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Peat-GHG tool

A greenhouse gas calculator for peatland management in Indonesia

User manual

TECHNICAL WORKING PAPER

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Executive summary

Globally, peatlands occupy only 3 percent of global land area. Yet, they are able to store twice as much carbon as the world forests. Indonesia contains approximately 36 percent of the world's tropical peatlands. Despite their importance as carbon storage, Indonesian peatlands have experienced deforestation and drainage due to logging, agriculture, fires, fuel wood collection, and livestock grazing especially since 1980s. Peat-related greenhouse gas (GHG) emissions have been estimated to be responsible for at least 38 percent of total national carbon budget. Indonesia's climate change mitigation efforts are oriented towards reducing emissions from deforestation and degradation of natural forests and peatland decomposition through conservation and restoration activities. By 2030, more than 2 million hectares of degraded peatlands in Indonesia is expected to be restored to meet the reduction targets as reported in the country's Nationally Determined Contribution (NDC) to the Paris Agreement which was submitted to the United Nations Framework Convention of Climate Change (UNFCCC) in 2016. The new submission of the NDC, expected in 2021, most likely shows new figures.

Under the project 'Development of an Innovative Peatland Monitoring System (PRIMS)', the Peat-GHG calculator and its manual have been developed as part of the technical support of FAO. The Peat-GHG is an Excel-based tool that provides ex-ante estimates on anthropogenic GHG emissions resulting from peatland management practices in Indonesia. It was developed to support key national stakeholders in Indonesia and answers questions such as what activities and practices to do and where – based on a quick analysis of the potential GHG outcome. This manual covers every step of the tool and will be updated to reflect any improvements.

The ultimate objective of using the tool is to ex-ante quantify the climate change mitigation potential of peatland management practices and activities carried out and coordinated among others by the Indonesian Peatland Restoration Agency (BRG). It can also be used to estimate roughly other actors' peatland restoration in Indonesia. The tool has been peer-reviewed and developed through collaboration and technical support and feedback received from Chris Evans, Hans Joosten, Susan Page, John Couwenberg, to name a few peatland experts who have also contributed to the IPCC's Wetland Supplement (2014) as well as BRG's technical staff, Ministry of Environment and Forestry in Indonesia, and CIFOR and FAO Colleagues.

Keywords: *greenhouse gas; peatlands; tropical organic soils; monitoring; accounting; UNFCCC; transparency framework; climate change; reducing emissions*

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Abbreviations and acronyms

BRG	Indonesian Peatland Restoration Agency (until 2020, after BRGM)
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
DOC	Dissolved organic carbon
EF	Emission factor
FAO	Food and Agriculture Organization of the United Nations
FRL	Forest Reference Level
GHG	Greenhouse Gas
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
LUC	Land-use change
MoEF	Ministry of Environment and Forest in Indonesia
N_2O	Nitrous oxide
T	Tonne
$tCO_2eq.$	Tonne of carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change
yr	Year

1. Introduction

The Peat-GHG tool (Figure 1) is a user-friendly greenhouse gas (GHG) calculator, which, at the time of writing this manual, has been tailored for Indonesia's tropical peatlands. It is an appraisal tool that provides estimates on how the carbon balance is impacted by peatland management interventions in the country. It estimates the carbon (C) stock changes per unit of land, and GHG emissions (CO_2, N_2O and CH_4) in tonnes of CO_2 equivalent (CO_2eq.) per hectare per year.

The Peat-GHG tool calculates the total GHG emissions and changes in the amount of GHGs emitted (including avoided emissions) as a result of the implementation of peatland management practices, when compared to a without-project scenario. The main output of the tool consists of carbon and other GHG balance resulting from the difference between two scenarios: with-project scenario and a without-project scenario considering changed management practices.

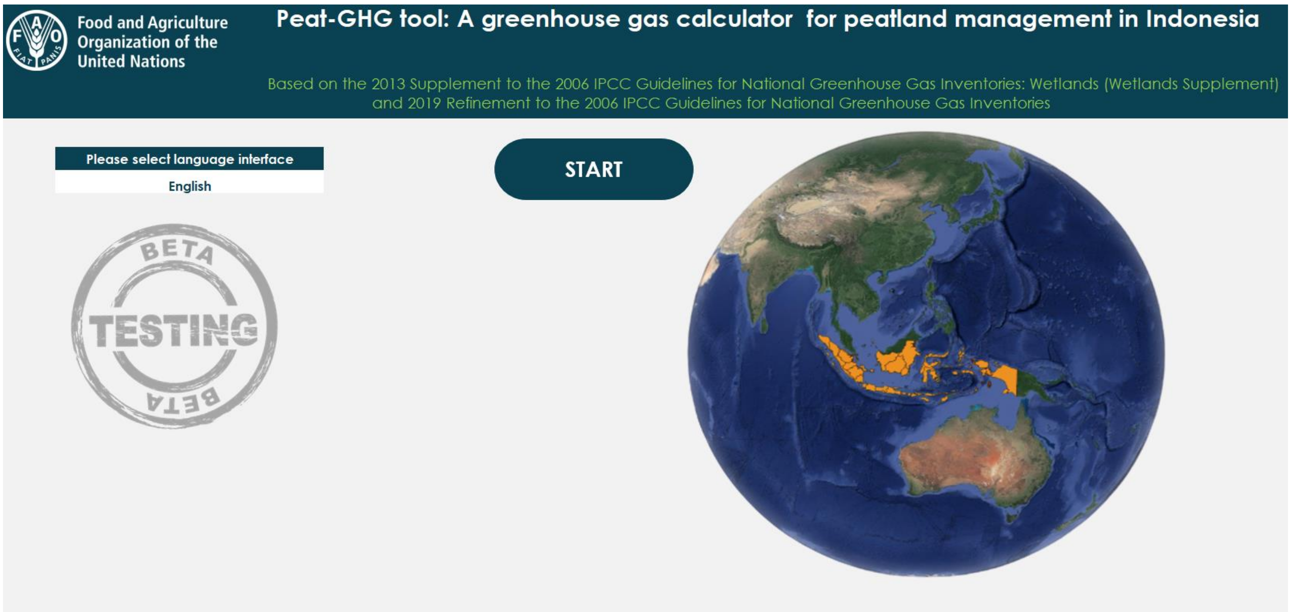
Box 1. Target audience and objectives of the Peat-GHG tool

The Peat-GHG tool aims to help those with an interest in the future of a peatland area, such as policy makers, project managers, donors, planners, and other stakeholders to make informed decisions about peatland management by:

- providing quantitative ex-ante estimates of the impact of peatland management practices on GHG emissions;
- facilitating stakeholders to gain a better understanding of key sources of peat-related GHG emissions;
- quantifying the climate change mitigation potential of peatland interventions using internationally recognized methodologies developed by the Intergovernmental Panel on Climate Change (IPCC); and
- providing data and information about the most effective mitigation options.

This Excel-based tool consists of a set of linked excel sheets that comprise six topic modules, namely: (1) Description, (2) Land-use changes, (3) Managed agricultural peatlands, (4) Managed forested peatlands, (5) Inputs, and (6) Detailed results.

Figure 1. Start page of the Peat-GHG calculator



Source: Peat-GHG tool screenshot.

The tool covers all GHG emissions associated with drained and rewetted tropical organic soils, carbon stock changes during land use conversions, cultivation of peatland soils including oil palm ('estate crop'), rice and other crops, and tree production (e.g., for pulp and paper), as well as inputs of lime and fertilizers. However, at present CO_2 and non-CO_2 emissions from fires on organic soils and biomass or residue burning are not currently included in the tool, given the lack of reliable key data.

The Peat-GHG tool has been developed by FAO tailored to support the Indonesian agencies through the project 'Development of an Innovative Peatland Monitoring System, PRIMS' 2018–2020. The tool is based on the Ex-Ante Carbon-balance Tool (EX-ACT), an appraisal system developed by FAO, providing estimates of the impact of agriculture, forestry and fishery development projects, programmes and policies on the carbon balance (Bernoux et al. 2010). To note: this tool is not meant to serve alone as the sole justification for decision-making, and it should be used in combination with other data e.g., on biodiversity, socio-economic, and other considerations.

Overall, the tool is quick and relatively easy to use and requires only a small amount of data for rough carbon balance estimate. The Peat-GHG tool is freely available on the Internet and is translated in English and Bahasa. This manual covers every step of the tool and will be updated to reflect any improvements.

2. Background and methodological overview

The tool was developed based on the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC, 2014) and 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019) in conjunction with information and data reported in the modified submission on the proposed Forest Reference Level for REDD+ of Indonesia (MoEF, 2016). This makes the tool applicable on a country-specific basis.

The tool follows the basic methodology for estimating C emissions from tropical organic soils as presented in Equation 1 below, where the area of drained and managed organic soils under tropical climate is multiplied by the associated emission factor[1] to derive an estimate of annual emissions or removals.

Equation 1. Annual carbon loss from drained organic soils

$$L_{Organic} = \sum (A * EF)$$

Where:

$L_{Organic}$: Annual carbon loss from drained organic soils, tonnes C yr^{-1}

A: Land area of drained tropical organic soils, ha

EF : Emission factor for tropical climate, tonnes C ha^{-1} yr^{-1}

Source: IPCC, 2014.

2.1 Drainage and greenhouse gas emissions

This section provides the equations that are used by the tool to estimate the impacts of drainage on a set of GHGs (CO_2, CH_4 and N_2O) known to be released as emissions through different management approaches (including forestry) utilized on tropical drained organic soils. The GHG emission parts of the tool apply to tropical organic soils that have been drained, e.g., drainage of lands that started in the past and that still persists (that is, the peat layer has not been entirely depleted nor the peat has become inundated, and therefore partly protected from oxidation), or newly drained lands. This means that the water table level is

[1] See the Glossary section for definitions of activity data, emissions factors and other relevant terms.

at least temporarily below natural levels. Natural levels mean that the mean annual water table is near the soil surface but can experience seasonal fluctuations (IPCC, 2014).

Carbon dioxide

Drainage of peatlands increases the oxygen content of the soil, promoting organic matter decomposition, which ultimately increases carbon dioxide (CO_2) emissions. Annual on-site CO_2 emissions from drained tropical organic soils are estimated following Equation 2.

Equation 2. Annual on-site CO_2 emissions from drained organic soils

$$CO_2 - C_{On-site} = \sum_{c,d} (A * EF)\ c, d$$

Where:

$CO_2 - C_{On-site}$: Annual on-site CO_2-C emissions from drained organic soils in a land-use category, tonnes C yr^{-1}

A: Land area of drained organic soils in a land-use category in climate domain c and drainage class d, ha

EF: Emission factors for drained organic soils, by climate domain c, drainage class d, tonnes C $ha^{-1}yr^{-1}$

Source: IPCC, 2014.

Dissolved organic carbon

Dissolved organic carbon (DOC) forms the largest component of waterborne carbon export, and can be affected by drainage, and flushed by the water to the drainage canals or other types of water-extracting infrastructure. Most DOC is thought to ultimately convert to CO_2 and be emitted to the atmosphere (as off-site emissions) via photochemical or biological breakdown processes. Annual off-site CO_2 emissions associated with waterborne carbon loss from drained organic soils are calculated following Equation 3.

