

REVISION

Submission of revised manuscript: Drainage of organic soils and GHG emissions: Validation with country data

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This document contains a marked-up version of the original manuscript. We believe this revision fully addresses the comments from the three anonymous referees. Point-by-point responses to the comments are included at the end of the manuscript as annotations posted directly to the original pdf uploaded by the referees.

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The following are the principal changes to the manuscript:

1. As suggested by Referee #1, we extended the section on Limitations and uncertainties to include a discussion on how EFs from the Supplement on Wetlands would alter our estimates. We added two additional tables (Table 5 and Table A3) to support the new analysis. The section further clarifies the differences in methods from the Supplement.
- 15 2. Limitations and uncertainties are now presented after the main results and the sections are now numbered differently than in the original manuscript.
3. Further to suggestions from Referee #1 and Referee #2, we further specified in the section on Limitations and uncertainties that the current discussion is limited to the drainage of organic soils for agriculture and acknowledged that peat degradation occurs under other land covers/uses. In the same vein and further to the comment from Referee #2, we specified that our methodology focuses on agricultural land uses and does not analyse the impacts of wildlife on organic soils.
- 20 4. Further to comments from Referee #1 and Referee #2, we provided additional explanation on the discrepancy observed between results from Page et al., 2011 and estimates from Gumbrecht et al., 2017.
- 25 5. Further to comments from Referee #1 and Referee #2, we revised extensively section 5.2.3 to improve the clarity of the discussion. In response to Referee #1, we specified that we chose for the comparison with our estimates the EFs from literature that refer to mature plantations (+5 years since drainage) and added relevant information to Table 8.

Yours faithfully,

30 Francesco Tubiello and Giulia Conchedda

Drainage of organic soils and GHG emissions: Validation with country data

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Abstract. Drainage of large areas with organic soils was conducted over the past century to free land for agriculture. A significant acceleration of such trends was observed in recent decades in South-East Asia, largely driven by drainage of tropical peatlands, an important category of organic soils, for cultivation of oil palm. This work presents methods and main results of a new methodology developed for FAOSTAT, whereby the overlay of dynamic maps of land cover and the use of information on histosols allows the production of a global annual dataset of drained area and emissions over a time series, covering the period 1990–2019. This is an improvement over the existing FAO approach, which had produced only a static map of drained organic soils for the year 2000. Results indicate that drained area and emissions increased by 13 percent globally since 1990, reaching in 2019 24 million ha of drained organic soils, with world total emissions of 830 million tonnes of carbon dioxide (CO₂) equivalent. Of these totals, the largest contribution was from the drainage of tropical peatlands in South-East Asia, generating nearly half of global emissions. Results were validated against national data reported by countries to the UN Climate Convention and to well-established literature. Overall, the validation yielded a good agreement with these sources. FAOSTAT estimates explained about 60 percent of the variability in official country reported data. The predicted emissions were virtually identical – with over 90 percent of explained variability – to official data from Indonesia, currently the top emitting country by drained organic soils. Also, calculated emissions factors for oil palm plantations in Indonesia and Malaysia were in the same range and very close to emissions factors derived from detailed field measurements. This validation suggests that the FAO estimates may be a useful and sound reference in support of countries reporting needs. Data are made available as open access via the Zenodo portal (Tubiello and Conchedda, 2020) with DOI 10.5281/zenodo.3942370.

55 1 Introduction

Organic soils are, generally speaking, wet ~~soils~~soil ecosystems, characterized by high levels of organic matter, which accumulates in large quantities under the anoxic conditions that exist in the presence of water. They include tropical peatlands, high-latitude bogs and mires. Indeed, while organic soils cover globally a mere 3 percent of the terrestrial land area, they represent up to 30 percent of the total soil carbon, playing an important role in maintaining the earth's carbon balance (FAO, 2020a). Drainage of organic soils releases large quantities of carbon dioxide (CO₂) and nitrous dioxide (N₂O) into the atmosphere, as a result of the increased oxidation and decomposition rates of the underlying organic matter once water is

removed. These emissions typically last for several decades after the drainage event, due to the large quantities of available organic substrate ~~available~~. Agriculture is a major cause of drainage of organic soils around the world, ~~and especially since 1990~~ after the 90s due to the cultivation of permanent crops such as oil palm in South-East Asia. Restoration of degraded organic soils is currently a priority in several countries as part of their greenhouse gas mitigation and ecosystem restoration commitments under the UN climate convention (Leifeld and Menichetti, 2018; Tiemeyer et al., 2020). Measuring current trends, globally and with country detail, is therefore important to identify and quantify existing and fast-developing new hotspots of degradation and to help reduce emissions from drained organic soils in future decades. Estimates of drainage area and greenhouse gas (GHG) emissions from organic soils for the year 2000 were developed by FAO and used by the Intergovernmental Panel on Climate Change (IPCC) for global analysis (Tubiello et al., 2016; Smith et al., 2014). That preliminary work was based on the geospatial overlay of two static maps, one for land cover, indicating presence of agriculture, and one for soil characteristics, indicating presence of organic soils, through the use of histosols as proxy. This paper describes additional methodological developments made possible by the availability of time dependent land cover maps, resulting in the production, for the first time, of estimates over a complete time series (1990–2019).

75 **2 Material and Methods**

Organic soils are characterized by high concentrations of organic matter. They mostly develop under poorly drained, wetland ~~wet~~ conditions and are found at all altitudes, with the vast majority occurring in lowlands (Gorham, 1991; Rieley and Page, 2016). Peatlands are an important type of organic soils (Page et al., 2011; IPCC, 2014a). According to IPCC (2006), organic soils can be largely identified with the *histosols* group of the FAO-UNESCO classification. FAO and Wetlands International (2012) ~~indeed~~ described *histosols* as soils that develop in (predominantly) “moss peat in boreal, arctic and subarctic regions, *via* moss peat, reeds/sedge peat and forest peat in temperate regions to mangrove peat and swamp forest peat in the humid tropics”. Common names for *histosols* are ‘peat soils’, ‘muck soils’, ‘bog soils’ and ‘organic soils’ (FAO et al., 1998). In this work, we follow IPCC guidelines and identify organic soils with histosols. It should be noted that these might include areas that are not strictly defined as peat soils. Cropland and grassland organic soils are drained permanently or semi-permanently, as well as regularly limed and fertilized, to permit annual or permanent crop cultivation, including tree plantations, or to support livestock grazing. ~~For these reasons, the presence of cultivated crops or grazing animals on organic soils (Noble et al., 2018) — which have otherwise low productivity — may be associated with drainage, causing N and C losses and overall degradation (Martin et al., 2013). Peat emissions are unique in that~~ Peat emissions are unique as they continue emitting for long periods after the initial drainage (FAO, 2020).

Area of drained organic soils and associated greenhouse gas (GHG) emissions were estimated following default Tier 1 methods of the IPCC (2006) over IPCC land use classes *Cropland* and *Grassland* (corresponding to FAO land use classes “Cropland” and “Land under permanent meadows and pastures”). This methodology was already applied within

FAOSTAT (Tubiello et al., 2016) and was extended herein by introducing a time-dependent component, as follows in Eq.

95 (1):

$$Emissions_{y,i,j} = \sum_{y,j} A * EF_{i,j,k} \quad \text{Eq. (1)}$$

where:

$Emissions_{y,i,j}$ = Emissions for year y of greenhouse gas $i = N_2O, CO_2$ over land use type $j =$ cropland, grassland;

100 $\sum_{y,j} A$ = Total area for year y of drained organic soils under land use type $j =$ cropland, grassland;

EF_{ijk} = Emissions Factors, emissions per unit area of drained organic soils of greenhouse gas i , land use type j and climatic zone k ;

y = Years in the period 1992–2018 as yearly time-steps representing time-dependent land cover maps;

k = Boreal, temperate, tropical climatic zones, following IPCC (2006).

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At pixel level, the work we carried out included the use of a geospatially-detailed map of organic soils (FAO and IIASA, 2012) annual maps of land cover (ESA CCI, 2020); a combined livestock density map (Robinson et al., 2014); and a map of climatic zones (JRC, 2010). Details on these inputs are given in following sections. The area drained for cropland and grassland organic soils represent the time-dependent components of Eq. (1). They were calculated as follows:

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$$A_{cropland,y} = LU_{cropland,y} * WMS_{histosols} \quad \text{Eq. (2)}$$

$$A_{grassland,y} = LU_{grassland,y} * WMS_{histosols} * LDR_{>0.1} \quad \text{Eq. (3)}$$

Where:

115 $A_{cropland,y}$; $A_{grassland,y}$ = Area of drained organic soils on cropland and grassland, for the year y obtained as the overlay of

$LU_{cropland,y}$; $LU_{grassland,y}$ = Area, for the year y under IPCC and FAO land use class “cropland” and “grassland”, derived from land cover classes (cropland or grassland) in global land cover maps (C3S, 2019) of the year y ;

$WMS_{histosols}$ = Area with soil type *histosols* from the Harmonized Soil Map of the World (FAO and IIASA, 2012).

120 Following IPCC (2006), *histosols* are used as proxy for organic soils;

$LDR_{>0.1}$ = For grassland organic soils only, area with livestock density of ruminants (in livestock units) above a defined threshold, derived from global maps of the FAO Gridded Livestock of the World (Robinson et al., 2014), to identify grazed grassland.

125 The IPCC basic methodology for carbon (C) and nitrous oxide (N₂O) emissions estimates from organic soils assigns an annual
EF (i.e. quantity of gas emitted per ha and per year per unit of activity data) associated with the loss of these gases following
the drainage for agriculture. Drainage stimulates the oxidation of organic matter previously built up under a largely anoxic
environment. The rates of emissions are influenced by climate, with warmer climates accelerating the processes of oxidation
of soil organic matter hence causing higher emissions than in temperate and cooler climates. The emission factors by gas thus
130 are climate-dependent. In this methodology, we spatialized the relevant IPCC emission factors following a global map of
climatic zones (JRC, 2010) to produce global maps EF for the two gases. The pixel-computations then multiply the area of
drained and managed organic soils from Eq. (2) and Eq. (3) above by global maps of emission factors to derive estimates of
annual N₂O and CO₂ emissions by pixel as summarized in Eq. 1.

As described in Tubiello et al., (2016), the approach is based on reclassification tables to extract the proportions of cultivated
135 and grassland area from the yearly land cover maps. When all input layers overlap, the underlying assumption is that of an
equal likelihood within each pixel to find cultivated (or grassland) area and organic soils. Operationally, the methodology
multiplies the area of organic soils in the pixel by the area of the pixel that is cropped or has grassland cover. In this way, we
derived by pixel the area of organic soils that is drained for agricultural activities. ~~Organic soils must be indeed be drained~~
~~In order to allow for crop support cultivation activities. In the case of, organic soils need to be drained. Heavy grazing on grassland,~~
140 ~~livestock grazing beyond the carrying capacities of organic soils leads instead to peat might result in N and C losses and overall~~
~~degradation and drainage.~~ (Worrall and Clay, 2012; Martin et al., 2013; Noble et al., 2018). The following sections provide
more details about the information necessary to implement the computations above.

2.1 Soils

Information on the geographical distribution of *histosols*, for use in the term WSM of Eq. (2) and Eq. (3) above, was derived
145 from the Harmonized World Soil Database (HWSD v 1.2), a raster dataset with a nominal resolution of 30 arc second on the
ground (corresponding approximately to 1 x 1km at the equator) published in 2012 by FAO and the International Institute for
Applied Systems Analysis (IIASA) (FAO and IIASA, 2012). The HWSD compiles more than 40 years of soil information
from several sources worldwide, re-classified and harmonized according to the FAO-UNESCO classification. The
standardized structure of the HSWD v 1.2 allows displaying and querying the composition in terms of soil units and of soil
150 parameters such as the organic carbon content, the pH, or the water storage capacity. The HSWD dataset was queried to extract
values representing the percentage of the pixel area that contains histosols, as either dominant or secondary soil type (Fig. 1).
~~Soil units in the HSWD dataset dominated by histosols are characterized by soils with a thick layer of strongly decomposed~~
~~acidic organic material, 70 cm thick, with continuous rock at 80 cm and that develop in environments with a large excess of~~
~~precipitation.~~

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2.2 Land cover and land use

Information on the area extent of IPCC categories *cropland* and *grassland* for use in terms $LU_{cropland}$ and $LU_{grassland}$ in Eq. (2)-(3) was taken from the land cover maps produced by the Catholic University of Louvain (UCL) Geomatics (UCL Geomatics, 2017), produced under the Climate Change Initiative of the European [SpatialSpace](#) Agency (ESA CCI, 2020) and hereinafter referred to as CCI LC maps. The CCI LC maps were first released in April 2017 as 24 global annual and consistent land cover maps covering the period 1992 to 2015 (UCLouvain Geomatics, 2017). [At the end of 2019 and in the framework Since 2016, CCI LC maps became part](#) of the European Copernicus Climate Change Service [which released at the end of 2019](#) (C3S, 2019) three [new additional](#) global land cover (LC) products [were released](#) for the years 2016, 2017 and 2018 that are consistent with earlier maps (Fig. 2).

The long-term consistency of this dataset, yearly updates and high thematic detail on a global scale make it uniquely suitable to observe and assess changes in area drained and GHG emissions from organic soils. The CCI LC maps contain information for 22 global land cover classes, based on the FAO Land Cover Classification Systems (Di Gregorio, 2005), with a spatial resolution of approximately 300m.

