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Peat-based emissions in Finland's national greenhouse gas inventory

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Peat-based emissions are reported under three different reporting sectors in Finland's national greenhouse gas inventory: Agriculture, Land Use, Land-Use Change and Forestry (LULUCF) and Energy. Peat-based emissions comprise together around one third of the total reported net greenhouse gas emissions in Finland when also sinks and emissions from LULUCF sector are included. Most of the emissions come from the combustion of peat for energy but emissions from the agricultural use of peatlands and drained forest soils are also of importance. The IPCC (Intergovernmental Panel on Climate Change) provides the basic guidelines for the inventory calculations. However, the use of national methods and emission factors is encouraged. Introducing new country-specific methods or emission factors in the inventory calculations requires transparent documentation of the input parameters and the process how emission factors, parameters and models are derived. Here we describe the national system for estimating peat-based emissions for the greenhouse gas inventory, and the methods that are used in deriving the emission estimates, as well as possibilities to use new national emission factors for improving the estimates.

Introduction

The national system for compiling the greenhouse gas inventory

Finland as a party to the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol (UNFCCC 1997) is committed to reporting annually its greenhouse gas emissions and removals to the UNFCCC secretariat and the European Union. Finland has made a commitment to keep its average emissions over the 2008 to 2012 period at the level they were in 1990. Greenhouse gases included in UNFCCC and Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (UNFCCC 1997). Emissions are reported by gases and by emission sources from six reporting sectors namely (1) Energy, (2) Industrial processes, (3) Solvents and other product use, (4) Agriculture, (5) Land Use, Land-Use Change and Forestry (LULUCF), and (6) Waste. Reporting is done from the base year 1990 to the latest inventory year by using the Common Reporting Format (CRF) tables. In addition to the CRF tables, which contain the actual emissions figures and some background data, also a National Inventory

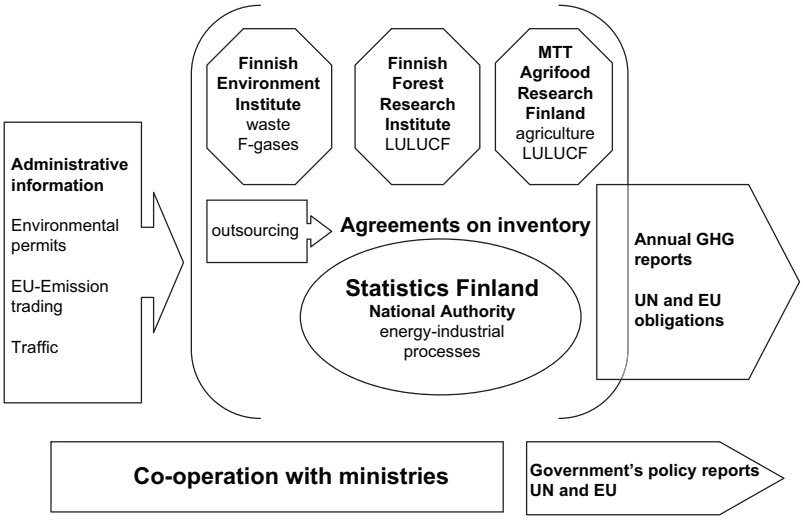

Fig. 1. National greenhouse gas inventory system in Finland.

Report (NIR) is required for the annual inventory submission to the UNFCCC secretariat. Methodologies and input data used in the calculations as well as uncertainty analysis, quality assessment of the reported figures and inventory process shall be transparently described in the NIR. Plans for improvement of the inventory data shall also be reported in the NIR. UNFCCC reporting guidelines on annual inventories (UNFCCC 2004) determine the reporting framework, the format and the content of the CRF tables and the NIR (UNFCCC 2004). In the latest 2006 inventory submission, the CRF tables were produced with the new CRF-reporter software developed by the UNFCCC secretariat (Inventory year is year $t-2$, submission year refers to year t).