Equation 3. Annual off-site CO_2 emissions due to DOC loss from drained organic soils

$$CO_2 - C_{DOC} = \sum_c (A * EF_{DOC})\, c$$

Where:

$CO_2 - C_{DOC}$: Annual off-site CO_2-C emissions due to DOC loss from drained organic soils, tonnes C yr^{-1}

A: Land area of drained organic soils in a land-use category in climate zone c, ha

EF_{DOC}: Emissions factors for annual CO_2 emissions due to DOC loss from drained organic soils, by climate zone c, tonnes C $ha^{-1} yr^{-1}$

Source: IPCC, 2014.

Other components of waterborne carbon fluxes, such as particulate organic carbon (POC) and dissolved inorganic carbon (DIC) are not included in the tool, due to a lack of data, and uncertainty about sources and effects of management; as such, no IPCC default emissions factors are available at the time of writing (2021). In Indonesian peatlands, it is likely that most waterborne carbon loss is in the form of DOC.

Methane

Methane (CH_4) emissions can be relatively high from undrained and re-wetted peatlands. When organic soils are drained, the natural production of CH_4 is reduced and organic **soil itself** may even become a CH_4 sink. However, ditch networks provide a continued source of CH_4 emissions from areas of drained organic soil and can be significant at the scale of an entire landscape. This occurs due to a combination of CH_4 transfer from the organic soil matrix (peat areas and the drainage system), and in-situ CH_4 production within the ditches themselves. Available data suggest that CH_4 emissions from the ditches are high in tropical peatlands (Deshmukh et al 2020).

The tool calculates annual CH_4 loss from drained organic soils using Equation 4.

Equation 4. Annual CH4 emissions from drained organic soils

$$CH_{4_{Organic}} = \sum_{c} \left(A_c * ((1 - Frac_{ditch}) * EF_{CH_{4_{land}}} + Frac_{ditch} * EF_{CH_{4_{ditch}}}) \right)$$

Where:

$CH_{4_{Organic}}$: Annual CH_4 loss from drained organic soils, kg CH_4 yr^{-1}

A_c: Land area of drained organic soils in a land-use category in climate zone c, ha

$EF_{CH_{4_{land}}}$: Emission factors for direct CH_4 emissions from drained organic soils, by climate zone c kg CH_4 $ha^{-1}yr^{-1}$

$EF_{CH_{4_{ditch}}}$: Emission factors for CH_4 emissions from drainage ditches, by climate zone c kg CH_4 ha^{-1} yr^{-1}

$Frac_{ditch}$: Fraction of the total area of drained organic soil which is occupied by ditches.

Ditches are considered to be any area of manmade channel cut into the peatland. The ditch area may be calculated as the width of ditches multiplied by their total length. Where ditches are cut vertically, ditch width can be calculated as the average distance from bank to bank. Where ditch banks are sloping, ditch width should be calculated as the average width of open water plus any saturated fringing vegetation.

Source: IPCC, 2014.

Nitrous oxide

Drained organic soils can emit significant amounts of nitrous oxide (N_2O). Reasons for increased N_2O emissions include nitrogen mineralization associated with organic matter decomposition in drained organic soils, and denitrification of nitrate added in fertilizers. Direct N_2O emissions from managed soils are estimated using Equation 5.

Equation 5. Annual direct N_2O emissions produced from managed/drained organic soils

$$N_2O - N_{OS} = \left(F_{Trop} * EF_{2,Trop} \right)$$

Where:

$N_2O - N_{OS}$: Annual direct N_2O–N emissions from managed/drained organic soils, kg N_2O N yr^{-1}

F_{Trop} : Annual area of managed/drained tropical organic soils, ha

$EF_{2,Trop}$: Emission factor for N_2O emissions from drained/managed tropical organic soils, kg N_2O–N $ha^{-1}yr^{-1}$

Source: IPCC, 2014.

2.2 Rewetting and greenhouse gas emissions

This section provides the equations that are used by the tool to estimate the impacts of rewetting[2] on GHG emissions (CO_2, CH_4 and N_2O) from tropical rewetted organic soils. The tool applies to tropical organic soils that have been fully rewetted including emission factors that are associated with shallow-drained plantations typically used for tree cultivation (e.g., sago palm). IPCC refers to these as “Plantations, shallow-drained (typically less than 0.3 m), typically used for agriculture, e.g., sago palm”.

Carbon dioxide

Generally, rewetting of peatlands significantly decreases CO_2 emissions from organic soils compared to the drained condition, and under optimal conditions, and once the peat-forming vegetation starts reforming may lead to the recovery of a net ecosystem CO_2 sink – but this may take a significantly long period. In the tropical ecosystems in particular, regaining the sink function may, according to some experts, take even several hundreds of years, depending of the severity of the peat’s degradation status.

Re-establishing the vegetation cover on rewetted organic soils is necessary to avoid further drying and heating of the peat surface, and eventually start regaining the carbon sink function that ultimately leads to soil C sequestration. After a vegetation succession promoted by rewetting, the CO_2 sink may reach the level typical of undrained ecosystems. However, even if during the first years after rewetting a site can remain a CO_2 source, after a few years from the start of restoration activities the significance of the reduced emissions is much more important (Günther et al. 2020).

The tool follows Equation 6 (Tier 1) where the area of rewetted organic soils is multiplied by the respective emission factor.

[2]See the Glossary section for rewetting definition.

Equation 6. Annual on-site CO_2 emissions/removals from rewetted organic soils

$$CO_2 - C_{composite} = \sum (A * EF_{CO_2})$$

Where:

$CO_2 - C_{composite}$: CO_2-C emissions/removals from the soil and non-tree vegetation, tonnes C yr^{-1}

A: Area of rewetted organic soils in tropical climate, ha

EF_{CO_2}: CO_2-C emission factor for rewetted organic soils in tropical climate, tonnes C ha^{-1}

Source: IPCC, 2014.

Tier 1 methodology is applicable from the year of rewetting. Under Tier 1, the basic methodology assumes that there is no transient period and that rewetted organic soils immediately behave like natural/undrained organic soils in terms of CO_2 flux dynamics. The tool follows this approach.

Dissolved organic carbon

Natural/undrained organic soils export DOC and these fluxes tend to increase with drainage. Data from rewetted sites suggest that the level of DOC reduction after rewetting is equal to the DOC increase after drainage. Consequently, it is assumed in that rewetting eventually leads back to natural DOC flux levels (IPCC, 2014). The tool calculates annual off-site CO_2 emissions due to DOC losses from rewetted tropical organic soils following Equation 7 below.

Equation 7. Annual off-site CO_2 emissions due to DOC losses from rewetted organic soils

$$CO_2 - C_{DOC} = \sum_{c} (A * EF_{DOC_{REWETTED}})_c$$

Where:

$CO_2 - C_{DOC}$: Off-site CO_2-C emissions from dissolved organic carbon exported from rewetted organic soils, tonnes C yr^{-1}

A: Area of rewetted organic soils in tropical climate zone, ha

$EF_{DOC_{REWETTED}}$: CO_2-C emission factor from DOC exported from rewetted organic soils in tropical climate tonnes C ha^{-1} yr^{-1}

Source: IPCC, 2014.

Methane

Methane (CH_4) emissions/removals from rewetted organic soils result from the balance between biochemical CH_4 production and oxidation, and emissions of CH_4 produced by the combustion of soil organic matter during fire. At present, the tool does not capture CH_4 emissions from burning of rewetted organic soils. It is good to note as well, that when fully rewetted, it is rare that a peatland would burn intensely. The tool calculates annual CH_4 emissions from rewetted soils following Equation 8.

Equation 8. Annual CH_4 emissions/removals from rewetted organic soils

$$CH_4 - C_{soil} = \frac{\sum_c \left(A * EF_{CH4_{soil}}\right)}{1000}$$

Where:

$CH_4 - C_{soil}$: CH_4 -C emissions from rewetted organic soils, tonnes C yr^{-1}

A: Area of rewetted organic soils in tropical climate, ha

$EF_{CH4_{soil}}$: Emission factor from rewetted organic soils in tropical climate, kg CH_4-C ha^{-1} yr^{-1}

Source: IPCC, 2014.

Nitrous oxide

Upon rewetting, N_2O emissions are controlled by the quantity of N available for nitrification and denitrification, and the availability of the oxygen required for these chemical reactions. Oxygen availability is in turn controlled by the depth of the water table. Raising the water table will cause N_2O emissions to decrease rapidly, and fall practically to zero if the depth of the water table is less than 20 cm below the surface.

2.3 Categories and representation of land classes

The tool is based on the national land classification system which is line with the land use and land cover classification that was used in the submission on Forest Reference Level (FRL) for REDD+ (MoEF, 2016). It is important to note that Indonesia is expected to submit its new FRL soon, and therefore the classification may require updating. Indonesia stratifies land into 23 land classes including six land classes of natural forest, one land class of plantation forest, 15 land classes of non-forest, and one land class of 'clouds-no data' (MoEF, 2016).

Since the tool applies to organic soils, only the land classes that are found on organic soils are included in the tool. The classes that are included in the tool are given below, as defined and described in the FRL submission (MoEF, 2016):

1. **Primary mangrove forest:** Wetland forests in coastal areas such as plains that are still influenced by the tides, muddy and brackish water, and dominated by species of mangrove and nipa palm (*Nypa frutescens*), which is not or is influenced only at a low level by human activities or logging.
2. **Secondary mangrove forest**[3]**:** Wetland forests in coastal areas such as plains that are still influenced by the tides, muddy and brackish water and dominated by species of mangrove and nipa, and exhibit signs of logging activities, indicated by patterns and spotting of logging activities.
3. **Primary swamp forest:** Natural tropical forest growing on wet habitat in swamp form, including brackish swamp, marshes, sago and peat swamp, which is not or low is influenced only at a low level by human activities or logging.
4. **Secondary swamp forest:** Natural tropical forest growing on wet habitat in swamp form, including brackish swamp, marshes, sago and peat swamp that exhibit signs of logging activities indicated by patterns and spotting of logging (appearance of roads and logged-over patches).
5. **Plantations:** The appearance of the structural composition of the forest vegetation in large areas, dominated by homogeneous trees species, and planted for specific purposes. Planted forest include areas of reforestation, industrial plantation forest, and community plantation forest. The majority of forest plantations on peat in Indonesia are on a short-rotation cycle (e.g., Acacia sp.).
6. **Shrubland:** Highly degraded logged-over areas on wet habitat that are in an ongoing process of succession but have not yet reached a stable forest ecosystem, with naturally scattered trees or shrubs.
7. **Savanna/grasses:** Areas with grasses and scattered natural trees and shrubs. This is typical of natural ecosystem and appearance on Sulawesi Tenggara, Nusa Tenggara Timur, and south part of the province of Papua. This type of land cover could exist both on wet or non-wet habitat.
8. **Mixed dry agriculture:** All land covers associated with agricultural activities on dry/non-wet land mixed with shrubs, thickets, and logged-over forest. This cover type often results of shifting cultivation and its rotation.

[3] Secondary forests encompass all disturbed (drained) forest types (swamp, mangrove) that are influenced by logging operations and other activities. Secondary forest is a class that represents only remaining forest that suffered from selective logging, not refers to regeneration areas after temporary unstocking. Indonesia considers all of the secondary forest as drained forests.