The land cover maps (1992–2018) were used to assign to each pixel the proportion of its area under relevant land cover categories. This information was combined to provide proxy information on the proportion of pixel area under land cover / land use classes *cropland* and *grassland* (Tables 1 and 2). [To cover the 1990–2019 period of the final FAOSTAT dataset, the 1992 land cover values are carried backwards to 1990. Land cover data for 2019 are carry-forwards of the latest available year \(2018\).](#)

2.3 Livestock

Information on the spatial distribution of livestock for use in estimating the term LDR in Eq. (3) above, was taken from the Gridded Livestock of the World (GLW)(Robinson et al., 2014), providing geospatial data on the density of three ruminants species: cattle, sheep and goats (Fig. 3). [Namely, we used version 2.1 of the GLW maps, with 1 km resolution and 2010 as reference year.](#) Animal numbers by pixel were first converted in livestock units (LSU) (FAO, 2011), and pixels with values higher than 0.1 (Critchley et al., 2008; Worrall and Clay, 2012) [were](#) selected for use in Eq. (3). [As this methodology focuses on agricultural land uses it does not investigate the impacts of wildlife on the organic soils.](#)

2.4 Climatic Zones and emission factors

185 As discussed above, pixel-level climatic information for use in terms EF_{ijk} in Eq. (1), was derived from a map of climatic zones: (JRC, 2010). The Joint Research Centre (JRC) of the European Commission, developed this spatial layer in line with IPCC specifications based on latitude and elevation of each pixel (Figure 4).
Default IPCC emissions ~~factor~~ factors by land use and gas (Table 3) were then assigned by pixel to each climatic zone and three additional geospatial layers were produced to cover possible combinations of EFs (
190 Figure 5). As one country may encompass more than one climatic ~~zones~~ zone, when emissions are aggregated at national level in FAOSTAT, the resulting emissions factors represent weighted averages of the various EFs assigned at pixel level. In computations, CO₂-C losses are converted to CO₂ values multiplying by 44/12 while N₂O emissions are calculated multiplying N₂O-N values by 44/28.

2.5 Data Availability: Structure of the FAOSTAT datasets on “Organic Soils” and online access

195 Results from the spatial computation are aggregated at national level for 101 countries and 4 territories, representing the subset of FAOSTAT countries and territories where organic soils are present. Statistics are disseminated in three separate FAOSTAT domains (FAO 2020b,c,d), over the period 1990–2019, in line with country reporting requirements to the [Climate-United Nations Framework Convention on Climate Change \(UNFCCC\)](#) and following the IPCC (2006). Namely, statistics are disseminated by gas and land use class: emissions of N₂O on cropland and grassland are disseminated under the domain
200 Cultivation of Organic soils (FAO, 2020b) of FAOSTAT Emissions-agriculture; whereas emissions of CO₂ on Cropland (FAO, 2020c) and Grassland (FAO, 2020d) are disseminated within the FAOSTAT Emissions-Land use domain. As part of ongoing efforts to provide users with reliable and transparent data, the complete spatial dataset that underlies FAOSTAT statistics ~~will be also disseminated~~ is available through [the new FAO new maps catalog Map Catalog and Geospatial Platform](#) (FAO, 2020e). Under the dataset, Cultivation of Organic soils, N₂O emissions are also disseminated in CO₂eq by applying three different sets
205 of Global Warming Potential (GWP) coefficients (100-year time horizon) from the IPCC assessment reports: *a*) IPCC Second Assessment Report (IPCC, 1996); *b*) IPCC Fourth ~~Assesment~~ Assessment Report (IPCC, 2007); and *c*) IPCC Fifth Assessment Report (IPCC, 2014b) (Table 4). All data are also available at Zenodo as open access (Tubiello and Conchedda, 2020) with DOI 10.5281/zenodo.3942370. They ~~and~~ can be downloaded at <https://zenodo.org/record/3942370#.XxWJjygzblU>.

210 2.6 Limitations and uncertainty

~~Previous work had estimated the uncertainty of our estimates at ±40% for the area information and an uncertainty range (−14%, +166%) for the emission estimates. These uncertainties, valid at pixel level, were assumed to also characterize the nationally-aggregated values (Tubiello et al., 2016). Furthermore, the new methodology developed herein may result in some cases in~~

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215 reduction in the drained area during the 30 years of the analysis (see Appendix A, Table A1). In such cases, the pixel-level
proportions that are applied to identify the cropland and grassland cover, have detected corresponding changes in land cover.
The scale of the analysis prevents however to understand whether these changes actually happened in the area of organic soils
thus resulting in a rewetting of the drained peats or are instead an artefact of the spatial methods. The IPCC Wetlands
220 Supplement introduced already in 2014 additional methodological guidance, with a specific focus on the rewetting and
restoration of peatland that was not included in the 2006 Guidelines (IPCC, 2014a). Limited country-specific activity data on
rewetting prevented however implementing the Supplement refined methods in the FAOSTAT dataset.

3 Main results: Global trends

In 2019, nearly 25 Mha or about 7.5 percent of the 328 Mha of worldwide *histosols* had been drained for agriculture with a
limited increase since 1990. Data suggest that the largest extent of organic soils in Northern America and Eastern Europe have
undergone little changes during the past decades likely because these peats have been drained for agriculture already for many
225 centuries (Joosten and Clarke, 2002). The drainage of organic soils is instead a more recent phenomenon in South East Asia.
In this region, the drained area grew by 5 percent points since 1990 and in 2019 more than 26 percent of the original organic
soils were already drained. Asia is on average the region with the highest share of drained *histosols* (30 percent) while, at sub-
regional level Western Europe had over two thirds of its organic soils that were drained already in 1990.

In 2019, global GHG emissions from drained cropland and grassland organic soils were 833 Mt CO₂eq, calculated applying
230 AR5 GWP for the N₂O emissions (IPCC, 2014b). They were 13 percent and 10 percent higher when compared to 1990 and
2000 respectively, representing 8 percent of total agriculture and related land use emissions (Figure 6). In 2019, CO₂ and N₂O
contributed 87 percent and 13 percent of global emissions. Grassland organic soils were responsible for about 10 percent of
these emissions while the vast majority was due to the drainage for cropping. These relative contributions have changed little
since 1990 (Appendix A, Table A1).

In 2019, among countries where the area of *histosols* is above 1Mha (see ~~Annex~~Appendix A, Table ~~A+A2~~), the larger
proportions of drained organic soils were in Mongolia (over 80 percent), Germany (75 percent), Poland (60 percent), United
Kingdom and Belarus (about 50 percent). Nearly one fourth of the original extent was drained in Indonesia and Zambia and
30 percent in Malaysia.

240 In 2019, Indonesia had the largest area of drained organic soils (newly 5Mha), followed by the Russian Federation (about 1.9
Mha) and the United States of America (nearly 1.6 Mha). Among these top ten countries, Indonesia and Malaysia also
registered the largest relative increases in area drained since 1990 (+5 and +10 percent for Indonesia and Malaysia,
respectively).

245 Global GHG emissions from drained organic soils were 833 Mt CO₂eq. In 2019, emissions were 13 percent higher when compared to 1990 and 10 percent higher when compared to 2000 (Figure 6). This value represented almost 8 percent of total agriculture and related land use emissions.

In 2019, CO₂ and N₂O gas contributed 87 percent and 13 percent of global emissions. Grassland organic soils were responsible for about 10 percent of all emissions while the vast majority was due to the drainage for cropping. These relative contributions have changed little since 1990 (Appendix A, Table A2).

250 In 2019, three-fourths of the global emissions from organic soils were from only 11 countries (Figure 7), Malaysia and Indonesia together were responsible for nearly half (47 percent) of total emissions.

4. Results:4 Limitations and uncertainty

255 Previous work had estimated the uncertainty of our estimates at ±40% for the area information and an uncertainty range (–14%, +166%) for the emission estimates. These uncertainties, valid at pixel level, were assumed to also characterize the nationally-aggregated values (Tubiello et al., 2016) and may be extended to this revision. Importantly, while this methodology focuses on the impact of drainage on agricultural organic soils, it should be acknowledged that peat degradation may occur under other land uses such as in forest soils. We presented in earlier papers our work on peat fires and their role on global GHG emissions (Rossi et al., 2016; Proserpi et al., 2020) and disseminate the associate statistics in FAOSTAT (FAO, 2020f). This component is however not part of the present discussion.

260 The methodology developed herein may result in some cases in reduction in the drained area of organic soils during the 30 years of the analysis (see Appendix A, Table A2). In such cases, the pixel-level proportions that are applied to identify the cropland and grassland cover, have thus detected corresponding changes in land cover. The lack of information on rewetting and the scale of this analysis prevent however to understand whether these changes actually happened in the area of organic soils as result of rewetting of the drained peats or are instead an artefact of the spatial methods.

265 The IPCC introduced with the 2013 Wetlands Supplement additional methodological guidance on inland drained organic soils (IPCC, 2014a), with a specific focus on the rewetting and restoration of peatland that was not included in the 2006 Guidelines. Limited country-specific activity data on rewetting prevented however implementing the Supplement refined methods in this methodology.

270 We estimated that by applying the revised EFs for C and N₂O (Table 5) from the Supplement on Wetlands (IPCC, 2014a) to our methodology, the global emissions from agricultural drained organic soils in 2019 would be 883 Mt CO₂eq, thus about 6 percent more than estimated using the EFs from the 2006 Guidelines (see Appendix A, Table A3). This figure would be the result ceteris paribus of the downward revision of both C and N₂O EFs for cropland organic soils in the tropics combined with the large upward revision of grasslands C and N₂O EFs in the boreal and temperate zones. In addition, C emissions from

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275 grassland organic soils in the tropics would increase about twofold with the revised EFs whereas N₂O emissions would
decrease threefold. Thanks to the new scientific evidence, the uncertainty of the EFs in the Supplement on Wetlands are overall
smaller than in the 2006 Guidelines (Table 5) but remain very large (47–186 percent) for the main component of emissions—
the C emissions from cropland organic soils in the tropics. With the only exception of the estimates for grassland organic soils
in boreal and temperate zones, our estimates are well within the range of the uncertainties if the revised EFs from the
280 Supplement were applied to our methodology. It should be noted that the Supplement on Wetlands (IPCC, 2014a) also includes
new guidance to estimate the amount of dissolved organic carbon (DOC) that is carried out on ditches in drained peatlands
which was not part of the 2006 Guidelines (IPCC, 2006). This was however not part of this comparison.

285 The Tier 1 methods applied in this study do not differentiate between long-term drained organic soils and soils after initial
drainage when carbon losses are the highest (Hooijer et al., 2012; IPCC, 2014a). It should be also noted that the progressive
soil mineralization associated with prolonged drainage may lead eventually to peat depletion, particularly in shallow soils
(Humpenöder et al., 2020). This in turn, might affect the scale of emissions thus adding uncertainty to our current estimates.
Country-specific information on the thickness of the organic layer and the depth and length of drainage is however currently
missing to assess the extent of peat depletion worldwide.

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5 Data Validation

The FAOSTAT estimates of the extent of organic soils, which are used as input to Eq. (2)–(3), were compared to published
data at country, regional and global level. Resulting emissions and emissions factors for oil palm plantations are also included
295 to validate FAOSTAT results.

45.1 Area of organic soils and peatlands

Comparison of the extent of drained organic soils is hindered by a number of factors, including the fact that the FAOSTAT
data refers to area of organic soils, while a majority of published studies has focused on area of peatlands. The FAOSTAT
global estimates of 3.3 million square ~~kilometers~~kilometres (Mkm²) of organic soils (*histosols*) were 25 percent smaller than
300 the published range of 4.0–4.3 Mkm² of peat soils. This is consistent with statements by Xu et al. (2018), who highlighted that
histosols tend to underestimate areas in tropical swamp-forested peatlands. At regional level, FAOSTAT data agreed well with
the most recent estimates of Xu et al. (2018) and mean estimate from Immirzi et al. (Table 56). In addition, while
acknowledging the large differences existing between published estimates by regions, FAOSTAT estimates remained
consistently within the observed ranges. More specifically, FAOSTAT ~~estimates~~estimate of the area of organic soils for North
305 America was 1.3 Mkm² vs. a published range of 1.3 – 1.9 Mkm²; for Asia, FAOSTAT estimated 0.3 Mkm² vs. a range of 0.3

– 1.5 Mkm²; for Europe, FAOSTAT estimated 1.5 Mkm² vs. a range of 0.6 – 1.9 Mkm²; for Africa, FAOSTAT estimated 0.07 Mkm² vs. a range of 0.05–0.2 Mkm²; for South America, FAOSTAT estimated 0.1 Mkm² vs. a range of 0.09 – 0.5 Mkm²; and for Oceania, FAOSTAT estimated 0.05 Mkm² vs. a range of 0.00 – 0.07 Mkm².

We continued the validation analysis by comparing FAOSTAT estimates to published data for about 60 tropical countries,

310 compiled from the widely recognized meta-analysis of Page et al. (2011), and for the same set of countries to values computed using a recent map of tropical peat distribution (Gumbricht et al., 2017)(Appendix B, Table B1). In 2017, Gumbricht and associates published new estimates of wetland and peatland areas, depths and volumes. The expert system approach is based on three biophysical indices related to wetland and peat formation: (1) long-term water supply exceeding atmospheric water demand; (2) annually or seasonally water-logged soils; and (3) a geomorphological position where water is supplied and
315 retained. These authors define peat as any soil having at least 30 cm of decomposed or semi-decomposed organic material with at least 50 percent of organic matter. At the aggregate level—the sum of area of organic soils in countries covered by Page et al. (2011)—the extent of tropical organic soils estimated by FAOSTAT was 0.43 Mkm², which compared well with the value of 0.44 Mkm² of Page, both about a third of the total in Gumbricht et al. (2017) (1.37 Mkm²), but both estimates are about a third of the total reported in Gumbricht et al. (2017) (1.37 Mkm²). The following factors may contribute to explain the
320 discrepancy observed with Page et al. (2011). Firstly, the expert model of Gumbricht et al. (2017) does not account for soil lithology and composition other than through soil wetness responses and the assessment of the hydrological conditions suitable to peat storage measured primarily through elevation data, soil moisture (phenology) and climate. Secondly, while Gumbricht et al. (2017) report that mangroves are considered to meet the criteria of depth and organic matter content needed for peat definition, these authors acknowledge that mineral soils may prevail in mangroves and that additional ground-truthing is
325 needed to validate if mangroves contain peat as defined in their expert system.