Statistics Finland bears the overall responsibility for the national greenhouse gas inventories. It prepares the national emission inventory and co-ordinates quality management in the manner intended in the Kyoto Protocol. Statistics Finland also publishes and archives the inventory results, runs the general administration of the inventory, communicates with the UNFCCC and co-ordinates the matters related to inventory reviews. Besides Statistics Finland, Finland's greenhouse gas inventory system includes the following expert organisations: Finnish Forest Research Institute, MTT Agrifood Research Finland and Finnish Environment Institute (Fig. 1). Each expert organisation is responsible for those parts of the inventory calculations which belong to their area of expertise. Finnish Forest Research Institute has the responsibility over the Land Use, Land-Use Change and Forestry (LULUCF) sector's inventory calculations, excluding emissions from agricultural soils, which are calculated by the MTT Agrifood Research Finland. The area of Finland is divided into different land use categories according to the recommendations of a working group co-ordinated by the Ministry of Agriculture and Forestry (MMM 2005). MTT also delivers all the emission estimates for the Agriculture sector. The Finnish Environment Institute is responsible for the reporting of emissions from the Waste sector, Solvents and other product use and F-gases (HFCs, PFCs and SF_6). Emission estimates for the Energy sector and Industrial processes are calculated by Statistics Finland.

IPCC Guidelines for national greenhouse gas inventories

Parties to the UNFCCC and Kyoto Protocol prepare their national greenhouse gas inventories according to the guidelines of the Intergovernmental Panel on Climate Change (IPCC). Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Houghton *et al.* 1997) constitute the basic guidance for the inventory calculations. Due to the development of methodologies and research they have been completed and updated with the IPCC Good Practice Guidance and Uncertainty Man-

agement in National Greenhouse Gas Inventories (Penman *et al*. 2000) which provides more comprehensive guidance on estimating greenhouse gas emissions from all sectors except Land use, Land-Use Change and Forestry. Good Practise Guidance for Land Use, Land-Use Change and Forestry (GPG LULUCF) was published a few years later (Penman *et al*. 2003). Most of the parties to the UNFCCC followed the new IPCC GPG LULUCF guidelines in their inventory reporting for the first time in the inventory submission of 2005.

Reporting requirements in the Land use, land-use change and forestry sector have increased substantially since adopting the GPG LULUCF (Penman *et al*. 2003). Previously most of the parties reported only the changes in carbon stock in above-ground biomass on forest land and CO_2 emissions from agricultural soils in the LULUCF sector. The new reporting requirements comprise the anthropogenic (human induced) emissions and removals from all the relevant carbon pools (above and below ground biomass, soil organic matter, litter and dead wood) divided to six different land use categories (forest land, cropland, grassland, wetlands, settlements and other land). Guidance is given separately for the land area which has remained in the same land use category and land which has been converted to another land use category.

Peat-based emissions in Finland's national greenhouse gas inventory

Guidance for the calculation of peat-based greenhouse gas emissions is found under several chapters of the IPCC guidelines (Table 1). Guidance for calculating N_2O emissions from cultivated agricultural soils is provided in IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (Penman *et al*. 2000). Most of the guidance for calculating peat-based emissions from the land use, land-use change and forestry sector is given in the GPG LULUCF (Penman *et al*. 2003) including organic forest soils, organic agricultural soils (only CO_2 emissions from cropland and grassland), industrial peat production areas and wetlands (Table 1). Wetlands are defined in the GPG LULUCF as land that is covered or saturated by water for all or part of the year (e.g. peatland) and does not fall into the forest land, cropland, grassland or settlement categories. The wetland category in the GPG LULUCF includes peat extraction areas. New IPCC 2006 Guidelines, which will replace the IPCC 1996 Guidelines (Houghton *et al*. 1997), will combine the reporting of Agriculture and LULUCF sectors to one sector called AFOLU (Agriculture, Forestry and Other Land Use). Methodologies for the estimation of emissions from peat combustion are provided in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (Penman *et al*. 2000).

In 2004 all the peat-based emissions reported in the Finnish inventory comprised about one third of the total net emissions in Finland (LULUCF sector included in total) (Table 2). When only emission sources and reporting sectors included in the accounting of Finland's

Table 1. Reporting of peat-based emissions according to the IPCC guidelines.

