’ in the ‘Agriculture’ sector (Table 3.D). The difference of 0.02 kha is because of rewetted organic ‘Cropland’ soils included in CRF table 4(II).B but not in CRF table 3.D.6. The spatial data in CRF table 4(II) can also be found in the NIR (p. 410, 469), where 117.36 kha of ‘Cropland’ and 51.33 kha of ‘Grassland’ on organic soils are mentioned. Summed up with 10.04 kha of ‘Cropland’ assumed to be too wet for use and therefore abandoned, the ‘Cropland’ area given in the NIR equals the ‘Cropland’ area on drained organic soils of Denmark in CRF table 4(II).B (excluding rewetted organic soils and drained organic soils of Greenland). The ‘Grassland’ area given in the NIR equals the ‘Grassland’ area on drained organic soils of Denmark (excluding 0.28 kha drained organic ‘Grassland’ soils on Greenland).

Table 4.9. Organic soil areas given in CRF tables and NIR of Denmark.

CRF table code	Source and sink (sub-)category	Area [kha]		Comment
3.D.a	Cultivation of organic soils (i.e. histosols)	179.02		Should equal the area of organic soils in the ‘Cropland’ and ‘Grassland’ categories
4.B	Cropland, Organic soils	126.88	185.72	
4.C	Grassland, Organic soils	58.84		
4.C.1	Greenland Unmanaged (Grassland)	7.23		Included in table 4.C but not in tables 3.D.a, 4(II) or the NIR
4.C.1	Greenland Managed (Grassland)	0.28		Included in table 4.C and 4(II) but not in the NIR
4(II).B	Cropland	127.43	179.04	Includes 0.2 kha of rewetted organic soils not included in 3.D.a
4(II).C	Grassland	51.62		
4(II).B	Wet, abandoned cropland	10.04		Included in 4(II).B but not in the NIR
	Cropland in NIR	117.36	168.69	
	Grassland in NIR	51.23		

Denmark has derived tier 2 EFs for all relevant GHGs emitted by drained organic soils. Soils with a content of 1.5-3 % OC are assumed to be in an equilibrium state whereas soils with 6 % or more OC are assumed to emit CO_2, CH_4 and N_2O (NIR, p. 400). Due to a lack of data for soils containing 6–12 % OC, EFs for these soils are estimated to amount to 50 % of the values for soils with >12 % OC (NIR, p. 400). Although emissions from peaty soils can indeed be lower than from ‘true’ peat soils, much higher emissions have also been observed (even in Denmark: Elsgaard et al. 2012; see also Tiemeyer et al. 2020). For areas with >12 % OC, Denmark calculates emissions using tier 1 EFs from the 2013 IPCC Wetlands Supplement (IPCC 2014). As mentioned above, 10.04 kha of drained organic cropland soils do not occur in the field map. Farmers have not applied for subsidies for these areas and Denmark suspects them to have become wet and abandoned. They are therefore treated as shallow-drained, nutrient-rich ‘Grassland’ (NIR, p. 469). The remaining area of organic soils is treated as deep-drained, nutrient-rich. The spatial distribution of organic soils with the different OC contents is listed in table 4.10.

In CRF table 4(II), Denmark reports additional CO_2 emissions with an EF of 0.06 t C ha^{-1} y^{-1} for both ‘Cropland’ and ‘Grassland’. The source of these emissions is not mentioned in the CRF table, nor in the NIR. Although their source is unclear, we do include these emissions in my assessment of reported emissions.

Table 4.10. Area of organic soils, adopted from NIR, p. 400.

	Area [ha]
Cropland, >12 % SOC	44 999
Grassland, >12 % SOC	27 838
SN grassland*, >12 % SOC	5 395
Cropland, 6–12 % SOC	72 364
Grassland, 6–12 % SOC	23 493
SN grassland*, 6–12 % SOC	4 645

*SN-grassland – shallow-drained, nutrient-rich grassland

The Danish EFs are not based on national GHG measurements. The assumption that peaty soils emit only half as much GHGs as peat soils in Denmark is untenable regarding the current state of knowledge (see above) and is likely to lead to an underestimation of GHG emissions from organic soils. We therefore use the IPCC Wetlands Supplement default EFs (IPCC 2014) for both organic soil types.

In conclusion, Denmark needs to unify spatial data in the different parts of its NIS in order to present reliable GHG emission estimates. Existing scientific evidence should be considered for the derivation of country-specific EFs. The recalculation results in an increase of emissions by 8 % (Table 4.8.), caused by higher EFs and the application of the revised GWP CFs from AR5 (Myhre et al. 2013).

4.1.8. ESP – Spain

Table 4.11. Spanish emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	-	13	-	6.9	-	0.14
Cropland	CO_2	-	-	-	-	-	-
	CH_4_land	-	-	-	-	-	-
	CH_4_land+ditch	-	-	-	-	-	-
Grassland	CO_2	-	13	-	6.01 (5.7 + 0.31 DOC)	-	286.48
	CH_4_land	-	13	-	17	-	-
	CH_4_land+ditch	-	13	-	66.5	-	24.21
Subtotal CO_2						**-**	**286.48**
Subtotal CH_4 [CO_2-eq]						**-**	**24.21**
Subtotal N_2O [CO_2-eq]						**-**	**37.35**
Total [CO_2-eq]		**-**	**13**	**-**	**-**	**-**	**329.71**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Spain does not report any emissions from organic soils. Organic soils are estimated to cover 0.1 % of the whole area of Spain. Corresponding emissions are argued to not exceed the significance threshold in accordance with Decision 24/CP.19 (NIR, p. 465).

For this study, default EFs from the 2013 IPCC Wetlands Supplement (IPCC 2014) and area data from the GPD are used (see also Heras Pérez et al. 2017). The resulting estimate amounts to 329.71 kt of CO_2-eqivalents from grassland on organic soils (see table 4.11.).

4.1.9. EST – Estonia

Table 4.12. Estonian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported*	corrected **
Cultivation of histosols	N_2O	39.09	76.43	8	9.2	0.49	1.1
Cropland	CO_2	28.39	28.39	6.1	8.21 (7.9 + 0.31 DOC)	635.08	854.63
	CH_4_land	28.39	28.39	0	0	-	-
	CH_4 _land +ditch	28.39	28.39	0	58.3	-	1.65
Grassland	CO_2	48.03	48.03	0.5	6.01 (5.7 + 0.31 DOC)	89.00	1058.42
	CH_4_land	48.03	48.03	0	17	-	-
	CH_4 _land +ditch	48.03	48.03	0	66.5	-	3.19
Agriculture undiff.	N_2O	-	169.48	-	1.5	-	0.4
	CO_2	-	169.48	-	2.67 (2.36 + 0.31 DOC)	-	1659.21
	CH_4 _land +ditch	-	169.48	-	72.6	-	12.31
Subtotal CO_2						**724.08**	**3572.26**
Subtotal CH_4[CO_2-eq]						**-**	**480.33**
Subtotal N_2O [CO_2-eq]						**146.45**	**397.56**
Total [CO_2-eq]		**39.09; 76.43**	**245.9**	**-**	**-**	**870.52**	**4450.15**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Estonia reports emissions from organic soils following the 2006 IPCC Guidelines (IPCC 2006).

Land-use and land-use change is assessed in the National Forest Inventory (NFI) by tracking permanent sample plots in 5-year cycles (NIR, p. 287). Organic soils are determined in the field, where all sample plots are categorized as either 'mineral' or 'organic'. Per definition, organic soils have an organic layer of at least 30 cm or 25 cm when drained (NIR, p. 294).

The areas in the 'Agriculture' and the 'LULUCF' sectors do not match. For 'Cultivation of organic soils (i.e. histosols)' only roughly half of the area of 'Cropland' and 'Grassland' organic soils are considered. 37 % of the grassland soils are abandoned and thus not reported under ‘Cultivation of organic soils (i.e. histosols)’ according to the NIR (p. 270). Yet, this omission does not completely explain the discrepancy between both sectors.

The areas of organic soils should be equal in the ‘Agriculture’ and the ‘LULUCF’ sector, or the difference should be well argued. The fact that organic soils are not actively drained does not mean they do not emit GHGs. Estonia must account for emissions from all organic soils which are or have been subject to human intervention.

Barthelmes et al. (2015, see Paal & Leibak 2011) report another 170 kha of shallow-drained agriculturally used organic soils, additional to the 76 kha of deep-drained organic soils that are reported. The share of cropland and grassland in these shallow-drained soils could not be clearly identified. They are thus categorized as ‘Agriculture undiff.’ in this study.

Estonia estimates N_2O emissions from ‘Cultivation of organic soils (i.e. histosols)’ with the default EF from the 2006 IPCC Guidelines (IPCC 2006).

As a tier 2 approach, CO_2 and CH_4 emissions are calculated with EFs from the Swedish NIS due to a lack of country-specific data. Sweden uses the default EF for forest land to account for its organic ‘Grassland’ soils, thus likely underestimating emissions from this category (see chapter 4.1.28.). The final IEF for organic ‘Grassland’ soils is even 3 times lower in the Estonian CRF table 4.C (0.5 t C ha^{-1} y^{-1}) than the one used by Sweden (1.67 t C ha^{-1} y^{-1}). This might be a result of the exclusion of abandoned sites from GHG accounting which is, however, not explained in the relevant chapters of the Estonian NIR.

We used default EFs from the IPCC Wetlands Supplement (IPCC 2014). For the category ‘Agriculture undiff.’, the EFs for shallow-drained grassland were used as a conservative approach (Table 4.12.).

Estonia is a country with extensive areas of peatlands (Ilomets 2017), emitting considerable amounts of GHGs (Barthelmes et al. 2015). Soils drained for agriculture are responsible for more than 4000 kt of CO_2-equivalents (Table 4.12.). It is thus very important that emissions are estimated correctly and that effective GHG mitigation strategies are developed. Acquisition of country-specific data is the first step on this path and should be in the interest of Estonia, as it considers the IPCC default EFs as not suitable for the national conditions and prefers to use the Swedish EFs instead.

4.1.10. FIN –Finland

Table 4.13. Finnish emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	329.42	329.42	9.7	9.7	5.04	5.04
Cropland	CO_2	262.52	262.52	6.6	6.68 (6.5 + 0.18 DOC)	6314.68	6427.05
	CH_4_land	262.52	262.52	-	0	-	-
	CH_4_land+ditch	262.52	262.52	-	58.3	-	15.29
Grassland	CO_2	66.91	66.91	3.5	3.68 (3.5 + 0.18 DOC)	858.63	902.05
	CH_4_land	66.91	66.91	-	17	-	-
	CH_4_land+ditch	66.91	66.91	-	66.5	-	3.99
Subtotal CO_2						**7173.31**	**7329.10**
Subtotal CH_4 [CO_2-eq]						**-**	**539.78**
Subtotal N_2O [CO_2-eq]						**1501.37**	**1335.11**
Total [CO_2-eq]		**329.42**	**329.42**	**-**	**-**	**8674.68**	**9203.99**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Finland reports relevant emissions following the IPCC 2006 Guidelines (IPCC 2006). CH_4 and DOC-related emissions from Cropland and Grassland are not reported. The Finnish vegetation zones range from temperate to boreal (IPCC 2006, fig. 3.1.). How agriculturally used organic soils are disaggregated across these zones is not evident from the NIR.

Areas of land-use and land-use change are based on the Finnish sampling-based National Forest Inventory (NFI). Each year, 20 % of the sample plots are measured in five-year cycles, the most recent one finished being NFI12 (2014 – 2018). The NFI covers the whole country (NIR, p. 309). Mineral and organic soils are partly identified in the field, partly with help of the Finnish georeferenced soil database, consisting of a soil map (scale 1:250,000) and a description of soil properties (NIR, p. 310).
The 'Cropland' share is rather high in Finland (262.52 kha, 80 %) compared with the 'Grassland' share (66.91 kha, 20 %), because grass cropping is included in the 'Cropland' category (NIR, p. 306). Most areas in the 'Grassland' category are described as abandoned fields (NIR p. 277).
As already mentioned, agriculturally used organic soil areas are not disaggregated by climate in the NIR.

We use the ratio of organic soils in the boreal and temperate climate zone from the GPD to disaggregate, which is a conservative estimate, as most agriculture takes place in the southern, temperate climate zone where agriculturally used soils emit more GHGs. 70 % of Finland are in the boreal climate zone and 30 % in the temperate climate zone.

N_2O emissions in the 'Agriculture' sector are calculated using tier 2 country-specific EFs. Regarding cropland areas with perennials and annual crops, EFs equal the IPCC default EFs for drained boreal grassland (9.5 kg N_2O-N ha^{-1} y^{-1}) and drained boreal/temperate cropland (13 kg N_2O-N ha^{-1} y^{-1}), respectively (IPCC 2014). Finland adopts these values as country-specific, simply because a lot of the underlying data were measured in Finland (NIR, p. 278). For the Grassland category (not including grassland cropping), a country-specific EF is taken from Maljanen et al. (2010) (5.7 kg N20-N ha^{-1} y^{-1}), which is calculated from measurements on five Finnish and one Norwegian abandoned cropland sites. The value is considered to reflect the Finnish grassland conditions more accurately than the IPCC default EF, as abandoned fields make up the largest share of the Finnish Grassland category according to the NIR.