9. **Estate crops:** Estate areas that have been planted, mostly with perennial crops or other agricultural trees commodities. In the Indonesian classification, oil palm, rubber and sago palm are referred to as estate crops. In the tool, 'estate crop' is further stratified into shallow-drained and deep drained. Shallow-drained estate crop has a mean annual water table depth of less than 30 cm below the surface (e.g., sago palm) whereas the class 'estate crop deep-drained' has a mean annual water table depth of 30 cm and deeper below the surface such as oil palm plantations (adapted with further guidance from MoEF, 2016.)
10. **Paddy field:** Agriculture areas on wet habitat, especially for paddy, that typically exhibit dyke patterns (pola pematang). This cover type includes rain fed, seasonal paddy field, and irrigated paddy fields.
11. **Transmigration areas:** A unique settlement areas that normally contain association of houses and agroforestry and/or garden in the surroundings.
12. **Settlement areas:** Settlement areas include rural, urban, industrial and other built-up areas with typical appearance.
13. **Bare ground:** Bare grounds and areas with no vegetation cover, including open exposure areas, craters, sandbanks, sediments, and areas that have been burning and that do not yet exhibit regrowth.
14. **Mining areas:** Mining areas exhibit open mining activities such as open-pit mining including tailing ground.

The 2013 IPCC Wetlands Supplement (IPCC, 2014) categorizes emission factors into IPCC land classes under the assumption that certain peatland drainage will occur within a particular land cover class. Table 1 below shows how the land classes of Indonesia (MoEF, 2016) are matched with the IPCC land use categories provided in Table 2.1 of the Wetlands Supplement (IPCC, 2014).

2.4 Carbon pools

Five carbon pools[4] are included in the tool namely: (1) above-ground biomass, (2) below-ground biomass, (3) dead wood, (4) litter and (5) soil carbon in peatland.

Above-ground biomass: Default values correspond to estimates provided by IPCC (2019) and MoEF (2016) stratified by land use and main islands of Indonesia and expressed in tonnes per ha of dry matter.

[4] See the Glossary section for definitions of carbon pools.

Below-ground biomass: The below-ground biomass is estimated using a ratio (R) of below-ground biomass to above-ground biomass. The tool uses the default values provided by IPCC (2013 and 2019). In some cases, the total above plus below ground biomass is used, if it is not mandatory for calculation to have separate estimates.

Litter and dead-wood: It is assumed that litter and dead wood pools are zero in all non-forest categories (excluding tree crops and perennial systems). Therefore, transitions between non-forest categories involve no C stock changes in these two pools. Regarding other transitions, default IPCC Tier 1 values are used.

Organic soil: The tool uses default Tier 1 emission factors for tropical organic soils, which were generated using GHG flux data published until 2013 (IPCC, 2014). Flux measurements are commonly used on all types of organic soils to determine gas exchange at frequencies from minutes to weeks over monitoring periods of up to a few years.

Table 1. The land cover classes of Indonesia included in the tool

N	Land classes	Categories	IPCC land use categories	Drainage status	IPCC Wetland Supplement land categories
1	Primary mangrove[5]	Natural	Forest	Natural/ undrained	-
2	Secondary mangrove	Natural	Forest	Drained	Forestland and cleared forestland, drained
3	Primary swamp	Natural	Forest	Natural/ undrained	-
4	Secondary swamp	Natural	Forest	Drained	Forestland and cleared forestland, drained
5	Plantations	Plantations	Forest	Drained	Plantations, drained, short rotations, e.g., acacia sp.

[5] With regard to natural primary forest, the tool uses the emission factors which are reported in Chapter 3: Rewetted Organic Soils of the IPCC Wetlands Supplement (IPCC, 2014). The default Tier 1 emission factors for 'rewetted' tropical organic soils were derived from data on undrained tropical peat swamp forest in Southeast Asia. Therefore, the default Tier 1 emission factors are applicable to natural primary forest.

N	Land classes	Categories	IPCC land use categories	Drainage status	IPCC Wetland Supplement land categories
6	**Estate crop (deep-drained)**	Non-forest	Cropland - Perennial	Drained	Plantations, drained, oil palm
7	**Estate crop (shallow-drained)**	Non-forest	Cropland - Perennial	Drained	Plantations, shallow-drained (typically less than 0.3 m), typically used e.g., for sago palm
8	**Mixed dry agriculture**	Non-forest	Cropland-Annual	Drained	Cropland and fallow, drained
9	**Paddy Field**	Non-forest	Cropland – Rice	Drained	Cropland, drained, paddy field
10	**Shrub land**	Non-forest	Grassland	Drained	Forestland and cleared Forestland, drained
11	**Savanna/grasses**	Non-forest	Grassland	Drained	Cropland, drained, paddy field
12	**Transmigration areas**	Non-forest	Settlement	Drained	Cropland and fallow, drained
13	**Settlement areas**	Non-forest	Settlement	Drained	Cropland, drained, paddy field
14	**Mining areas**	Non-forest	Other land	Drained	Cropland and fallow, drained
15	**Bare ground**	Non-forest	Other land	Drained	Cropland and fallow, drained

Source: MoEF, 2016.

2.5 Building the scenarios

When performing an ex-ante analysis, the tool enables users to make a comparative analysis with two scenarios namely: without-project and with-project scenarios. These theoretical scenarios should reflect as much as possible the national circumstances and may be related to important political decisions and in line with national policies and land use choices that users wish to study and compare.

In the without-project scenario, users estimate the likely GHG impact considering what might happen in the area of interest in the absence of a project or other time-bound activities and compare this situation to a “with-project scenario” in which a potential project or intervention is taking place. Emissions are calculated separately for “without-project” and “with-project scenarios” using separate copies of the Tool. The final GHG balance is the net difference between GHG emissions associated with the project implementation and without the project.

Currently, there is no methodology to build the without-project scenario (Bernoux et al. 2010). The future GHG emissions are driven by many factors such as economic development, political decisions, demographic movements and growth, etc. Therefore, building the without-project scenario can be realized differently. For example, by considering that the current situation may still occur in the future if no improved peatland management interventions take place. In this case, the without-project scenario is the same with the initial situation. Therefore, the without-project scenario is assumed to be static as no changes in management practices is expected to happen as compared to the current situation.

Also, the without-project scenario can be designed taking into consideration the historical trends in terms of growth, land use and land-use changes (e.g., historical deforestation rates) or integrating current local policies and laws to review past trends and adapt them to the current context. In this case, the without-project is assumed to be dynamic and can be developed based on assumptions, which must be well-documented and validated with key stakeholders taking into consideration accurate, reliable and robust data and information.

The without-project scenario will act as a reference for building the with-project scenario. Therefore, it is the responsibility of users to design a without-project scenario that reflect as much as possible the national circumstances without overestimating or underestimating the potential GHG impact of with-project scenario. It is important to note that the choices made for the without-project scenario have a major impact on the final difference between scenarios.

The with-project scenario reflects the objectives targeted with the implementation of improved peatland management interventions. The with-project scenario differs from the without-project scenario and may consider different land uses, water management practices, land use intensity and other land management practices. The design of the with-project scenario is up to users and should reflect the priorities of stakeholders and their medium- to long-term vision. Again, when users build the with-project scenario should identify interventions, which correspond to the actual land management practices of stakeholders and partners. The interventions of the with-project scenario should be well-described and defined by users. All assumptions should be clearly explained and documented, and the interventions should be verified by the relevant actors.

2.6 Dynamic of change

By default, the tool considers linear dynamic of changes. Under the linear dynamic, changes occur progressively. For example, at the initial situation 100 hectares of drained peatland is restored through rewetting by disabling the drainage system through back-filling and blocking canals. It is forecast that over the next 5 years due to project implementation the number of restored hectares will be increased to 200 ha of land. The rewetting of drained peatlands is associated with an emission factor of GHG expressed in tonnes CO_2eq per hectare per year. Under the linear dynamic, the restored/rewetted area will progressively increase by 20 ha per year (200–100)/5. The total corresponding amount of GHG release is therefore: $\text{Total}_{\text{Linear}} = 0.5^{*}\,(100^{*}5^{*}\text{EF})$ (Bernoux et al. 2010).

2.7 Greenhouse gas accounting period

In Peat-GHG tool, users can define two different time periods:

1. **Implementation phase:** which is the active phase of a project implementation commonly corresponding to the funding and investment phase of a project and
2. **Capitalization phase:** the time period where the benefits of the investments are still occurring and may be attributed to the changes induced by the project implementation (Bernoux et al. 2010).

The total duration of GHG accounting is the sum of implementation and capitalization phase. It is recommended that users consider a total period of accounting of minimum 30 or 50 years.

2.8 Recommendations before applying the tool

It is recommended that before applying the tool, users must have:

- Enough information to describe the site location(s) where peatland management interventions will be carried out including dominant climate, moisture, soil type, land cover information, number of hectares targeted,
- Information on the areas where land use and peatland management changes will take place,
- Information on land use/management that are associated with the initial condition of the area before the project implementation,
- A without-project scenario, and
  A with-project scenario in which users can list the various peatland management activities, which is expected to take place with the project implementation.

3. Structure of the tool

The tool adopts a modular approach based on the methodology and approach used in the EX-ACT tool developed by FAO (Bernoux et al. 2010). Similarly, the Peat-GHG tool follows a three-step logical framework.

Step 1: A general description of the peatland management practices (geographic area, climate and soil characteristics, duration of the peatland activities).

Step 2: The identification of changes in land use and management practices on organic soils using specific modules which are aggregated in difference excel sheets.

Step 3: The computation of GHG balance with- and without- the project scenario based on IPCC default values and – when available – country-specific data.

The tool is organized according to six visible spreadsheets, where users should provide information which may help to define or determine some aspects of the peatland management interventions. The list of excel spreadsheet is given in Table 2.