Emission source	Reporting category in the inventory	Reporting requirements and guidance
N_2O emissions from organic agricultural soils	Agriculture sector/cultivation of organic soils category	(Penman *et al*. 2000)
CO_2 emissions from organic agricultural soils	LULUCF sector/Cropland and Grassland categories	(Penman *et al*. 2003)
CO_2 emissions from drained organic forest soils	LULUCF sector/Forest land category	(Penman *et al*. 2003)
CO_2, N_2O and CH_4 emissions from peat extraction fields	LULUCF sector/Wetlands category	(Penman *et al*. 2003)
CO_2, N_2O and CH_4 emissions from peat combustion	Energy sector/fuel combustion	(Penman *et al*. 2000)

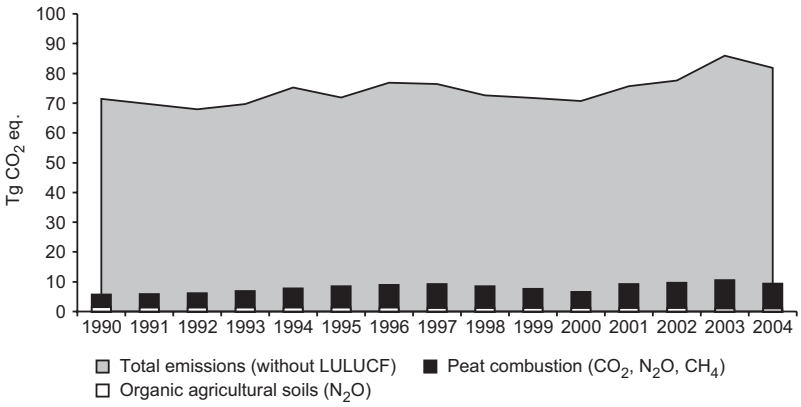

Fig. 2. Peat-based emissions in Finland compared with total greenhouse gas emissions in 1990–2004 under the assigned amount. Peat-based emissions calculated under Finland's assigned amount include emissions from peat combustion and N_2O emissions from organic agricultural soils.

assigned amount under the Kyoto Protocol are considered, the share of peat-based emissions from total emissions was around 13% (LULUCF sector excluded from total) (Fig. 2). The assigned amount is the total amount of greenhouse gases that each country is allowed to emit during the first commitment period 2008–2012 of the Kyoto Protocol. The assigned amount is calculated as: 1990 emissions of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 from the sources listed in Annex A of the Kyoto Protocol multiplied by the percentage (%) listed for a Party in Annex B of the Kyoto Protocol, multiplied by five (UNFCCC 1997: Article 3.7). According to the modalities for the accounting of assigned amounts under the Kyoto Protocol, the LULUCF sector is excluded for those parties whose LULUCF sector was a net sink in 1990 (The Marrakesh Accords 2001). Finland's LULUCF sector was a net sink in 1990, thus from all peat-based emissions only emissions from peat combustion and N_2O emissions from organic agricultural soils are included in the assigned amount (Table 2).

The largest source of peat-based emissions

Table 2. Peat-based emissions in 2004 in Finland's national greenhouse gas inventory. The term 'total net emissions' refers to total emissions including sinks and sources from the LULUCF sector. In 2004 the LULUCF sector was a net sink of –18.5 Tg CO_2 eq. and total net emissions were 63.3 Tg CO_2 eq. Total emissions from the emission sources and reporting sectors included in accounting of assigned amount (AA) were 81.8 Tg CO_2 eq. in 2004 (LULUCF sector as a whole excluded). CO_2 equivalence (CO_2 eq.) is a metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). The GWP for methane is 21 and for nitrous oxide 310.

Reporting category/ Emission source	Gas	Emissions in 2004 (Tg CO_2 eq.)	Relative uncertainty (%) 95% C.I.	Percentage of total net emissions	Percentage of total emissions incl. in AA
Agriculture					
Cultivation of organic agricultural soils	N_2O	1.06	–75 to 166	1.70	1.30
Energy					
Peat combustion	CO_2	9.26	±5	15.0	11.0
	N_2O	0.12	±60	0.20	0.10
	CH_4	0.01	±60	0.01	0.01
LULUCF					
Cultivation of organic cropland	CO_2	4.97	–90 to +96	7.90	not included
Cultivation of organic grassland	CO_2	0.05	–89 to +100	0.05	not included
Drainage of organic forest land	CO_2	6.76	±150	10.7	not included
Peat extraction	CO_2	0.61	–80 to +205	1.00	not included
	N_2O	0.01	–	0.02	not included
	CH_4	0.01	–80 to +205	0.02	not included
Total		22.9		36.1	12.7

