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Comparative Analysis of Peatland Emission Factors: Unravelling the Need for Standardized Measurement and Reporting

Dita KAZMERE[1*], Maksims FEOFILOVS[2], Francesco ROMAGNOLI[3]

[1–3]*Institute of Energy Systems and Environment, Riga Technical University, 12/1 Azenes iela, Riga, LV-1048, Latvia*

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***Abstract* – Peatlands have a crucial role in the global carbon cycle, acting as significant carbon sinks, but become a significant source of greenhouse gas (GHG) emissions when peatlands are drained, and during peat extraction. This article presents a comprehensive overview of peatland ecosystems, emphasizing their classification across various climatic zones and the complex set of different characteristics that determine contribution to GHG emissions. Currently, inconsistencies exist in the definition of emission factors used between countries leading to varied approaches in estimating peatland emissions and posing significant challenges in the comparison and aggregation of global data on peat extraction related GHG. The aim of the study is to analyse the disparities in emission factors and calculation methodologies employed by different countries. Data from national GHG emission reports are submitted under the UNFCCC and the Kyoto Protocol. Emissions report data calculations and emission factors can be based on either nationally determined data or data specified in the IPCC guidelines. Consequently, emission factor data for four countries - Latvia, Finland, Sweden and Germany - are collected and processed, which was compared with IPCC guidelines data. The data was compared by equating units of measurement. The results show there is a pronounced difference between the emission factors of each country, however, all of these factors are lower than the maximum values specified in the IPCC guidelines. The study concludes that emission factors are predetermined differently for each country, and it is not possible to determine the differences among assumptions for parameters included in the specification of the emission factors. The results suggest there is a need for development of a more transparent accounting for emissions with regard to the diverse environmental and anthropogenic factors influencing peatland ecosystems. Factors like composition, depth of peat, water table levels, and local land-use practices further compound this variability in emission accounting. Addressing these challenges is crucial for enhancing the accuracy and reliability of GHG emission reporting under international frameworks like the United Nations Framework Convention on Climate Change and the Kyoto Protocol.**

***Keywords* – Carbon sink; climate change; emission inventories; peatland emissions; peat and peatland types; tier.**

[*] Corresponding author.
E-mail address: dita.kazmere@rtu.lv

1. INTRODUCTION

Peat bogs are an important habitat for a broad variety of animals and plants where formation and accumulation of peat is taking place. Globally, peat bogs cover only 3 % of the total land area, yet they can accumulate around 23 g C m^{-2} y^{-1} every year [1], [2]. This means that peat bogs are the densest terrestrial carbon sink. Draining of peat bogs for the excavation is extremely harmful to the environment due to the destruction of the bog which damages the ecosystem by reducing biodiversity and releasing high amounts of emissions during peat extraction [3]. The release of emissions during peat extraction has a significant contribution to climate change. It is estimated that globally, 65 million ha of peatlands have been degraded, largely due to drainage. Peatland degradation releases about 1150 Gt CO_2 y^{-1} into the atmosphere every year, yet this amounts to only 3 % of the total atmospheric CO_2 [4].

During the extraction, oxygen penetrates into the carbon-rich soil, and oxidation of the peat soil occurs, leading to the production of large quantities of carbon dioxide (CO_2). The rapid access of oxygen to the soil creates a favourable environment for the proliferation of micro-organisms that contribute to the decay of organic matter, thus releasing large quantities of methane (CH_4) emissions into the atmosphere. Over the years, peat bogs are enriched in nitrogen, either naturally from plant residue or through groundwater containing fertiliser residue that is rich in nitrogen. Consequently, when peat is extracted, nitrogen is oxidised, and nitrous oxide (N_2O) is released into the atmosphere [5], [6]. The European Union has set a target to reduce CO_2 emissions by 55 % until 2030 and achieve climate neutrality by 2050. A solution is needed to achieve these targets. One possible solution is to promote circular economics in the manufacturing sector by developing processes and technologies that encourage the capture and storage of emissions. For example by encouraging new ways of cultivating the soil or improving the soil by restoring habitats [7], [8].

Recultivation of peatlands is needed to mitigate the effects of peatland drainage on the environment. Recultivation of peatlands is mentioned as one of the points of the European Commission proposal for a "Regulations of the European Parliament and of the Council on Nature Restoration" [9]. To date, peatland restoration measures have already been carried out in some European countries, but there is still a lack of information on the most effective form of restoration due to their in different land types. At least eight possible types of peatland restoration have now been identified [10], but more research is needed to determine which type is appropriate for a given peatland and what actions need to be taken to implement this restoration strategy.

It is therefore very important that accurate accounting of emissions and carbon cycles in these peatlands is carried out. These cycles are currently described and assessed through national greenhouse gas (GHG) emission inventories. These inventories calculate emissions using a country-specific emission factor or an emission factor defined in the Intergovernmental Panel on Climate Change (IPCC) reports [11], and based on this emission factor (EF), it is possible to estimate the emissions per unit area per year. However, these reports do not specify the parameters that must be applied in assessing the EF, and therefore it is not possible to determine that the defined EF are accurate and whether they reflect the true situation when accounting for emissions from peatlands.