Table 2. Description of the modules included in Peat-GHG

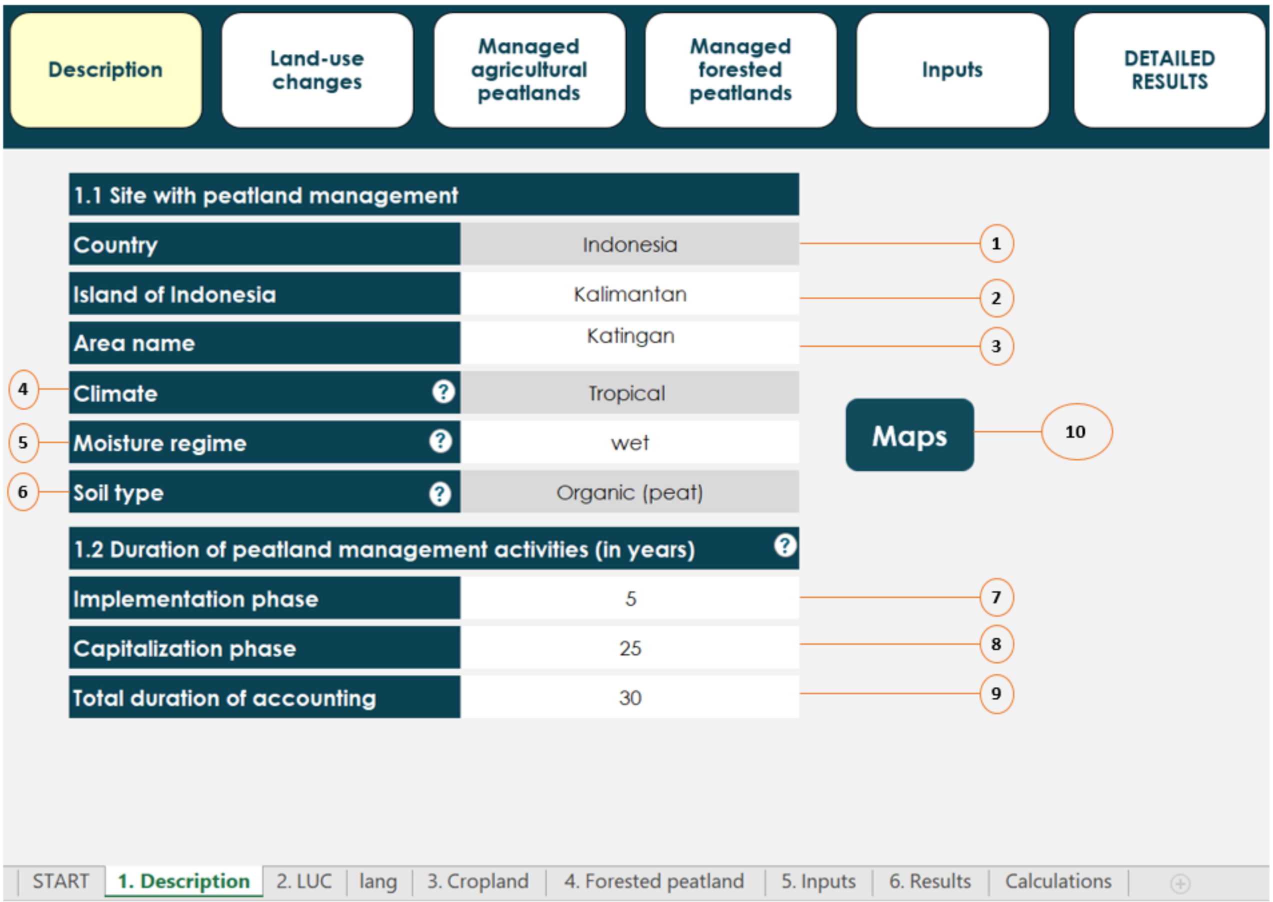
Excel spreadsheet names	Module names
1. Description	• Peatland management site • Duration of peatland management activities (in years)
2. Land use change (LUC)	• Peatland deforestation • Peatland reforestation • Non-forest land-use changes
3. Cropland	• Annual cropland • Estate crops (perennial tree crops such as oil palm, rubber, sago palm etc.) • Paddy field on drained peatland soils
4. Forested peatland	• Forested peatland management
5. Inputs	• Inputs (liming and fertilizers)
6. Results	• Detailed results

The tool uses a color code throughout all modules. Cells highlighted in white indicate where users have to enter information, while the background color (light grey) specifies the variables and units that have to be provided as well as resulting changes in GHG emissions and C stock changes. Columns highlighted in yellow indicate where users can refine the analysis by entering Tier 2 emission factors.

3.1 Module 1: Description module

The 'Description' module (Figure 2) allows users to provide the general characteristics of the peatland area that will be considered in the analysis.

Figure 2. Module 1: Description



Source: Peat-GHG tool screenshot.

1. Country

The country name is set to Indonesia, by default, as in its current, tailored form, it should not be used for other countries.

2. Islands of Indonesia

Select from the dropdown list the island where the peatland management interventions will take place. This will influence some default emission factors. For example, the above-ground biomass varies between forest types and main islands of Indonesia.

In our example, Kalimantan is selected

3. Area name

Enter the location name. The area may be an administrative unit (province, sub district or district) or a peatland hydrological unit (PHU). The name choice is up to users.

In our example, it is Katingan.

4. Climate

The climate is set to tropical, by default. Click ? to find a 'climate helper' that will assist you in identifying the climate type by entering the mean annual temperature (°C) and mean annual precipitation (mm) of your area (Figure 3).

5. Moisture regime

Select from the dropdown list the default options namely: wet or moist[6]. Click ? to find a 'climate helper' that will assist you in identifying the moisture regime of your area by entering the mean annual temperature (°C) and mean annual precipitation (mm). Moisture regime is needed to determine emission factors used in the analysis.

In our example, 'Wet' is selected.

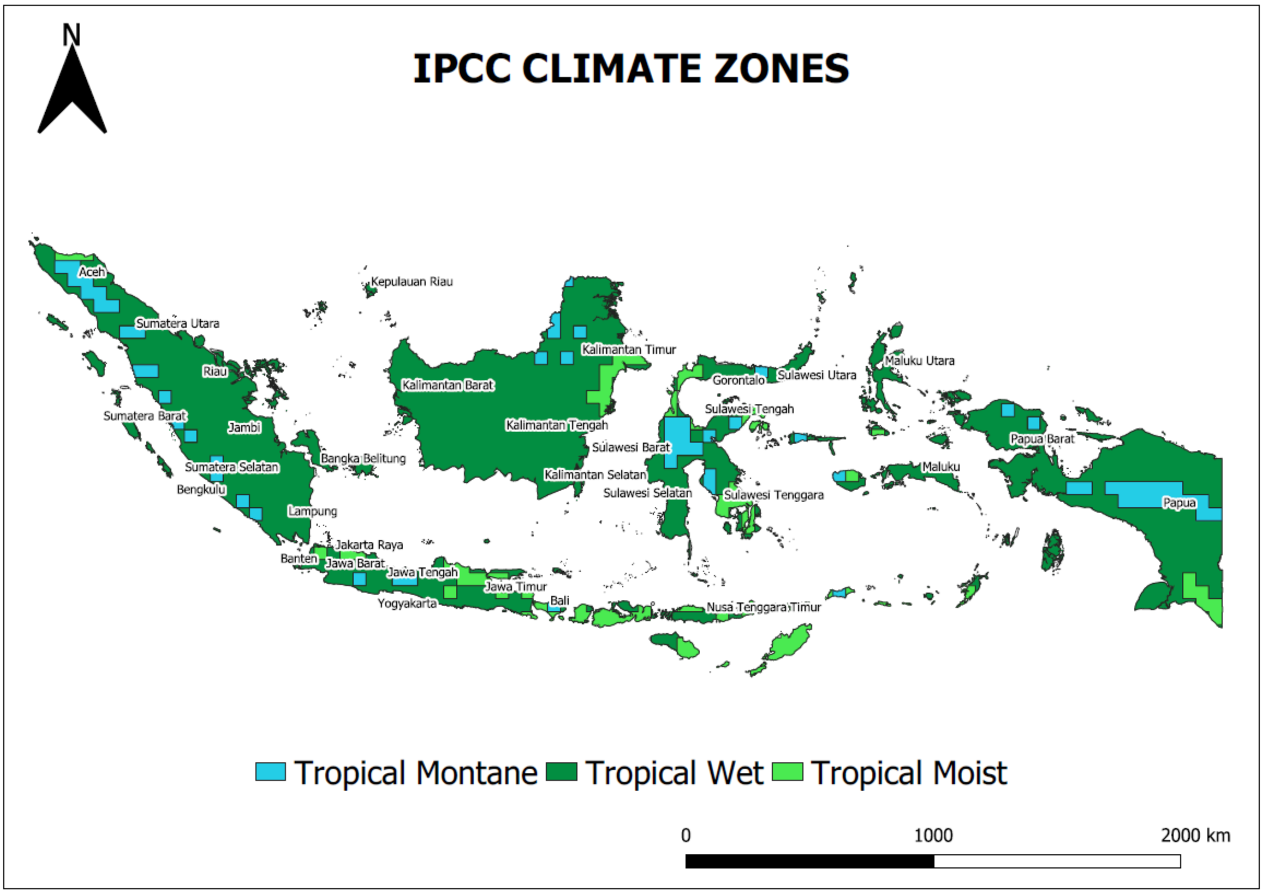
6. Soil type

The soil type is set to organic (peat)[7], by default. Click ? to see the definitions of organic soil and peatland (Figure 4).

[6] See the Glossary section for definitions of tropical moist and tropical wet climate.

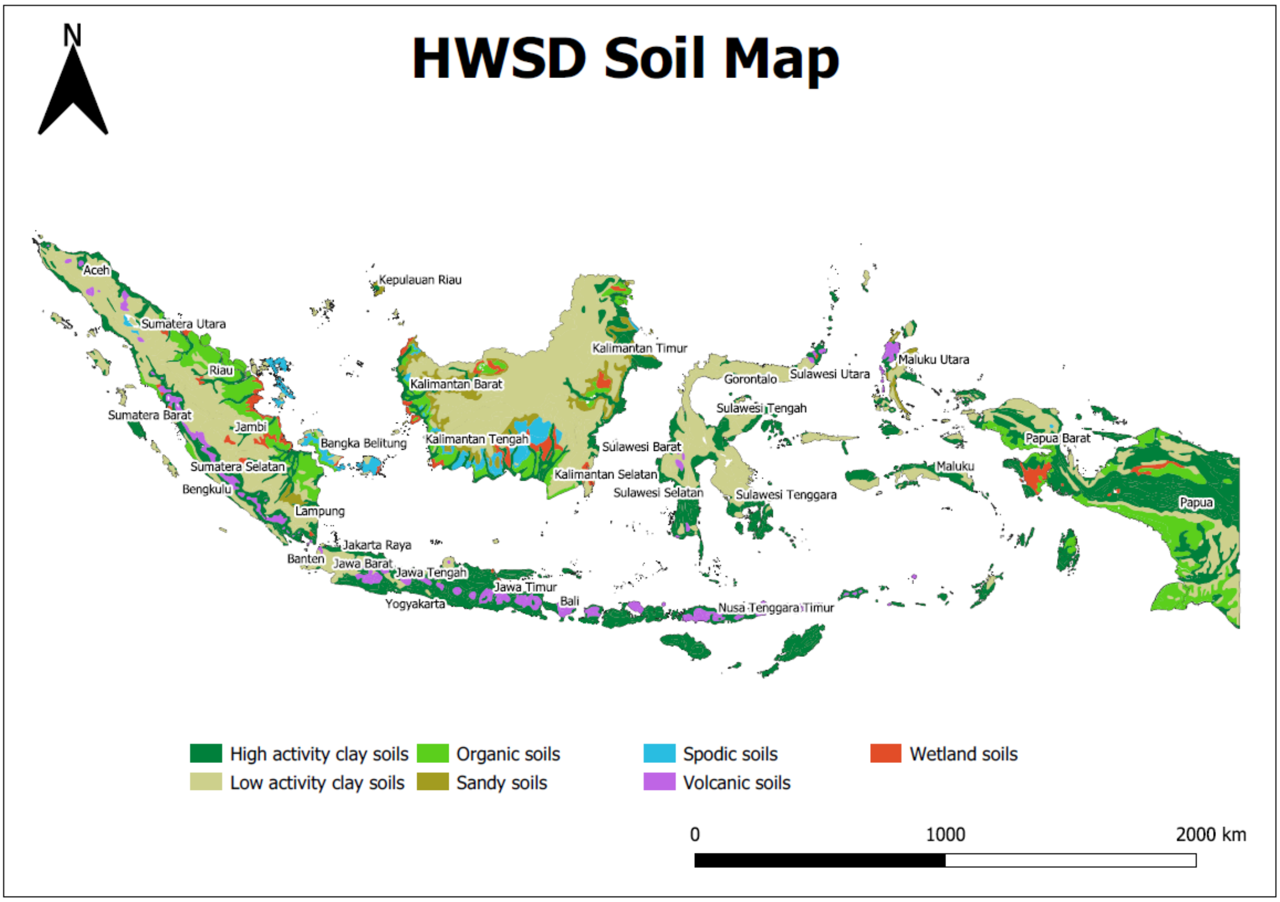
[7] See the Glossary section for definitions of organic (peat) soil.