Consequently, for CO_2 emissions in the 'Grassland' category, an EF of 3.5 t C ha^{-1} y^{-1} is adopted in the Finnish NIS and this study from Maljanen et al. (2010) as well, corresponding to a tier 2 approach. CO_2 emissions from 'Cropland remaining cropland' are estimated using the IPCC default EFs for drained cropland (7.9 t C ha^{-1} y^{-1}) and drained grassland for grass cropping (5.7 t C ha^{-1} y^{-1}) (IPCC 2014) (the cropland and grassland EFs are identical for boreal and temperate climate), whereas CO_2 emissions from soils converted to 'Cropland' are estimated using the mean EF (6.8 t C ha^{-1} y^{1}) of the default EFs for drained, boreal cropland and drained, boreal grassland. This calculation of emissions from 'Land converted to cropland' is an arbitrary approach and is – as far as can be judged – not based on scientific evidence. In line with the IPCC Guidelines (IPCC 2006), the 'Cropland remaining cropland' EF of 6.5 t C ha^{-1} y^{-1} should be – and is in this study - applied for the total 'Cropland' category if no country-specific data are available. These changes in methods make hardly any difference in the resulting emissions (approx. +/- 50 kt C y^{-1}) , but arise from a scientific, reproducible approach.

DOC emissions amount to 0.18 t C ha^{-1} y^{-1} considering a ratio of 70 % boreal and 30 % temperate climate (see explanation above).

For CH_4 emissions in the 'Cropland' category, we use an IEF of 39 % drained cropland (0 kg CH_4 ha^{-1} y^{-1}) and 61 % drained grassland (1.4 kg CH_4 ha^{-1} y^{-1}). As these area fractions are not reported, the cropland:grassland ratio was determined by trial and error comparing the IEF for CO_2 emissions from 'Cropland' with the country-specific EFs for the subcategories of annual and perennial crops.

For 'Grassland', the EF for CH_4 from abandoned fields from Maljanen et al. (2010) indicates a small sink (0.1 kg CH_4 ha^{-1} y^{-1}), whereas IPCC (2014) treats grassland as a CH_4 source (1.4 kg CH_4 ha^{-1} y^{-1} for boreal climate, 17 kg CH_4 ha^{-1} y^{-1} for temperate climate (modified for this study, see Methods section)). In emission recalculations of this study, we use an EF of zero because we only consider emission sources.

The recalculation results in an increase of emissions by about 6 % (Table 4.13.), caused by the additional estimates for DOC and CH_4 emissions. The GWP of N_2O emissions slightly decreases because we used the revised, lower GWP from AR5 (Myhre et al. 2013).

4.1.11. FRA – France

Table 4.14. French emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	139.06	139.06	8	10.4	1.75	2.28
Cropland	CO_2	80.44	80.44	8.2	8.21 (7.9 + 0.31 DOC)	2423.11	2421.5
	CH_4_land	80.44	80.44	0	0	-	-
	CH_4_land+ditch	80.44	80.44	0	58.3	0	4.69
Grassland	CO_2	58.62	58.62	3.9	6.01 (5.7 + 0.31 DOC)	842.53	1291.71
	CH_4_land	58.62	58.62	-	17	-	-
	CH_4_land+ditch	58.62	58.62	38.9	66.5	2.28	3.9
Subtotal CO_2						**3265.64**	**3713.21**
Subtotal CH_4 [CO_2-eq]						**57.05**	**240.34**
Subtotal N_2O [CO_2-eq]						**522.13**	**603.89**
Total [CO_2-eq]		**139.06**	**139.06**	**-**	**-**	**3844.83**	**4557.44**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Data reported in the French CRF tables include emissions from overseas territories. These data are included in this study as well. In the NIR, areas are disaggregated in metropolitan France and overseas territories and EFs are disaggregated in metropolitan France (temperate climate) and French Guiana (tropical climate). The mention of overseas territories on the one hand and French Guiana on the other hand leads to ambiguity. My assumption is that they are basically the same in terms of organic soils under agricultural use, i.e. that no such soils occur in other overseas territories than French Guiana. Actually, according to the available data (see below), emissions from overseas territories are negligible - and are treated as such in the recalculations and corrections of this study.

France reports N_2O emissions following the IPCC 2006 Guidelines (IPCC 2006) and CO_2 and CH_4 emissions following the IPCC Wetlands Supplement (IPCC 2014).

Since 2018, the areas of organic cropland and grassland soils in metropolitan France are estimated by overlaying soil maps from 1999 with land-use maps (Corine Land Cover, CLC) (NIR, p. 548). Overseas areas of organic soils are very small compared to metropolitan France (NIR, p. 505; Table 4.15.). In inventory submissions from 2017 and earlier, the data were less reliable and France reported 182 kha under 'cultivation of organic soils (i.e. histosols) and a total of 49 kha under 'Cropland' and 'Grassland'.

We use the default EFs from the IPCC Wetlands Supplement.

Regarding the French accounting for CO_2 emissions in the 'Grassland' category, the choice of a CO_2 default EF for metropolitan France of nutrient-rich, shallow-drained grassland is questionable. Deep drainage is the rule – simply because it allows access with heavy machinery. The NIR should provide evidence if all grassland drainage in France deviates from this norm. As no detailed information on water table depths is available, we use the IPCC default EF for nutrient-rich, deep-drained grassland to recalculate CO_2 emissions.

In the NIR, information regarding emissions from DOC is contradictory. In the 'Cropland' and 'Grassland' chapters, DOC emissions from both metropolitan France and French Guiana, referred to as 'indirect CO_2 emissions', are stated to be calculated with an EF of 0.1 t C ha^{-1} y^{-1} (NIR, pp. 548, 559). Yet, in table 134 of the NIR (Table 4.15. in this study), the IPCC Wetlands Supplement tier 1 EFs of 0.31 and 0.82 t C ha^{-1} y^{-1} are included. From CRF table 4(II), it can be learned that indeed the IPCC default EFs were used.

In the calculation of CH_4 emissions, a similar discrepancy as for DOC emissions occurs in the French NIR. In the 'Cropland' chapter, CH_4 EFs for both metropolitan France and overseas territories are stated to be 0 t C ha^{-1} y^{-1} (NIR, p. 548). In the 'Grassland' chapter, CH_4 emissions are stated to be neglected (NIR, p. 559). In table 134 (Table 4.15. in this study) and CRF table 4(II), default EFs for nutrient-rich, shallow-drained grassland from the IPCC Wetlands Supplement (IPCC 2014) are evident. The grassland EF in this study is corrected to nutrient-rich, deep drained grassland and complemented by emissions from drainage ditches (Table 4.14.).

Table 4.15. Parameters used in calculation of CO_2 and CH_4 emissions from drained organic soils under agricultural use in France. The table was taken from the French NIR, p. 505.

	Metropolitan France		Overseas Territories	
	Cropland	Grassland	Cropland	Grassland
EF CO_2 on-site	7.9 t C ha^{-1} y^{-1}	3.6 t C ha^{-1} y^{-1}	14 t C ha^{-1} y^{-1}	9.6 t C ha^{-1} y^{-1}
EF CO_2 DOC	0.31 t C ha^{-1} y^{-1}		0.82 t C ha^{-1} y^{-1}	
EF CH_4_land	0 kg CH_4 ha^{-1} y^{-1}	39 kg CH_4 ha^{-1} y^{-1}	7 kg CH_4 ha^{-1} y^{-1}	7 kg CH_4 ha^{-1} y^{-1}
Area	80.28 kha	58.46 kha	0.16 kha	0.16 kha

Overall, the recalculation results in an increase of emissions by about 20% (Table 4.14.), mainly caused by an additional ca. 450 kt CO_2 y^{-1} from 'Grassland' due to correction of the drainage class.

4.1.12. GBR – the UK

Table 4.16. British emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected **
Cultivation of histosols	N_2O	285.70	760.68	8	6.6	3.59	7.91
Cropland	CO_2	93.62	194.53	5	7.51 (7.2 + 0.31 DOC)	1716.87	5356.60
	CH_4_land	93.62	194.53	-	1	-	-
	CH_4 _land+ ditch	93.62	194.53	-	58.3	0	11.52
Grassland	CO_2	199.27	566.15	0.3	2.81 (2.5 + 0.31 DOC)	182.66	5761.50
	CH_4_land	199.27	566.15	-	41.9	-	-
	CH_4 _land+ ditch	199.27	566.15	-	76.9	0	43.55
Subtotal CO_2						**1899.54**	**11118.10**
Subtotal CH_4[CO_2-eq]						**-**	**1541.88**
Subtotal N_2O [CO_2-eq]						**1070.31**	**2096.19**
Total [CO_2-eq]		**285.70; 292.89**	**760.68**	**-**	**-**	**2969.85**	**14756.17**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Data reported in the British CRF tables include emissions from overseas territories. These are transparently segregated from the UK emissions in the relevant categories. Although overseas organic soil emissions from histosols in the 'Cropland' and 'Grassland' categories are reported as 'not occuring' or 'not estimated', organic soil areas from Crown Dependencies are exceeding those of the UK. These areas are excluded in this study as well, because judging emissions from organic soils in Crown Dependencies is beyond the scope of this study.
Organic soil emissions from the Falkland Islands are not included in the British inventory, as land-use maps are missing (Evans et al. 2017, p. 37).

The UK reports emissions from organic soils under agricultural use following the tier 1 approach of the IPCC 2006 Guidelines (IPCC 2006). In this study, emissions are recalculated using spatial data and country-specific EFs from Evans et al. (2017), who developed a detailed peatland emission inventory for the whole UK. DOC and CH_4 from ditches are recalculated with tier 1 EFs from the IPCC Wetlands Supplement (IPCC 2014). Spatial data in the study of Evans et al. (2017) date back to 2013. As area estimates in the relevant categories of the British inventory have hardly changed between 2013 and 2018, the data from Evans et al. can be viewed as suitable for 2018.

The recalculated emissions exceed the reported emissions dramatically. They are roughly five times higher (Table 4.16.). The large discrepancy results mainly from improvements in land-use and organic soil mapping as well as more detailed peat condition classification with corresponding country-specific EFs (Evans et al. 2017, p. 48, see table 4.17.).

The 2021 submission of the UK uses the improved methods and EFs of Evans et al. (2017, see Table 4.1.7.). Although the introduction of a tier 2 approach by the UK starting with its 2021 submission is laudable, it means that years went by in which reporting was knowingly subpar. The report at the basis of the tier 2 reporting bears a date of December 2017, but was only published officially one and a half years later. The improved reporting on organic soils turned the sector 'LULUCF' from a net sink into a net source (UK NIS 2021).

Table 4.17. Country-specific EFs per tier 2 category, aggregated in IPCC tier 1 categories and corresponding areas of organic soils under agricultural use for each UK administration. English spatial data are subdivided into deep and wasted (= shallow residual organic soils where much of the original peat has already been lost) peat areas. Adopted from Evans et al. 2017, p. 35. NI = Northern Ireland, IoM = Isle of Man

IPCC tier 1 category	UK tier 2 category	tier 2 EF*			Area [kha]					
		CO_2	CH_4	N_2O	England		Scotland	Wales	NI	IoM
					Deep	Wasted				
Cropland	Cropland	7.2	1	19.1	50,594	132,107	8,181	102	3,141	41
Grassland, drained, nutrient-poor	Modified eroded bog	0.2	48	0.1	5,653	0	75,147	19	2,170	0
	Modified bog	0.0	55	0.1	43,261	0	188,326	3,176	13,334	4
	Extensive grassland	3.6	73	3.2	1,377	518	31,794	8,993	1,932	99
Grassland, deep-drained, nutrient-rich	Intensive grassland	6.4	15	6.0	38,416	35,265	78,641	6,577	31,248	204

*Units: t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}, kg N_2O-N ha^{-1} y^{-1}

4.1.13. GRC – Greece

Table 4.18. Greek emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	6.66	6.66	8	13	0.08	0.14
Cropland	CO_2	6.66	6.66	10	8.21 (7.9 + 0.31 DOC)	244.37	200.62
	CH_4_land	6.66	6.66	-	0	-	-
	CH_4_land+ditch	6.66	6.66	-	58.3	-	0.39
Grassland	CO_2	-	-	-	-	-	-
	CH_4_land		-	-	-	-	-
	CH_4_land+ditch	-	-	-	-	-	-
Subtotal CO_2						**244.37**	**200.62**
Subtotal CH_4 [CO_2-eq]						**-**	**10.87**
Subtotal N_2O [CO_2-eq]						**24.97**	**36.08**
Total [CO_2-eq]		**6.66**	**6.66**	**-**	**-**	**269.33**	**247.57**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Greece reports emissions from organic soils under agricultural use following the tier 1 approach of the IPCC 2006 Guidelines (IPCC 2006). Organic grassland soils are reported as 'not occuring'.

Land-use and land-use change in Greece are determined via a land-use change matrix, which is based on data from several sources (NIR, p. 335). Organic soils areas are taken from a study of the Soil Science Institute of Athens from 2001 (NIR, p. 355). As no systematic inventory of peatlands exists for Greece (Christanis 2017, p. 437), these spatial data are viewed and used as best estimate in this study.

The recalculation of emissions with default EFs from the IPCC Wetlands Supplement (IPCC 2014) results in a decrease of emissions by about 9 % (Table 4.18.). The major share of the decrease is caused by the lower EF for CO_2 emissions compared to the default EF from the 2006 IPCC Guidelines (IPCC 2006) that Greece uses. It exceeds the addition of CH_4 in the balance as well as increased N_2O emissions. The revised GWP of N_2O from AR5 is lower than the factor used by Greece in reporting (Myhre et al. 2013).