The problems and shortcomings listed above can interfere with the rapid and efficient restoration of peatlands, therefore the aim of this study is to compare existing practices for accounting of emissions and carbon cycles in peatlands and peat extraction sites and reflect on the inconsistencies in the classifications of peatlands and peat within different literature. The results of this study will be useful for the identification of criticalities in accounting of emissions when framing peatland extraction site restoration scenarios.

2. Peat Bog Classification and Environmental Aspects

2.1. The Classification of Peat Bogs

Peat bogs are unique habitats that are able to form in virtually any climatic zone. In general terms, there are two main processes of peat bog formation: overgrowth of the water body and long-term inundation of the area. Peat is formed by the layering of plant debris, and these layers can be formed by covering an area of land in an upward and/or lateral direction. This peat layer formation contributes to changes in topography. From the late 19th to the early 20th century, studies of peat fields in the subarctic climatic zone showed that it was possible to divide the formation of peatlands into three phases [12], [13].

- Low marsh phase (eutrophic) – nutrient-rich;
- Middle marsh phase (mesotrophic) – medium nutrient;
- High or elevated marsh phase (oligotrophic) – low nutrient.

Peat can be classified according to its physical and chemical properties. One method of determining the physical properties of peat is to determine the degree of fibroses and humidification of the peat. The degree of humidification is a characteristic of the putrefaction of plants by living organisms and microorganisms and is determined by the Von Post method. The main principle of the Von Post method is to carry out a visual assessment of the peat mass. The peat mass can be divided into 10 categories, identified by the letter 'H' and a rank number [14].

The density, porosity, and water content of the peat determine its physio-chemical properties, which further subdivide peat. In general, "peat density varies from 0.02 g/cm^3 in the upper layers to 0.1–0.26 g/cm^3 in the lower layers" [15]. Research has shown that "the specific gravity of peat is between 1.3 and 1.6 g/cm^3 […] after a drought or drainage of a peat field, its bulk density increases to 0.4 g/cm^3" [16]. Porosity in peat is determined by its three main components: water, air, and solids. The ratio of water, air, and solids within peat is closely related, meaning that if the bulk density increases, humification, density, and porosity will decrease [15], [17].

The classification of peatland is a complex process that depends on many factors, such as the geographical location and habitat of the peatland, peat type, degree of peat humidification, etc [12]. Fig. 1. shows peatland classification used in different geographical areas. Peatlands can be divided into three groups based on their peat layers, their geomorphology and hydrology, and the topography of the peat bog. Each of these groups could be divided into sub-groups. These groups have been established in different time periods, from the early 1960s to the late 1980s.

The first classification is based on the composition of the decomposed plant residues and the thickness of each peat layer. Based on this classification, four sub-categories are distinguished: low, transitional, mixed and raised bog. Low bog consists of fully decomposed plant remains. Transitional bog consists of mesotrophic peat. Mixed peat bog consists of eutrophic, mesotrophic and oligotrophic peat. High peat bog type consists of oligotrophic peat [18].

The second classification is based on peat bog geomorphology, which is based on the conditions of peatland formation and the deposition of soil layers. Under this classification are four sub-categories. Floodplain meadows – peat bogs form in areas of floodplain grassland where water remains for a long time. Paleo-terrace – is a peat exposure, formed by peat as the bog forms, in the floodplain meadows; as the water recedes, layers of peat are exposed, forming a relief resembling steps. Leached peat accumulation – is formed by the movement of glaciers and large volumes of water, which carried the soil and peat with water and ice movement. Geomorphological peat bogs with no defined classification – this sub-category includes peat bogs which do not fall into any of the above classification groups [18].

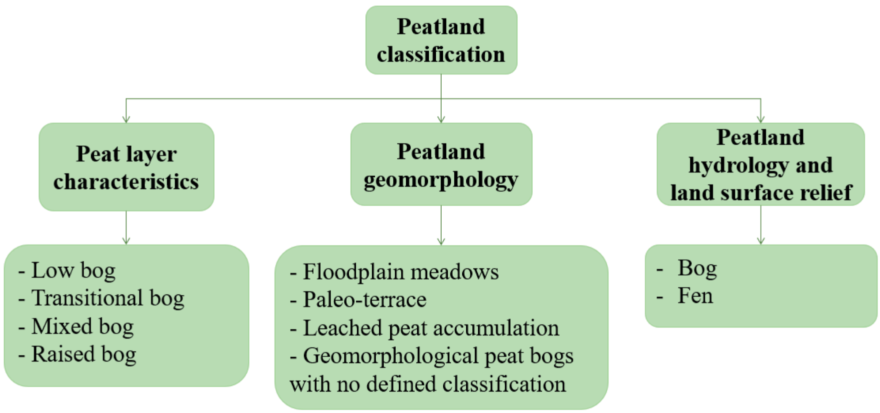

Fig. 1. Common peatland classification methods [18].