At country level, FAOSTAT estimates agreed well with data published by Page et al. (2011) ($R=0.677$, $p<0.001$). For one percent increase in the area of histosols, the log-transformed model shows about 5.5 percent increase in the area of peat as mapped by Page and colleagues ($R^2=0.458$) (Fig. 8). The largest differences were found in countries ~~in~~from South and Central
330 America—where special formations at high altitudes and dry conditions, known as *paramos*, may be poorly captured as *histosols* (Lähteenoja et al., 2012). FAOSTAT and Page et al. (2011) data were in very close agreement for key global contributors in Southeast Asia, Indonesia (0.20 vs. 0.21 Mkm²) and Malaysia (0.02 vs. 0.03 Mkm²).

FAOSTAT country-level estimates were, albeit to a lesser degree, also in good agreement with those obtained by aggregating geospatial information from Gumbricht et al. (2017) ($R=0.541$, $p<0.0005$). FAOSTAT histosols however ~~explain~~
335 ~~explain~~ only partially the variability in the peat area as mapped by these authors ($R^2=0.293$) (Fig. 9). For a one percent increase in the area of histosols, the log-transformed model shows a 8 percent increase in the area of peat as mapped by Gumbricht et al. Significant differences between FAOSTAT and this second, independent set of observed data included Brazil, where Gumbricht and colleagues (2017) estimated 0.31 Mkm² of organic soils, nearly forty times the area estimated in FAOSTAT and more than ten times the area published in Page et al. (2011); Peru, where Gumbricht et al. (2017) indicate some 0.08 Mkm², twice the

340 FAOSTAT estimates and 0.02 Mkm² more than Page et al. (2011); and the Democratic Republic of Congo, where the new peatland map suggests a significant presence of organic soils (0.12 Mkm²), ~~eonsistentlyconsistent~~ with recent studies (Dargie et al., 2017), while FAOSTAT estimated only 240 km² and Page et al. (2011) less than 3000 km².

The use of observed or estimated data is hampered by the wide uncertainties that still exist in defining, mapping and measuring actual extent of peatland throughout the world. To date, no globally accepted definition of ~~peatlandspeatland~~ exists. To this
345 end, ongoing international efforts such as the Global Peatlands Initiative (2020) are expected to improve and consolidate current knowledge.

45.2 Validation with country data reported to the Climate Convention of the United Nations

The FAOSTAT data uses Eq. (2)–(3) above to overlay information on organic soils extent with information on land use and other geospatial characteristics, to estimate the drainage area of organic soils due to agriculture (Tubiello et al., 2016). These
350 were in turn used as input to estimate resulting GHG emissions. We used data reported by countries to the ~~UN Framework Convention on Climate Change (UNFCCC)~~ for validation of these FAOSTAT estimates. We looked both at data from the 2019 National Greenhouse Gas Inventories (2017 as last available year in the data) of the Annex I Parties and to the most recent (2018) national communication from Indonesia, a top emitter country.

45.2.1 Annex I parties

355 UNFCCC data were available for thirty-eight countries belonging to the Annex I parties to the climate Convention- ~~(2019 inventories, 2017 last reported year)~~. These represent developed countries, mostly located in temperate and boreal zones of the world. First, we compared data on the area drained (activity data), which allowed to test assumptions underlying the use of Eq. (2)–(3) above. FAOSTAT country-level estimates were in good agreement with those officially reported by countries to the UNFCCC ($R^2=0.57$) of area drained of organic soils (Fig. 10). At regional level, FAOSTAT predicted a total of about 14 Mha
360 of drained organic soils for Annex I parties, versus country reported figures of nearly 12 Mha for the last inventory in 2017 (Appendix B, Table B2). On the one hand, estimates in several countries with significant contributions were well in line with national reporting, including the United States of America (1.5 vs 1.4 Mha); Belarus (close to 1.4 Mha in both cases); Germany (1.1 vs 1.2 Mha). On the other, significant differences were found in Poland (1.0 vs 0.7 Mha) and in the United Kingdom (1.3 vs 0.3 Mha). Wide differences also characterized two countries with major organic soil area extent, specifically the Russian Federation (1.8 vs 4.3 Mha) and Canada (1.3 vs 0.2 Mha). In these latter cases, differences have however opposite directions. FAOSTAT estimates were much larger than country reported data in Canada but smaller in the Russian Federation.

For the same set of UNFCCC countries as above, we also compared N₂O emissions, which are reported by countries under the IPCC sector Agriculture. C fluxes from the drainage of organic soils are instead reported by Annex I countries under Land Use, Land Use Change, and Forestry (LULUCF) ~~categories~~. In the inventories, relevant reporting categories are 4.B.1
370 “Cropland Remaining Cropland”; 4.B.2 “Land Converted to Cropland” and 4.C.1 “Grassland Remaining Grassland”; and 4.C.2 “Land Converted to Grassland”. Data for carbon are much sparser than for N₂O emissions possibly due also to

complexity in reporting (Barthelmes et al., 2015). Beside the differences in activity data (area drained) that were observed earlier, differences may also be due to countries applying higher Tiers than the default methodology we applied in FAOSTAT as well as to the definition of types of land uses causing drainage.

375 As for the area drained, FAOSTAT N₂O emissions estimates were also in good agreement with data officially reported to the UNFCCC (R²=0.553) (Fig.11), but with FAOSTAT consistently overestimating country data. At regional level, FAOSTAT predicted total emissions of 184 kt N₂O for Annex I parties, versus country reported figures of 143 kt N₂O (Appendix B, Table B2). Estimates of annual emissions in several countries with significant contributions were well in line with national reporting, including the United States of America (20 vs 27 kt N₂O); Belarus (19 vs 18 kt N₂O); Germany (14 vs 10 kt N₂O); and Ukraine (8 vs 6 kt N₂O). At the same time, significant differences characterized two countries with major organic area extent, specifically the Russian Federation (23 vs. 54 kt N₂O) and ~~(16 vs. 0.2 kt N₂O)-Canada (16 vs. 0.2 kt N₂O). In this latter country, the discrepancy was due to FAOSTAT estimating three times a larger extent of drained agricultural soils than reported by Canada in the 2019 inventory and report to the Climate Convention (2019, Canada National Inventory Report 1990–2017, Part 2).~~

385 FAOSTAT results are in line with other independent assessments, for instance a study for countries in the Baltic region (Barthelmes et al., 2015) suggested that the area and emissions from drained organic soils are often underestimated in UNFCCC reporting. In a recent paper, Tiemeyer et al. (2020) applied developed for Germany a refined methodology spatially representative Tier 2 approach for organic soils in national GHG inventories using detailed activity data and IPCC Wetlands national EFs. For a similar extent of drained organic soils (about 12 Mha) as in FAOSTAT, their emissions estimates from cropland and grassland drained organic soils were 45 Mt CO₂eq, about three-fold FAOSTAT results (14 Mt CO₂eq). This difference, which was mostly due to the different applied EFs, suggests that even FAOSTAT estimates may not fully grasp the potential for mitigation from the rewetting of drained organic soils.

45.2.2 Non-Annex I parties

395 Over forty percent of the global emissions from the agricultural drainage of organic soils is generated in Indonesia and Malaysia. In addition, these two countries have contributed the most to emissions increases since 1990 (FAO, 2020) (Fig. 12).

400 -We compared FAOSTAT estimates of GHG emissions from the drainage of organic soils in Indonesia to those reported by the country to the UNFCCC, over for the period 2000–2016 in their second Biennial Update Report (BUR), submitted to the Climate Convention (submission on December 2018-). Data reported from Malaysia do not allow instead for a similar comparison. National reported data from Indonesia were based on a national map of peatland and on refined EFs from the Wetlands Supplement (IPCC, 2014a) and reported as distinct category “peat decomposition” under Forestry and Other Land Use (FOLU) emissions. Results indicated good agreement between FAOSTAT estimates and nationally reported data. The average FAOSTAT GHG emissions over 1990–2016 were 281 Mt CO₂eq vs the 304 Mt CO₂eq reported by Indonesia to the

405 UNFCCC. Both series have a similar upward trend and their agreement extended over the entire time series ($R^2= 0.9446$),
albeit with increasing separation in the most recent years. A possible reason for the observed discrepancy is that the national
communication applies three distinct EFs for oil palm, rubber and other annual crops. Additionally, while FAOSTAT estimates
only include the drainage and emissions from agricultural uses, Indonesia also reports the emissions from peat decomposition
under forest land use. The distance between national data and our results is however well within the combined uncertainty (53
410 percent) for activity data and EFs as reported in the Indonesia BUR. This represents an additional validation of Eq. (2) and Eq.
(3) in the methodology addressing the issue of time dependence in drainage data (Fig. 13). As FAOSTAT only includes
drainage for agriculture, part of the differences may be due to the types of land use for which the BUR reports drainage and
emissions, as the BUR possibly includes drainage under forestry.

45.2.3 Emissions factors for palm oil plantations

415 The establishment of new oil palm plantations is recognized as a main driver for the drainage of tropical peatlands in Indonesia
and Malaysia (HojerHooijer et al., 2010; Hooijer et al., 2012; Miettinen et al., 2012; Dohong et al., 2018; Cooper et al., 2020;
FAO, 2020f2020g). As a supplementary validation of Eq. (1)–(2), we combined spatially theour layer of cropland land-use
layerorganic soils to an additional map of tree plantations produced by Petersen et al. (2016) (Fig. 14). These authors mapped
the distribution of different types of plantations including oil palm for the years 2012–2014 in seven countries: Brazil,
420 Cambodia, Colombia, Indonesia, Liberia, Malaysia, and Peru, using satellite imagery and extensive field validation,
particularly for Indonesia and Malaysia. The types of mapped plantations are oil palm and oil palm mix; rubber and rubber
mix; wood fibre / timber and other mixed types. This additional analysis allows to compare FAOSTAT resulting results to
those from peer-reviewed literature, with a focus on emissions factors from oil palm plantations (i.e. the emissions per unit
area of oil palm on drained organic soils); to those in established literature.

425
Peterson and associates estimated that oil palm plantations in Indonesia and Malaysia covered 11.7 Mha and 5.3 Mha in In
2014, respectively. These were consistent with 2014 FAOSTAT crop statistics (FAO, 2020h) on oil palm harvested area,
indicating reported a total of 8.1 Mha in Indonesia and 4.7 Mha respectively for in Malaysia. Petersen and associates generated
estimates that were consistent with FAOSTAT data. They mapped the two countries 2014 cover of oil palm plantations to be
430 11.7 Mha and 5.3 Mha, in Indonesia and Malaysia respectively. Of these, based on our combined analysis of the crop drained
soils and of the plantations map and of the cropland organic soils, about 9 percent (in Indonesia) and 4 percent (in Malaysia)
were located in drained organic soils (Table 6). Together, the drained for establishing tree plantations (Table 7). In Indonesia,
the oil palm plantations mapped by Petersen and colleagues were responsible for almost half about one third of the 2014
emissions from all cropland organic soils in Indonesia.
435 the country. In Malaysia, the relative contribution of oil palm plantations to the area drained for cultivation was even as
nearly larger and about half of the total area of crop emissions from cropland organic soils and emissions in this country was
due to oil palm plantations. Other types of plantations contributed an additional 10 percent to area drained and emissions;

which suggests the contribution of annual and temporary crops to peat conversion in this country may be less important than in Indonesia (Table 8).

440 The EFs for oil palm plantations derived from the analysis was around 78 CO₂e q ha⁻¹ yr⁻¹ in the two countries, and in close agreement with published estimates (Table 10). Available literature is largely based on direct in-situ measurements and which typically analyse the influence of the depth of drainage, soil subsidence rates, soil moisture and the period since the initial drainage and establishment of the oil palm plantations. Corresponding values When more than one EF was reported in the selected studies, we extracted for this comparison the EFs from mature oil palm plantations (5 or more years after initial drainage), considering these more directly comparable to our methods (Table 8). Values from the selected literature range from minimum average losses of 13 t CO₂e ha⁻¹ yr⁻¹ as in Hashim et al., (2018) to a maximum value of 117 t CO₂e ha⁻¹ yr⁻¹ as in Matysek et al. (2018) and a recent study by Cooper et al. (2020). FAOSTAT estimated EF is therefore very close to the average value from the selected studies (73 t CO₂e q ha⁻¹ yr⁻¹). This additional validation confirms that our methodology is compatible with most relevant and well-established estimates of a major source of emissions from drained organic soils in South East Asia and suggests that FAOSTAT estimates may be equally applied to other tropical countries.

5.6 Conclusions

Organic soils are a rich carbon pool and their drainage for agriculture has important impacts on the global carbon cycle. FAOSTAT statistics on greenhouse gas emissions relative to the drainage of organic soils were updated for the period 1990–2019 based on geospatial computation and pixel-level application of default Tier I method of the Intergovernmental Panel on Climate Change (IPCC). In line with country reporting requirements to the Climate Convention, and following the IPCC, statistics are disseminated disaggregated by gas (N₂O and CO₂) and land use classes, cropland and grassland. Results are disseminated in three separate FAOSTAT domains. These FAOSTAT statistics represent the only available global dataset in the world today showing country, regional and global time series on drained organic soils. Efforts are also in progress to disseminate publicly the underlying spatial data are also publicly available.

460 In 2019, FAOSTAT estimated that nearly 25 million ha of organic soils were drained from agriculture and were responsible for 833 million tonnes of Mt CO₂e q. This was about 8 percent of total agriculture and related land use emissions in that year. About half of the greenhouse gas emissions was due to the drainage of organic soils in South Eastern Asia and particularly Indonesia and Malaysia.