4.1.14. HRV – Croatia

Table 4.19. Croatian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected **
Cultivation of histosols	N_2O	2.69	2.69	8	12.5	0.03	0.05
Cropland	CO_2	2.46	2.46	10	8.21 (7.9 + 0.31 DOC)	90.19	74.05
	CH_4_land	2.46	2.46	-	0	-	-
	CH_4 _land +ditch	2.46	2.46	-	58.3	-	0.14
Grassland	CO_2	0.23	0.23	2.5	6.01 (5.7 + 0.31 DOC)	2.07	4.97
	CH_4_land	0.23	0.23	-	17	-	-
	CH_4 _land +ditch	0.23	0.23	-	66.5	-	0.1
Agriculture undiff.	N_2O	-	2	-	10	-	0.03
	CO_2	-	2	-	8.11 (7.8 + 0.31 DOC)	-	52.14
	CH_4 _land +ditch	-	2	-	62.3	-	0.12
Subtotal CO_2						**92.26**	**131.16**
Subtotal CH_4[CO_2-eq]						**-**	**7.92**
Subtotal N_2O [CO_2-eq]						**10.06**	**22.25**
Total [CO_2-eq]		**2.69**	**4.69**	**-**	**-**	**102.32**	**161.33**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Croatia reports emissions from organic soils under agricultural use following the tier 1 approach of the IPCC 2006 Guidelines (IPCC 2006).

Land-use areas of Croatia are determined using Corine Land Cover (CLC) maps and data from the Croatian Bureau of Statistics. The area of organic soils is based on data from the Croatian Land Parcel Information System (LPIS). The GPD reports an additional 2 kha of 'Agriculture undiff'. It is unclear how much of this area is used as cropland and how much as grassland. The EF used for correction is for 'Agriculture undiff' (see methods section).

The recalculation based on the IPCC Wetlands Supplement results in a large relative increase of emissions by about 60 % (Table 4.19.) and also reflects the larger area. Still, the increase is quite small in absolute numbers (Table 4.19.).

4.1.15. HUN – Hungary

Table 4.20. Hungarian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	-	55.74	-	12.5	-	1.09
Cropland	CO_2	-	50.74	-	8.21 (7.9 + 0.31 DOC)	-	1527.44
	CH_4_land	-	50.74	-	0	-	-
	CH_4_land+ditch	-	50.74	-	58.3	-	2.96
Grassland	CO_2	-	5	-	6.01 (5.7 + 0.31 DOC)	-	110.18
	CH_4_land	-	5	-	17	-	-
	CH_4_land+ditch	-	5	-	66.5	-	0.33
Subtotal CO_2						**-**	**1637.63**
Subtotal CH_4 [CO_2-eq]						**-**	**92.07**
Subtotal N_2O [CO_2-eq]						**-**	**289.05**
Total [CO_2-eq]		**-**	**55.74**	**-**	**-**	**-**	**2018.47**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

According to the Hungarian NIR, organic soils do not occur in the 'Cropland' and 'Grassland' categories. Hungary argues that organic soils are protected by law and that drainage is thus prohibited. 'Ameliorated' peat soils, which have been drained in the past, would now have an average organic matter content of 6 % and would thus not be classified as organic soils anymore according to the organic soil definition of the IPCC Guidelines (IPCC 2006; NIR, p. 280). Yet, it is highly unlikely that the peat soils drained in the past have indeed all lost so much peat that they can no longer be considered peatlands. Moreover, several studies indicate that organic soils with a low OC content still emit substantial amounts of GHGs (Tiemeyer et al. 2020, Elsgaard et al. 2012, see Chapter 5).

The GPD documents 55.74 kha of organic soils drained for agriculture. We estimated the related emissions to amount to approximately 2018 kt of CO_2-equivalents.

4.1.16. IRL – Ireland

Table 4.21. Irish emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	332.56	332.93	4.3	3.2	2.25	1.95
Cropland	CO_2	-	-	-	-	-	-
	CH_4_land	-	-	-	-	-	-
	CH_4_land+ditch	-	-	-		-	-
Grassland	CO_2	332.93	332.93	7.1[2]	3.91 (3.6 + 0.31 DOC)	8690.46	4394.68
	CH_4_land	332.93	332.93	-	73		
	CH_4_land+ditch	332.93	332.93	29.7	95.7	9.88	35.06
Subtotal CO_2						**8690.46**	**4394.68**
Subtotal CH_4 [CO_2-eq]						**247.11**	**981.56**
Subtotal N_2O [CO_2-eq]						**669.65**	**515.58**
Total [CO_2-eq]		**332.56; 332.93**	**332.93**	**-**	**-**	**9607.22**	**5891.82**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

[2]Mean EF from table 4.C and 4(II).C

The methodology used by Ireland to estimate relevant emissions is not fully clear from the NIR. The general approach seems to be adopted from the IPCC Wetlands Supplement (IPCC 2014; NIR, p. 271ff.).

Ireland determines areas of the 'Cropland' and 'Grassland' categories by combining data from various mapping approaches (NIR, pp. 196, 250). Organic soil areas within the land-use categories are estimated from Corine Land Cover (CLC) maps and the Indicative Soil Map for Ireland (Fealy and Green, 2009). The fraction of deliberately rewetted soils (see below) is not reported. The ditch area fraction is estimated using the IPCC default fraction of 0.05 (NIR, p. 274).

N_2O emissions are calculated using the default EF for nutrient-poor, drained grassland (IPCC 2014; table 4.21.).

The tier 1 EF for nutrient-poor, drained grassland (IPCC 2014) is also used for CO_2 emissions (5.3 t C ha^{-1} y^{-1}, NIR, p. 254). Emissions from 'Forest land' on organic soils converted to 'Grassland' are calculated using a tier 2 EF (NIR, p. 254). The Irish NIR does not specify whether DOC related emissions are included.

In Ireland there is a gradual decline in agriculturally used grassland. Areas that are no longer tracked in agricultural statistics are assumed to rewet spontaneously as drainage ditches are no longer maintained (NIR, p. 254). Default EFs for rewetted, nutrient-poor grassland are used to calculate on-site CO_2 removals (0.23 t C ha^{-1} y^{-1}), DOC emissions (0.24 t C ha^{-1} y^{-1}) and CH_4 emissions (92 kg CH_4-C ha^{-1} y^{-1}) for these sites (NIR, p. 255). It would be more straight forward to report these emissions and removals under 'rewetted organic soils' in CRF table 4(II).C. This was, however, not done. 'Rewetted organic soils' are not occurring in category 4(II).C of the CRF tables.

The interrelation between the methods described in the NIR and the emissions in CRF tables 4.C and 4(II).C is generally unclear and not explained. CO_2 emissions are reported in both CRF tables. The IEF for organic 'Grassland' soils in CRF table 4.C amounts to 6.8 t C ha^{-1} y^{-1} and the IEF in CRF table 4(II).C to 0.32 t C ha^{-1} y^{-1}. How these correlate with the EFs mentioned in the NIR, and whether rewetted soils are included, is not explained.

Ireland will need to improve transparency in these respects.

Regarding CH_4 emissions from drained 'Grassland' soils, Ireland states:

'EF_{CH4_land}= emission factor for methane emissions from nutrient poor soils serviced by drainage ditches in temperate zone. The default value for EF_{CH4_land} is 1.8 kg CH_4 $ha^{-1}yr^{-1}$ from table 2.3 of the 2013 Wetlands Supplement for shallow drained soils, which is typical drainage for Ireland.' (NIR, p. 274)

However, this statement is not correct, as 1.8 kg CH4 ha^{-1} y^{-1} is the default EF for nutrient-poor, drained grassland, and not for shallow-drained grassland (39 kg CH_4 ha^{-1} y^{-1}, IPCC 2014, modified to 48.7 kg CH_4 ha^{-1} y^{-1}, see Chapter 3.2.).

Regarding CH_4 emissions from drainage ditches of the 'Grassland' category, Ireland states:

'EF_{CH4_ditch}= emission factor for methane emissions from ditches in temperate zone, draining nutrient poor soils. The default value for EF_{CH4_land} is 527 kg CH_4 $ha^{-1}yr^{-1}$ from table 2.4 of the 2013 Wetlands Supplement, for shallow drained soils, which is typical drainage for Ireland.' (NIR, p. 274)

527 kg CH_4 ha^{-1} y^{-1} is indeed the default EF for CH_4 emissions from drainage ditches (not from on-site emissions as erroneously written in the cited section) on shallow-drained grassland soils (IPCC 2014). The cited section indicates that this EF refers to nutrient poor soils, but it actually applies to shallow-drained soils of all nutrient conditions. The default EF for nutrient-poor grassland soils, on the other hand, covers all drainage conditions. Tier 1 EFs for soils that are both shallow-drained and nutrient-poor do not exist in the IPCC Wetlands Supplement methodology.

Evaluation of the Irish method is difficult due to a lack of transparency. However, it seems that Ireland views the status of its organic 'Grassland' soils as overall nutrient poor and shallow-drained, which are indicators for low intensity use. Evans et al. (2017) offer EFs for low intensity grassland on organic soils for the UK. Climatic conditions of both neighbour states are comparable and in this study the UK EFs are thus used for the recalculation of emissions for the area reported in the NIR as well as for the additional area from the GPD.

The recalculation results in a decrease of emissions by roughly 40 %, mainly caused by the lower EF for CO_2 (Table 4.21.).

Agriculturally used organic soils are a relevant GHG emission source in Ireland. They are responsible for over 9 % of all Irish emissions (65232.23 kt according to the Irish 2020 NIS) and represent 25% of all emissions from agriculture (Sector 'Agriculture' plus 'Cropland' and 'Grassland'). Country-specific data are thus necessary to develop effective national mitigation strategies. Transparency and consistency need to improve as well.

4.1.17. ITA – Italy

Table 4.22. Italian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	23.25	23.20	8	12.5	0.29	0.45
Cropland	CO_2	21.17	21.13	10	8.21 (7.9 + 0.31 DOC)	776.38	636.01
	CH_4_land	21.17	21.13	-	0	-	-
	CH_4_land+ditch	21.17	21.13	-	58.3	-	1.23
Grassland	CO_2	2.07	2.07	2.5	6.01 (5.7 + 0.31 DOC)	19.01	45.57
	CH_4_land	2.07	2.07	-	17	-	-
	CH_4_land+ditch	2.07	2.07	-	66.5	-	0.14
Subtotal CO_2						**795.39**	**681.85**
Subtotal CH_4 [CO_2-eq]						**-**	**38.31**
Subtotal N_2O [CO_2-eq]						**87.09**	**120.32**
Total [CO_2-eq]		**23.25**	**23.20**	**-**	**-**	**882.48**	**840.21**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Italy reports emissions from organic soils under agricultural use following the tier 1 approach of the IPCC 2006 Guidelines (IPCC 2006).

Areas of organic grassland and cropland soils in the Italian inventory are adopted from the FAOSTAT database[4]. These area data are not completely up-to-date. They correspond to the years up to 2017. For the year 2018, the FAO has published new, slightly lower spatial data, which we use for recalculation of emissions (Table 4.22.).

The recalculation results in a minor decrease of emissions by about 5 % (Table 4.22.). The major share of the decrease is caused by the lower EF for CO_2 emissions compared to the default EF from the 2006 IPCC Guidelines (IPCC 2006) that Italy uses. It exceeds the increase in CH_4 and N_2O emissions, which are added using the default methods and EFs from the IPCC Wetlands Supplement (IPCC 2014).

[4] http://www.fao.org/faostat/en/#data/GV

4.1.18. LTU – Lithuania

Table 4.23. Lithuanian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	132.60	283.4	8	5.4	1.67	2.41
Cropland	CO_2	64	64	5	8.21 (7.9 + 0.31 DOC)	1117.86	1926.61
	CH_4_land	64	64	-	0	-	-
	CH_4_land+ditch	64	64	-	58.3	-	3.73
Grassland	CO_2	68.6	219.4	0.25	3.71 (3.4 + 0.31 DOC)	59.63	2988.1
	CH_4_land	68.6	219.4	-	38.8	-	-
	CH_4_land+ditch	68.6	219.4	-	70.7	-	15.51
Subtotal CO_2						**1177.49**	**4914.66**
Subtotal CH_4 [CO_2-eq]						**-**	**538.73**
Subtotal N_2O [CO_2-eq]						**496.76**	**637.79**
Total [CO_2-eq]		**132.6**	**283.4**	**-**	**-**	**1674.25**	**6091.22**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Lithuania reports emissions from organic soils under agricultural use following the tier 1 approach of the IPCC 2006 Guidelines (IPCC 2006).

The organic soil area in different land-use categories was assessed by the National Forest Inventory with permanent sample plots in the cycle 2014-2018 (NIR, p. 377). Soils are defined as organic if they have a peat layer not thinner than 40 cm or 60 cm of poorly decomposed peat in bogs and with a histic horizon of at least 70-75 % of organic matter by volume (NIR, p. 377). The organic soil areas reported for 'Cropland' and 'Grassland' in table 4(II) slightly differ from those in the tables 4.B and 4.C. This discrepancy shows that Lithuanian inventory compilers need to improve communication across different reporting categories to achieve consistency in the NIS. Mierauskas and Taminskas (2017) estimate the total area of organic soils drained for agriculture to amount to 283.4 kha. The GPD adopts the spatial data reported in the Lithuanian NIS and treats the remainder of the area from Mierauskas and Taminskas (2017) as shallow-drained grassland. Following the same approach, the grassland area used in this study amounts to 219.4 kha (Table 4.23.), the additional 150.8 kha are assumed to be shallow-drained.