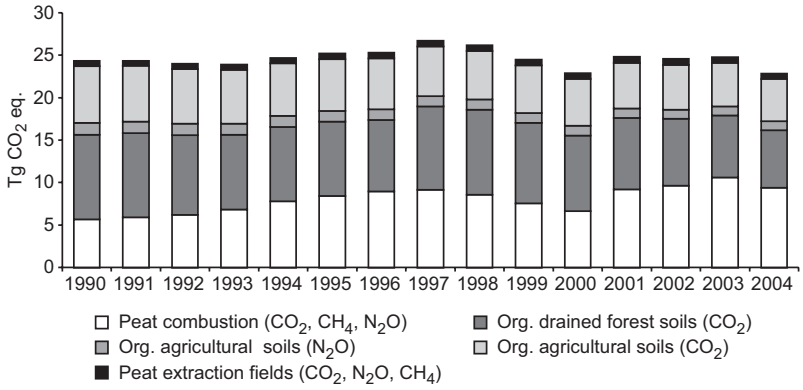

Fig. 3. All the peat-based emissions in 1990–2004 included in Finnish inventory (reporting sectors energy, agriculture and LULUCF).

in the inventory is the combustion of peat for energy and heat. In 2004 CO_2 emissions from peat combustion were around 9.3 Tg CO_2 eq. (preliminary figure) i.e. around 11% of the total greenhouse gas emissions in Finland excluding the LULUCF sector (Table 2). In addition, small amounts of N_2O and CH_4 emissions are related to peat combustion.

When also the LULUCF sector is taken into account, the second largest source of peat-based emissions are drained organic forest soils. In 2004, CO_2 emissions from drained organic forest soils totalled 6.8 Tg CO_2 (Fig. 3). Nitrous oxide emissions from drained forest soils have not been included in the inventory reporting so far.

Cultivated organic agricultural soils are another significant source of peat-based emissions in the Finnish inventory. Following the UNFCCC reporting guidelines (UNFCCC 2004) N_2O emissions from agricultural soils shall be reported in the agriculture sector of the inventory, while CO_2 emissions from corresponding agricultural soils shall be reported in the LULUCF sector divided between land use categories Cropland and Grassland. N_2O emissions from organic agricultural soils were 1.06 Tg CO_2 eq. in 2004 (Table 2). Corresponding CO_2 emissions in the same year were around 5 Tg CO_2, of which 4.97 Tg CO_2 eq. came from croplands and 0.05 Tg CO_2 eq. from grasslands. In total, the emissions from the cultivation of organic agricultural soils in 2004 were 6.1 Tg CO_2 eq.

Emissions from peat extraction areas were reported in the 2006 submission for the first time in LULUCF sector's Wetland category as the IPCC guidelines suggest (Penman *et al*. 2003). Previously they were reported as fugitive emissions in the Energy sector. In 2004, emissions from peat extraction areas totalled around 0.62 Tg CO_2 eq. Emissions from peat extraction areas include CO_2, CH_4 and N_2O emissions from the actual peat extraction areas (active and temporarily set-aside areas) and abandoned, former peat extraction areas without vegetation.

Reporting of some peat-based emissions from sources referred to in the GPG LULUCF is optional, because the scientific basis for providing general methodological guidance for their estimation is too sparse. Optional emission categories are placed in appendixes of the GPG LULUCF and include non-CO_2 emissions from drainage and rewetting of forest soils and emissions from wetlands which have remained wetlands. If a country presumably has significant emissions from an optional source category national methodologies should be developed to include them in the national inventory calculations.

Utilisation of new emission data in national greenhouse gas inventories

According to the IPCC GPG LULUCF (Penman *et al*. 2003) it is good practice to apply new inventory methods as new data becomes available if it improves the reliability and accuracy of the inventory. Whenever a new methodology or an emission factor is applied in the inventory, emission estimates from the previous inventory years (from the base year 1990 to the latest inventory year) shall also be recalculated using

the new method and/or emission factor. This ensures that the emissions estimated for different years are as comparable as practically possible.

When new country-specific emission factors or methodologies are adopted to national inventories, they shall be transparently documented. Documentation includes defining of input parameters and describing the process of how emission factors, parameters and models were derived. Related uncertainties should also be described. The whole inventory, including new data, will be reviewed annually by the international expert review teams as part of the inventory process.