465 We validated methods and results by comparing data reported by countries to the United Nations Climate Convention on Climate Change including in the comparison both data from developed countries of the Annex I group and Indonesia, a top emitter country for drained organic soils. For this latter country we also validated with additional analysis the resulting emission factor for oil palm plantations, a major driver of the emissions in South East Asia. FAOSTAT statistics are well aligned with country reported data and the most established literature. Overall, FAOSTAT statistics explained about 60 percent of the

470 variability in official reported data. However, in Indonesia, the top emitter country by drained organic soils, as well as in many developed countries FAOSTAT statistics yielded an even higher agreement and proved a robust estimator of country official data. This suggests that the FAOSTAT database may provide a useful global reference in support of countries reporting requirements while national capacities are being developed.

475 Following guidelines of the Intergovernmental Panel on Climate Change, FAOSTAT statistics are computed applying *histosols* as proxy for organic soils. However, wide uncertainties still remain as to whether organic soils may fully capture the dynamics in peat distribution and related emissions particularly in tropical countries. FAO ongoing efforts under the Global Peatland Initiative are expected to provide advancements for mapping and monitoring peatlands worldwide.

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- 630 Xu, J., Morris, P.J., Liu, J., and Holden, J.: PEATMAP: Refining Estimates of Global Peatland Distribution Based on a Meta-Analysis, *Catena* 160: 134–140, 2018.

Table 2. Proportion of area of relevant CCI-LC pixels corresponding to land cover *grassland*

CCI-LC Class Code	CCI-LC Land Cover Class Label	Grassland Assigned pixel area (%)
130	Grassland	
140	Lichens and mosses	
120	Shrubland	100% herbaceous cover
121 ^a	Evergreen shrubland	
122 ^a	Deciduous shrubland	
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	30% (20% herbaceous + 10% shrub cover)
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (< 50%)	40% (20% herbaceous + 20% shrub cover)
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	55% (30% herbaceous + 35% shrub cover)
110	Mosaic herbaceous cover (<50%) / tree and shrub (>50%)	80% (60% herbaceous + 20% shrub cover)
10	Cropland rainfed	
11 ^a	Herbaceous crops	5% natural herbaceous cover

^a Corresponding to more detailed classification (Level 2) in CCI-LC maps but with limited geographical availability.

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Table 4. Global Warming Potentials (GWP) relative to CO₂ (dimensionless)

Greenhouse gas	GWP	GWP	GWP
	SAR (IPCC 1966)	AR4 (IPCC, 2007)	AR5 (IPCC, 2014)
N ₂ O	310	298	265

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Table 5.

660 **Table 5. Emissions/Removal factors (EFs) for inland drained organic soils by land use and gas, in the 2013 Wetlands Supplement (IPCC, 2014) and percentage variations from the corresponding EFs in the IPCC 2006 Guidelines**

	<u>EF tonnes CO₂-C ha⁻¹yr⁻¹</u>	<u>95% CI</u>	<u>Change (%) from EF in 2006 Guidelines</u>	<u>EF kg N₂O-N ha⁻¹yr⁻¹</u>	<u>95% CI</u>	<u>Change (%) from EF in 2006 Guidelines</u>
<u>Cropland organic soils</u>						
Boreal / Cool Temperate	<u>7.9</u>	6.5–9.4	+58%	<u>13</u>	8.2–18	+63%
Warm Temperate	<u>7.9</u>	6.5–9.4	-21%	<u>13</u>	8.2–18	+63%
Tropical	<u>14.0^a</u>	6.6–26	-30%	<u>5</u>	2.3–7.7	-69%
<u>Grassland organic soils</u>						
Boreal / Cool Temperate	<u>5.7</u>	2.9–8.6	+2180%	<u>9.5</u>	4.6–14	+19%
Warm Temperate	<u>6.1</u>	5.1–7.3	+144%	<u>8.2</u>	4.9–11	+2%
Tropical	<u>9.6</u>	4.5–17	+92%	<u>5</u>	2.3–7.7	-69%

^a Corresponding to category Cropland and fallow, drained. This was reported as general EF in the absence of additional information on cropland type.

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Table 6. Comparisons of published global and regional estimates for area of peat / organic soils (km²)^a

	Immirmi et al. (1992) mean	Lappalainen (1996) best estimate	Joosten and Clarke (2002) maximum	Xu et al. (2018)	FAOSTAT 2020
North America	1,710,470	1,735,000	1,860,000	1,339,321	1,311,595
Asia	338,208	1,119,000	1,523,287	283,861	258,686
Europe	1,784,887 ^b	957,000	617,492	1,867,658 ^c	1,501,696 ^c
Africa	49,765	58,000	58,534	187,061	72,445
South America	86,271	102,000	190,746	485,832	99,860
Oceania	230	14,000	8,009	68,636	45,095
Total	3,969,831	3,985,000	4,258,068	4,232,369	3,289,377

^a Adapted and extended from Rieley and Page (2016). ^b Immirmi et al (1992) estimates for Europe include the Soviet Union. ^c Xu et al., 2018 and FAO estimates for Europe include the Russian Federation.

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Table 6. Contribution of oil palm and other tree plantations to area drained and emissions (mapped from erop Petersen et al., 2016), their distribution in cropland organic soils and corresponding emissions, Indonesia and Malaysia in 2014. Share of total emissions by type of plantation from the country cropland organic soils is also shown. In 2014, total emissions from cropland organic soils were 318 Mt CO₂eq in Indonesia and 45 Mt CO₂eq in Malaysia

	Area Mha (Petersen et al., 2016)	of which in cropland organic soils (<i>ibidem</i>)	Mt CO ₂	Mt N ₂ O	Mt CO ₂ eq	Share (%) of total emissions from country crop organic soils, by plantation type
Indonesia						
Oil palm	11.7	0.9	66.8	23*10 ⁻³	72.8	23%
Oil palm mixed	2.4	0.3	10.1	3*10 ⁻³	19.5	6%
Other tree plantations (rubber, fruits, fibre / wood)	8.7	0.8	58.2	20*10 ⁻³	63.5	20%
All tree plantations	22.8	2.0	76.9	26*10⁻³	155.9	49%
Malaysia						
Oil palm	5.3	0.2	16.3	6*10 ⁻³	17.8	38%
Oil palm mixed	1.9	0.1	3.8	1*10 ⁻³	4.1	9%
Other tree plantations (rubber, fruits, fibre / wood)	1.4	0.1	4.2	1*10 ⁻³	4.6	10%
All tree plantations	8.6	0.3	24.3	8*10⁻³	26.4	57%

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Table 78. Comparison of EFs for oil palm plantations on organic soils from established peer-reviewed literature and combined FAOSTAT / Petersen et al. (2016) spatial data analysis

Source	CO ₂ eq ha ⁻¹ yr ⁻¹
Published studies	
Page et al., 2011	86–100
Hojer Hooijer, et al., 2012 ^a	78
Agus et al., 2013 ^b	43
Couwenberg and Hooijer, 2013 ^b	66
Hashim et al. 2018	13–53
Matysek et al., 2018	86–117
Cooper et al., 2020 ^c	70–11797
FAOSTAT / Petersen et al., 2016	78

^a Value 18 years after drainage. ^b Value more than 5 years after drainage. ^c Value for mature oil palm plantations (over a 30-year cycle).

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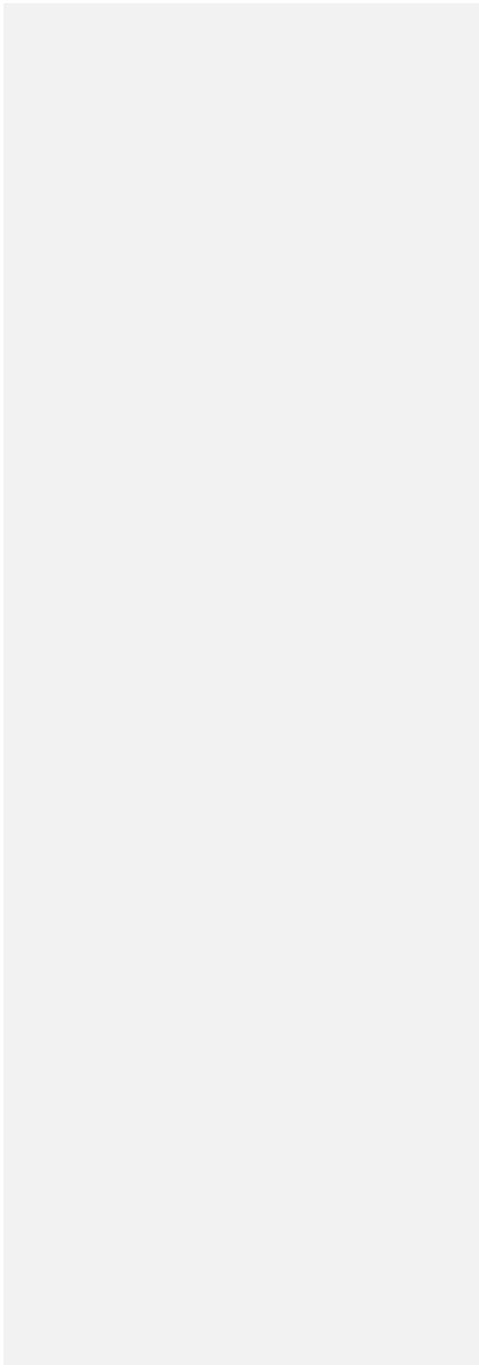
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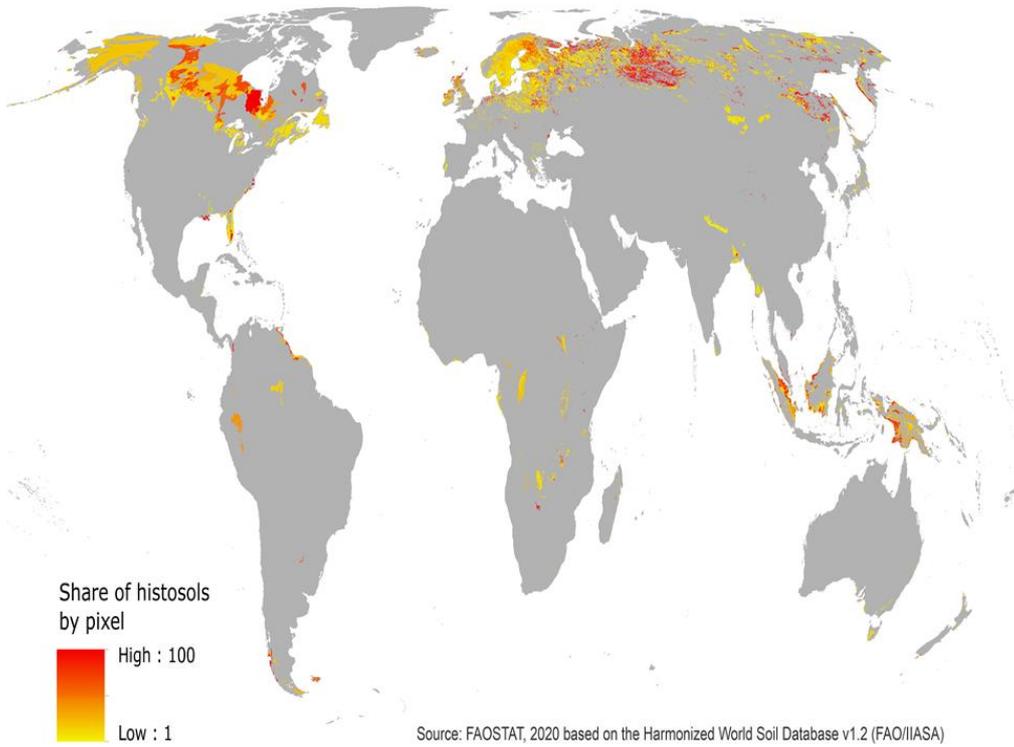
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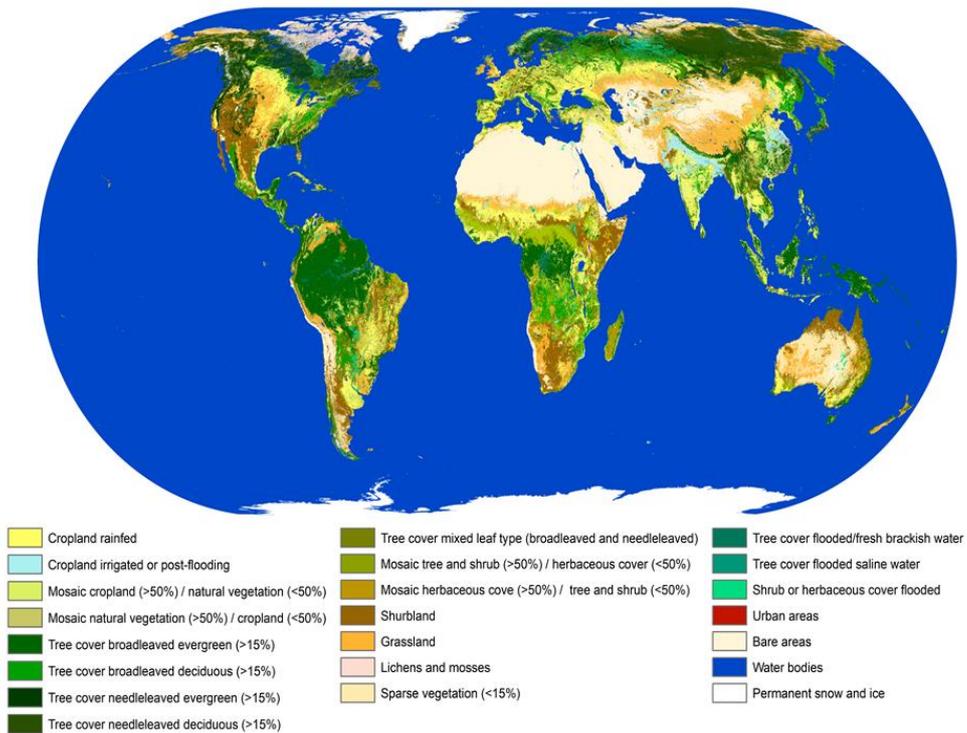
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Figure 1. Global distribution of histosols, percentage of pixel area