Lithuania erroneously uses EFs for the boreal vegetation zone, as climatic conditions in Lithuania are temperate (IPCC 2006, Fig. 3.1.). This leads to a strong underestimation of CO_2

emissions, especially for the ‘Grassland’ category (Table 4.23.). For recalculation of Lithuanian emissions, we use default EFs for the temperate climate zone from the IPCC Wetlands Supplement (IPCC 2014).

The recalculation results in a major increase of emissions, exceeding the reported emissions by more than two and a half times (Table 4.23.), mostly caused by the higher EFs for CO_2 emissions and the larger area. CH_4 and N_2O emissions increase as well with use of default EFs from the IPCC Wetlands Supplement (IPCC 2014) and the revised GWP from AR5 (Myhre et al.2013).

4.1.19. LUX – Luxembourg

Table 4.24. Luxembourgish emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	-	-	-	-	-	-
Cropland	CO_2	-	-	-	-	-	-
	CH_4_land	-	-	-	-	-	-
	CH_4_land+ditch	-	-	-	-	-	-
Grassland	CO_2	-	-	-	-	-	-
	CH_4_land	-	-	-	-	-	-
	CH_4_land+ditch	-	-	-	-	-	-
Agriculture undiff.	N_2O	-	0.18	-	9.95	-	0
	CO_2	-	0.18	-	8.11 (7.8 + 0.31 DOC)	-	4.69
	CH_4_land+ditch	-	0.18	-	62.3	-	0.01
Subtotal CO_2						**-**	**4.69**
Subtotal CH_4 [CO_2-eq]						**-**	**0.31**
Subtotal N_2O [CO_2-eq]						**-**	**0.75**
Total [CO_2-eq]		**-**	**0.18**	**-**	**-**	**-**	**5.75**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

According to the Luxembourgian NIR, organic soils do not occur in the 'Cropland' and 'Grassland' categories (NIR, pp. 555, 561). In this study, emissions are recalculated using tier 1 IPCC Wetlands Supplement (IPCC 2014) EFs and 180 ha of 'Agriculture undiff.' from the GPD. It is unclear how much of this area is used as cropland and how much as grassland. The EF used for correction is for 'Agriculture undiff.' (see methods section).

Organic soil emissions from agriculture in Luxembourg are very low (Table 4.24.).

4.1.20. LVA – Latvia

Table 4.25. Latvian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	158.32	158.32	10.6	9.9	2.63	2.47
Cropland	CO_2	78.63	78.63	7.9	8.21 (7.9 + 0.31 DOC)	2277.57	2366.94
	CH_4_land	4.34	78.63	0	0	-	-
	CH_4_land+ditch	4.34	78.63	928.1[2]	58.3	4.03	4.58
Grassland	CO_2	79.69	79.69	5	6.01 (5.7 + 0.31 DOC)	1460.57	1756.06
	CH_4_land	63.5	79.69	17	17	-	-
	CH_4_land+ditch	63.5	79.69	73.5[2]	66.5	4.66	5.30
Subtotal CO_2						**3738.14**	**4123.00**
Subtotal CH_4 [CO_2-eq]						**217.27**	**276.62**
Subtotal N_2O [CO_2-eq]						**784.67**	**654.63**
Total [CO_2-eq]		**158.32**	**158.32**	**-**	**-**	**4740.08**	**5054.25**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Latvia reports relevant emissions following the IPCC Wetlands Supplement (IPCC 2014).

Latvia uses recent National Forest Inventory data for its land-use change matrix, based on 16,156 permanent plots measured once during 5-year cycles. (Krumsteds et al. 2019; NIR p. 519). The area of organic soils in the 'Cropland remaining cropland' category is adopted from two research projects (Lazdiņš et al.2016; Vēsturiskā augsnes digitāla datubāze) (NIR p. 373). The share of organic soil area is assumed to be equal for the initial land-use and for areas converted to 'Cropland' (NIR, p. 375). 'Grassland' areas on organic soils are estimated based on the study of Lazdiņš et al. from 2016 (NIR, p. 380). There is no recent peatland inventory for Latvia (Pakalne and Aleksans 2017, p. 480). The areas reported in the Latvian submission are therefore adopted as best estimate, except for the following: In CRF table 4(II).B, the drained 'Cropland' area amounts to 4.34 kha instead of 78.63 kha listed in CRF table 4.B. In the NIR report, this is explained as the area of drainage ditches only, because default on-site CH_4 emissions are zero. As Latvia uses the default ditch fraction of 0.05, the area is not correct (5 % of 78.63 kha is 3.93 kha). Also, the area of drained organic 'Grassland' soils differs between CRF table 4.C (79.69 kha) and 4(II).C (63.5 kha). There is no explanation offered for this inconsistency. We use the spatial data given in CRF tables 4.B and 4.C to recalculate all emissions.

The IPCC Wetlands Supplement (IPCC 2014) default EFs are used in the Latvian inventory to calculate GHG emissions from 'Cropland' and 'Grassland' soils. However, some inconsistencies in the calculation of CO_2 and CH_4 emissions occur. The IEF for CH_4 emissions used in CRF table 4(II).B (928.14 kg CH_4 ha^{-1} y^{-1}) differs from the default EF for drainage ditches in nutrient-rich, deep-drained soils (1165 kg CH_4 ha^{-1} y^{-1}), the latter allegedly being used according to the Latvian NIR (NIR, p. 374). The EF for CO_2 emissions from 'Land converted to Grassland' (4.17 t C ha^{-1} y^{-1}) deviates from the default EF for nutrient-poor, deep-drained 'Grassland' (6.1 t C ha^{-1} y^{-1}) resulting in an overall IEF of 5 t C ha^{-1} y^{-1}. These discrepancies are not explained in the NIR.

DOC emissions are not reported.

We use the default EFs for temperate, drained soils from the IPCC Wetlands Supplement (IPCC 2014) to recalculate all emissions.

The recalculation results in an increase of emissions by about 7 % (Table 4.25.). Most of the increase is caused by higher CO_2 emissions due to consideration of DOC emissions and the higher IEF for CO_2 emissions from the 'Grassland' category. CH_4 emissions are higher after adjustments as well (see above) and because of the revised GWP from AR5 (Myhre et al. 2013). N_2O emissions are lower than reported because we used the revised GWP from AR5 and the unspecific EF for temperate, drained 'Grassland' (see methods section), which is lower compared with the default EF for deep-drained 'Grassland' applied in the Latvian inventory.

4.1.21. MLT – Malta

Organic soils under agricultural use do not occur in Malta (Haslam 2017, p. 509).

4.1.22. NLD – The Netherlands

Table 4.26. Dutch emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	328.56	338.2	4.5	3.6	2.3	1.94
Cropland	CO_2	60.8	60.8	3.6	8.21 (7.9 + 0.31 DOC)	811.83	1830.4
	CH_4_land	60.8	60.8	-	0	-	-
	CH_4_land+ditch	60.8	60.8	-	58.3	-	3.54
Grassland	CO_2	277.4	277.4	4.1	6.01 (5.7 + 0.31 DOC)	4119.4	6112.97
	CH_4_land	277.4	277.4	-	17	-	-
	CH_4_land+ditch	277.4	277.4	-	42.5	-	11.79
Subtotal CO_2						**4931.24**	**7943.37**
Subtotal CH_4 [CO_2-eq]						**-**	**429.28**
Subtotal N_2O [CO_2-eq]						**684.12**	**513.99**
Total [CO_2-eq]		**328.56; 338.2**	**338.2**	**-**	**-**	**5615.35**	**9685.29**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

The Netherlands report relevant emissions following the IPCC 2006 methodology (IPCC 2006). The Dutch approach is described in Arets et al (2020).

The Dutch organic soil areas are determined by overlaying high resolution land-use and land-use change matrices updated in 2017 (resolution: 25 x 25 m) with soil maps updated in 2014 and a water level map. Data are extrapolated for following years including the year 2018, relevant for this study. The Netherlands distinguish two organic soil types, peat soils and peaty/peat-like soils. The share of each soil type of the total organic soil area is not given in the Methodology Report LULUCF (Arets et al. 2020). It is however listed in Van Bruggen et al. (2015, table B18.1) for the year 2013 with 193.4 kha of grassland and 28.7 kha of arable land on peat soils and 87 kha of grassland and 65.2 kha of arable land on peat-like soils. The total extent of these spatial data differ from those of Arets et al. (2020, table 3.12) for the year 2013. Total organic soil arable land area in Van Bruggen et al. (2015) is 93.9 kha and total organic soil grassland area is 280.4 kha, while Arets et al. (2020) report 75.97 kha and 276.03 kha, respectively. In the Methodology Report Agriculture (Lagerwerf et al. 2019), the following is documented with respect to the extent of cultivated organic soils:

‘The extent of the areas of cultivated land are estimated from the land-use maps of the sector designated as ‘Land Use, Land Use Change and Forestry’ (LULUCF). […] An overview of the resulting areas is provided in Annex 18 of Van Bruggen et al. (2015).’ (Lagerwerf et al.2019, p. 109)

Both references were consulted and yet it remains unclear, which data are used to estimate the areas in 2018. Furthermore, spatial data in the ‘Agriculture’ sector and the ‘LULUCF’ sector of the CRF tables do not match. The organic soil area of the ‘Cropland’ and ‘Grassland’ categories exceeds that of ‘Cultivation of organic soils (i.e. histosols)’ by roughly 10 kha. This discrepancy is not explained in the Dutch NIR. The larger area of organic soils is adopted in the recalculation of emissions in this study (Table 4.26.).

The Netherlands have derived country-specific EFs for N_2O and CO_2, corresponding to a tier 2 method. The EFs are calculated based on subsidence measurements (Arets et al. 2020, p. 65f). These measurements were carried out over multiple decades, but only in a limited number of locations, where different ditch water levels were (roughly) maintained (Schothorst 1977, van den Akker et al. 2008). The EFs, particularly for peat soils covered with clay or sand, seem too low when compared with actual flux measurements carried out in the Netherlands (Weideveld et al. 2020). As pointed out before (Chapters Denmark, Germany), emissions from peaty soils are best treated to be as high as from pure peat soils. For recalculation of emissions, we therefore use default EFs from the IPCC Wetlands Supplement.

The recalculation results in an increase of emissions by about 70 % (Table 4.25.). Most of the increase is caused by higher CO_2 emissions due to use of the default EFs from the IPCC Wetlands Supplement (IPCC 2014). CH_4 emissions are not reported and thus contribute to the higher corrected emissions (Table 4.25.). The GWP of N_2O is lower than reported because the revised GWP from AR5 (Myhre et al. 2013) was used as well as the unspecific EF for temperate, drained ‘Grassland’ (see methods section).

4.1.23. POL – Poland

Table 4.27. Polish emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	921.79	921.79	8	8	11.59	11.53
Cropland	CO_2	160.1	160.1	1	8.21 (7.9 + 0.31 DOC)	586.67	4819.54
	CH_4_land	160.1	160.1	-	0	-	-
	CH_4_land+ditch	160.1	160.1	-	58.3	0	9.33
Grassland	CO_2	761.69	761.69	0.25	6.01 (5.7 + 0.31 DOC)	698.21	16785.11
	CH_4_land	761.69	761.69	-	17	-	-
	CH_4_land+ditch	761.69	761.69	-	66.5	-	50.65
Subtotal CO_2						**1284.88**	**21604.66**
Subtotal CH_4 [CO_2-eq]						**-**	**1679.39**
Subtotal N_2O [CO_2-eq]						**3453.28**	**3055.33**
Total [CO_2-eq]		**921.79**	**921.79**	**-**	**-**	**4738.16**	**26339.37**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Poland reports emissions from organic soils following the IPCC 2006 methodology (IPCC 2006). CH_4 emissions are consequently missing.

The area of cultivated organic soils in Poland was revised in the 2020 submission (Walęzak et al. 2020), based on the Spatial Information System on Wetlands in Poland and proxies from Corine Land Cover (CLC) (NIR, p. 228). In the 1990s, approximately 67 % of Polish peatlands were under grassland use according to Dembek et al. (2000; Kotowski et al. 2017, p. 563). The area of organic soils reported by Poland is comparable with this previous estimate and therefore adopted as best estimate in this study. Nonetheless, regarding the large extent of peatlands in Poland, a detailed inventory with information e.g. on drainage status and exact spatial extent of peatlands is needed to provide a realistic estimate of organic soil emissions.

Poland erroneously uses EFs for the boreal vegetation zone; climatic conditions in Poland are clearly temperate (IPCC 2006, fig. 3.1.). This leads to a strong underestimation of CO_2 emissions, especially for 'Grassland' (Table 4.27.). The EF of 1 t C ha^{-1} y^{-1} is justified in the 'Cropland' section of the Polish NIR referring to Turbiak and Miatkowski (2010). EFs of 759 – 1264 mg CO_2 m^{-2} h^{-1} are adopted from that study (NIR, p. 229). When recalculating to the IPCC unit of t C ha^{-1} y^{-1} by assuming emissions during 12 hours a day and 220 days of the year (Bartoszek et al. 2015), these measurements actually suggest EFs of 5.5 – 9 t C ha^{-1} y^{-1}, which is close to the IPCC Wetlands Supplement default value for deep-drained, nutrient-rich cropland (8.2 t C ha^{-1} y^{-1}; IPCC 2014). Basing the choice of EFs for cold temperate climate on Turbiak and Miatkowski (2010) must therefore be based on a calculation error. Turbiak and Miatkowski (2010) have not made measurements over the whole year, nor several times a day at different light conditions as is commonly done before upscaling measurements using other measured site parameters (see e.g. Huth et al. 2017). Moreover, vegetation was cut prior to measurements by Turbiak and Miatkowski (2010), which makes the measured values uncertain and not representative.