Actual guidance given in the GPG LULUCF (Penman *et al*. 2003) for estimating peat-based emissions from land use and land-use change is rather scarce due to the inadequate and partly contradictory research results from the subject matter. Therefore the results of the research programme "Greenhouse impact of the use of peat and peatlands in Finland", which produced valuable country-specific data of peat-based emissions, were utilised in the latest Finnish national greenhouse gas inventory submission of 2006. In the research programme emission factors for different forms of the use of peatlands were developed, including emission factors for peat extraction areas, drained forested peatlands, cultivated organic fields, afforested agricultural peat soils, bare organic soils and different types of natural bogs and fens. Publishing of the emission factors developed in the research programme is a response to the recommendation of Good Practice Guidance for LULUCF to share the information of the country-specific emission factors and methodologies between other countries with similar environmental conditions. It also broadens the scientific basis of this research field in general.

Good practice guidance allows reporting parties to choose the level of reporting (Tier levels) depending on the availability of resources. While Tier level 1 reporting uses default values and simple equations provided in the guidelines, higher Tier reporting in general requires country-specific emission factors, measured data and more sophisticated methodologies like dynamic modelling. At higher Tiers, the reporting parties may also subdivide emission factors and area data according to peat fertility, peat type and/or previous land use. According to the good practice guidance, the highest possible Tier level for which data and methods are available should be used in the inventories. Higher Tier-level methods should be developed for significant emission sources. Emission factors developed in the research programme "Greenhouse Impacts of the Use of Peat and Peatlands" correspond to Tier levels 2–3 of the IPCC guidance for inventory reporting. The results are utilised in Finnish greenhouse gas inventories as much as is practical. To get the best benefit from all the developed emission factors, also the area data used in the inventory calculations should be stratified to correspond as far as possible to those site and climatic conditions against which the emission factors were developed. In order to give the best estimate of the areas of different types of organic soils in Finland, a monitoring system for land use and land-use change for organic soils should be developed.

New CO_2 and N_2O emission factors for agricultural organic soils were used in the Finnish greenhouse gas inventory submission of 2006 to revise N_2O emissions arising from cultivation of organic soils in the Agriculture sector and CO_2 emissions from organic croplands in the LULUCF sector. In the 2006 submission also CO_2 emissions from drained forest land were reported for the first time using an emission factor developed in that research programme. Emission factors for CO_2 and CH_4 for peat extraction sites, also developed in the research programme, were already in use in the 2005 inventory submission.

Calculation of peat-based emissions in the sector Agriculture

Method for calculating N_2O emissions from cultivated organic soils

In the greenhouse gas inventory, N_2O emissions from cultivated organic soils are classified as "direct N_2O emissions from agricultural soils" together with emissions from synthetic fertilisers, animal manure, sewage sludge, nitrogen fix-

ation and crop residues. Emissions from organic soils are calculated using the following equation (modified from eq. 4.20 of Penman *et al*. 2000):

$$N_2O_{OS} = A \times EF \quad (1)$$

where N_2O_{OS} = Annual N_2O emissions from cultivated organic soils, A = Land area of cultivated organic soils, ha, EF = Emission factor.

Area estimates

The organic soils included in the inventory are defined as in Penman *et al*. (2003). The area of organic soils in active cultivation for the years 1990–2003 is based on linear interpolation between the estimates presented in Kähäri (1987) and Myllys and Sinkkonen (2004) (Table 3). From 2004 on, the area estimates are extrapolated from these data. The original estimates were based on the soil analysis databases of the largest soil analysis laboratories which analyse the soil fertility samples taken by farmers. A manual soil type analysis is part of the analysis procedure. The area trend has been decreasing due to the removal of peat soils from cultivation (e.g. afforestation), and the loss of carbon from these soils which slowly turns these fields to mineral soils. However, because of the lack of systematic data collection, the area of cultivated organic soils can be considered very uncertain.

Emission factors

New emission factors for calculating N_2O emissions from agricultural organic soils were used in the inventory submission of 2006. Different emission factors for grass and other crops were developed on the basis of national research results (Table 4). The emission factor for grass is 4.0 kg N_2O-N ha^{-1} yr^{-1} and for other crops 11.7 kg N_2O-N ha^{-1} yr^{-1} (Monni *et al*. [in press]). The default emission factor of 8 kg N_2O-N ha^{-1} a^{-1} for all crops (Penman *et al*. 2000) was applied in the inventory before the 2006 submission. According to the research results, mitigation of the emissions from cultivated organic soils is possible by favouring grass cultivation, and the availability of two different emission factors enables the reporting of such emission reductions in the inventory.