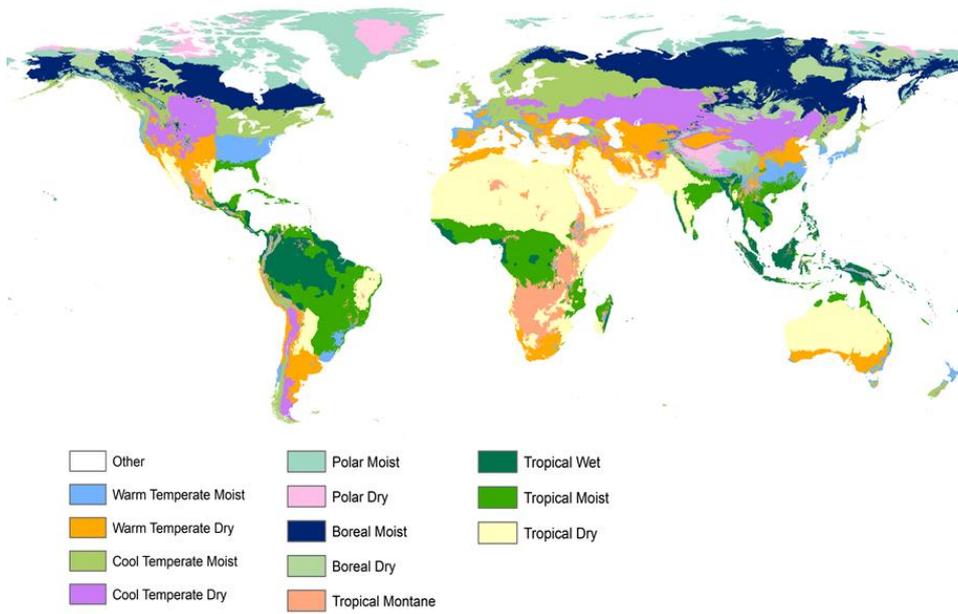


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Source: FAOSTAT, 2020 based on the ESA CCI and Copernicus Climate Change Service Land Cover Maps

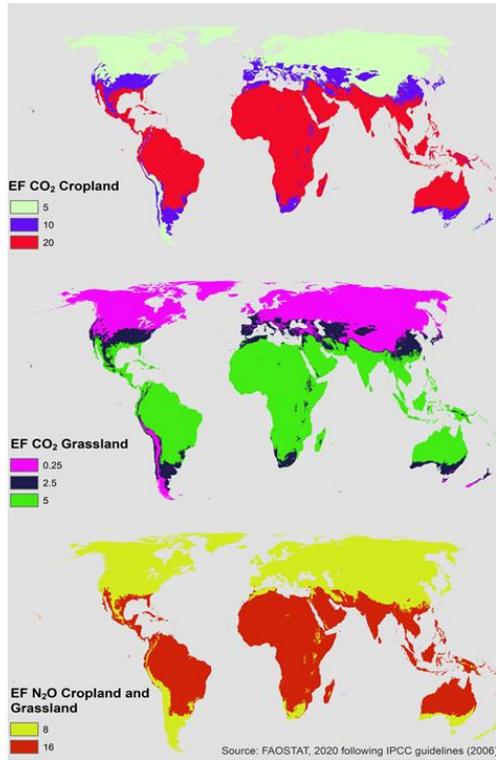
Figure 2. Global land cover, 1992–2018 composite information from CCI-LC maps [\(ESA CCI, 2020\)](#)

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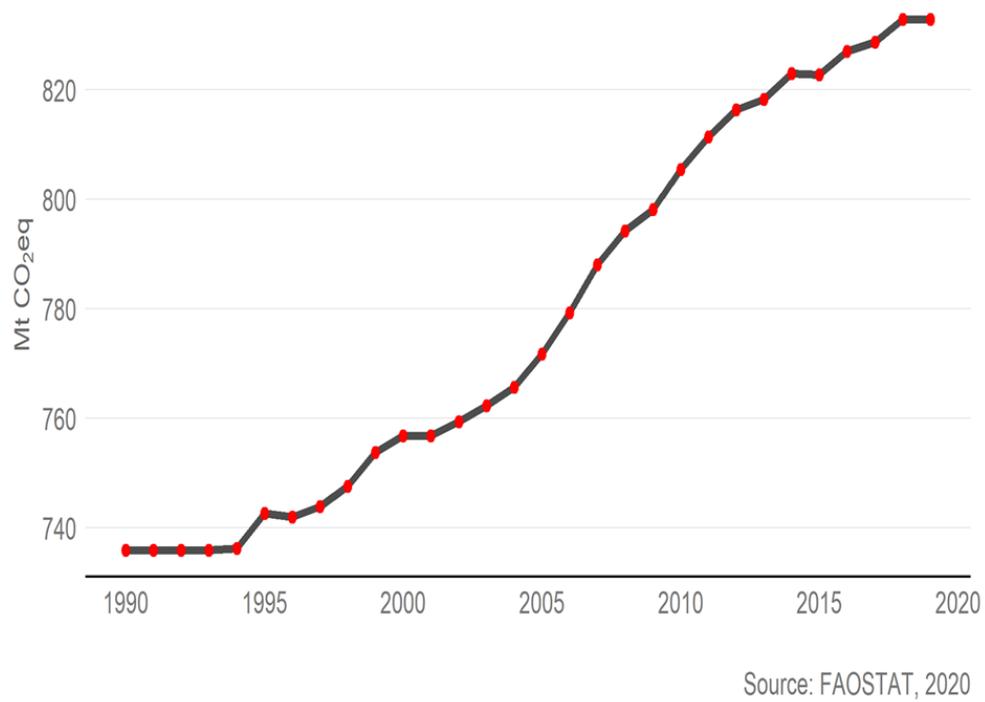
Source, FAO, 2020 based on IPCC climatic zones (JRC, 2010)

725 **Figure 4. Climatic zones based on IPCC classification (JRC, 2010)**

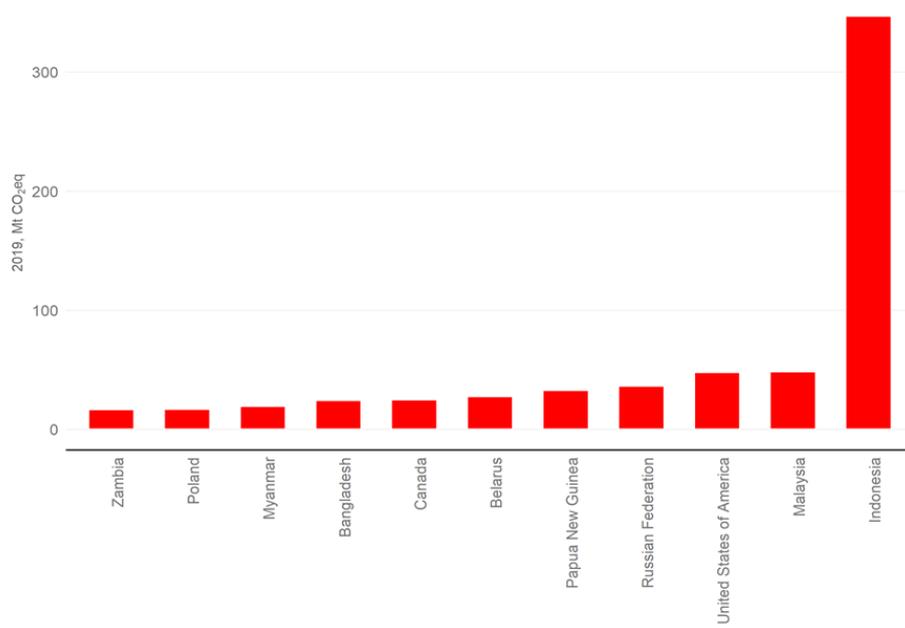


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Figure 5. Spatial layers of emission factors from the IPCC Guidelines (2006) by gas, land use and climatic zone



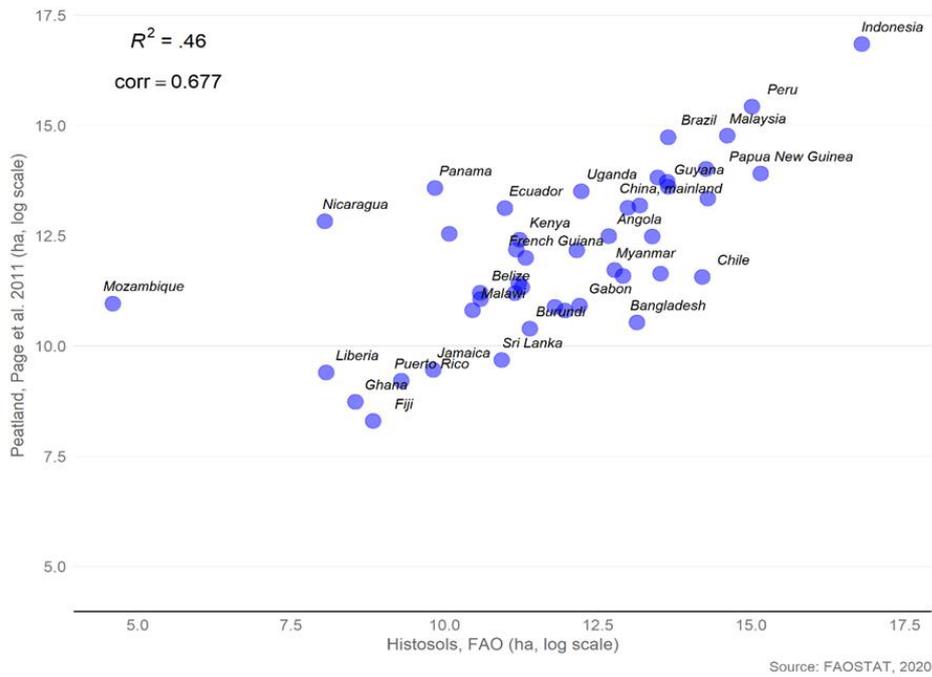
740 **Figure 6. Global emissions from drained organic soils, 1990–2019**



Source: FAOSTAT, 2020

745

Figure 7. Top 10 countries by emissions from drained organic soils (75 percent of global emissions)



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Figure 8. Scatterplot of log-transformed area estimates for organic soils (Page et al., 2011) and FAOSTAT.

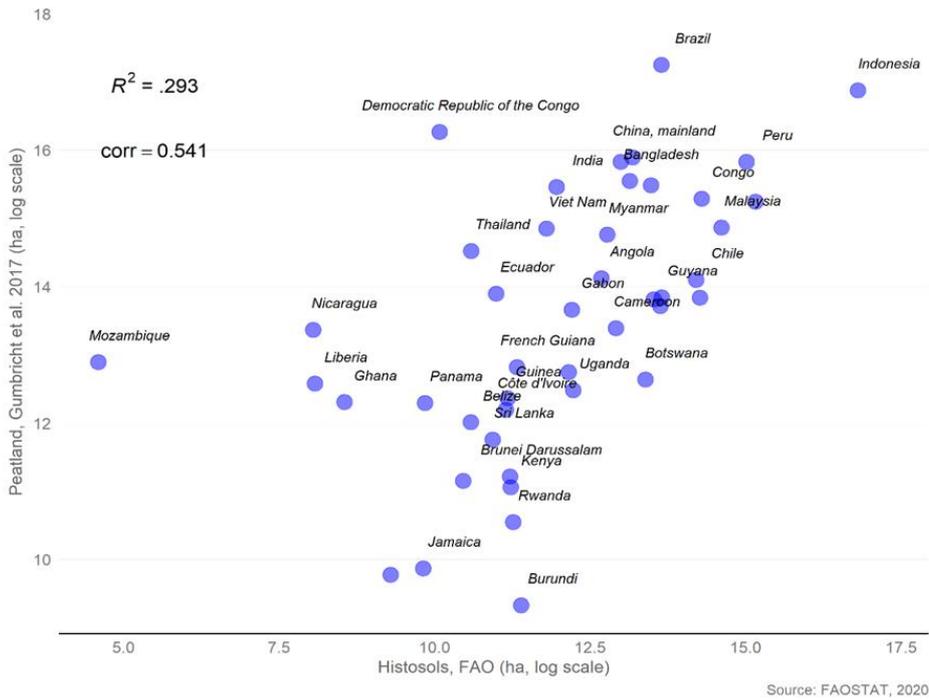
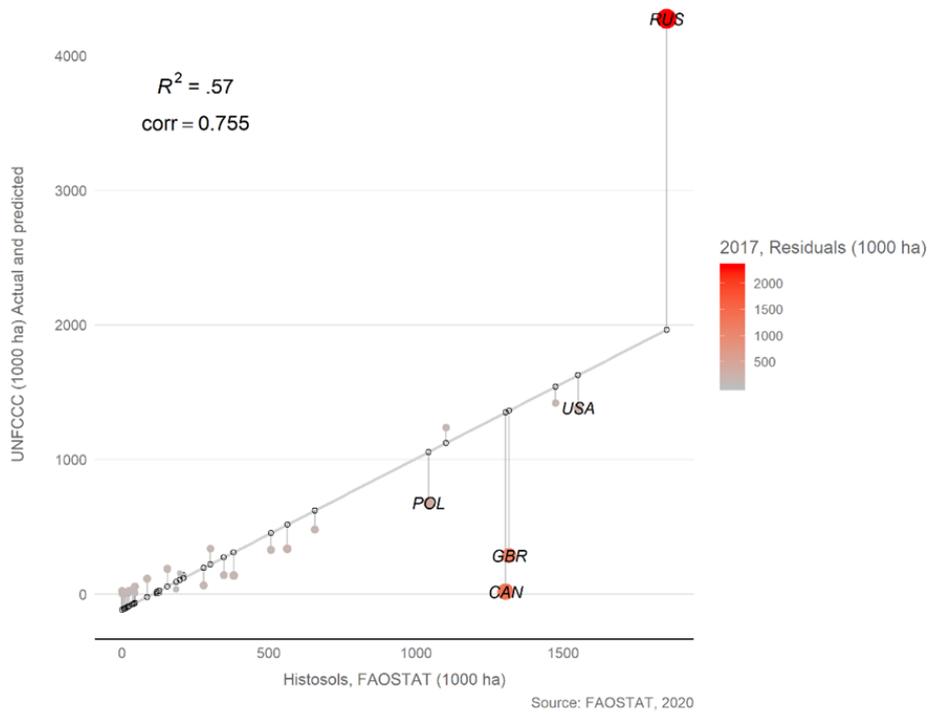


Figure 9. Scatterplot of area estimates for organic soils in published data (Gumbricht et al., 2017) and FAOSTAT. Data have been log-transformed to avoid dependence on a few large vales.