For recalculation of Polish emissions, we use default EFs for temperate climate.

The recalculation results in a major increase of emissions by about 450 % (Table 4.27.), mostly caused by the higher IEFs for CO_2 emissions. N_2O emissions decrease with use of the revised GWP from AR5 (Myhre et al. 2013).

4.1.24. PRT – Portugal

Table 4.28. Portuguese emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	-	-	-	-	-	-
Cropland	CO_2	-	-	-	-	-	-
	CH_4_land	-	-	-	-	-	-
	CH_4_land+ditch	-	-	-	-	-	-
Grassland	CO_2	-	-	-	-	-	-
	CH_4_land	-	-	-	-	-	-
	CH_4_land+ditch	-	-	-	-	-	-
Agriculture undiff.	N_2O	-	26.1	-	9.95	-	0.41
	CO_2	-	26.1	-	8.11 (7.8 + 0.31 DOC)	-	680.43
	CH_4_land+ditch	-	26.1	-	62.3	-	1.63
Subtotal CO_2						**-**	**680.43**
Subtotal CH_4 [CO_2-eq]						**-**	**45.55**
Subtotal N_2O [CO_2-eq]						**-**	**108.14**
Total [CO_2-eq]		**-**	**26.1**	**-**	**-**	**-**	**834.12**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

According to the Portuguese NIR, histosols do not occur (NIR, pp. 389).

The area of cultivated organic soils in this study is adopted from Mateus et al. (2017). The precise type of land-use on these soils is not well quantified so far; they are thus classified as 'Agriculture undiff.'.

Although Portugal has relatively few peatlands, organic soil emissions are not negligible (Table 4.28.). It would therefore be good practice if Portugal reported emissions from organic soils in future submissions to fulfill requirements of the IPCC methodology (IPCC 2006; IPCC 2014).

4.1.25. ROU – Romania

Table 4.29. Romanian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	6.39	11.42	8	10.3	0.08	0.19
Cropland	CO_2	6.39	6.39	5	8.21 (7.9 + 0.31 DOC)	117.10	192.27
	CH_4_land	6.39	6.39	-	0	-	-
	CH_4_land+ditch	6.39	6.39	-	58.3	-	0.37
Grassland	CO_2	5.04	5.04	0.25	6.01 (5.7 + 0.31 DOC)	-4.62	110.98
	CH_4_land	5.04	5.04	-	17	-	-
	CH_4_land+ditch	5.04	5.04	-	66.5	-	0.33
Agriculture undiff.	N_2O	-	614.77	-	9.95	-	9.61
	CO_2	-	614.77	-	8.1 (7.8 + 0.31 DOC)	-	16027.05
	CH_4_land+ditch	-	614.77	-	62.3	-	38.32
Subtotal CO_2						**112.48**	**16330.3**
Subtotal CH_4 [CO_2-eq]						**-**	**1092.63**
Subtotal N_2O [CO_2-eq]						**23.93**	**2596.32**
Total [CO_2-eq]		**6.39; 11.42**	**626.19**	**-**	**-**	**136.41**	**20019.26**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Romania reports relevant emissions following the IPCC 2006 methodology (IPCC 2006).

The organic soil area under agricultural use is massively underestimated in the Romanian NIR. In addition to the areas reported for 'Cropland' and 'Grassland', the GPD documents another 614.77 kha of 'Agriculture undiff.' (Table 4.29.). It is unclear how much of this area is used as cropland and how much as grassland. The EF used for correction is for 'Agriculture undiff.' (see methods section).
Romania calculates N_2O emissions from 'Cultivation of organic soils (i.e. histosols)' only for the 'Cropland' and not for the 'Grassland' area (Table 4.29.). In terms of completeness (IPCC 2014), 'Grassland' areas should be reported in the 'Agriculture' sector as well.

Romania erroneously uses EFs for the cold temperate, i.e. boreal vegetation zone, as climatic conditions in Romania are temperate (IPCC 2006, fig. 3.1.). This leads to a strong underestimation of CO_2 emissions, especially for 'Grassland' (Table 4.29.). For recalculation of Romanian emissions, we use default EFs for the temperate climate zone from the IPCC Wetlands Supplement (IPCC 2014).

The recalculation results in a major increase of emissions of two orders of magnitude (Table 4.29.), which mainly reflects the increase in the organic soil area considered.

Regarding the large extent of peatlands in Romania, a detailed inventory with information on drainage status and exact spatial extent of peatlands is needed to provide a realistic estimate of organic soil emissions. Following the IPCC Wetlands Supplement (IPCC 2014), good practice requires Romania to come up with a tier 2 or higher approach.

4.1.26. SVK – Slovakia

Table 4.30. Slovakian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	-	-	-	-	-	-
Cropland	CO_2	-	-	-	-	-	-
	CH_4_land	-	-	-	-	-	-
	CH_4_land+ditch	-	-	-	-	-	-
Grassland	CO_2	-	-	-	-	-	-
	CH_4_land	-	-	-	-	-	-
	CH_4_land+ditch	-	-	-	-	-	-
Agriculture undiff.	N_2O	-	11.5	-	9.95	-	0.18
	CO_2	-	11.5	-	8.1 (7.8 + 0.31 DOC)	-	299.81
	CH_4_land+ditch	-	11.5	-	62.3	-	0.72
Subtotal CO_2						**-**	**299.81**
Subtotal CH_4 [CO_2-eq]						**-**	**20.07**
Subtotal N_2O [CO_2-eq]						**-**	**47.65**
Total [CO_2-eq]		**-**	**11.5**	**-**	**-**	**-**	**367.52**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

According to the Slovakian NIR, organic soil area is negligible (5.5 kha in total) and therefore reported as 'not occuring' (NIR, p. 329).

The area of cultivated organic soils in this study is adopted from the GPD and treated as 'Agriculture undiff.'. The number is based on the estimate for drained peatland area by Šefferová Stanová & Hájek (2017), under the assumption that two thirds of the drained area are used for agriculture. Forestry on peat soils is of lesser importance in Slovakia. It is unclear how much of this area is used as cropland and how much as grassland. The EF used for correction is for 'Agriculture undiff.' (see methods section). The area is twice as large as reported, but still small (11.5 kha). It emits approximately 367.52 kt of CO_2-equivalents (Table 4.30.).

4.1.27. SVN – Slovenia

Table 4.31. Slovenian emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area		IEF		GHG emission	
		reported [kha]	corrected [kha]	reported*	corrected*	reported **	corrected **
Cultivation of histosols	N_2O	2.49	3.58	8	10.9	0.03	0.06
Cropland	CO_2	2.49	2.49	10	8.21 (7.9 + 0.31 DOC)	91.26	74.93
	CH_4_land	2.49	2.49	-	0	-	-
	CH_4 _land +ditch	2.49	2.49	-	58.3	0	0.14
Grassland	CO_2	1.09	0.95	-	6.01 (5.7 + 0.31 DOC)	-	24.10
	CH_4_land	1.09	0.95	-	17	-	-
	CH_4 _land +ditch	1.09	0.95	-	66.5	-	0.07
Agriculture undiff.	N_2O	-	5.34	-	9.95	-	0.08
	CO_2	-	5.34	-	8.11 (7.8 + 0.31 DOC)	-	138.95
	CH_4 _land +ditch	-	5.34	-	62.3	-	0.33
Subtotal CO_2						**91.26**	**237.98**
Subtotal CH_4[CO_2-eq]						**-**	**15.40**
Subtotal N_2O [CO_2-eq]						**9.32**	**38.70**
Total [CO_2-eq]		**2.49; 3.58**	**8.92**	**-**	**-**	**100.59**	**292.08**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Slovenia reports relevant emissions following the IPCC 2006 methodology (IPCC 2006). CH_4 emissions are consequently missing. 'Grassland' organic soil areas are reported without corresponding emissions (NIR, p. 275).

The Slovenian area of organic soils is determined by overlay of land-use data from the Ministry of Agriculture, Forestry and Food (scale 1:5000) and the Pedology map (1:25000) (NIR, p. 217).

For N_2O emissions from 'Cultivation of organic soils (i.e. histosols)', only cropland areas are considered (NIR, p. 217). The reason might be that 'Grassland' emissions are assumed to be zero (see below). Nonetheless 'Grassland' areas are reported and in terms of completeness, *good practice* requires that these areas are reported in the sector 'Agriculture' as well.

The corrected area includes 5.33 kha of ‘Agriculture undiff.’ from the GPD (see Martinčič & Skoberne 2017). It is unclear how much of this area is used as cropland and how much as grassland. The EF used for correction is for ‘Agriculture undiff’ (see methods section).

‘Grassland’ organic soils are assumed to be undrained in the Slovenian inventory. Therefore, no organic soil emissions are reported in this category (NIR, p. 275). Managed but undrained soils can still emit GHG emissions. Slovenia should therefore take own measurements of GHG emissions from its organic grassland soils, if the default EFs from the IPCC Wetlands Supplement (IPCC 2014) are not applicable. As no country-specific EFs exist to date in the Slovenian NIS, default EFs from the IPCC Wetlands Supplement are used in this study.

Emissions from agriculturally used organic soils are generally low in Slovenia. The recalculation results in an increase of emissions by about 200 % (Table 4.31.), mainly caused by the larger area considered.

4.1.28. SWE – Sweden

Table 4.32. Swedish emissions from organic soils under agricultural use as reported in the categories 'Cultivation of organic soils (i.e. histosols)' (sector 'Agriculture') and 'Cropland' and 'Grassland' (sector 'LULUCF'). Reported areas, implied emissions factors (IEF) and GHG emission values are taken from the National Inventory Submission: for an explanation of corrections, see text. Implied emission factors refer to the overall average emission factor for the reporting categories.

Source and sink (sub-) category	Reported emission	Area [kha]		IEF		GHG emission	
		reported	corrected	reported*	corrected*	reported**	corrected**
Cultivation of histosols	N_2O	135.99	164.73	13	11.1	2.78	2.86
Cropland	CO_2	137.01	137.01	6.1	6.14 (5.98 + 0.16 DOC)	3067.85	3085.65
	CH_4_land	137.0	137.01	0	0	-	-
	CH_4_land+ditch	137.0	137.01	58.3	58.3	7.98	7.98
Grassland	CO_2	27.72	27.72	1.7	2.56 (2.36 + 0.2 DOC)	169.61	259.80
	CH_4_land	22.1	27.72	-	48.7	-	-
	CH_4_land+ditch	22.1	27.72	12.9	72.6	0.28	2.01
Subtotal CO_2						**3237.46**	**3345.45**
Subtotal CH_4 [CO_2-eq]						**206.62**	**279.83**
Subtotal N_2O [CO_2-eq]						**827.88**	**759.04**
Total [CO_2-eq]		**135.99; 164.73**	**164.73**	**-**	**-**	**4271.96**	**4384.33**

*Units: kg N_2O-N ha^{-1} y^{-1}, t CO_2-C ha^{-1} y^{-1}, kg CH_4 ha^{-1} y^{-1}

**Units: kt N_2O y^{-1}, kt CO_2 y^{-1}, kt CH_4 y^{-1}

Sweden reports relevant emissions following the IPCC Wetlands Supplement (IPCC 2014).

The land-use and land-use change matrix provided by the National Forest Inventory is based on 30.000 sample plots. The last full record is from the inventory cycle 2010-2014. For more recent years, land-use is extrapolated. The area of organic soils has been estimated in two studies for the years 2008 (Berglund 2009) and 2015 (Pahkakangas et al. 2017). The organic soil area for the year 2018 is extrapolated from the linear trend between the measurement years, also taking into account the decline in total cropland area in Sweden.

The areas in the different relevant categories do, however, not match. In the 'Cultivation of organic soils (i.e. histosols)' category, only the cropland area is reported. Moreover, this area differs from the area in the 'Cropland' category by 1.02 kha. It seems as if the cropland area has been calculated separately by inventory compliers of the two sectors, resulting in a slightly different outcome. We use the sum of the 'Cropland' and the 'Grassland' organic soil areas to recalculate emissions from the 'Cultivation of organic soils (i.e. hisosols)' category.

Sweden has two different climate zones, the temperate and the boreal. The IPCC offers different default EFs for grassland in each of the two climate zones. In the Swedish NIR, the area of organic 'Grassland' soil is split into 13 kha in the temperate and 4 kha in the boreal zone (NIR Annex, p. 134). This does, however, not match the 22.1 kha of 'Grassland' in CRF table 4.C. Furthermore, it remains unclear how the IEF of 1.67 t C ha^{-1} y^{-1} in CRF table 4.C would result as it does not reflect the given temperate:boreal climate ratio. It should be noted that the default cropland EFs from the IPCC Wetlands Supplement (IPCC 2014) are the same for boreal and temperate climate.

N_2O emissions are only estimated for 'Cropland'. We use the default EFs for drained cropland and shallow-drained, extensive grassland (Table 4.32., see below).