The third group is divided into two sub-categories – bog and fen [18]. These sub-categories include multiple habitat types that are described in the Annex Table A1 and Table A2. Bog is a type of wetland characterised by an impermeable clay layer at the bottom, which stops water from draining away. The bog can be characterised by acidic soil and plants that are adjusted to grow in low nutrient soil [19], [20].

Fen is a type of wetland that originates from the infiltration of groundwater into a valley. The soil layer is alkaline or slightly acidic, due to streaming groundwater from underlying calcareous deposits. These types of conditions create an excellent environment for a habitat that is rich in biological diversity and provides a home for a wide variety of plants and animals [19], [20].

The main difference between a fen and a bog is the pH level of the soil and the amount of nutrients in the soil. Both types are found mostly in northern and boreal climatic zones; therefore, it is possible to observe that there are similar plant species. Additionally, fens and bogs differ in terms of water source. Fens are typically fed by groundwater, while bogs rely on rainwater and are often acidic due to the accumulation of decomposed plant material. Despite these variations, both fen and bog ecosystems play important roles in carbon storage and provide habitats for unique plant and animal species.

2.2. Carbon Sequestration in Peat Bogs

A number of factors arising from anthropogenic (man-made) and natural sources influence the complex process of climate change, which affect both human health and the development and formation of habitats. Peat bogs play an important role in climate regulation, not only as an accumulator of GHG emissions but also as an emitter [35]. Peat bogs are considered an important carbon storage because it has been determined that peat bogs contain approximately one third of the global terrestrial carbon reserve [3]. Active drainage of peat bogs for industrial peat development, creation of agricultural lands, or afforestation creates an increased risk of a large amount of GHG emissions entering the atmosphere over a long period of time, mainly CO_2, N_2O, and CH_4 [3].

The formation of peatbogs is determined by how quickly the plants decompose. As plants decompose. They release a number of substances into the soil, including carbon. The carbon that has entered the soil through plant remains is called dissolved organic carbon (DOC). This carbon accumulates differently in each peat layer and soil analyses must be carried out to determine the amount of DOC in the peat. However, it has been established that peat traps in low bogs have higher DOC levels than those in raised bogs [21].

The formation of peat bogs in the Northern Hemisphere in the subarctic and temperate climatic zones began in the agrarian phase of the Holocene, and with the accumulation of layers of plant remains, the process of carbon accumulation began. During this time period, carbon accumulation was approximately 25 g C m^{-2} y^{-1} annually. In the tropical climatic zone, peat bogs began to form shortly before the peat bogs in the subarctic climatic zone. The accumulation of carbon in these bogs occurred gradually, and the most rapid carbon accumulation occurred during the last 2000 years, when the amount of carbon in peat bogs increased by about 20–50 g C m^{-2} y^{-1}. In the subequatorial climatic zone, the area of peat bogs is the smallest compared to tropical and northern bogs. Table 1 presents preliminary information on the amount of carbon in different climatic zones, considering the Holocene period as a starting point [36].

TABLE 1. AREA OF PEAT BOGS IN CLIMATE ZONES AND VOLUME OF CARBON ACCUMULATION

Climatic zones	**Area, km^2**	**Carbon stock, Gt C**	**Average carbon index in Holocene period (g C m^{-2} y^{-1})**	**Source**
Northern peat bogs	~3.88–4.09 ×106	473–621	18.6	[22]
Tropical peat bogs	368500	44–55	12.8	[22]
Subequatorial peat bogs	45000	13–18	22.0	[22]

Peat bogs are the largest terrestrial carbon store in the world, with the most extensive bog system in the subarctic and boreal climate zones. Carbon storage in these bogs is 3.5 times greater than in other ecosystems in these regions. On a global scale, peat bogs store about 1375 t C per hectare of bog area, making them the densest terrestrial carbon store. The division of peat bogs is based on their location: the Northern Hemisphere, encompassing North America, Europe and Russia, and the Southern Hemisphere, encompassing Indonesia, the Congo Basin, and the Amazon Basin.

2.3. Impact of European Peat Bog Industrialization

Europe's industrialization of peat bogs resulted in the disappearance of approximately 10 % of peat bogs and the degradation of 44 %. As a result of peat oxidation, not only CO_2 and CH_4 gases but also N_2O enter the atmosphere. Drainage of peat bogs and their adaptation for agriculture and forestry emit between 0.9 and 9.5 t CO_2 ha^{-1} y^{-1} in the forestry sector and between 21 and 29 t CO_2 ha^{-1} y^{-1} in the agricultural sector. Peat bogs with intact natural ecosystems emit about 30 Mt CH_4 y^{-1} and 0.02 Mt N_2O-N y^{-1} to the atmosphere annually, while areas of peat bogs altered for industrial purposes emit 0.1 Mt CH_4 y^{-1} and 0.2 Mt N_2O-N y^{-1}. As mentioned above, the carbon accumulation of a peat bog and its changes throughout the year vary depending on the climatic zone in which it is located. The same situation applies to CO_2 emissions. Table 2 summarises information on the amount of emissions and the reduction of carbon stock in the largest peat-producing countries and the overall situation in the European Union (EU) and the Baltic States.