765 **Figure 10. Comparison of FAOSTAT estimates of drained organic soils area vs official country data reported to UNFCCC (year 2017). Distance from predicted (on the fitted line) and actual data**

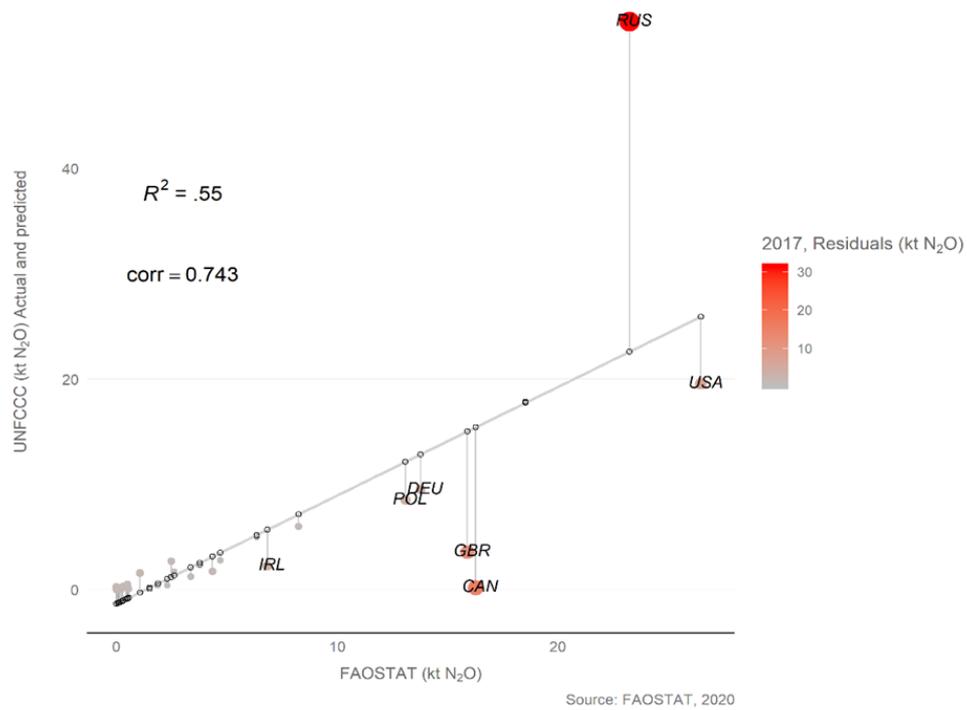
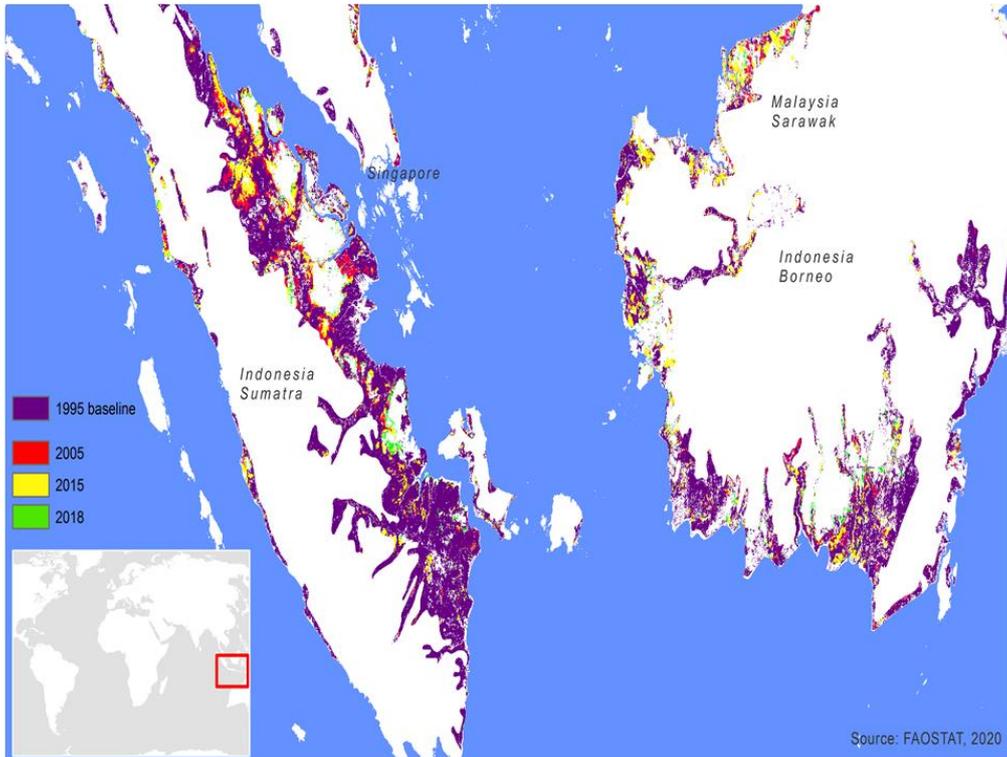


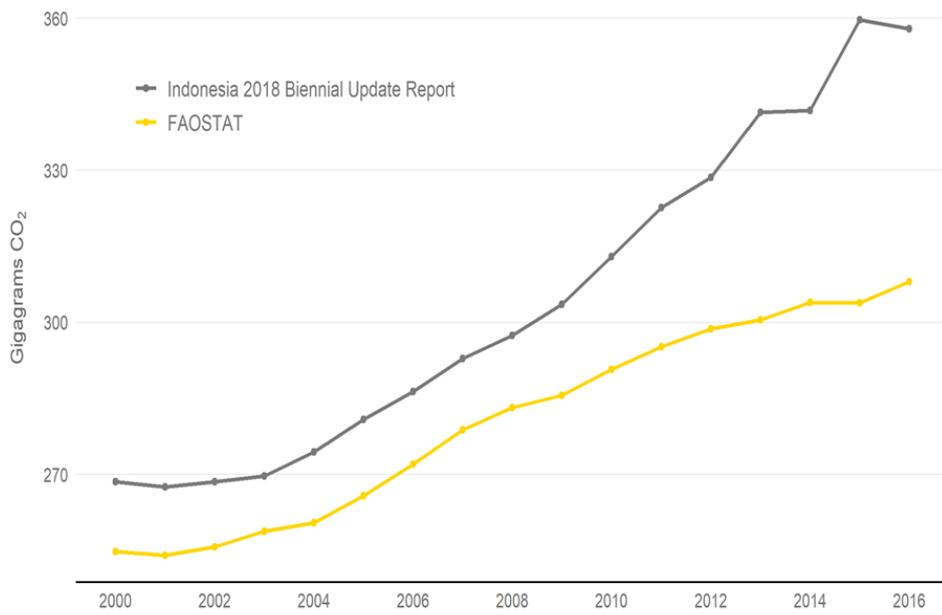
Figure 11. Comparison of FAOSTAT estimates of GHG emissions (N₂O) compared to UNFCCC data (year 2017)



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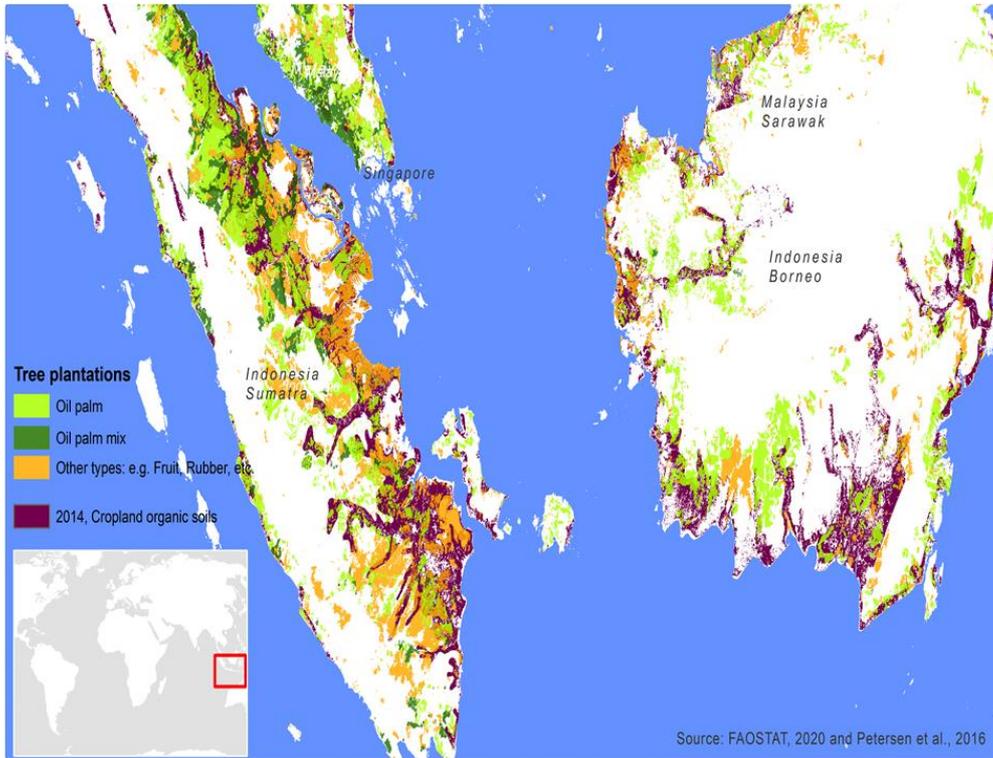
Figure 12. FAOSTAT estimates of the extent of drained organic soils in Indonesia and Malaysia over time, showing total drained area in 1995 and successive additions by 2005, 2015 and 2018

785



Source: FAO STAT, 2020

790 **Figure 13. FAO STAT estimates vs reported CO₂ emissions from the drainage of organic soils in Indonesia, 1990–2016 (2nd Biennial Update Report, 2018 submission to the Climate Convention)**



795

Figure 14. Oil palm and other tree plantations (Petersen et al., 2016) and FAOSTAT Cropland organic soils in 2014

800 APPENDIX A: Additional results

Table A1. Global emissions in 1990 and 2019 by gas and by land use

Land use	Mt by gas		Total in Mt CO ₂ eq
	N ₂ O ^a	CO ₂	
Cropland organic soils	66.4	589.9	656.3
Grassland organic soils	34.9	44.8	79.6
Total emissions in 1990	101.2	634.7	735.9
Cropland organic soils	74.4	675.9	750.3
Grassland organic soils	36.0	46.5	82.5
Total emissions in 2019	110.5	722.4	832.9

^a N₂O emissions converted to CO₂eq applying IPCC AR5 GWP (IPCC, 2014b).

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Table A2. Original area of *histosols* and shares of drained *histosols* in 1995¹ and 2019

Country	Area of <i>histosols</i> (ha)	of which drained (%)	
		1995	2019
Turkey	16	95.5%	95.5%
Serbia	90	0.0%	92.7%
Guinea-Bissau	101	14.2%	14.2%
Luxembourg	308	0.0%	58.7%
Namibia	853	15.0%	15.0%
Solomon Islands	1,062	1.0%	1.0%
Isle of Man	1,332	80.7%	76.8%
Equatorial Guinea	1,747	0.5%	0.5%
Croatia	2,987	12.6%	11.3%
Nicaragua	3,124	55.7%	39.7%
Liberia	3,208	56.4%	74.8%
Eritrea	3,485	2.3%	2.3%
Slovakia	4,294	58.4%	56.0%
Albania	4,509	85.9%	84.0%
Ghana	5,155	38.7%	33.4%
Central African Republic	5,745	12.2%	17.3%
Fiji	6,867	30.4%	29.5%
Slovenia	7,653	58.7%	83.0%
Montenegro	7,775	0.0%	10.2%
Puerto Rico	10,850	23.4%	15.4%
Republic of Moldova	12,274	52.7%	47.2%
Bosnia and Herzegovina	12,770	36.4%	34.9%
Uruguay	18,213	52.0%	51.2%
Jamaica	18,309	24.7%	34.2%
Panama	18,859	78.5%	78.2%
Costa Rica	21,135	18.5%	14.7%
Belgium	22,985	0.0%	34.3%
Democratic Republic of the Congo	23,750	36.8%	35.7%
Portugal	25,810	50.1%	48.4%
Austria	27,863	41.2%	45.8%
Italy	28,540	81.4%	81.3%
South Africa	31,955	54.3%	63.7%
Malawi	34,745	45.2%	45.2%
Spain	36,030	41.3%	50.7%