CO_2 emissions from organic 'Cropland' soils are calculated with a country-specific EF in the Swedish NIS. The applied method results from a literature review of studies from Sweden, Norway and Finland, many of which are also used to derive the default EFs in the IPCC Wetlands Supplement.

Sweden calculates CO_2 emissions from 'Grassland' using a tier 1 method and the default EF for forest on organic soils. Sweden argues that the default EF for grassland represents mainly fertilized grassland, whereas nutrient application is said not to be common in Sweden and that the default EF for forest land would thus represent the soil conditions more accurately. If a country deems the default EFs provided by the IPCC as not applicable, it should ideally provide data from measurements made in the country itself. The use of default EFs from another land-use category is unusual and lacks scientific support. As an alternative solution, we use the default modified EF for shallow-drained grassland (see methods section). The EFs for deep-drained grassland do not differ substantially for the two climate zones (IPCC 2014). It can be assumed that shallow-drained grassland soils emit similar amounts of GHGs in both zones as well. So, we use the above-mentioned EFs for the whole area.

DOC emissions from both 'Cropland' and 'Grassland' are calculated with the default EFs for boreal climate (NIR Annex, pp. 134, 138). In the recalculation of 'Grassland' emissions weestimate DOC with the temperate:boreal ratio of 13 to 4 from the Swedish NIR (NIR Annex, p. 134, see above) and the default EFs from the IPCC Wetlands Supplement. For the 'Cropland' DOC EF, we use the temperate:boreal ratio from the GPD of 40 % temperate and 60 % boreal climate for the whole country. This is a conservative estimate, as agriculture takes place mainly in the Swedish south and the default EF for the boreal climate zone is lower (IPCC 2014).

Sweden calculates CH_4 emissions from 'Cropland' and 'Grassland' with default EFs from the IPCC Wetlands Supplement. For 'Grassland' again the EF for forest is used. We replace it with the adjusted EF for shallow-drained, extensive grassland (Table 4.32., see above).

The recalculation of emissions results in a minor increase by roughly 3 %, mainly caused by the higher EFs for 'Grassland' (Table 4.32.). However, Sweden needs to improve monitoring of its agriculturally used organic soils. They are responsible for over 40 % of all of the emissions from Sweden (sinks included). To develop effective mitigation strategies, detailed information on the condition of national organic soils and related emissions is needed.

5. Discussion II and Conclusions

Within this study, a number of shortcomings could be identified in the national inventory submissions on agriculturally used organic soils of EU countries (and the UK). Many countries still do not use the 2013 IPCC Wetlands Supplement or do not use it completely. The main change between the 2006 and 2013 guidelines is the revision and further stratification of existing default EFs as well as the implementation of EFs for CH_4 emissions. On a tier 1 level, the additional effort necessary to report emissions according to the Wetlands Supplement is low, if not to say negligible. Neither further measurements are necessary, nor any kind of modelling or other extensive use of human resources. Some simple multiplications of organic soil areas with the revised EFs are the only action needed. It may seem more complicated for countries that follow a 2006 tier 2 approach (currently only Estonia, Finland and The Netherlands). These countries could argue that tier 2 emission factors would require a considerable amount of CH_4 flux measurements (which are not considered in the IPCC 2006 Guidelines). Yet, in absence of measurement data, the tier 1 EF can be used. Germany and Denmark follow this approach; they largely use country-specific tier 2 EFs, but both use the tier 1 EF for CH_4 from ditches. The implementation of a tier 1 approach is just as simple and produces better estimates than not reporting CH_4 emissions from ditches at all. Only six countries follow the guidance of the IPCC Wetlands Supplement (Austria, Germany, Denmark, Ireland, Latvia, Sweden) and one only in part (France). Regarding the considerable underestimates in emissions involved, the situation is problematic.

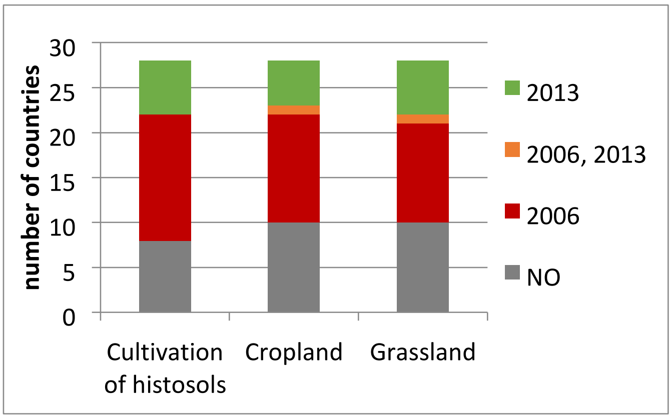

Fig. 5.1. Methodology used by EU member states (and the UK) in the relevant categories. NO: organic soils are reported as ‘not occurring’ in the NIS; 2006: organic soil emissions are reported according to the 2006 IPCC Guidelines (IPCC 2006); 2006, 2013: organic soil emissions are partly reported according to the 2006 IPCC Guidelines and partly according to the IPCC Wetlands Supplement (IPCC 2014); 2013: organic soil emissions are reported according to the IPCC Wetlands Supplement.

Another very important aspect of GHG inventory reporting is adequate mapping of organic soil areas in each land-use category. To evaluate the relevance of organic soils in a category, i.e. whether they are a key GHG source, the area must be known. Of the 27+1 countries, 11 have mapping approaches that provide realistic estimates of organic soil areas under agricultural use in the LULUCF sector, which are comparable with data published in Joosten et al. (2017a). In Cyprus and Malta, agriculture on organic soils does not occur. In the remaining 15 countries the organic soil area is underestimated (Fig 5.2.). While most of these countries have only a small area of organic soils of < 100 kha under agriculture, five countries stand out. Austria, Estonia, the UK, Lithuania and Romania each have organic soil areas under agricultural use of > 100 kha (Fig. 5.3.). They all report less than half of the relevant organic soil areas estimated in recent studies, Romania even less than 2 %. Although the other 10 countries might play minor roles individually, they still contribute 155.14 kha of organic soils in the relevant categories when summed together. Of these 155.14 kha, only 8.99 kha are reported (Fig. 5.2.).

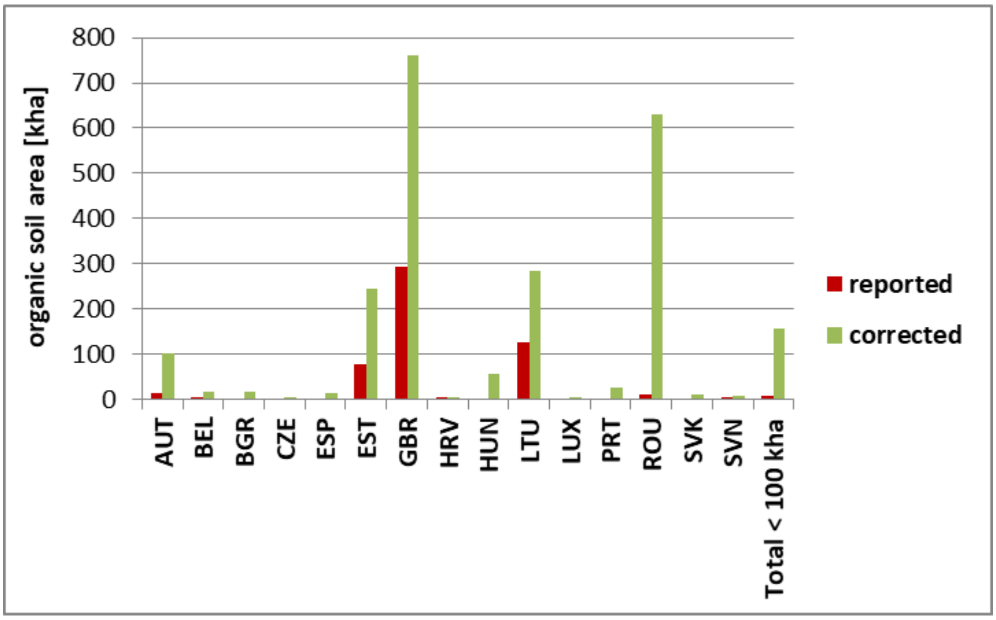

Fig. 5.2. Discrepancies in organic soil areas. Shown are countries for which organic soil areas under agricultural use are corrected within this study. Corrected areas are > 100 kha for Austria, Estonia, Great Britain, Lithuania and Romania. The bar titled 'Total < 100 kha' refers to the sum of organic soil area under agricultural use of all other EU member states with corrected organic soil area under agricultural use of less than 100 kha.

Reliable data on the extent of organic soil areas under agriculture are still scarce in the EU, as detailed organic soil inventories are still missing in many member states. The corrected area of this study (Fig. 5.3.) likely still underestimates the actual extent. Correct estimation of the organic soil area is important as it determines the tier level at which a country should report in order to fulfill *good practice* requirements.

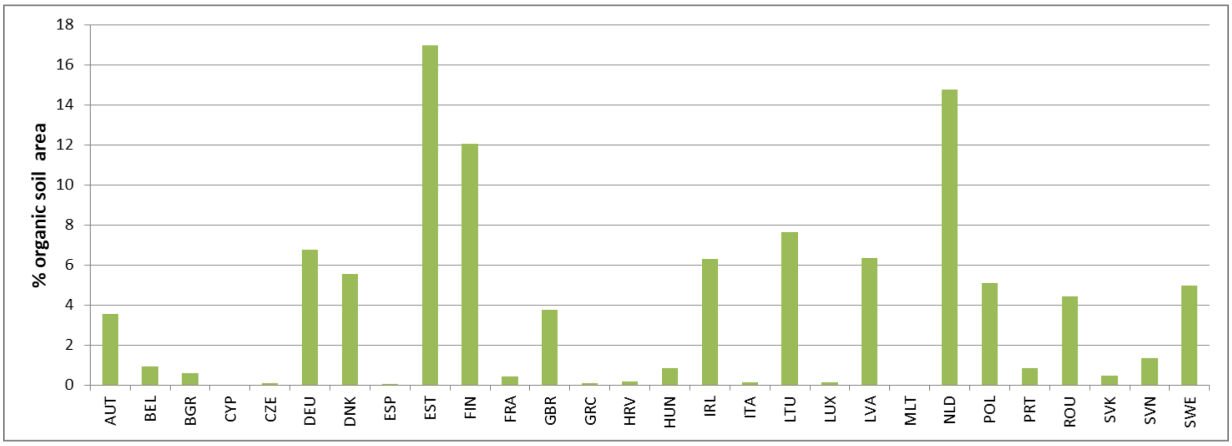

Fig. 5.3. Organic soil area as percentage of total agricultural area of all EU member states (and the UK).

Total organic soil emissions can make up a large part of total national emissions (Fig. 5.4.). In reporting, the most important emission sources are identified with a key category analysis. In a first step, the emissions of each source and sink category are roughly estimated using a tier 1 approach. Organic soil emissions are thus estimated by multiplication of the default EFs and the organic soil area of the relevant category. As a default EF is a constant value, area is thus the crucial measure for the performance in key category analysis. If it is not determined correctly, organic soils of a land-use category may erroneously be identified as not key. In a second step of the key category analysis, emission sources are ordered from largest to smallest and those categories that together constitute 95 % of total emissions are deemed 'key'. Key category analysis should be carried out separately for each of the gases and separately for sources and sinks (IPCC 2006, Vol. 1, Ch. 4).

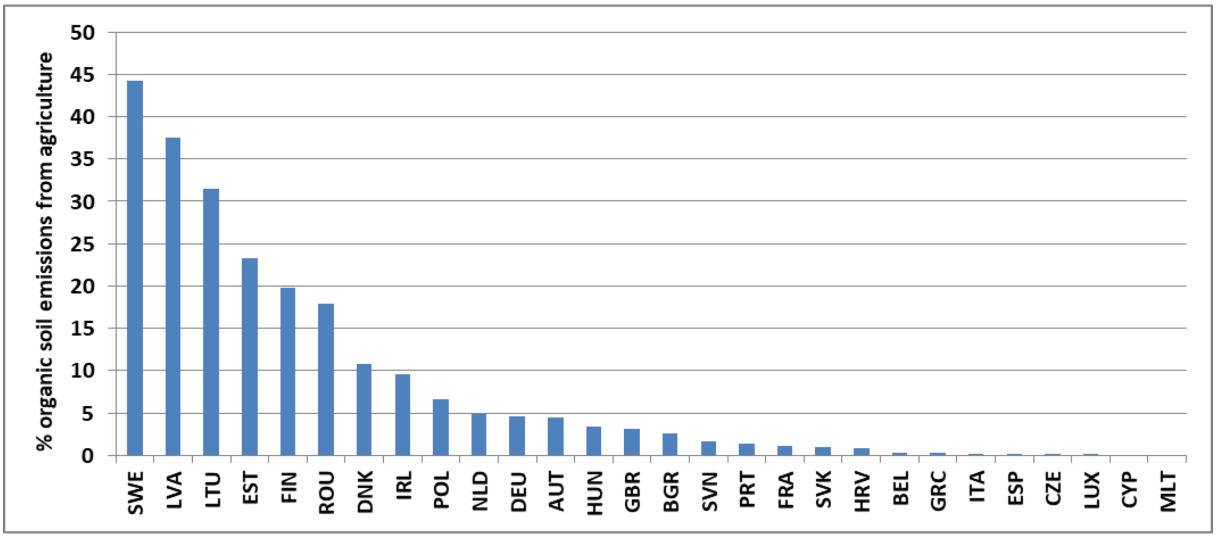

Fig. 5.4. Contribution of organic soil emissions from agriculture to the total emissions of EU countries (and the UK). The total emissions are taken from CRF table Summary2 of the NIS of each country and corrected for organic soil emissions from agriculture calculated in this study.