Figure 3. The IPCC climate zones map of Indonesia used on the tool



Source: IPCC, 2019

Figure 4. The harmonized world soil map of Indonesia based on the IPCC soil types



Source: Fischer et al., 2008

7. Implementation phase

Enter the number of years associated with the project implementation (See section 2.7: Greenhouse gas accounting period).

In our example, the implementation phase is 5 years.

8. Capitalization phase

Enter the number of years associated with the capitalization phase taking into account that the total duration of accounting should is thirty years (See section 2.7: Greenhouse gas accounting period).

In our example, the capitalization phase is 25 years considering a total period of 30 years.

9. Total duration of accounting

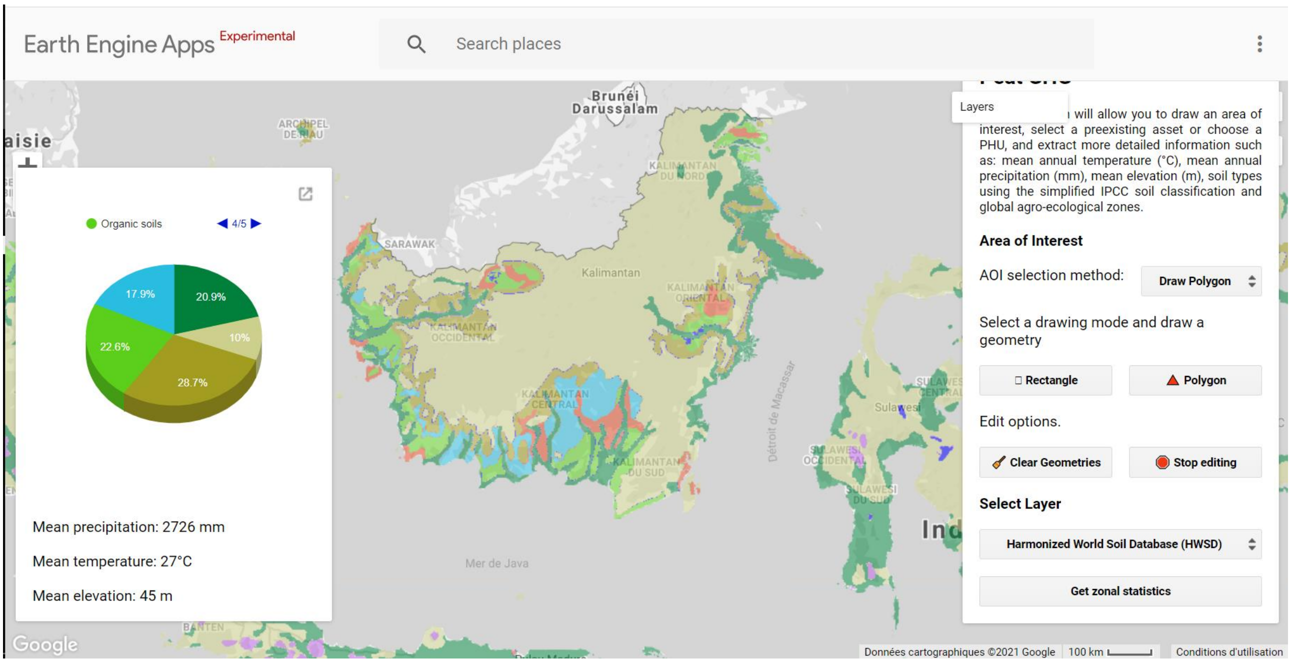
Length of time over which greenhouse gas emissions and/or removals are quantified. The reference period is set at minimum 30 years (See section 2.7: Greenhouse gas accounting period).

10. Maps

Click Maps to access interactive maps via Google Earth Engine (Figure 5). The application will allow users to draw the area of interest and extract more detailed information such as: mean annual temperature (°C), mean annual precipitation (mm), mean elevation (m), soil types using the simplified IPCC soil classification and global agro-ecological zones. The zonal statistics can be derived from the following maps:

- Harmonized World Soil Database (Fischer et al., 2008),
- IPCC climate zones (IPCC, 2019), and
- Global Agro-ecological Zones (IIASA/FAO, 2012).

Figure 5. An example of the representation of soil types using the Google Earth Engine application



Source: Screenshot of the Google Earth Engine application integrated in the Peat-GHG tool.

3.2 Module 2: Land-use changes module

This section describes the steps required for calculating GHGs emissions associated with peatland deforestation and/or restoration through land-use changes and various peatland management practices on tropical organic soils. This excel sheet contains three modules:

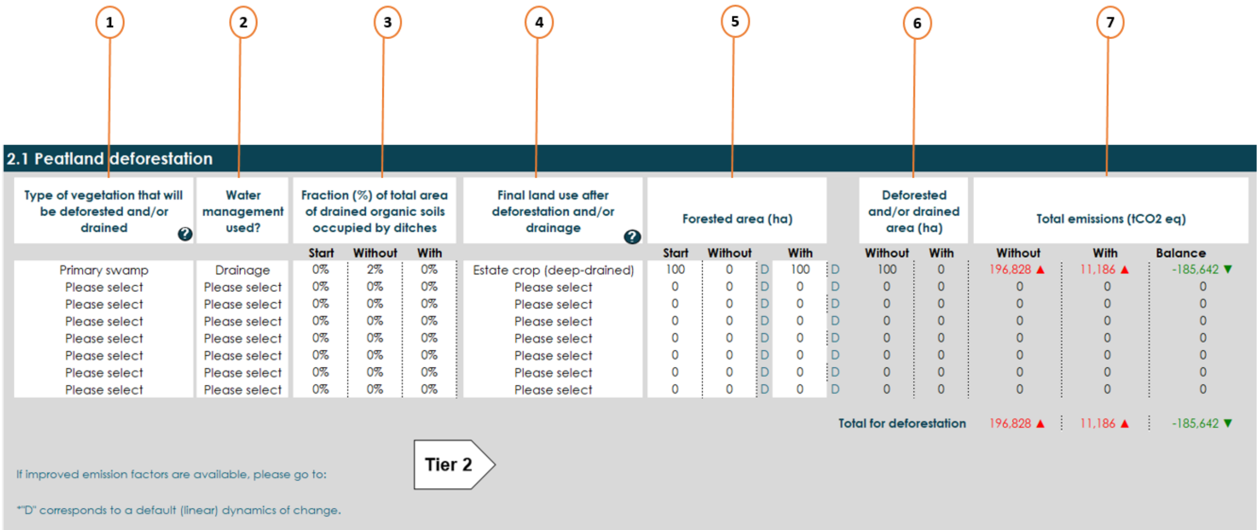
- Module 2.1: Peatland deforestation,
- Module 2.2: Peatland reforestation, and
- Module 2.3: Non-forest land-use changes.

The descriptions below allow to clarify certain important but commonly misunderstood differences between these modules.

Module 2.1: Peatland deforestation

In module 2.1 Peatland deforestation (Figure 6), users can calculate the GHG (avoided) emissions associated with peatland deforestation, that is forested peatlands logged or other ways converted to non-forest land classes.

Figure 6. Module 2.1: Peatland deforestation



Type of vegetation that will be deforested and/or drained	Water management used?	Fraction (%) of total area of drained organic soils occupied by ditches			Final land use after deforestation and/or drainage	Forested area (ha)					Deforested and/or drained area (ha)		Total emissions (tCO2 eq)		
		Start	Without	With		Start	Without		With		Without	With	Without	With	Balance
Primary swamp	Drainage	0%	2%	0%	Estate crop (deep-drained)	100	0	D	100	D	100	0	196,828 ▲	11,186 ▲	-185,642 ▼
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
											Total for deforestation		196,828 ▲	11,186 ▲	-185,642 ▼

If improved emission factors are available, please go to: Tier 2

*"D" corresponds to a default (linear) dynamics of change.

Source: Peat-GHG tool screenshot.

1. Type of vegetation that will be drained and/or deforested

Select from the dropdown list the forest type that will be deforested and drained. The tool includes four natural forest types and one class of plantation forest, which corresponds to short rotation plantations that grow on peatland (e.g., *Acacia spp*.). Click ? to see the definitions of forest types.

In our example, 'Primary swamp' forest is selected.

2. Water management used

Select from the dropdown list the water management practices that will be implemented.

In our example, drainage is selected.

3. Fraction of total area of drained organic soils occupied by ditches

Enter the fractional ditch area at three points in time: at the start, without-project and with-project scenarios. The Fractional ditch ($Frac_{ditch}$) area can be calculated from spatially explicit information about ditch and canal networks. From these the length and width of ditches can be derived, or alternatively ditch spacing and ditch width on organic soils, giving the ditch area on organic soils. This geometrical information is converted to fractional ditch area by dividing the ditch area on organic soils by the area of drained organic soils. The indicative Tier 1 default value is 2 percent which was derived from published studies carried out in drained tropical peatlands in Indonesia. The default percent can be modified, if site-specific information is available. Note that the $\mathrm{Frac}_{\mathrm{ditch}}$ associated with primary peatland forests, is set to 0 percent due to the absence of ditches or drainage canals. Secondary forests and plantations often have logging canals. Therefore the $\mathrm{Frac}_{\mathrm{ditch}}$ associated with secondary forest and plantations must be greater than 0 percent.

In our example, $\mathrm{Frac}_{\mathrm{ditch}}$ is set to 0 percent at the start and without-project scenario, as it is assumed that are no ditches or drainage canals in a primary peatland forest. For the with-project scenario $\mathrm{Frac}_{\mathrm{ditch}}$ is set to 2 percent which is associated with the drainage for the establishment of estate crops, deep-drained (e.g., oil palm plantations).

4. Final land use after drainage and/or deforestation

Select from the dropdown list the final land use after deforestation and drainage. Click ? to see the definitions of non-forest land classes.

In our example, estate crop (deep-drained) is selected.

5. Forested area

Enter the extent of the specific forest type in hectares at three scenarios: 1) the situation at the start, 2) without-project and 3) with-project scenarios.

In our example, the forest area at the start is 100 hectares. In the without-project scenario, it is forecasted that the 'Primary swamp' will be deforested, drained and converted to oil palm plantations (estate crops, deep-drained). In the without project scenario, the forested area is set to 0. With the project implementation scenario, we expect here that the forest will be preserved and the oil palm plantations will not be established on the previously forested land.

6. Deforested and/or drained area

Once users have indicated the name and size of forest type, the tool calculates automatically the deforested and drained area for the without-project and with-project scenarios.

In our example, the deforested area is 100 ha and 0 ha for the without and with-project scenarios respectively.

7. Total emissions

Emissions expressed in tonnes of carbon dioxide equivalents emitted (tCO_2 eq.) or removed per year through the land uses and land-use changes. The emissions are calculated separately for the two scenarios. The GHG balance is calculated as the difference between the emissions from the with- and without-project scenarios.

Box 2. Emissions and removals in the Peat-GHG tool

In Peat-GHG**,** emissions are shown as positive values while removals are negative values.

The tool converts CH_4 and N_2O emissions to CO_2 eq based on its 100-year time horizon global warming potential published in the IPCC Fifth Assessment Report (Myhre et al., 2013).