TABLE 2. VOLUME OF CARBON ACCUMULATION IN EUROPEAN PEATLANDS, 2021

	Peat extraction				Land converted for peat extraction				
Country	**Area, kha**	**CO_2 emissions, kt**	**Carbon stock change, tC/ha**	**Carbon stock change, ktC**	**Area, kha**	**CO_2 emissions, kt**	**Carbon stock change, tC/ha**	**Carbon stock change, ktC**	**Source**
Latvia	31.62	140.70	–1.21	–38.37					[23]
Lithuania	13.41	871.71	–17.73	–237.74					[24]
Estonia	25.13	1437.61	–15.60	–392.08	0.37	2.39	–1.74	–0.65	[25]
Russia	325.24	3708.83	–3.11	–1011.50					[26]
Sweden	4.46	239.48	–14.65	–65.31					[27]
Finland	100.59	1810.21	–4.91	–493.69	1.40	20.81	–4.06	–5.68	[28]
Germany	13.51	2305.65	–46.54	–628.81	2.80	24.34	–1.60	–4.48	[29]
Ireland	74.30	1624	–6.17	–458.07	0.40	4.56	–3.11	–1.24	[30]
United Kingdom	139.42	2111.19	–4.13	–575.78	1.40	23.31	–4.55	–6.36	[31]
The European Union	270.50	8572.84	–8.67	–2344.59	9.10	1626.2	–1.32	–12.05	[32]

The data shown in Table 2 is summarised for 2021 and was obtained from the UN Climate Change website, which contains national GHG emission inventory reports for the period from 1990 to 2021. Only the unit area of the specific subcategory, measured in kilohectares (1 kha = 1000 ha), determines emissions. Carbon gain is indicated by a positive number (+), while carbon loss is indicated by a negative number (–). Both an indirect factor of change in the carbon stock per unit area and a change in the total carbon stock generally define carbon loss or gain. This table shows that the highest carbon loss per hectare is from Germany (–46.54 t C/ha), and the highest total carbon loss is from Russia (–1011.50 kt C). The lowest carbon loss per hectare and total carbon loss are in Latvia (–1.21 t C/ha and –38.37 kt C, respectively).

3. COMPARATIVE ANALYSIS OF GHG DATA REPORTING PRACTICES

3.1. Overview of Peatland GHG Emissions Reporting Practices

The "Good Practice" handbooks chapter 7 [33] states that each country should individually determine the most appropriate categories for accounting GHG emissions, and conducting a more detailed evaluation of these categories leads to obtaining more accurate and valuable data, thereby increasing the reliability of the national GHG emission inventory report [33], [34]. Country GHG inventory reports often use trends, which are divided into two segments, each of which is further divided into three levels designated as tiers (tier1, tier2, and tier3) usually abbreviated in literature as T1, T2, and T3. Tiers are defined as level of methodological complexity and they are used to calculate emissions from their source; the higher the tier, the smaller uncertainty [33]. T1 is general without specific information and is based on internationally accepted data on EF. T2 collects data mostly from a specific country, making it applicable only to emissions originating in that country. T3, the most detailed level, considers the most detailed changes in emission sources and other applied indicators [33].

The overview of GHG emission accounting is presented in four countries – Latvia, Sweden, Finland, and Germany – for conducting a more in-depth study of GHG emission inventory reports. These countries were selected for their significant role in producing and exporting peat products. The GHG emission inventory reports of all countries are based on the guidelines developed by the IPCC, the legislative documents in the specific country, and the documents developed by the EU. By examining each specific country's case, it is possible to observe that the determination and calculation of emissions and EFs are different from country to country. Each country's GHG emissions report includes a description of the applied calculation methodology and information on the specific calculation methods used. All countries set 1990 as the base year for GHG emissions.

3.2. Peatland GHG Emissions Reporting in Latvia

Country-specific (CS) EFs are used for the Latvian GHG emission report [35]. The GHG emissions report of Latvia provided information on calculation methodologies for emissions arising from the drainage of organic soil. One of the sources of CH_4 emissions is the drainage of organic soils in forest lands. The Forest Law stipulates that forest lands include swamps; therefore, it is possible to calculate CH_4 emissions according to Eq. (1) [35].

$$CH_{4\mathrm{org}} = A\left\lfloor \left(1 - Frac_{\mathrm{d}}\right) \cdot EF_{\mathrm{CH_{4,1}}} + Frac_{\mathrm{d}} \cdot EF_{\mathrm{CH_{4,d}}} \right\rfloor, \tag{1}$$

where

$CH_{4\mathrm{org}}$ annual CH_4 loss from drained organic soils, kg CH_4 y^{-1};

A land area of drained organic soils in a land-use category, ha;

$EF_{\mathrm{CH4,l}}$ emission factor for direct CH_4 emissions from drained organic soils, kg CH_4 ha^{-1} y^{-1};

$EF_{\mathrm{CH4,d}}$ emission factor for CH_4 emissions from drainage ditches, kg CH_4 ha^{-1} y^{-1};

$Frac_{\mathrm{d}}$ fraction of the total area of drained organic soil which is occupied by ditches [35].