Table 3. Area distribution of organic soils in Finland in 1990–2004. In the area estimate of Cropland the area of grass > five years has been subtracted from the original estimate of Myllys and Sinkkonen (2004). The area of grassland includes permanent grasslands and abandoned fields.

Year	Cropland kha	Grassland kha	Percentage of organic soils of the total agricultural area
1990	366.48	104.86	16
1991	360.21	95.96	16
1992	353.88	89.63	15
1993	347.56	84.96	15
1994	341.27	70.85	15
1995	334.79	92.59	16
1996	328.06	94.69	15
1997	321.22	87.59	15
1998	314.94	74.97	15
1999	308.74	70.56	14
2000	301.82	67.16	14
2001	295.59	65.78	13
2002	289.15	61.52	13
2003	282.77	58.80	13
2004	276.40	56.44	12

Table 4. Emission factors used for calculating N_2O and CO_2 emissions from organic soils.

Emission source	Emission factor	
	N_2O (kg N ha^{-1} yr^{-1})	CO_2 (t C ha^{-1} yr^{-1})
Cropland		
Grass in crop rotation	4.0 (Monni *et al.* [in press])	4.1 (Maljanen *et al.* 2007)
Other crops	11.7 (Monni *et al.* [in press])	5.7 (Maljanen *et al.* 2007)
Grassland	–	0.25 (Penman *et al.* 2003)

Uncertainty estimates

The uncertainty range for the new emission factors has been estimated on the basis of annual emission estimates from field measurements and is currently –70% ... +170%. Uncertainties in the area estimates of cultivated organic soils were estimated by expert judgement as ±30% for 1990 and ±20% for 2003. No systematic data collection about the area of cultivated organic soils exists in Finland, and thus the development of a soil monitoring system could greatly improve the area estimate and reduce the uncertainty.

Calculation of peat-based emissions in the sector LULUCF

Organic agricultural soils

Method of calculating CO_2 emissions from organic agricultural soils

The emissions from the mineralization of peat in organic agricultural soils are calculated as annual losses of CO_2 per hectare of organic soil using the following equation:

$$\Delta C_{ccOrganic} = A \times EF \quad (2)$$

where $\Delta C_{ccOrganic}$ = annual CO_2 emissions from cultivated organic soils in cropland/grassland, A = land area (ha), EF = emission factor (t C ha^{-1} yr^{-1}). The emissions are calculated both for the category cropland and grassland. Cropland includes fields under crops and temporary fallow, Grassland includes permanent grasslands and abandoned fields. The category cropland is further divided into grass (included in crop rotations) and other crops. Both national and default IPCC emission factors have been used in the calculation (Table 4).

Area estimates

For calculating the CO_2 emissions from the category "cropland remaining cropland", the total area of cultivated organic soils is the same as that in the sector Agriculture for calculating N_2O emissions. Grass included in crop rotation (not defined as permanent grassland) is estimated to be grown on 50% of the organic soils, and the rest is mainly used for growing cereals.

The category "grassland remaining grassland" includes the fields, meadows and pastures growing grass continuously for more than five years and abandoned fields that cannot yet be classified as forests. The area estimate of agricultural soils in the National Forest Inventory includes both actively cultivated and abandoned fields whereas the agricultural statistics report only the area in active cultivation (MMM 2004). Since separate area estimates for grassland more than five years old can be found in the agricultural statistics, the area of permanent grasslands can be calculated by subtracting the area agricultural soils (excluding the area of grasslands more than five years old) from the area of agricultural soils reported in the National Forest Inventory. This area estimate includes all soil types. The area estimate for organic soils within this category is estimated by multiplying the area of grasslands with the percentage of organic soils of the total agricultural area (Table 3).

Emission factors

New emission factors for CO_2 emissions from cropland on organic soil produced by the research programme "Greenhouse impact of the use of peat and peatlands in Finland" were used in the inventory submission 2006. There were separate emission factors for grass in crop rotation and other crops (Table 4). The emission factor for grass on organic soil was 4.1 t CO_2-C ha^{-1} yr^{-1} and that for other crops 5.7 t CO_2-C ha^{-1} yr^{-1} (Maljanen *et al.* 2007). The carbon loss from grasslands on organic soils was still calculated using the default emission factor of IPCC (0.25 t CO_2-C ha^{-1} yr^{-1}) (Penman *et al.* 2003) in the inventory submission 2006. The new emission factors are higher than the previously used national emission factors (2.0 t CO_2-C ha^{-1} yr^{-1} for grass and 4.0 t CO_2-C ha^{-1} yr^{-1} for other crops) which were based on fewer measurements (Berglund 1989, Nykänen *et al.* 1995).