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Czechia	37,943	29.6%	28.0%
Faroe Islands	38,952	34.6%	34.6%
Belize	39,354	13.3%	14.4%
Thailand	39,548	65.4%	63.0%
Bulgaria	52,362	76.6%	73.8%
Greece	55,569	81.8%	79.8%
Sri Lanka	55,942	57.6%	54.4%
Ecuador	58,961	1.0%	3.3%
Côte d'Ivoire	69,150	55.5%	60.6%
Guinea	71,016	27.0%	26.3%
Brunei Darussalam	73,964	9.0%	7.5%
Kenya	74,610	11.9%	11.9%
Rwanda	77,814	47.7%	46.3%
French Guiana	82,487	0.4%	1.0%
Switzerland	86,097	43.9%	39.9%
Burundi	88,387	77.0%	78.8%
Denmark	111,011	77.5%	76.5%
Democratic People's Republic of Korea	113,916	3.4%	4.1%
Viet Nam	132,725	52.0%	49.9%
India	156,362	67.0%	65.5%
Madagascar	189,666	55.4%	57.6%
Gabon	199,075	4.7%	5.6%
Uganda	204,211	57.1%	56.7%
Nepal	233,847	31.2%	32.8%
Romania	248,517	7.7%	7.7%
New Zealand	254,339	50.2%	49.8%
Hungary	275,678	71.2%	69.0%
Ethiopia	289,128	44.1%	44.9%
France	308,893	70.7%	67.8%
Angola	319,617	2.1%	2.1%
Myanmar	352,812	83.0%	81.8%
Japan	358,961	52.4%	42.9%
Netherlands	395,113	78.4%	75.9%
Cameroon	404,266	6.0%	7.0%
Colombia	437,958	2.8%	4.0%
Australia	440,351	27.0%	27.1%
United Republic of Tanzania	492,667	21.8%	20.6%

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Bangladesh	507,083	69.4%	66.9%
China, mainland	530,701	27.5%	28.2%
Botswana	651,384	1.5%	1.7%
Falkland Islands (Malvinas)	667,141	43.3%	43.2%
Iceland	684,893	6.4%	6.4%
Argentina	694,519	29.4%	30.1%
Lithuania	701,767	51.4%	49.4%
Venezuela (Bolivarian Republic of)	710,571	4.0%	5.7%
Latvia	735,751	23.3%	26.9%
Suriname	746,249	1.0%	1.7%
South Sudan	827,363	0.0%	32.9%
Brazil	840,917	1.3%	1.7%
Guyana	844,866	7.4%	9.4%
Estonia	918,164	16.4%	20.1%
Ireland	1,118,046	51.8%	50.3%
Ukraine	1,262,568	55.9%	52.0%
Mongolia	1,311,509	80.6%	81.0%
Chile	1,472,126	3.3%	3.4%
Germany	1,482,858	76.0%	74.4%
Zambia	1,565,696	23.3%	23.2%
Congo	1,609,628	3.3%	3.5%
Poland	1,769,225	61.0%	59.0%
Norway	1,947,518	13.1%	14.4%
Malaysia	2,210,193	20.3%	30.4%
United Kingdom	2,610,052	51.4%	50.4%
Belarus	3,014,298	49.7%	48.9%
Peru	3,300,367	0.0%	0.1%
Papua New Guinea	3,806,847	10.6%	11.5%
Sweden	6,797,032	4.4%	6.0%
Finland	9,205,429	4.5%	5.7%
Indonesia	19,791,043	19.9%	24.4%
United States of America	25,399,312	6.2%	6.1%
Canada	105,758,515	1.2%	1.2%
Russian Federation	116,116,633	1.6%	1.6%
World	328,935,932	7.0%	7.5%

^a 1995 is chosen arbitrarily to account for the reporting of countries after the split of the Soviet Union.

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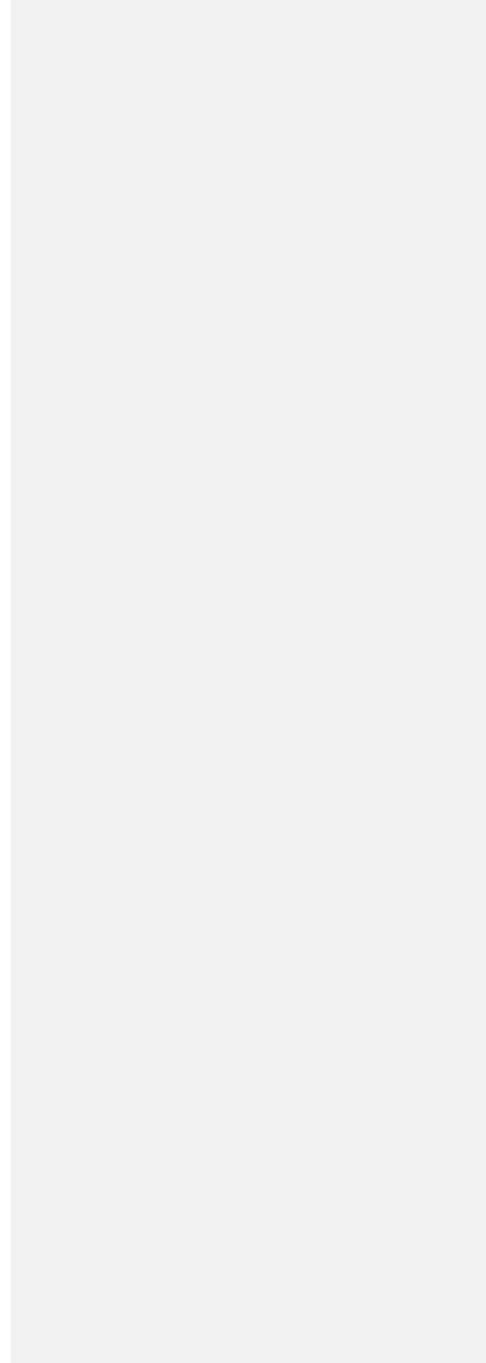


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Table A3. Comparison of our emissions estimates by land use and gas generated applying the EFs from the 2006 Guidelines (IPCC, 2006) with emissions estimates if *ceteris paribus* the EFs from the Wetlands Supplement (IPCC, 2014a) were applied instead to the methodology

	FAOSTAT emissions with EFs from IPCC 2006			Simulated emissions estimates if applying EFs from IPCC 2014		
	Mt CO ₂ eq			Mt CO ₂ eq		
	C	N ₂ O	Total	C	N ₂ O	Total
Cropland organic soils						
<i>Boreal – Temperate</i>	202.8 ^a	22.3 ^a	225.1	240.3	36.3	276.6 (219.9–336.0)
<i>Tropics</i>	473.1	52.1	525.2	331.2	16.3	347.5 (163.1–591.4)
	675.9	74.4	750.3	571.5	52.6	624.0 (383.0–927.4)
Grassland organic soils						
<i>Boreal – Temperate</i>	14.0 ^a	10.8 ^a	24.8	176.2	12.0	188.1 (125.1–371.3)
<i>Tropics</i>	32.6	25.2	57.8	62.5	7.9	70.4 (33.0–122.8)
	46.5	36.0	82.5	238.7	19.8	258.6 (158.2–494.1)
All agriculture-drained organic soils						
	722.4	110.5	832.9	624.0	258.6	882.6 (541.2–1421.5)

^a Estimates are made averaging the EFs for Boreal and Cool Temperate and EFs for the Temperate zones as reported in the 2006 Guidelines (IPCC, 2006).

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Global emissions in 1990 and 2010 by gas and by land use

Land use	Mt by gas		Total in Mt CO ₂ eq
	N ₂ O ^a	CO ₂	
Cropland organic soils	66.4	589.9	656.3
Grassland organic soils	24.9	44.8	70.6
Total emissions in 1990	101.3	634.7	735.9
Cropland organic soils	74.4	675.9	750.3
Grassland organic soils	26.0	46.5	82.5
Total emissions in 2010	110.5	722.4	832.9

^a N₂O emissions converted to CO₂eq through IPCC AR5 GWP (IPCC, 2014b).

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APPENDIX B: Tables for validation

820 Table B1. Peat extent from Page et al., 2011, Gumbrecht et al., 2017, and FAO area of *histosols*, all in 1000 ha

		Page et al., 2011	Histosols (FAO)	Gumbrecht et al. 2017
		Best estimate from meta-analysis	Spatial layers	
Africa	Angola	264	320	1,359
	Botswana	265	651	308
	Burundi	33	88	11
	Cameroon	108	404	654
	Congo	622	1,610	4,357
	Democratic Republic of the Congo	280	24	11,592
	Gabon	55	199	855
	Ghana	6	5	221
	Guinea	195	71	234
	Côte d'Ivoire	73	69	198
	Kenya	244	75	64
	Liberia	12	3	290
	Madagascar	192	190	343
	Malawi	49	35	70
	Mauritania	6	0	0
	Mauritius	0	0	0
	Mozambique	58	0	398
	Nigeria	184	0	0
	Réunion	0	0	0
	Rwanda	83	78	38
Senegal	4	0	0	
Sierra Leone	0	0	0	
South Sudan	907	827	906	
Uganda	730	204	263	
Zambia	1,220	1,566	1,021	
	Africa total	5,586	6,419	23,182
Asia (South East)	Brunei Darussalam	91	74	74
	Indonesia	20,695	19,791	21,342
	Malaysia	2,589	2,210	2,858
	Myanmar	123	353	2,577
	Papua New Guinea	1,099	3,807	4,163

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	Philippines	65	0	0
	Thailand	64	40	2,024
	Viet Nam	53	133	2,815
	Asia (South East) total	24,778	26,407	35,851
Asia (other)	Bangladesh	38	507	5,667
	China	531	531	8,001
	India	49	156	5,179
	Sri Lanka	16	56	128
	Asia (other) total	634	1,250	18,974
Central America & Caribbean	Belize	74	39	165
	Cuba	364	0	0
	El Salvador	9	0	0
	Haiti	119	0	0
	Honduras	453	0	0
	Jamaica	13	18	19
	Mexico	100	0	0
	Nicaragua	371	3	638
	Panama	787	19	218
	Puerto Rico	10	11	18
	Trinidad and Tobago	1	0	0
	Central America & Caribbean total	2,300	90	1,058
Pacific	Australia	15 ^a	440	2,142
	Fiji	4	7	0
	Pacific total	19	447	2,142
South America	Bolivia (Plurinational State of)	51	0	0
	Brazil	2,500	841	30,965
	Chile	105	1,472	1,327
	Colombia	504	438	7,473
	Ecuador	500	59	1,084
	French Guiana	162	82	370
	Guyana	814	845	1,028
	Peru	5,000	3,300	7,499
	Suriname	113	746	998
	Venezuela (Bolivarian Republic of)	1,000	711	5,300
	South America total	10,749	8,495	56,045
	Total	44,066	43,108	137,252

^a In Page et al., 2011, Australia estimates limited to Australia, Queensland.

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825 Table B2. FAOSTAT estimates and UNFCCC reported country data: area drained and N₂O (kt) emissions, by country in Annex I group^a, 2017

ISO3	Country	UNFCCC	FAOSTAT	UNFCCC	FAOSTAT
		Area drained (ha)		N ₂ O emissions (kt)	
AUS	Australia	4,000	119,195	0.05	1.51
AUT	Austria	12,954	12,763	0.17	0.16
BEL	Belgium	2,520	7,899	0.03	0.10
BGR	Bulgaria	41,267	38,750	0.52	0.49
BLR	Belarus	1,419,100	1,474,262	17.84	18.53
CAN	Canada	16,156	1,304,454	0.20	16.27
CHE	Switzerland	17,339	34,369	0.22	0.43
CZE	Czechia	--	10,593	--	0.13
DEU	Germany	1,235,057	1,102,052	9.52	13.77
DNK	Denmark	112,792	84,980	1.60	1.06
ESP	Spain	--	18,342	--	0.23
EST	Estonia	34,815	183,505	0.44	2.30
FIN	Finland	327,616	506,840	5.03	6.34
FRA	France	139,056	209,149	1.75	2.62
GBR	United Kingdom	285,700	1,316,388	3.6	15.9
GRC	Greece	6,665	44,520	0.08	0.56
HRV	Croatia	2,685	336	0.03	0.00
HUN	Hungary	--	190,462	--	2.39
IRL	Ireland	333,853	562,872	2.26	6.83
ISL	Iceland	55,598	43,859	0.08	0.51
ITA	Italy	25,480	23,247	0.32	0.29
JPN	Japan	185,592	154,160	0.39	1.89
LTU	Lithuania	138,758	346,350	1.74	4.35
LUX	Luxembourg	--	181	--	0.00
LVA	Latvia	152,160	197,363	2.71	2.48
NLD	Netherlands	337,102	300,076	2.36	3.77
NOR	Norway	63,862	277,520	1.26	3.36
NZL	New Zealand	8,020	126,770	0.10	1.51
POL	Poland	678,000	1,042,266	8.52	13.08
PRT	Portugal	--	12,598	--	0.15

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ROU	Romania	6,387	19,234	0.08	0.24
RUS	Russian Federation	4,274,300	1,852,512	53.93	23.24
SVK	Slovakia	--	2,399	--	0.03
SVN	Slovenia	2,501	6,361	0.03	0.08
SWE	Sweden	136,692	379,122	2.79	4.71
TUR	Turkey	21,840	15	0.27	0.00
UKR	Ukraine	478,400	656,586	6.01	8.25
USA	United States of America	1,383,162	1,551,534	19.56	26.48
Total		11,939,429	14,213,882	144	184

^a Data for this reporting category are not occurring (NO) in the UNFCCC tables for Cyprus, Czechia, Hungary, Kazakhstan, Luxembourg, Malta, Monaco, Portugal and Spain. Data were not estimated in Slovakia (NE).