N_2O emissions from drained organic soils are calculated as follows:

$$N_2O - N_{\mathrm{OS}} = \left\lfloor \left(F_{\mathrm{OS,CG,tem}} \cdot EF_{2CG,tem}\right) + \left(F_{\mathrm{OS,F,temp,NR}} \cdot EF_{\mathrm{2F,tem,NR}}\right) \right\rfloor, \tag{2}$$

where

$N_2O–N_{\mathrm{OS}}$ annual direct N_2O-N emissions from managed/drained organic soil, kg N_2O-N y^{-1};

F_{OS} annual area of managed/drained organic soils, ha. The subscripts CG, F, Temp, NR refer to cropland and grassland, forestland, temperate and nutrient rich, respectively;

EF_2 emission factor for N_2O emissions from drained/managed organic soils, kg N_2O-N ha^{-1} y^{-1} [35].

If industrial activity is carried out in a peat field but peat extraction is not carried out, GHG emissions for this piece of land are calculated by assuming EFs, which are used to calculate the emissions of cultivated land. The carbon loss of cultivated soil is calculated according to Eq. (3) [35].

$$L_{\mathrm{org}} = \sum\nolimits_c \left(A \cdot EF\right) c, \tag{3}$$

where

L_{org} annual carbon loss from drained organic soils, tons C y^{-1};

A land area of drained organic soils in climate type c, ha;

EF emission factor for climate type c, tons C $ha^{-1}y^{-1}$ [35].

The EFs used for the calculations were obtained within the LIFE REstore project; therefore, it is possible to determine that peat bog emissions were categorised according to the T2 method [36]. To gain a broader understanding of the emissions created during the use of a peat field, it is necessary to carry out a study of the Land Use, Land Use Change, and Forestry (LULUCF) sector categories.

3.3. Peatland GHG emissions Reporting in Sweden

The CO_2 emissions of a drained peatlands in Sweden were determined as a criterion by T2, and a country-specific calculation method was used in the calculations. After T1, researchers determined N_2O and CH_4 emissions as key criteria for a drained peatland. In peat extraction fields, GHG emissions have been calculated taking into account the area of the peat extraction field and the emission factor for each gas individually. The calculation is made according to Eq. (4) [37].

$$Emission\left(gas\right) = P \cdot EF \, , \tag{4}$$

where
P production area, ha;
EF emission factor, tons ha^{-1} y^{-1} [38].

These emissions are based on information on peat extraction volumes and national estimates of the carbon content of peat products. The carbon calculations are based on measurements of the density of peat extracted, the percentage of carbon and the percentage of organic matter [38].

3.4. Peatland GHG Emissions Reporting in Finland

In the Finnish GHG emissions report, the emissions generated in the LULUCF sector, and the accumulation of emissions are calculated, taking into account CS EF. The T2 method (peat extraction in the fields for living biomass) and the T3 method (peat extraction in the fields for dead organic mass and soil organic mass) perform carbon and CO_2 calculations. Equation (5) calculates the emissions and accumulation of emissions generated by peat during the drainage of bogs for forest management [39].

$$\begin{gathered}\text{Change in } DOM + SOM = \text{change in } DW + \\ \text{below ground litter input} - \text{emmissions from soil}\end{gathered} \tag{5}$$

where
DOM dead organic mater;
SOM soil organic mater;
DW dead wood [39].

Applying CS EF according to the T2 method calculates CH_4 and N_2O emissions in peat extraction fields. Draining the peat bog and cultivating the soil contributes to the reduction of carbon in the soil and increases emissions [39].

3.5. Peatland GHG Emissions Reporting in Germany

In Germany, emission calculations are based on the formulas developed in the IPCC 2006 guidelines. However, German-specific adjustments are made to reflect the situation in Germany. In the German GHG emission report, CO_2, N_2O, and CH_4 emissions are determined for industrially produced peat. The GHG emissions of a drained peat bog are calculated, taking into account the subcategories within the wetland category. The land areas of these subcategories are multiplied by the EF of the respective subcategory, and the GHG emissions generated during the use of organic soil are calculated according to Eq. (6) [40].

$$E_{\text{org.soil}} = \sum_{i=1}^{n} \left(A_i \cdot F_i \right), \tag{6}$$

where

$E_{\text{org.soil}}$ CO_2, N_2O and CH_4 emissions from organic soils of a land-use category, kt C;
A_i peatland area subject to a certain land use, kha;
EF_i land-use-specific emission factor, t C ha^{-1} y^{-1};
i conversion categories or remaining categories;
n number of conversion and remaining categories [40].

CO_2, CH_4 and N_2O emissions are generated during peat extraction, which are calculated as follows [40].

$$CO_2eq_{\text{peat extraction}} = CO_2eq_{\text{on-site}} + CO_2eq_{\text{off-site}}, \tag{7}$$

where

$CO_2\ eq_{\text{peat extraction}}$ GHG emissions from peat extraction, t CO_2-eq. y^{-1};
$CO_2\ eq_{\text{on-site}}$ GHG emissions that occur on-site, during production, t CO_2-eq. y^{-1};
$CO_2\ eq_{\text{off-site}}$ GHG emissions that occur via extracted peat that is spread for horticultural purposes, t CO_2-eq. y^{-1} [40].