It is *good practice* to apply at least a tier 2 method for calculation of emissions from key categories (if it can be achieved with a reasonable amount of resources; IPCC 2006, Vol. 1, Ch. 4). As a consequence, where organic soil areas are underestimated, a tier 1 approach may be applied were at least a tier 2 approach would be necessary for calculation of organic soil GHG emissions, leading to a lower accuracy of the estimates. Poor mapping of organic soils may thus negatively affect calculation of corresponding GHG emissions both directly and indirectly.

Key category analysis considers reporting categories or even sub-categories. For example, in the 'LULUCF' sector, key category analysis looks at the subcategories of 'cropland remaining cropland' and 'land converted to cropland'. The disaggregation of gases and sources of agricultural land use of organic soils of course lowers the likelihood that they will be deemed key. IPCC (2006) argues that disaggregation by gases is sensible even if they are explicitly tied together like in the case of organic soils or in case of road transportation in the example of the IPCC (2006). The argument is that assessment methods and uncertainties will differ between the gases and therefore they should be disaggregated in analysis. CO_2 contributes the largest share to emissions from agriculturally used organic soils (see tables at the beginning of each country chapter) and is thus most likely to potentially rank as key.

Whereas the argument to disaggregate gases also makes sense for organic soils, disaggregating between 'land-use category remaining land-use category' and 'land-use category converted to another land-use category' does not. Whereas IPCC approaches land-use change on mineral soils with a 20-year default transition period for soil organic carbon stores (IPCC 2006), it assumes immediate change in emissions for land-use change on organic soils (IPCC 2014).

With respect to organic soils, IPCC rules for key category analysis are not ideal. A full key category analyses for each party covered in this report exceeds the scope of this study.

Countries are allowed to deviate from the IPCC guidelines. One approach could be to indeed treat emissions from agriculturally used organic soils, independent of gas or type of land use (change), as a single item in key category analysis and develop more sophisticated methods and EFs for their assessment. Several EU countries and the UK have published their key category analyses with the per cent contribution of each category in their NIR. It can easily be checked whether emissions from agriculture on organic soils are larger than from the key category with the lowest emissions (Table 5.1). In the end, whether agriculture on organic soils is identified as key source or not, the task is the same: to rewet as many of those soils as possible in a short period of time (see below.).

Table 5.1. Agriculture on organic soils as potential key category in each EU country (and the UK). The key category threshold refers to the share of the key category with the lowest emissions. The share of organic soil emissions from agriculture is given relative to the total amount of emissions of the respective country.

Code	Country	Key category threshold [%]	Share of organic soil emissions from agriculture [%]	Potential key category
AUT	Austria	0.2	4.41	Yes
BEL	Belgium	0.19	0.37	Yes
BGR	Bulgaria	0.4	2.57	Yes
CYP	Cyprus	0.34	0.00	No
CZE	Czech Republic	-	0.09	-
DEU	Germany	-	4.62	-
DNK	Denmark	-	10.78	-
ESP	Spain	0.49	0.12	No
EST	Estonia	-	23.25	-
FIN	Finland	0.8	19.72	Yes
FRA	France	0.2	1.07	Yes
GBR	The UK	0.46	3.15	Yes
GRC	Greece	-	0.28	-
HRV	Croatia	0.5	0.86	Yes
HUN	Hungary	0.36	3.33	Yes
IRL	Ireland	0.34	9.58	Yes
ITA	Italy	0.3	0.21	No
LTU	Lithuania	1	31.41	Yes
LUX	Luxembourg	0.53	0.06	No
LVA	Latvia	-	37.59	-
MLT	Malta	1.06	0.00	No
NLD	The Netherlands	0.3	4.92	Yes
POL	Poland	0.3	6.62	Yes
PRT	Portugal	1	1.35	Yes
ROU	Romania	-	18.07	-
SVK	Slovakia	-	0.96	-
SVN	Slovenia	-	1.63	-
SWE	Sweden	0.3	44.3	Yes

To date, only Germany and Denmark have come up with tier 2 methods for all relevant emissions in accordance with the IPCC Wetlands Supplement (IPCC 2014) (Table 4.1.). Of these two, only Germany uses extensive country-specific data and modelling (Chapter 4.1.6.). With its 2021 submission, the UK has established a reporting system of similar complexity as Germany. Other countries (Estonia, Finland, The Netherlands) use tier 2 approaches, but these are based on the 2006 IPCC Guidelines (IPCC 2006).

According to the IPCC definition, organic soils have at least 12 % OC content by weight (IPCC 2006). However, recent studies show that soils with less OC content by weight can emit considerable amounts of CO_2 as well (Elsgaard et al. 2012, Eickenscheidt et al. 2015, Tiemeyer et al. 2016). The very low specific weight of OC compared with clastic material means that low OC by weight results in much heavier soils. As a result, the OC by volume of these 'heavy' 'peaty soils' can be even higher than in 'true' peat soils (cf. Ruehlmann and Körschens 2009) and emit equal amounts of GHGs (Tiemeyer et al. 2016). While most EU countries still struggle to map their 'true' peat soils adequately (as pointed out in this study, see discussion above and chapter 4.1.), few member states have included peaty soils in their accounting. In Germany, they are well incorporated in the model-based approach. Denmark applies half of the default EFs from the IPCC Wetlands Supplement (IPCC 2014) to peaty soils (Chapter 4.1.7.). The EFs applied by the Netherlands seem inappropriate as well (Chapter 4.1.22).

Handling of peaty soils must be improved in EU GHG reporting, as they play an important role especially in Europe where peatlands are highly degraded (Chapter 2.1.) and peat soils change into peaty soils on a large scale with ongoing degradation. Currently, it is (implicitly) common practice to stop reporting of GHGs from organic soils as soon as their OC content by weight drops below 12 %. This practice may be in line with the IPCC guidelines (IPCC 2014), but denies recent advances in scientific knowledge. It underlines that the importance of peatlands and their emissions remain misunderstood and underestimated. A change in the treatment of peatlands is long overdue.

The quality of a national inventory also depends on consistency within the report. Consistency is one of the key concepts the ANNEX I countries agreed on, yet deficits in its implementation are not uncommon. The most eye-catching inconsistency is a discrepancy between the organic soil areas given in the 'Agriculture' and the 'LULUCF' sectors. The organic soil area in the sector 'Agriculture' should be equal to the combined area of 'Cropland' and 'Grassland' in the sector 'LULUCF'. The two numbers differ in 10 countries. Only Germany explains the discrepancy (Chapter 4.1.6.). For all other countries, the inconsistency in the reported area most likely expresses a lack of communication between inventory compilers of the two sectors. In some cases, even the areas within a sector do not match (Denmark, Latvia, Sweden). Where such discrepancies occur, better coordination between sectors and also categories within a sector is needed to fulfill the self-proclaimed target of consistency.

The key concept of transparency is not sufficiently upheld in a number of EU member states either. In several NISs, description of methods is incomplete and it remains unclear how areas and IEFs in the CRF tables are determined. In some cases, the missing information can be derived from the context – e. g. the cropland and grassland (grass cropping) share in the 'Cropland' category of Finland. In other cases, this is not possible – e. g. when trying to find the source of the spatial data used by the Netherlands.

In order to reach the goal of the UNFCCC to keep global warming below 2° C, a net CO_2 sink must be achieved by the second half of this century (IPCC 2018). In order to maximize this sink as many organic soils as possible should be rewetted (Humpenöder et al. 2020). Ideally, all organic soil emissions from managed land should be reduced to net zero until 2050 (Günther et al. 2020, Tanneberger et al. 2021). Effective mitigation strategies thus have to include rewetting of drained peatlands. Suggestions to grow highly-productive bioenergy crops as substitute for fossil fuels on drained peatland soils to offset their GHG emissions (Järveoja et al. 2013) are short-sighted and cannot lead to zero emissions as long as drained peatlands continue to be sources of GHGs. Paludiculture on rewetted peatlands has a much better climate effect as it stops CO_2 emissions from drained peatlands while it provides similar amounts of biomass at the same time (Wichtmann et al. 2016).

Rewetting does not lead to peatlands with zero emissions. Wet peatlands and mires are considerable emitters of CH_4. So, the choice is between CO_2 emissions in the drained situation or CH_4 in the rewetted situation. Whereas efforts to lower CH_4 emissions are necessary (Ocko et al. 2021), if the choice is between reducing CH_4 or reducing CO_2 emissions, the choice is to reduce CO_2 emissions and accept unavoidable CH_4 emissions. Although the radiative effect of CH_4 is much higher than that of CO_2, its atmospheric lifetime is much shorter. In terms of radiative effect, it is best to rewet drained peatlands as soon as possible (Günther et al. 2020, Fig. 5.5.).

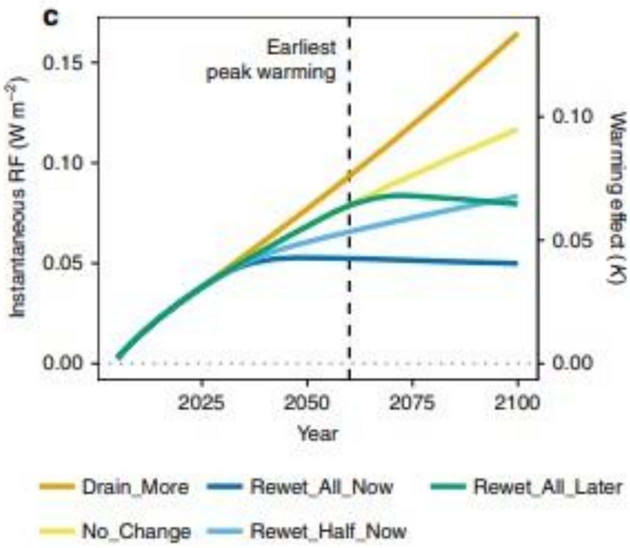

Fig. 5.5. Global warming and climatic effects of peatland management. Mean global temperature effect relative to 2005. Forcing of peatlands that remain pristine is assumed to be zero. (from Günther et al. 2020)

Whereas immediate action is needed, rewetting has hardly happened in the EU (Joosten et al. 2017a). Reliable organic soil maps are available and data on agricultural land use should be available as well, as such use commonly involves EU payments that require accurate bookkeeping. Organic soils under agricultural use emit the highest amounts of GHGs per ha, more than e. g. forest on organic soils (Maljanen et al. 2010, IPCC 2014). They cover a relatively small portion of the total agricultural area but contribute a disproportionally large share to the total emissions from agriculture (Fig. 5.6.). Rewetting of these soils can be regarded as a 'low-hanging fruit' in GHG mitigation, meaning that much reduction can be achieved with low effort and actual cost. Of course, currently drained agriculturally used organic soils receive EU per hectare payments that are not paid for wet crops (Greifswald Mire Centre 2019). Farmers will be reluctant to give up this source of income and switch to paludicultures. A revision of EU regulations that not only grant payments to wet crops, but also installs a CO_2 price for land use activities, would effectively force farmers to shift to land-use on wet organic soils. Such a measure would likely require less effort and resources than many other mitigation policies.

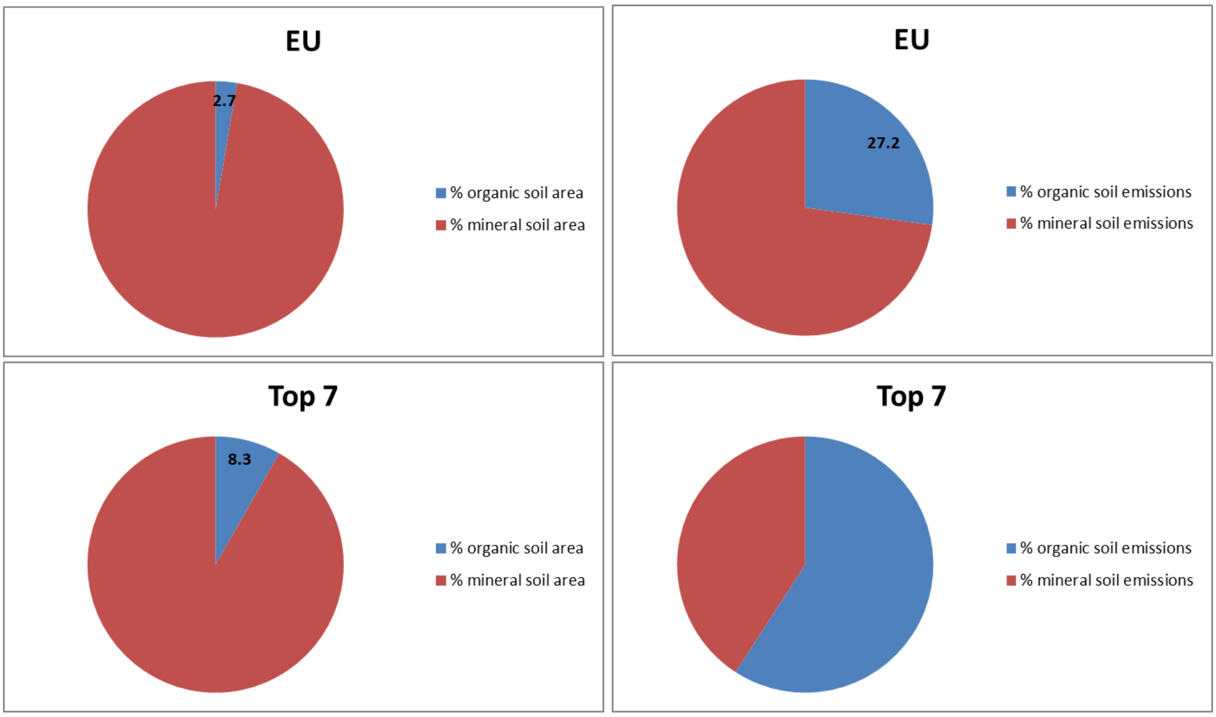

Fig. 5.6. Organic soil contribution to agriculture. Share of organic soil area of the total area of 'Cropland' and 'Grassland' (corrected) (left) compared to the contribution of emissions from drained organic soils to the total emissions from agriculture (corrected) (right). EU = all EU member states (and the UK), Top 7 = EU countries with a contribution of more than 10 % of GHG emissions from agriculture on organic soils to the total emission budget. Contribution of emissions from drained organic soils to the total emissions from agriculture (corrected): Estonia (85 %), Latvia (72 %), Lithuania (71 %), Finland (58 %), Romania (53 %), Poland (49 %), Sweden (40 %).