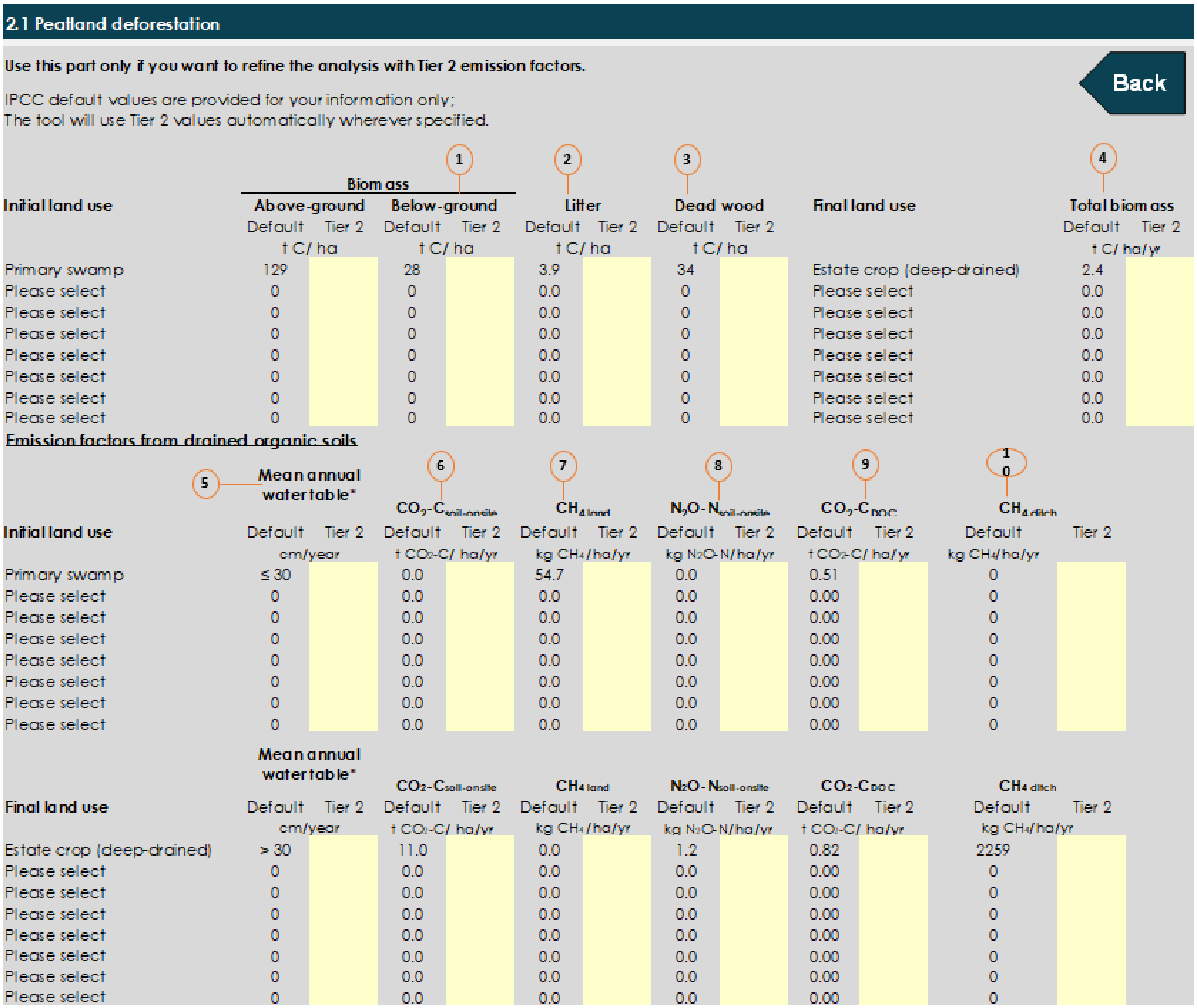
In our example, the total emissions in the without-project scenario is 196,828 ▲ tCO_2eq. while the emissions for with-project scenario is calculated as 11,186 ▲ tCO_2eq. over a period of 30 years. Finally, the total balance is -185,642 ▼ tCO_2eq. which corresponds to the **avoided emissions** (and **not the actual emissions reduction**) associated with the avoided deforestation and forest protection.

Tier 2

If you want to enter country- or site-specific emissions factors, for more detailed information, click Tier 2. The following table will appear (Figure 7). The emission factors presented here can be valid at the Tier 2[8] level; they are specific to Indonesia but do assume uniform emissions over large areas.

[8] See the Glossary section for tier definitions.

Figure 7. Tier 2 section of Module 2.1: Peatland deforestation



2.1 Peatland deforestation

Use this part only if you want to refine the analysis with Tier 2 emission factors.

IPCC default values are provided for your information only;
The tool will use Tier 2 values automatically wherever specified.

Back

Initial land use	Biomass (1) Above-ground Default	Above-ground Tier 2	Below-ground Default	Below-ground Tier 2	Litter (2) Default	Litter Tier 2	Dead wood (3) Default	Dead wood Tier 2	Final land use	Total biomass (4) Default	Total biomass Tier 2
	t C/ ha		t C/ ha		t C/ ha		t C/ ha			t C/ ha/yr	
Primary swamp	129		28		3.9		34		Estate crop (deep-drained)	2.4	
Please select	0		0		0.0		0		Please select	0.0	
Please select	0		0		0.0		0		Please select	0.0	
Please select	0		0		0.0		0		Please select	0.0	
Please select	0		0		0.0		0		Please select	0.0	
Please select	0		0		0.0		0		Please select	0.0	
Please select	0		0		0.0		0		Please select	0.0	
Please select	0		0		0.0		0		Please select	0.0	

Emission factors from drained organic soils

Initial land use	Mean annual water table* (5) Default	Tier 2	CO_2-$C_{soil-onsite}$ (6) Default	Tier 2	$CH_{4\,land}$ (7) Default	Tier 2	N_2O-$N_{soil-onsite}$ (8) Default	Tier 2	CO_2-C_{DOC} (9) Default	Tier 2	$CH_{4\,ditch}$ (10) Default	Tier 2
	cm/year		t CO_2-C/ ha/yr		kg CH_4/ha/yr		kg N_2O-N/ha/yr		t CO_2-C/ ha/yr		kg CH_4/ha/yr	
Primary swamp	≤ 30		0.0		54.7		0.0		0.51		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	

Final land use	Mean annual water table* Default	Tier 2	CO_2-$C_{soil-onsite}$ Default	Tier 2	$CH_{4\,land}$ Default	Tier 2	N_2O-$N_{soil-onsite}$ Default	Tier 2	CO_2-C_{DOC} Default	Tier 2	$CH_{4\,ditch}$ Default	Tier 2
	cm/year		t CO_2-C/ ha/yr		kg CH_4/ha/yr		kg N_2O-N/ha/yr		t CO_2-C/ ha/yr		kg CH_4/ha/yr	
Estate crop (deep-drained)	> 30		11.0		0.0		1.2		0.82		2259	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	

Source: Peat-GHG tool screenshot.

1. Biomass

The default above-ground biomass (AGB) and below-ground biomass (BGB) stocks can be modified by clicking on 'Tier 2'. Default values for AGB are shown in Table 3 below. To estimate the amount of carbon in each forest type, information on carbon fraction is needed. The carbon fraction of biomass (dry weight) is assumed to be 47 percent (1 ton biomass = 0.47 tons C) following the IPCC Guidelines (IPCC, 2006). Conversion of C-stock into CO_2 is obtained by multiplying C-stock with a factor of 3.67 (44/12) (IPCC, 2006).

Table 3. Above-ground biomass stratified by forest type and islands

Forest type	Main island	Mean above-ground biomass (tonne d.m ha^{-1})
Primary swamp	Bali/Nusa Tenggara	-
	Jawa	-
	Kalimantan	275.5
	Maluku	-
	Papua	178.8
	Sulawesi	214.4
	Sumatra	220.8
Secondary Swamp	Bali/Nusa Tenggara	-
	Jawa	-
	Kalimantan	170.5
	Maluku	-
	Papua	145.7
	Sulawesi	128.3
	Sumatra	151.4
Primary Mangrove	Kalimantan	263.9
Secondary Mangrove	Kalimantan	201.7
	Sulawesi	201.7

Source: MoEF, 2016.

For our example, the above-ground biomass of a 'primary swamp' forest in Kalimantan is estimated as 129 tC ha^{-1} (275.5 * 0.47).

The default values for below-ground biomass are estimated using a specific (R) ratio of below-ground biomass to above-ground biomass expressed in tonnes root dry matter (tonnes shoot dry matter)$^{-1}$]. (Table 4). The values correspond to default ratio reported in Table 4.4, IPCC 2019, in Table 4.5, IPCC 2014 and values reported by a study carried out by Verwer and van der Meer (2010).

Table 4. Ratio of below-ground biomass to above-ground biomass in various forest types

Forest type	Below-ground biomass to above-ground biomass ratio (R)	Sources
Primary swamp	—	Verwer and van der Meer 2010
Secondary Swamp	87	Verwer and van der Meer 2010
Primary mangrove	64	IPCC, 2014
Secondary mangrove	37	IPCC, 2014
Plantations	93	IPCC, 2019

Source: IPCC 2014 and 2019 and Verwer and van der Meer 2010.

For our example, the below-ground biomass of a 'primary swamp' forest in Kalimantan under a tropical moist climate is 28 tC ha^{-1}. If site-specific data are available, the default value can be modified.

2. Litter

Default Tier 1 emission factors for litter carbon stocks (tonnes C ha^{-1}) are shown in Table 5.

Table 5. Default values for litter stratified by ecological zone and forest type

Forest type	Litter (tonnes C ha^{-1})	Sources
Primary swamp	3.9	Verwer and van der Meer, 2010
Secondary Swamp	3.9	Verwer and van der Meer 2010
Primary mangrove	0.7	IPCC, 2014
Secondary mangrove	0.7	IPCC, 2014
Plantations	0	-

Source: IPCC, 2014 and Verwer van der Meer 2010.

For our example, the proposed value for litter is 3.9 tC ha^{-1}

3. Dead wood

Default Tier 1 emission factors for dead wood carbon stocks (tonnes C ha^{-1}) are shown in Table 6.

Table 6. Default values for dead wood stratified by ecological zone and forest type

Forest type	Dead wood (tonnes C ha^{-1})	Sources
Primary swamp	34	Verwer and van der Meer 2010
Secondary Swamp	34	Verwer and van der Meer 2010
Primary mangrove	10.7	IPCC, 2014
Secondary mangrove	10.7	IPCC, 2014
Plantations	0	-

Source: IPCC, 2014 and Verwer van der Meer 2010.

For our example, the proposed value for deadwood is set to 34 tC ha^{-1}

4. Total biomass

Default biomass carbon stocks present on land after deforestation are shown in Table 7 below.

Table 7. Default biomass carbon stocks present on land after deforestation

Final land use	Total biomass tonnes C ha^{-1} yr^{-1}	Sources
Bare ground	0	
Estate crop (deep-drained) e.g., oil palm	2.40	Table 5.3, IPCC 2019
Estate crop (shallow-drained) e.g., sago palm	2.40	Table 5.3, IPCC 2019
Mining areas	0	-
Mixed dry agriculture	4.70	Table 5.9, IPCC 2019
Paddy field	4.70	Table 5.9, IPCC 2019
Savanna/grasses	7.57	Table 6.4, IPCC 2006
Settlement areas	0	-
Transmigration areas	0	-
Shrub land	7.57	Table 6.4, IPCC 2006

Source: IPCC, 2014 and 2019.