In the calculations it is shown that emissions are calculated by including on-site and off-site emissions. On-site emissions (in the context of peat bogs, are those from peat extraction for farming/horticulture purposes, peat extraction for energy production is not taken into account here). Off-site emissions include emissions from peat extraction for energy production [40].

3.6. Peatland GHG Emissions Reporting in IPCC

The information on emission calculations in the previous subsections is based on the data specified in the IPCC Guidelines. These guidelines state that a country is allowed to use certain EFs to perform the calculations, however this leads to a higher calculation error and therefore reduces the reliability of the data. In 2013, a supplement to the IPCC Guidelines was issued which describes more details on wetlands and how to make calculations in this sector more accurate [41].

This document also provides CO_2, CH_4 and N_2O EFs for peat bogs in different regions. These values are determined for boreal and temperate and tropical climate zones. These EFs are calculated and determined on the basis of information available in various literature sources. Basically, an EF interval is defined, which is expressed as a minimum and maximum EF value, and then based on these values a mean value is calculated, which is defined as the EF of the specific climatic zone [41]. In this paper it was decided to use the maximum and minimum values for further comparisons in order to be able to determine whether the emission factors of Latvia, Finland, Sweden and Germany fall within the defined range.

3.7. Comparison of National Emission Factors for Peatlands

By examining the national GHG emission reports for Latvia, Sweden, Finland, and Germany, EFs were determined for each country, which are used to calculate emissions. Based on these EFs, it is possible to determine the tier method according to which emissions will be calculated, this data is summarized in Table 3. The only thing for which the tier method is not determined for is the data contained in the IPCC reports, because they are determined as standards that countries can optionally use in emission calculations.

TABLE 3. DRAINED PEATLAND EMISSION FACTOR DATA OBTAINED FROM NATIONAL GHG EMISSION REPORTS AND IPCC REPORTS

Country	**Emission factor**			**Tier**			**Source**
	CO_2	**CH_4**	**N_2O**	**CO_2**	**CH_4**	**N_2O**	
Latvia	1.21 t CO_2–C ha^{-1} y^{-1}	0.0108 t CH_4 ha^{-1} y^{-1}	0.0004 t N_2O–N ha^{-1} y^{-1}	T2	T2	T2	[35]
Finland	14.25 t CO_2 eq ha^{-1} y^{-1}	0.637 t CO_2 eq ha^{-1} y^{-1}	0.767 t CO_2 eq ha^{-1} y^{-1}	T3	T2	T2	[39]
Sweden	2.8 t CO_2–C ha^{-1} y^{-1}	0.0061 t CH_4 ha^{-1} y^{-1}	0.0003 t N_2O–N ha^{-1} y^{-1}	T2	T1	T1	[37]
Germany	1.6 t CO_2–C ha^{-1} y^{-1}	0.0059 t CH_4–C ha^{-1} y^{-1}	0.0009 t N_2O–N ha^{-1} y^{-1}	T2	T2	T2	[40]
IPCC min	1.1 t CO_2–C ha^{-1} y^{-1}	0.0016 t CH_4–C ha^{-1} y^{-1}	$-3.00*10^{-5}$ t N_2O–N ha^{-1} y^{-1}	–	–	–	[41]
IPCC max	4.2 t CO_2–C ha^{-1} y^{-1}	0.0011 t CH_4–C ha^{-1} y^{-1}	0.00064 t N_2O–N ha^{-1} y^{-1}	–	–	–	[41]

Based on the data from Table 3, the first step of the data analysis includes the conversion of emission data to the same units of measurement. Recalculations of measurement units are made based on the calculations made in the article [6], therefore Eq. (8) was used for recalculations.

$$CO_2 = CO_2 - C\left(\frac{M_{\mathrm{CO2}}}{M_{\mathrm{C}}}\right), \tag{8}$$

where

CO_2-C CO_2 and CH_4 emissions in units of carbon (in case of N_2O-N emissions in units of nitrogen);

M_{CO2} molecular weight, for CO_2 44 g/mol, for N_2O 28 g/mol, for CH_4 16 g/mol;

M_{C} molecular weight for C or N (for C is 12 g/mol, for N is 14 g/mol).

Similarly, the approach was used for CH_4-C and N_2O-N by changing these measurements to N_2o and CH_4. After calculating N_2O, CH_4 and CO_2, the conversion of EFs to the same measurement units (t CO_2 eq) was performed. The transition to the same measurement units occurs by multiplying the corresponding global warming potential by EFs (global warming potential: CO_2 = 1, CH_4 = 27, and N_2O = 273). The calculation process is reflected in Eq. (9).

$$CO_2eq = EF \cdot GSP, \tag{9}$$

where

EF emission factor for N_2O, CO_2 or CH_4 gas;

GWP global warming potential for N_2O, CO_2 or CH_4 gas.