Overall, the EU member states differ a lot in the quality of their mapping of organic soils and in the estimation of associated emissions. Some countries have established high resolution mapping approaches providing detailed organic soil inventories (e.g. Germany), while others underestimate the area of organic soils in their countries by several orders of magnitude (notably Romania). Even if the area of organic soils is large and drained organic soils are a key source of emissions, many countries do not apply a higher tier approach in their assessment. Moreover, available resources are often not used. Instead of the IPCC Wetlands Supplement (IPCC 2014), most EU countries still use the 2006 IPCC Guidelines (IPCC 2006), which disregards recent scientific advances concerning the extent of - and emissions from - organic soils (notably Great Britain, Chapter 4.1.12.).

This study has shown that considerable improvements in the estimation of organic soil emissions in the EU can be achieved with only low effort. It is easy to apply tier 1 methods and EFs from the IPCC Wetlands Supplement (IPCC 2014). Yet, more can be done to improve mapping and to add more measurement data, which are necessary to calculate GHG emissions from organic soils appropriately. Even a simple comparison of EFs and IEFs with factors used by neighbouring countries can help evaluate the own approach. As long as country-specific data are scarce, use of default EFs from the IPCC Wetlands Supplement (IPCC 2014) is preferable to tier 2 EFs based on the 2006 IPCC Guidelines (IPCC 2006). Consistent implementation of the guidelines from the IPCC Wetlands Supplement and adjustment of the area estimates increases EU wide emissions from agriculture on organic soils from 92316.36 kt CO_2-equivalents to 166700.96 kt CO_2-equivalents.

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Annex 1: National Inventory Reports

Country code	Country	Reference
AUT	Austria	Anderl M, Friedrich A, Gangl M, Haider S, Köther T, Kriech M, Lampert C, Mandl N, Matthews B, Pazdernik K, Pfaff G, Pinterits M, Poupa S, Purzner M, Schieder W, Schmid C, Schmidt G, Schodl B, Schwaiger E, Schwarzl B ,Titz M, Weiss P, Wieser M, Zechmeister A (2020) Austria's National Inventory Report 2020. Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Umweltbundesamt GmbH, Vienna, Austria. 780 p.
BEL	Belgium	Flemish Environment Agency, Flemish Institute for Technological Research, Walloon Agency for Air and Climate, Brussels Environment, Federal Public Service of Health, Food Chain Safety and Environment, Belgian Interregional Environment Agency, ECONOTEC (2020) Belgium's greenhouse gas inventory (1990-2018). National Inventory Report Submitted under the United Nations Framework Convention on Climate Change. 422 p.
BGR	Bulgaria	Reporting Entity – Executive Environment Agency at the Ministry of Environment and Water (2020) National Inventory Report 2020. Greenhouse Gas Emissions in Bulgaria 1988-2018 *Ministry of Environment and Water*, Sofia, Bulgaria. 509 p.
CYP	Cyprus	Kythreotou N, Mesimeris T (contact) (2020) Cyprus National Greenhouse Gas Inventory 2020. *Department of Environment at the Ministry of Agriculture, Rural Development and Environment*, Nicosia, Cyprus. 372 p.
CZE	Czech Republic	Krtkova E, Müllerova M, Saarikivi R (contact) (2020) National Greenhouse Gas Inventory Report of the Czech Republic (reported inventories 1990 – 2018) *Czech Hydrometeorological Institute & Ministry of the Environment of the Czech Republic*, Praha, Czech Republic. 512 p.
DEU	Germany	Federal Environment Agency UBA (2020) Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2020. *Umweltbundesamt*, Germany. 997 p.
DNK	Denmark	Nielsen O-K, Plejdrup M S, Winther M, Nielsen M, Gyldenkærne S, Mikkelsen M H, Albrektsen R, Thomsen M, Hjelgaard K, Fauser P, Bruun H G, Johannsen V K, Nord-Larsen T, Vesterdal L, Callesen I, Caspersen O H, Scott-Bentsen N, Rasmussen E, Petersen S B, Olsen T M & Hansen M G(2020) Denmark's National Inventory Report 2020. Emission Inventories 1990-2018 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, Aarhus, Denmark. 900 p. Scientific Report No. 372 http://dce2.au.dk/pub/SR372.pdf
ESP	Spain	Fernández Barrena M, Fernández Díez-Picazo M, Flores García L Flores Sanz F J, Lázaro Navas S, Méndez Magaña G, del Rosario Sendin García, (2020) Informe de Inventario Nacional Gases de Efecto Invernadero. Comunicación al Secretariado de la Convención Marco de las Naciones Unidas sobre el cambio climático. Ministerio para la Transición Ecológica y el Reto Demográfico, Spain. 953 p.
EST	Estonia	Mändmets A, Pärn C-T (eds) (2020) Greenhouse Gas Emissions in Estonia 1990-2018. National Inventory Report. *Ministry of the Environment*, Tallinn, Estonia. 475 p.
FIN	Finland	Pipatti R (contact) (2020) Greenhouse Gas Emissions in Finland 1990 to 2018. National Inventory Report und the UNFCCC and the Kyoto Protocol. *Statistics Finland*, Finland. 566 p.
FRA	France	Andre J-M, Barrault S, Cuniasse B, Druart A, Durand A, Feutren E, Gavel A, Glass T, Grellier L, Gueguen C, Imad V, Jeannot C, le Borgne G, Mathias E, Mazin V, Robert C, Rodriguez D, Taieb N, Tapia-Villareal I, Vandromme N, Vieira da Rocha T (2020) Rapport National d'Inventaire pour la France au titre de la Convention cadre des Nations Unies sur les Changements Climatiques et du Protocole de Kyoto. CITEPA, France. 786 p.

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GRC	Greece	Climate Change Emissions Inventory. National Inventory Report of Greece for Greenhouse and Other Gases for the Years 1990-2018 (2020) Ministry of Environment and Energy, Greece. 566 p.
HRV	Croatia	Obučina T (coord) (2020) National Inventory Report 2020. Croatian greenhouse gas inventory for the period 1990 – 2018. *Ministry of Environment and Energy*, Republic of Croatia. 464 p.
HUN	Hungary	Kis-Kovács G,Labancz K,Lovas K, Ludányi E L, Somogyi Z, Szakálas J, Tarczay K, Tobisch T. National Inventory Report for 1985-2018 (2020) Unit of National Emissions Inventories of the Hungarian Meteorological Service, Hungary. 544p.
IRL	Ireland	Duffy P, Black K, Fahey D, Hyde B, Kehoe A, Murphy J, Quirke B, Ryan A M, Ponzi J (2020) National Inventory Report 2020. Greenhouse Gas Emissions 1990 – 2018 reported to the United Nations Framework Convention on Climate Change. Environmental Protection Agency, Johnstown Castle, Ireland. 487 p.
ITA	Italy	Arcarese C, Bernetti A, Caputo A, Contaldi M, Cordella M, De Lauretis R, Di Cristofaro E, Gagna A, Gonella B, Moricci F, Romano D, Taurino E, Vitullo M (2020) Italian Greenhouse Gas Inventory 1990-2018. Annual Report for submission under the UN Framework Convention on Climate Change and the Kyoto Protocol. Istituto Superiore per la Protezione e la Ricerca Ambientale, Roma, Italy. 610 p.
LTU	Lithuania	Konstantinavičiūtė I, Byčenkienė S, Kavšinė A, Vilniškė L, Juška R, Žiukelytė I, Lenkaitis R, Kazanavičiūtė V, Mačiulskas M, Ozarinskienė M,Juraitė T, Čeičytė L, Merkelienė J, Kairienė E, Šulinskas K (2020) Lithuania's National Inventory Report 2020. Greenhouse Gas Emissions 1990-2018. Vilnius, Lithuania. 567 p.
LUX	Luxembourg	Becker N, Schuman M (Mgmt) (2020) Luxembourg's National Inventory Report 1990-2018. Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. *Ministère de l'Environnement, du Climat et du Développement Durable – Administration de l'environnement*, Esch-sur-Alzette, Luxembourg. 806 p.
LVA	Latvia	Bārdule A,Butlers A, Butlers A, Cakars I, Gancone A, Gračkova L, Klāvs G, Laima Bērziņa L, Lazdiņš A, Līcīte I, Lupiķis A, Lupkina L, Puļķe A, Rubene L, Siņics L, Skrebele A, Zustenieks G (2020) Latvia's National Inventory Report. Submission under UNFCCC and the Kyoto Protocol. Ministry of Environmental Protection and Regional Development of the Republic of Latvia, Riga, Latvia. 519 p.
MLT	Malta	Vassallo S, Apap A, Mallia N, Busuttil M, Zammit D, Attard Refalo L, Said A, Pace C (2020) Malta's National Inventory of Greenhouse Gas Emissions and Removals, 2020. Annual Report for Submission under the United Nations Framework Convention on Climate Change and the European Union Monitoring Mechanism. The Malta Resources Authority, Marsa, Malta. 375 p.
NLD	The Netherlands	Ruyssenaars P G, Coenen P W H G, Rienstra J D, Zijlema P J, Arets E J M M, Baas K, Dröge R, Geilenkirchen G, 't Hoen M, Honig E, van Huet B, van Huis E P, Koch W W R, Lagerwerf L A, te Molder R M, Montfoort J A, Vonk J, van Zanten M C (2020) Greenhouse gas emissions in the Netherlands 1990-2018. National Inventory Report 2020. National Institute for Public Health and the Environment, Bilthoven, the Netherlands. 528 p.
POL	Poland	Olecka A, Bebkiewicz K, Chłopek Z, Doberska A, Jędrysiak P, Kanafa M, Kargulewicz I, Rutkowski J, Sędziwa M, Skośkiewicz J, Waśniewska S, Zasina D, Zimakowska-Laskowska M, Żaczek M (2020) Poland's National Inventory Report 2020. Greenhouse Gas Inventory for 1988-2018. National Centre for Emission Management at the Institute of Environmental Protection – National Research Institute, Warszawa, Poland. 472 p.

PRT	Portugal	Amaro A, Borges M, Canaveira P, Costa Pereira T, Pina A, Silva R (2020) Portuguese National Inventory Report on Greenhouse Gases, 1990 – 2018. Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Portuguese Environmental Agency, Amadora, Portugal. 722 p.
ROU	Romania	Deaconu S, Varlam M, Constantinescu M, Alexandru-Claudiu D, Bădele O, Brulea A, Bucura F, Calcan A, Calciu I, Ciceu A, David C, Drăgan C V, Dulgheru C, Franga I, Garcia Duro J, Ionete R, Olteanu L, Paciurea B, Radu R, Silviu-Pascu I, Simota C C, Stanciu M-L, State P, Vizireanu I, Vizitiu O (2020) Romania's Greenhouse Gas Inventory 1989-2018. National Inventory Report. National Environmental Protection Agency, Romania. 806 p.
SVK	Slovakia	National Greenhouse Gas Inventory Report 1990-2018 to the UNFCCC and the Kyoto Protocol (2020) Slovak Hydrometeorological Institute, Ministry of Environment of the Slovak Republic, Bratislava, Slovak Republic. 492 p.
SVN	Slovenia	Mekinda Majaron T, Kus Z, Malešič I, Oberstar H, Rotter A, Logar M, Simončič P, Mali B, Verbič J, Tolar Šmid V (2020) Slovenia's National Inventory Report 2020. GHG emissions inventories 1986-2018. Ministry of the Environment and Spatial Planning, Slovenian Environment and Spatial Planning, Ljubeljana, Republic of Slovenia. 390 p.
SWE	Sweden	Morfeldt J, Bengtsson J, Adriansson E, Al-Hanbali H, Allerup J, Almqvist S, Berggren S, Bergström J, Bolinder M, Danielsson H, Eklund V, Guban P, Gustafsson T, Helbig T, Jerksjö M, Kanth M, Karlsson G, Karltun E, Kindbom K, Löfström F, Lundblad M, Norlin T, Ortiz C, Petersson H, Pihl Mawdsley I, Skårman T, Szudy M, Viklund L, Wärmark K, Wikberg P-E, Yaramenka K (2020) National Inventory Report Sweden 2020. Greenhouse Gas Emission Inventories 1990-2018. Swedish Environmental Protection Agency, Stockholm, Sweden. 545 p.