For our example, the proposed value for estate crop (oil pam) is set to 2.4 tC ha^{-1} yr^{-1}

5. Mean annual water table

The drainage level affects the emissions and can be considered where appropriate and only with higher Tier method. The user needs to specify the associated emission factors for a given water table. When using the IPCC default emission factors, the water table is defined by the land use category that the user specifies. Selecting a specific water management in the tool does not affect the emissions, unless Tier 2 emission factors are introduced as well.

If the typical range of mean annual water table levels of drained organic soils for each land use category is unknown, the default assumption is that the organic soil is deep-drained because deep-drained conditions are the most widespread and have been considered suitable for a wide range of drainage-based management intensities. By default, the deep drained class is defined as the mean annual water table depth of 30 cm or more below the soil surface. The tool follows this approach. The default assumption is that only primary peatland forests are natural, undrained can maintain the water table approximately ≤ 30 cm below the surface. Please note that the groundwater table may naturally lower during the dry season, but in this case, the emissions are not human-made. Undrained peatlands are calculated in the tool as ones that have never been affected by drainage and have never been logged.

The tool also includes default emission factors that are associated with shallow-drained estate crops (e.g., sago palm) with a mean annual water table less than 30 cm. If site-specific information about the mean annual water level is available for each land use/cover category, it should be entered in Tier 2 section. A Tier 2 approach could include updated emission factors disaggregated by drainage depth (shallow-drained, deep-drained) and land class.

For our example, the default mean annual water table for 'Primary swamp' is ≤ 30 while mean annual water table of 'Estate crop (deep-drained) for oil palm plantations is more than 30 cm below the soil surface.

6. Emission factors for CO_2 from tropical organic soils

The tool uses the default IPCC Tier 1 emissions factors for CO_2 from tropical organic soils (CO_2-$C_{soil\text{-}onsite}$) stratified by climate and land use (Table 8). The default emissions factors were derived from data representing long-term land uses drained for more than 6 years, and which are located in the tropical climate zone. The default emission factors exclude all CO_2 emissions in the first 5 years after drainage.

For Tier 1 methods, the default assumption is that there is no differentiation between emissions from long-term drained organic soils and organic soils after initial drainage or where drainage is deepened. High levels of carbon loss from drained organic soils normally start occurring immediately after initial drainage of organic soils even if land use does not change. However, the tool does not capture the emissions in the transitional phase due to lack of data for deriving country-specific emission factors. If site-specific information is available, the default tier 1 emission factors can be modified. The default values were obtained from the Table 2.1 of the IPCC Supplement (2014).

For the undrained land classes ('Primary mangrove' and 'Primary swamp') CO_2-$C_{soil\text{-}onsite}$ is set to zero. This value is derived from undrained tropical organic soils and applies to sites where water saturation prevents further oxidation of the soil's organic matter (IPCC, 2014).

Table 8. CO_2 emission factors for drained organic soils in land use categories

Peat-GHG land classes	**IPCC land use category**	**CO_2-$C_{soil\text{-}onsite}$ tonnes CO_2-C $ha^{-1}yr^{-1}$**
Primary mangrove	-	0
Secondary mangrove	Forest Land and cleared Forest Land (shrubland), drained	5.3
Primary swamp	-	0
Secondary swamp	Forest Land and cleared Forest Land (shrubland), drained	5.3
Plantations	Plantations, drained, short rotations, e.g., acacia	20
Estate crop (deep-drained)	Plantations, drained, oil palm	11
Estate crop (shallow-drained)	Plantations, shallow-drained (typically less than 30 cm), typically used for agriculture, e.g., sago palm	1.5
Mixed dry agriculture	Cropland and fallow, drained	14
Paddy Field	Cropland, drained, paddy field	9.4
Shrub land	Forest Land and cleared Forest Land (shrubland), drained	5.3
Savanna/grasses	Cropland, drained, paddy field	9.4
Transmigration areas	Cropland and fallow, drained	14
Settlement areas	Cropland, drained, paddy field	9.4
Mining areas	Cropland and fallow, drained	14
Bare ground	Cropland and fallow, drained	14

Source: IPCC 2014.

For our example, the default emission factor for 'Primary swamp' is 0.0 tC ha^{-1} yr^{-1} and for 'Estate crop' deep drained is 11 tC ha^{-1} yr^{-1}.

7. Emission factors for CH_4 from tropical organic soils

The tool uses IPCC default emissions factors for CH_4 from tropical organic soils $EF_{CH_{4_{land}}}$ to be used for Equation 4. The default values associated with drained land area obtained from Table 2.3 on IPCC (2014) while values for primary peatland forests (natural/undrained) are obtained from Table 3.3 of the IPCC Supplement (2014). The emission factor ($EF_{CH4_{soil}}$) for 'Primary mangrove' and 'Primary swamp' (natural/undrained) is 41 CH_4-C $ha^{-1}yr^{-1.}$ This value has been multiplied by 16/12 to convert kg-C to kg CH_4 (Table 9). The default emission factor for primary peatland forest has been developed from data on undrained tropical peat swamp forest in Indonesia. It assumes a near-surface water table throughout the year.

Table 9. Methane emission factors for tropical drained organic soils in all land use categories

Peat-GHG land classes	IPCC land use category	$EF_{CH_{4_{land}}}$ kg CH_4 ha^{-1} yr^{-1}
Primary mangrove	-	55
Secondary mangrove	Forest Land and cleared Forest Land (shrubland), drained	4.9
Primary swamp	-	55
Secondary swamp	Forest Land and cleared Forest Land (shrubland), drained	4.9
Plantations	Forest plantations, drained	2.7
Estate crop (deep-drained)	Plantation: oil palm	0
Estate crop (shallow-drained)	Plantation: sago palm	26.2
Mixed dry agriculture	Cropland	7
Paddy Field	Rice	143.5
Shrub land	Forest Land and cleared Forest Land (shrubland), drained	4.9
Savanna/grasses	Cropland	7
Transmigration areas	Cropland	7
Settlement areas	Grassland	7
Mining areas	Cropland and fallow, drained	0
Bare ground	Cropland and fallow, drained	0

Source: IPCC, 2014.

For our example, the default emission factor is 55 kg CH_4 ha^{-1} yr^{-1} for 'Primary swamp' and 0 kg CH_4 ha^{-1} yr^{-1} yr^{-1} for 'Estate crop'(oil palm plantations) from drainage.

8. Emission factors for N_2O from tropical organic soils

The tool uses Tier 1 emission factors for N_2O from tropical organic soils ($N_2O\text{-}N_{soil\text{-}onsite}$) for drained tropical organic soils stratified by land use (Table 10). The default emission factors for drained land were obtained from Table 2.5 of the IPCC Supplement (2014). Nitrous oxide emissions from primary peatland forest are assumed to be negligible (Tier 1 assumption).

Table 10. Direct nitrous oxide emission factors for drained organic soils in all land use categories

Peat-GHG land classes	IPCC land use category	$N_2O\text{-}N_{soil\text{-}onsite}$ kg N_2O-N $ha^{-1}yr^{-1}$
Primary mangrove	-	0
Secondary mangrove	Forest Land and cleared Forest Land (shrubland), drained	2.4
Primary swamp	-	0
Secondary swamp	Forest Land and cleared Forest Land (shrubland), drained	2.4
Plantations	Forest plantations, drained	2.4
Estate crop (deep-drained)	Plantation: oil palm	1.2
Estate crop (shallow-drained)	Plantation: sago palm	3.3
Mixed dry agriculture	Cropland	5.0
Paddy Field	Rice	0.4
Shrub land	Forest Land and cleared Forest Land (shrubland), drained	2.4
Savanna/grasses	Cropland	5.0
Transmigration areas	Cropland	5.0
Settlement areas	Grassland	5.0
Mining areas	Cropland and fallow, drained	0
Bare ground	Cropland and fallow, drained	0

Source: IPCC, 2014.

For our example, the default emission factor for 'Primary swamp' is set to 0 kg N ha^{-1} yr^{-1} and for 'Estate crop (oil palm plantations) is set to 1.2 kg N ha^{-1} yr^{-1}.

9. Emission factors for DOC from tropical organic soils

For tropical climate, an emission factors for DOC from tropical organic soils (CO_2-C_{DOC}) of 0.82 tC ha^{-1} yr^{-1} – as per the Table 2.2 of the IPCC Supplement (2014)– is proposed for all drained organic soils and land use types. For the undrained primary peatland forest the value was obtained from Table 3.2 of the IPCC Supplement (2014). By default, the tool uses the IPCC Tier 1 for $EF_{DOC_{REWETTED}}$ of 0.51 tonnes CO_2-C ha^{-1} yr^{-1}. This value has been calculated using data from natural, undrained sites. See Table 11.

Table 11. Default dissolved organic carbon emission factor for tropical organic soils

Peat-GHG land classes	CO_2-C_{DOC} tonnes C ha^{-1} yr^{-1}
Primary mangrove	0.51
Secondary mangrove	0.82
Primary swamp	0.51
Secondary swamp	0.82
Plantations	0.82
Estate crop (deep-drained)	0.82
Estate crop (shallow-drained)	0.82
Mixed dry agriculture	0.82
Paddy Field	0.82
Shrub land	0.82
Savanna/grasses	0.82
Transmigration areas	0.82
Settlement areas	0.82
Mining areas	0.82
Bare ground	0.82

Source: IPCC, 2014.

For our example, the default emission factor is 0.51 tonnes C ha^{-1} yr^{-1} for 'Primary swamp' and 0.82 tonnes C ha^{-1} yr^{-1} yr^{-1} for estate crop (deep-drained).

10. Emission factors for CH_4 emissions from drainage ditches

A single Tier 1 emission factor for CH_4 emissions from drainage ditches ($EF_{CH_{4}ditch}$) is provided for all drained land-use classes for tropical organic soils (Table 12). The landscape-average CH_4 emission from ditches also depends on the ditch surface area ($Frac_{ditch}$). The area occupied by ditches may be very low for secondary forest, and much higher for industrial oil palm plantations – so the actual ditch CH_4 emission could vary a lot, even if the $EF_{CH_{4}ditch}$ is the same for all land classes.

Table 12. Default methane emission factors for drainage ditches

Peat-GHG land classes	$EF_{CH_{4}ditch}$ kg CH_4 ha^{-1} yr^{-1}
Primary mangrove	0
Secondary mangrove	2259
Primary swamp	0
Secondary swamp	2259
Plantations	2259
Estate crop (deep-drained)	2259
Estate crop (shallow-drained)	2259
Mixed dry agriculture	2259
Paddy Field	2259
Shrub land	2259
Savanna/grasses	2259
Transmigration areas	2259
Settlement areas	2259
Mining areas	2259
Bare ground	2259

Source: IPCC, 2014.