Fig. 2 shows the results of converting the data from Table 3 to the same units of measurement. After converting the GHG emission data into the same measurement units, the total values of these emissions were calculated. These values were compared with each other, and to the minimum and maximum values foreseen by the IPCC reports. The obtained results clearly show the difference in EF for countries from the minimum and maximum values of IPCC.

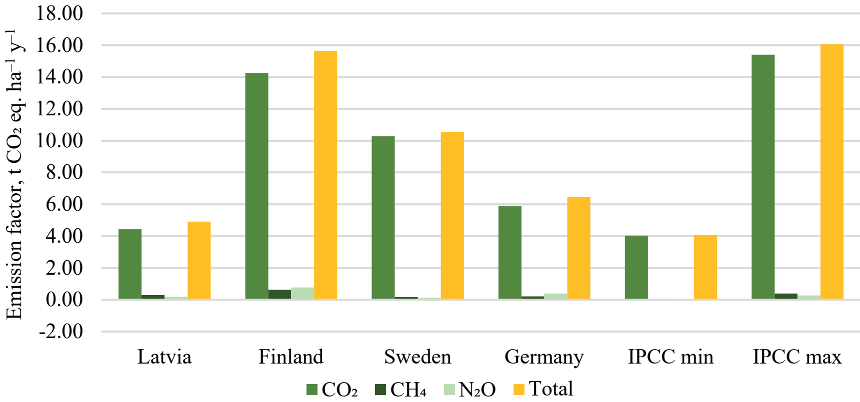

Fig. 2. Calculated national EF for drained peat fields in 2021, t CO_2 eq. ha^{-1} y^{-1}.

Results show the CO_2, CH_4 and N_2O emission factors for each country. These EFs are compared with each other and with the minimum and maximum values set out in the IPCC guidelines. After cross-checking the data, it was determined that the national EF values fall within the IPCC range, and it is therefore possible to assume that the EFs of Latvia, Finland, Sweden and Germany are reliable. However, it should be highlighted that these minimum and maximum values are for the boreal and temperate climate zone and therefore it is not possible to claim that these values are reliable.

A comparison between four country and IPCC EF values showed the following:

- The Latvian and German CH_4 and N_2O EF values are similar, however the German CO_2 value is 1.43 t CO_2 eq. ha^{-1} y^{-1} higher than the Latvian;
- Finland has the highest EF of the countries considered and the total EF is 0.42 t CO_2 eq. ha^{-1} y^{-1} lower than the IPCC total EF value;
- After examining Swedish GHG emissions report and after the calculations was done it is possible to determine that the Swedish EF is equal to the IPCC guideline mean value.

3.8. Suggestions for Standardization of Peatland GHG Emission Accounting

The EFs used in each country reports are developed based on the IPCC guidelines, but it is not clear why there is such a distinct difference between emission factors and methods for calculating further emissions. Therefore, several factors were identified in this study, which, according to the author, are essential for determining EFs. One of the factors that should be taken into account is the type of bog and its geographical location when studying the available material, this factor was described and taken into account only in the Finnish GHG emission report. An optional factor, which should be taken into account, is the type of peat when looking at the material, it was not observed that such a factor is taken into account to determine EFs. It should also be noted that the age and period of formation of peat bogs should be taken into account in determining the EFs of peat bogs. In this way, period-specific plants which may be rich in carbon would be included. Information on the type of peat bog and the conditions under which it was formed, and the physio-chemical composition of the peat should also be included. If possible, including these parameters would allow more accurate EF figures to be determined. Looking at the national GHG emission reports, it is possible to suggest that these parameters may have been taken into account in Finland, as these reports indicate that the EF is determined from a database that lists data on peat bogs.

By developing a more in-depth study, it was found that countries determine their EFs based on Tier methods, and thus it is possible to partially determine how reliable the provided data is. Tiers are divided into three levels, each indicating the requirements for this level to be used. However, it should be emphasized that these levels do not reflect the real situation and are only intended to indicate the approximate way in which EFs were obtained. In the case of Latvia, the EFs are based on the data obtained during the research, and therefore it is considered more reliable than the information that is taken from the data provided in the IPCC guidelines. However, this study represents EFs at a specific point in time and should be updated to provide a more accurate description of the situation. Based on the available information, it has become clear that in order to accurately describe the current situation and make regular improvements to the reporting system, a unified approach must be developed in which it is possible to obtain data on the types of bogs in different regions and the best methods of recording emissions.

4. CONCLUSION

The main goal of this article is to gather information about peat and peat bogs, as well as to give an insight into emission accounting in different countries in order to underscore the current challenges in standardizing global emission factors for peatlands. The study found a lack of information regarding factors that are used for EF calculations, it is therefore not possible to make specific statements about the data, so assumptions are made that the data is reliable given only the available information. Peat is mainly defined by its physical and/or chemical properties, but there is no one specific method for classifying peat. Similar to peat, for peat bogs there is no uniform method of classification for peat bogs, but it is possible to divide them in a generalised way according to:

a) peat bog water access (rain or groundwater);
b) terrain and hydrology of peat bogs;
c) the characteristic features of peat layers;
d) for the geomorphological features of peat bogs.