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Interactive comment on “Drainage of organic soils and GHG emissions: Validation with country data” by Giulia Conchedda and Francesco N. Tubiello

Anonymous Referee #1

Received and published: 28 August 2020

This study presents the approach and main results of a new methodology developed for FAOSTAT. By combining overlays of maps of land cover with the distribution of wetland soils (histosols) and IPCC emission factors, the authors present a global annual dataset of peatland drained area and greenhouse gas emissions (CO₂ and N₂O) over a time series encompassing three decades (1990–2019). This allows the authors to identify trends in drained areas and emissions over time and to validate the FAO emissions estimates with country data. Sources of uncertainty are discussed. Importantly, the FAO dataset currently provides the only available country/regional/global time series data on GHG emissions from drained organic soils, thereby supporting analysis of trends and the identification of current or emerging emissions hotspots that could be targeted for mitigation measures. The paper is generally well written with a clear

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description of methodological approach, limitations and uncertainties, although I do have some suggestions for further improvement of several aspects relating to uncertainty. The results are very relevant to current actions to reduce land-use derived GHG emissions; they are generally well presented and discussed. I recommend publication following minor revision – see my specific comments and suggestions below. Specific comments: Line 25 – change wet soils ecosystems to wet soil ecosystems  Line 46 – by citing Rieley & Page (2016) you are only referring to tropical peatlands  please include an additional balancing reference for northern peatlands  Section 2 – can the authors acknowledge that by using data on the distribution of histosols as a proxy for peat soils, some areas of histosols will be included that are not strictly defined as peat soils (e.g. if one followed the definition of a minimum peat depth of 40 cm with organic content > 65%  line 105 – suggest rephrase: In order to support crop cultivation activities, organic soils need to be drained  lines 106 – 107 – sentence on livestock needs to be rephrased – sense is not clear : grazing per se does not result in drainage  lines 115-116 – what are the range of values for soil carbon content, pH, water storage content used to characterise histosols  line 122 – replace Spatial with Space (European Space Agency  line 147 – replace climatic zones with climate zones  line 164 – remove ‘and’ Line 165 – section 2.6 Limitations and uncertainty – a) Would the authors consider applying and including emissions based on the revised IPCC emission factors presented in the updated 2013 IPCC guidelines? Perhaps presented alongside the EFs from the 2006 guidelines? For the most part, the 2013 EFs are based on a wider literature base and provide a more accurate assessment of Tier 1 emissions across land-use categories/climate zones. Alternatively, the authors should at least acknowledge and discuss how use of the 2013 EFs would alter their emissions estimates  Can the authors consider adding a further couple of sentences into this section on the uncertainties that arise, over time, from peat wastage – i.e. where drainage leads to the depletion and eventual loss of organic matter from shallow peat soils there is the potential for a change in the scale of emissions. Without accurate country data on peat depth and rate of peat loss it will not be possible to estimate peat depletion rates  it

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this could at least be acknowledged. N.B. At least in drained temperate peatlands, a reduction in soil organic carbon does not necessarily result in a reduction in CO₂ emissions (e.g. see Tiemeyer et al. 2016 - <https://doi.org/10.1111/gcb.13303>), but in tropical peatlands peat loss is usually accompanied by an increasing occurrence of flooding which will necessarily reduce CO₂ emissions over time. Line 187 – the authors could considering clarifying here, or in the discussion, that whilst the analysis is only for drained peat soils under cropland and grassland, in fact in some countries (e.g. Indonesia) there are extensive additional areas of peatland subject to drainage that are under other land covers (e.g. degraded forest, scrub in the case of countries in SE Asia) and emissions from these land covers are not captured in this analysis. Line 211 – add a full stop after ranges; change estimates to estimate. Line 218 and following – there is indeed a discrepancy between estimates in Page et al. (2011) and the data presented by Gumbrecht et al. (2017), particularly in relation to S. America. The authors might wish to expand here on why these discrepancies could have arisen e.g. the remote sensing approach (remote sensed wetness index) used by Gumbrecht provides very limited data over tropical forested peatlands and therefore in these areas their estimates appear to be more based on topography, climatic wetness etc – which may be reasonable assumptions for predicting the location of wetlands but cannot be used to determine whether or not these wetlands are peat forming systems. The estimates for Brazil likely therefore indicate extensive areas of wetland, but not necessarily peatland. Line 224 – replace ‘both about a third’ with ‘but both estimates are about a third of’. Line 232 – change explains to explain. Line 233 – change ‘For one percent’ to ‘For a one percent ..’. Line 239 – change consistently to consistent. Line 242 – change peatlands to peatland. Line 243/section 4.1 – I would encourage the authors to also mention that their estimates of emissions do not, for example, include emissions from water surfaces (e.g. CO₂/CH₄ evasion from drainage channels, e.g. in plantation landscapes). Nor do they include fire emissions. In SE Asia, GHG emissions from peat fires can be of a comparable magnitude to emissions arising from peat oxidation driven by drainage and agricultural uses. But peat fires are also an increasing feature

of other drained peatlands – e.g. in Russia. Line 261 – change organic area to organic soil area. Line 270 – change ‘due to’ to ‘be due to’. Line 278 – country name is missing before the final bracketed numbers. The difference here in emissions seems particularly large (16 vs. 0.2 kt N₂O) – do the authors have an explanation for this? Line 285 – can the authors provide some more detail on why the Tiemeyer emissions estimates for organic soils in Germany are so much higher than FAOSTAT emissions? Line 288 – replace fourty with forty. Section 4.2.2. – at the start of this section you refer to both Indonesia and Malaysia, but then go on to only compare the FAOSTAT and country data on emissions for Indonesia. For completeness, is it possible to also include a comparison of the Malaysian datasets? Also, Miettinen et al (2016) give the area of peatland under crops (plantations and smallholder agriculture) in Indonesia as 6.3 Mha compared with the FAOSTAT estimate of 5 Mha. Perhaps worth mentioning this difference. Does the 5 Mha area estimated in FAOSTAT include all plantations (including pulpwood) or only oil palm and other food crop plantations? Your Table 6 implies you include all types of plantations (but this should be clarified). Line 302 – insert ‘a’ before ‘main driver’. Line 303 – Hooijer is mis-spelt (2010 citation). Lines 317 – 318 – improve expression – sense not clear. Line 320 – insert ‘be’ after ‘may’. Line 335 – should ‘disseminated’ read ‘disaggregated’. Sense not clear. Line 352 – insert ‘to’ before ‘whether’. Table 6 – please clarify whether the ‘all plantations’ category includes pulpwood plantations as well as oil palm and other food crop plantations (e.g. coconut) (see point above on Section 4.2.2). Table 7 – correct mis-spelling of Hooijer. Also, some of these studies (e.g. Hooijer et al. 2012, Cooper et al. 2020) take account of the initial pulse of carbon that is lost from peat soils in the immediate (up to 5) years following peatland drainage and deforestation. Other studies, however, do not account for this initial pulse and represent emissions once the peat landscape has stabilised under the new land use (+5 years after drainage). Figure 5 – the figure caption should indicate that the emission factors are derived from IPCC (2006). Figure 13 – in the relevant part of the discussion, the discrepancy in the FAOSTAT estimate of emissions and the country reported emissions in Indonesia should be addressed. Could the dis-

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crepancy (lower FAOSTAT estimate) but due to the in-country data reporting emissions from all forms of degraded peatland land covers/uses, i.e. not just cropland/grassland? For example, the INCAS (Indonesian Carbon Accounting System) reports emissions from degraded, non-agricultural peatland (e.g. degraded forest and scrub). 

Interactive comment on Earth Syst. Sci. Data Discuss., <https://doi.org/10.5194/essd-2020-202>, 2020.

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Interactive comment on “Drainage of organic soils and GHG emissions: Validation with country data” by Giulia Conchedda and Francesco N. Tubiello

Anonymous Referee #2

Received and published: 8 September 2020

This study is highly valuable and timely in the context of GHG mitigation strategies and country submissions and reporting under UNFCCC and commitments to the Paris Agreement. Currently FAO is the only global consistent database providing information on activity data, emission factors and GHG emissions from drained organic soils, and not only. The authors update the old static map of drained organic soils from the year 2000 and their CO₂/N₂O emissions with a new methodology developed for FAO-STAT which includes dynamic maps. The authors present times series of global annual dataset of drained area and CO₂/N₂O emissions between 1990 - 2019 and validate it with country information. Some uncertainty information is provided but would be very useful if uncertainties on emissions could be quantified. I would also encourage in the future updates, the use of more recent land use and land use change products

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(e.g. HILDA+) (<https://landchange.imk-ifu.kit.edu/news/sneak-preview-hilda-coming>). Paper reads well but I would suggest to be read by a native speaker to help improving its flow. Similar to reviewer #1, I agree to its publication after minor/technical revisions.

Specific technical comments: Line 31: ...large quantities of available organic substrate
Line 32: replace “and especially since 1990” with “the world, especially after the 90s. ... and perhaps add in brackets where oil palm became permanent crop
Line 45: to be clear if wetland condition or wet condition
Agree with referee #1: add references not only for boreal but also for alpine organic soils (bogs, fens)
Line 48: delete indeed
Line 56: as “as they continue emitting..” Lines 74-76: I would reference or name in brackets all the maps used in this study (land use, density etc.) when they appear for the first time
Line 105: delete “indeed be”
Line 139: how about other species? I guess for the boreal areas with organic soils other animals are present – e.g. reindeer
Line 144: which map did you use from the JRC? Please reference/name the original map as we
Line 154: please reference the Climate Convention
Line 167: you mention here drained peats: is it only peat or drained organic soils in general? Line 178: “data suggests”
Line 182: To which period are you referring to about Asia drainage (3000)? Over the whole studied period or one particular year? Line 191: If 833 Mt refers here to 2019 then I would reformulate: “In 2019, global GHG emissions from drained organic soils were 833 Mt CO₂eq. They were 13 % and 10 % higher when compared to 1990 and 2000 respectively, representing 8 % . . .”
Line 194 and 195: I would delete gas. Are the global emissions/all emissions you refer here total GHG emissions in CO₂ or CO₂eq or total emissions from drainage? Please explain. Lines 211-215: I would add to table 5 all specific comparisons. I was also wondering why you are using the old reference of Joosten 2002 and not a more recent updated information from his peatland database which I think Prof. Joosten is updating regularly for the areas and emissions from organic soils. (<https://greifswaldmoor.de/global-peatland-database-en.html>)
Line 227: countries from South and Central America
Lines 235-240: do you know what causes the main difference between the way Gumbrecht, Page and FAOSTAT calculate country level estimates? Are these uncertainties due to area, method, level of detail

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or input to the maps? Perhaps add a sentence at the end of the paragraph summarizing these differences. Line 247: please specify which UNFCCC data was used? 2019, 2020? Same for line 252: UNFCCC (year) data are available... Lines 262: do you know why these differences? I think it should be mentioned that Canada uses a high Tier model (CBM) to report to the UNFCCC. Line 266: I would name LULUCF sector and not category. As you define further, categories are 1.B, 4.C etc. Line 270: higher Tiers than... Line 271: delete As Line 282: please reference the IPCC Wetlands EFs, are the values from the Wetlands Supplement or the IPCC 2006 chapter 7. Line 295: delete the in "vs the 304". Please add everywhere the year for the UNFCCC data. Line 309: to those from established or better peer-reviewed literature. Line 311: please check references: Petersen or Peterso. Line 318: which emissions (CO2, N2O, total?) in this country? Emissions were due to.. Please add a % in brackets. Line 320: may less...please complete: may be less or may not be less important. Line 322: are direct measurements the in-situ measurements? And typically analyse. Line 336: available Line 339: million tonnes, be consistent until now Mt was used Line 351: consistent with writing IPCC Figures 11 and 13: why the use of both gigagrams and kt?

Interactive comment on Earth Syst. Sci. Data Discuss., <https://doi.org/10.5194/essd-2020-202>, 2020.

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***Interactive comment on* “Drainage of organic soils and GHG emissions: Validation with country data” by Giulia Conchedda and Francesco N. Tubiello**

Anonymous Referee #3

Received and published: 24 September 2020

This study is a highly valuable and useful further development of the dataset on drained organic soils emissions already available on FAOSTAT. While that dataset was a picture of the global situation in 2000, here the authors produced a spatially-explicit timeseries of global estimations for the period 1990-2019 through the use of the ESA CCI Land Cover dataset, which offers yearly global land cover maps for the years 1992-2018. The other datasets remained those used in producing the previous FAOSTAT dataset: the HWSO map to identify histosols (adopted as proxy for organic soil, based on the IPCC guidelines), and the FAO Gridded Livestock of the World to identify grazed land. The work is extremely valuable due to the importance of emissions from drained organic soils in the global carbon budget, and the very limited data available about this carbon pool and GHG source. Organic soils contain about 30% of the total soil carbon

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despite their relatively limited global area, and drainage of organic soils for agriculture or grazing purposes releases enormous amounts of carbon and N₂O (a very powerful GHG) for long time periods (decades after the drainage). Drainage of organic soils has increased dramatically in the last decades for agricultural purposes, especially in South-East Asia. Information on areas of drained organic soils used for agricultural or grazing purposes is therefore essential in GHG emissions assessments. A very important added value is that this study implements the Tier 1 IPCC methodology, which can be used for producing GHG inventories in the context of the global climate treaties, making it a very useful tool also for inventory preparation. No other dataset is at the moment providing this yearly information at the global level and in a spatially explicit way (although at the moment the data will be primarily distributed as country and regional statistics through FAOSTAT). Overall, this dataset is an important new part of the FAOSTAT emissions database. The paper is well written but needs some adjustments for increasing clarity. Here some suggestions beside what has been already suggested in other comments. - the authors say that their dataset covers the period 1990-2019, but the ESA-CCI timeseries cover the period 1992-2015 (then extended to 2018). Please clarify this point  would add some more details to the description of the datasets used. For example, to which year the livestock map refers to? How it was produced (just some details  Which is the spatial resolution of the grid? - how is the proportion of areas of the various categories within each pixel assigned? i.e. how is the original LCCS legend used by the ESA CCI product translated to the IPCC land use categories  Page 5 line 148: I suppose that the weighted averages refer to the Implied Emission Factors contained in the FAOSTAT dataset, not to the Emission Factors used in the estimation, which is done at pixel level and not at country level  there are some minor language issues (e.g. page 4 line 105 "must be indeed be"), etc. so a thorough language revision would be useful.

Interactive comment on Earth Syst. Sci. Data Discuss., <https://doi.org/10.5194/essd-2020-202>, 2020.