Uncertainty estimates

Uncertainty in the area of organic cropland was estimated as ±30% for 1990 and ±20% for 2003 based on expert judgement. The uncertainty estimate was not yet updated according to the national emission factors but the default uncertainty estimate of ±90% of the IPCC (Penman *et al*. 2003) for the CO_2 emission factors for organic soils was applied in the inventory submission of 2006. The proportion of grasslands on organic soils as well as the distribution of grass and other crops were estimated by expert judgement and thus are very uncertain.

Organic forest soils

Method of calculating CO_2 emissions from drained organic forest soils

For the 2006 inventory submission, CO_2 emissions from drained organic forest soils were included for the first time and reported as part of the land-use category Forest land in the LULUCF sector.

Table 5. Area of drained organic forest soils in Finland in 1990–2004. Source: National forest inventory.

Year	Rhtkg (kha)	Mtkg (kha)	Ptkg (kha)	Vatkg (kha)	Jätkg (kha)	Total (kha)
1990	706	1143	1488	838	8	4184
1991	706	1143	1488	838	8	4184
1992	701	1158	1498	843	15	4215
1993	685	1161	1505	861	20	4233
1994	689	1185	1546	867	24	4312
1995	699	1227	1546	861	30	4363
1996	699	1227	1546	861	30	4363
1997	717	1270	1694	868	37	4586
1998	729	1282	1769	859	39	4678
1999	729	1282	1771	856	39	4677
2000	729	1282	1771	856	39	4677
2001	729	1282	1771	856	39	4677
2002	729	1282	1771	856	39	4677
2003	729	1282	1771	856	39	4677
2004	729	1282	1771	856	39	4677

Rhtkg = herb-rich type
Mtkg = *Vaccinium myrtillus* type I and II
Ptkg = *Vaccinium vitis-idaea* type I and II
Vatkg = dwarf-shrub type
Jätkg = *Cladina* type

Emissions from changes in C stock in organic forest soils are calculated as the difference between the CO_2 emissions from decomposition (heterotrophic soil respiration) and below-ground litter production. CO_2 emissions from decomposition were estimated on the basis of the national emission factors (Minkkinen *et al*. 2007). Below-ground litter production includes litter production of roots of trees, shrubs and graminoids and roots of trees the subject of cutting and natural mortality. Other C pools (dead organic matter and biomass) on drained organic forestland acted as CO_2 sinks (Statistics Finland 2006).

Area data

Area data for drained organic forest soils is obtained from the Finnish National Forest Inventory. The area data was divided into different site types for the calculation purposes to correspond to the developed emission factors (Table 5).

Emission factors

New site-type specific emission factors used in calculations were developed in the research programme "Greenhouse Impacts of the Use of Peat and Peatlands" by Minkkinen *et al*. (2007) (Table 6). Descriptions for the site types can be found from Laine (1989).

Uncertainties

Uncertainty for the emission estimates from

Table 6. Carbon emissions from heterotrophic soil respiration of drained forest soils. Source: Minkkinen *et al.* (2007).

Site type*	Emission factor (g C m^2 a^{-1})	Standard deviation
Jätkg	185.2	9.1
Vatkg	218.9	15.4
Ptkg	242.3	15.6
Mtkg	312.1	20.2
Rhtkg	425.7	25.7

* For explanations *see* Table 5.

organic forest soils are high and were estimated for the inventory by experts as around 120%–150% (T. Penttilä and K. Minkkinen pers. comm.).

Peat extraction areas

Method of calculating CO_2, N_2O and CH_4 emissions from peat extraction areas

The default methodology provided in the GPG LULUCF (Penman *et al*. 2003) for estimating emissions from the peat extraction areas includes the changes in carbon stock in soil organic matter due to oxidation of peat in the aerobic layer on the land during the extraction as well as the emissions from the removal of vegetation from the area prepared for peat extraction. Finland reports CO_2, CH_4 and N_2O emissions from peat extraction areas under the LULUCF sector's Wetland category as GPG LULUCF (Penman *et al*. 2003) suggests. The emissions from peat extraction are calculated by multiplying the area estimates with national emission factors. Emissions from removal of tree biomass from the extraction areas are reported under the category Forest land.