The lack of a unified classification of peat and peat bogs leads to the fact that emissions are incorrectly accounted for, and therefore, it is impossible to determine the true amount of emissions arising from peat fields. After conducting an in-depth analysis of the literature, a compilation and analysis of national emission factors was performed. The emission factors for peatlands in GHG emission reports are determined differently for each country. Finland's emission factors for CO_2, CH_4, and N_2O gases are the highest among the four countries that were analysed. It is unknown which parameters are included in the determination of these emission factors for each country in this study. Therefore, the result of this study indicates the need for definition of a more precise, uniform and fair reporting system for emission accounting, which can be verified by an international standardized procedure.

The conclusions of this study advocate for the establishment of a globally accepted framework for classifying peat and peat bogs, alongside a standardized methodology for calculating emissions from these carbon-rich ecosystems. Such a framework would facilitate accurate, transparent, and comparable reporting of emissions across countries, thereby enhancing the reliability of GHG inventories. The adoption of standardized methodologies for classifying and assessing peatland emissions will pave way for more informed and effective climate actions, benefiting both the environment and society at large.

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During the writing of this article, DeepL and Google translate was used to translate the text from Latvian to English. QuillBot was used to improve the language.

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ANNEX

TABLE A1. BOG CLASSIFICATION BY TOPOGRAPHY AND HYDROLOGY

Type of habitat	Characteristics	Areas	Locations	Typical plants	Reference
Bogs					
Blanket bog	Ombrotrophic peatland with high soil acidity	Formed on plains underlain by a low permeability mineral soil	Western and Northern British Isles, Faroe Islands and Western Scandinavia	*Calluna vulgaris, Eriophorum angustifolium, Molinia caerulea, Narthecium ossifragum, Schoenus nigricans, Scirpus cespitosus, Sphagnum compactum*	[18], [19], [42]
Raised bog	Oligotrophic peatland with acidic topsoil, raised center resembling a hill	Formed on flat ground, in cool climate and with heavy rainfall	Lowlands and hills of northern Europe, the foothills of the Hercynian Ranges, the Alpine and Carpathian Mountain regions	*Andromeda polifolia, Carex pauciflora, Drosera rotundifolia, Eriophorum, vaginatum, Ledum palustre, Scirpus cespitosus, Trichophorum cespitosum*	[18], [19], [43]
Eccentric bog	Mostly ombrotrophic with minerotrophic peat around edges	Located near lakes with a slop	Scotland, United States, Finland, Sweden, Canada	*Chamaedaphne calyculata, Kalmia angustifolia, Sphagnum fuscum, Carex trisperma*	[18], [44]

TABLE A2. FEN CLASSIFICATION BY TOPOGRAPHY AND HYDROLOGY

Type of habitat	Characteristics	Areas	Locations	Typical plants	Reference
Fen					
Horizon-type fen	Mostly known by its sub-type "Schwingmoor"*	Thin peat layer above the water surface	Central Europe, Irland, Sweden and Finland	*Carex lasiocarpa, Carex limosa, Carex rostrata, Menyanthes trifoliata, Calla palustris*	[18], [45], [46]
Aapa fen	Minerotrophic or ochrotrophic peat features	Forms in lowland, with a straight or slightly sloping surface. The edges are significantly raised, forming hills	Sub-Atlantic and sub-continental zones of Europe and in the Artic and sub-Artic zones of Russia	*Betula nana, Carex livida, Carex rostrata, Carex rotundata, Chamaedaphne calyculata, Dactylorhiza incarnata, Empetrum nigrum,*	[18], [19], [47]

Polygon-type fen	Distinct areas with a ridge about 0.5 m high	Usually arranged in polygons of 10 to 30 m in size	Typical in the tundra (northern areas where the average annual temperature is below –1 °C)	*Salix pulchra, Betula nana, Ledum decumbens, Vaccinium vitis-idaea, Rubus chamaemorus, Dryas punctata, Carex chordorrhiza, Hylocomium splendens, Sphagnum fimbriatum*	[18], [19], [48]
Palsa fen	Hills up to 8 m high	Forms in, lowlands where water accumulates	Iceland, Russia, Scandinavia	*Betula nana, Carex rotundata, Carex saxatilis, Eriophorum russeolum, Ledum palustre, Vaccinium microcarpum, Dicranum elongatum*	[18], [19], [49]
Sloping fen	Slope range from 1° to 20°, topographically similar to Aapa fen	Forms in mountain area with cool climate	Central Europe Scandinavia mid-boreal to northern boreal zones, United States and Canada mountain regions	*Carex pauciflora, Trichophorum cespitosum, Eriophorum vaginatum, Sphagnum compactum*	[18], [50]
Spring fen	Two types: artesian spring fen and surface spring fen	Forms at the source of a spring when there is a long-term accumulation of water	Central and western Europe, United States and Canada	*Bryum* spp., *Philonotis* spp., *Pohlia spp*	[18], [19], [45]

* The Schwingmoor subtypes characteristics is quite similar to transition mires and quaking bogs characteristics, it was therefore assumed that: Schwingmoor subtypes locations and typical plants are similar to transition mires and quaking bogs [51]