Activity data

Annual activity (area) data is calculated from the data received from the Association of Finnish Peat Industry and the environmental administration of Finland (Regional Environmental Center of North Ostrobothnia). From the beginning of 2006 area data will be collected with a combined electronic inquiry from Statistics Finland and Finland's environmental administration covering all the peat producers with the environmental permit for the peat production. The area data include active and temporarily set-aside peat extraction fields and abandoned, non-vegetated and emptied peat extraction areas. In 2004 they totalled around 69 000 ha.

Emission factors

CO_2 and CH_4 emission factors are based on the results from the research programme "Greenhouse Impacts of the Use of Peat and Peatlands" (Table 7). They were already used in the inventory submission of 2005. The emission factor for N_2O emissions is from Nykänen *et al*. (1996).

Uncertainty estimates

In the latest National Inventory Report (2006 submission), the total uncertainty in emissions from peat extraction sites is estimated to be –80% to +205%. Uncertainty associated with peat production area is estimated to be ±15%. The uncertainty estimate covers possible errors or misunderstandings in responses to the survey. Uncertainty information from the new emission factors was not available for the year 2006 inventory submission, therefore the same uncertainties for the CO_2 and CH_4 emission factors were used as in the previous inventory submissions.

Calculation of peat-based emissions in the sector Energy

Peat combustion

Method

The CO_2, CH_4 and N_2O emissions from the combustion of peat for energy and heat are reported

Table 7. Emission factors used in calculation of emissions from peat production sites (kg CO_2-eq. ha^{-1} yr^{-1}).

	Surface flux/ North boreal	Surface flux/ Middle boreal	Surface flux/ South boreal	Stockpiles	Ditches
CO_2					
Peat production area	6020	7210	7350	1750	90
Abandoned (non-vegetated) area	4640	5040	5070		
CH_4	50	50	50	–	46
N_2O	120	120	120		0.5

in the energy sector of the greenhouse gas inventory. Peat is classified as a fossil fuel in the inventory. Emissions from fuel combustion in point sources are in general calculated with the ILMARI calculation system in Statistics Finland. In the ILMARI system emissions are calculated with a bottom-up method using the annual fuel consumption of boilers and processes. Fuel combustion data is available by boiler/process level and by fuel type. Calculation of the CO_2 emissions is based on a country-specific method using detailed activity (fuel consumption) data and fuel-specific emission factors. Technology-specific emission factors depend on the type, capacity, main fuel and combustion technology of the installation (power plant/boiler/process) (Statistics Finland 2006).

Basic calculation formulas used in the calculations are Eq. 3 for CO_2 and Eq. 4 for other gases (Statistics Finland 2006).

$$E_{CO2} = F \times \mathrm{EF(fuel)} \times \mathrm{OF(fuel)} \quad (3)$$

$$E_{\text{other gases}} = F \times \mathrm{EF(technology)} \quad (4)$$

where E_{CO2} = emissions of CO_2, $E_{\text{other gases}}$ = emissions of other gases, F = fuel consumption, EF(fuel) = fuel-specific emission factor, OF(fuel) = fuel-specific oxidation factor, and EF(technology) = technology-specific emission factor.

National emission factor used for milled peat is 105.9 g CO_2 MJ^{-1} and for sod peat 102 g CO_2 MJ^{-1}. The IPCC default emission factor for peat is 106 g CO_2 MJ^{-1}. The value 0.99 is used as the oxidation factor.

Uncertainty estimates

The uncertainty in the total use of peat fuel and also the uncertainty of the emission factors for peat was estimated as ±5% in the national greenhouse gas inventory reporting (Statistics Finland 2006).

Conclusions

Peat-based emissions make a significant part of the greenhouse gas emissions included in Finnish greenhouse gas inventory. Due to the biological nature of these emissions there are high uncertainties related to the calculation of them (emission from peat combustion as an exception). Several new national emission factors produced by the research program "Greenhouse impact of the use of peat and peatlands in Finland" enable more accurate estimation of the peat-based emissions in Finnish inventory. However, further research is still needed to decrease the high uncertainties. In addition, the establishment of a land use and land-use change monitoring system would increase the reliability and accuracy of the emissions estimates in the LULUCF sector.

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