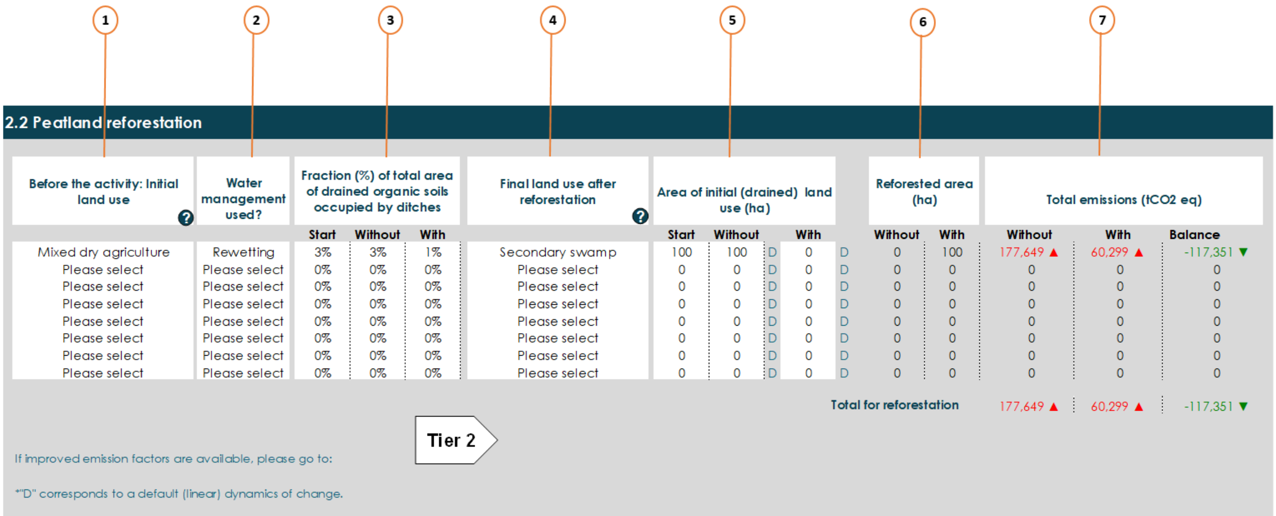
For our example, the default emission factor for ‘Primary swamp’ is set to 0 kg CH_4 ha[-1] yr[-1] .

$EF_{CH_{4}ditch}$ for estate crop is 2259 kg CH_4 ha^{-1} yr^{-1}

Module 2.2: Peatland reforestation

The focus of module 2.2 Peatland reforestation (Figure 8) is the restoration of previously drained peatlands accompanied by different water management practices and re-establishing the forest vegetation cover.

Figure 8. Module 2.2: Peatland reforestation



Before the activity: Initial land use	Water management used?	Fraction (%) of total area of drained organic soils occupied by ditches			Final land use after reforestation	Area of initial (drained) land use (ha)					Reforested area (ha)		Total emissions (tCO2 eq)		
		Start	Without	With		Start	Without		With		Without	With	Without	With	Balance
Mixed dry agriculture	Rewetting	3%	3%	1%	Secondary swamp	100	100	D	0	D	0	100	177,649 ▲	60,299 ▲	-117,351 ▼
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0	D	0	D	0	0	0	0	0
											Total for reforestation		177,649 ▲	60,299 ▲	-117,351 ▼

Tier 2

If improved emission factors are available, please go to:

*"D" corresponds to a default (linear) dynamics of change.

Source: Peat-GHG tool screenshot.

1. Before the activity initial land use

Select from the dropdown list the non-forest land classes that will be reforested. Click ? to see the definitions of non-forest land classes.

For our example, ‘Mixed dry agriculture ’is selected.

2. Water management used

Select from the dropdown list the water management practices that will be implemented.

In our example, rewetting is selected.

3. Fraction of total area of drained organic soils occupied by ditches

See description in Module 2.1 Peatland deforestation.

For our example, $\mathrm{Frac}_{\mathrm{ditch}}$ is set to 3 percent at the start and without-project scenario. $\mathrm{Frac}_{\mathrm{ditch}}$ for the with-project scenario is set to 1 percent.

4. Final land use after reforestation

Select from the dropdown list the final forest type after reforestation. Click ? to see the definitions of forest types.

In our example, ‘Secondary swamp’ forest type is selected. The default assumption is that even if rewetting is selected in the above example, secondary forests are still considered drained due to logging activities or other human disturbances that take place in secondary forests. If rewetting is applied and emission factors are available for shallow-drained secondary forest then data should be entered in Tier 2 section.

5. Area of initial (drained) land use

Enter the extent of the initial non-forest drained land use in hectares at three points in time: at the start, without -project and with-project scenario.

In our example, the area of ‘Mixed dry agriculture’ is set to 100 ha at the start and without-project scenario. In the with-project scenario , the area of ‘Mixed dry agriculture’ is 0, as the whole agricultural area is converted to ‘Secondary forest’

6. Reforested area

Once users have indicated the name and size of the initial land uses, the tool calculates automatically the reforested area for the two scenarios.

In our example, 100 ha of ‘Secondary swamp’ are established with-project scenario. The reforested area without-project scenario is 0, as no reforestation takes place in the absence of the project.

7. Total emissions

See description in Module 2.1 Peatland deforestation. The emissions will be shown in tCO_2eq.

Tier 2

If you want to check the emission factors used or provide better ones click [Tier 2]. The following table in Figure 9 will appear.

Figure 9. Tier 2 section of Module 2.2: Peatland reforestation

2.2 Peatland reforestation

Use this part only if you want to refine the analysis with Tier 2 emission factors.

IPCC default values are provided for your information only:
The tool will use Tier 2 values automatically wherever specified.

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Final land use	Biomass (1): Above-ground Default (t C/ ha/yr)	Above-ground Tier 2	Below-ground Default (t C/ ha/yr)	Below-ground Tier 2	(2) Litter Default (t C/ ha)	Litter Tier 2	(3) Dead wood Default (t C/ ha)	Dead wood Tier 2	Initial land use	(4) Total biomass Default (t C/ ha)	Total biomass Tier 2
Secondary swamp	1.08		0.23		3.9		34.3		Mixed dry agriculture	4.7	
Please select	0.00		0.00		0.0		0.0		Please select	0.0	
Please select	0.00		0.00		0.0		0.0		Please select	0.0	
Please select	0.00		0.00		0.0		0.0		Please select	0.0	
Please select	0.00		0.00		0.0		0.0		Please select	0.0	
Please select	0.00		0.00		0.0		0.0		Please select	0.0	
Please select	0.00		0.00		0.0		0.0		Please select	0.0	
Please select	0.00		0.00		0.0		0.0		Please select	0.0	

Emission/removal factors from drained organic soils

Initial land use	(5) Mean annual water table* Default (cm/year)	Tier 2	(6) CO_2-$C_{soil-onsite}$ Default (t CO_2-C/ ha/yr)	Tier 2	(7) $CH_{4\,land}$ Default (kg CH_4/ha/yr)	Tier 2	(8) N_2O-$N_{soil-onsite}$ Default (kg N_2O-N/ha/yr)	Tier 2	(9) CO_2-C_{DOC} Default (t CO_2-C/ ha/yr)	Tier 2	(10) $CH_{4\,ditch}$ Default (kg CH_4/ha/yr)	Tier 2
Mixed dry agriculture	> 30		14		7		5		0.82		2259	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	

Emission/removal factors from rewetted organic soils

Final land use	Mean annual water table* Default (cm/year)	Tier 2	CO_2-$C_{soil-onsite}$ Default (t CO_2-C/ ha/yr)	Tier 2	$CH_{4\,land}$ Default (kg CH_4/ha/yr)	Tier 2	N_2O-$N_{soil-onsite}$ Default (kg N_2O-N/ha/yr)	Tier 2	CO_2-C_{DOC} Default (t CO_2-C/ ha/yr)	Tier 2	$CH_{4\,ditch}$ Default (kg CH_4/ha/yr)	Tier 2
Secondary swamp	> 30		5.3		4.9		2.4		0.82		2259	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	

Source: Peat-GHG tool screenshot.

1. Biomass

Above-ground biomass and below-ground biomass growth rate of forest types are shown below in Table 13. The default values can be modified if better data are available.

Table 13. Default above-ground biomass and below-ground biomass growth rate

Forest types	Climate	Above-ground biomass $tC\ ha^{-1}\ yr^{-1}$	Below-ground biomass $tC\ ha^{-1}\ yr^{-1}$
Secondary swamp	Tropical moist	1.08	0.26
	Tropical wet		0.23
Secondary mangrove	Tropical	2.8	1.37
Plantations	Tropical	4.8	0

Source: MoEF, 2016.

In our example, the propose default above and belowground biomass for 'Secondary swamp' is 1.08 tC $ha^{-1}\ yr^{-1}$ and 0.26 tC $ha^{-1}\ yr^{-1}$ under tropical moist climate.

2. Litter

They are treated in this module in the same way as in Module 2.1: Peatland deforestation and drainage. Refer to Module 2.1 for emission factors used.

In our example, the propose default value for litter is 3.9 tC ha^{-1}.

3. Dead wood

They are treated in this Module in the same way as in Module 2.1 Peatland deforestation and drainage. Refer to Module 2.1 for emission factors used.

In our example, the propose default value for deadwood is 34 tC ha^{-1}.

4. Total biomass

Default biomass carbon stocks removed due to land conversion to forest are shown below in Table 14.

Table 14. Default biomass carbon stocks on land converted to forest

Initial land use	Biomass tonnes C ha^{-1}	Sources
Savanna or grasses	7.6	Table 6.4, IPCC 2006
Shrub land	7.6	Table 6.4, IPCC 2006
Estate crop (deep-drained), e.g., oil palm	30	Table 5. 3, IPCC 2019
Estate crop (shallow-drained), e.g., sago palm	30	Table 5. 3, IPCC 2019
Mixed dry agriculture	4.7	Table 5. 9, IPCC 2019
Paddy field	4.7	Table 5. 9, IPCC 2019
Settlement areas	0	
Transmigration areas	0	
Bare ground	0	-
Mining areas	0	-

Source: IPCC 2006 and 2019.

In our example, the proposed default value is 4.7 tonnes C $ha^{-1.}$

5. Mean annual water table

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used.

In our example, the default mean annual water table for 'Mixed dry agriculture' and 'Secondary swamp' is set to 30 cm below the soil surface. These two land classes are considered by default deep drained land classes.

6. Emission factors for CO_2 for tropical organic soils

Emission factors for CO_2 for tropical organic soils (CO_2-$C_{soil\text{-}onsite}$) are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used.

In our example, the proposed default value for 'Mixed dry agriculture' and 'Secondary swamp' is 14 tC ha^{-1} yr^{-1} and 5.3 tC ha^{-1} yr^{-1}, respectively.

7. Emission factors for CH_4 from tropical organic soils

Emission factors for CH_4 from tropical organic soils ($\boldsymbol{EF_{CH_{4_{land}}}}$) are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used.

In our example, the proposed default value for 'Mixed dry agriculture' and 'Secondary swamp' is 7 kg Ch_4 ha^{-1} yr^{-1} and 4.9 kg Ch_4 ha^{-1} yr^{-1}, respectively.

8. Emission factors for N_2O from tropical organic soils

Emission factors for N_2O from tropical organic soils ($N_2O\text{-}N_{soil\text{-}onsite}$) are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation . Refer to Module 2.1 for emission factors used.

In our example, the proposed default value for 'Mixed dry agriculture' and 'Secondary swamp' is 5 kg N ha^{-1} yr^{-1} and 2.4 kg N ha^{-1} yr^{-1} respectively.

9. Emission factors for DOC from tropical organic soils

Emission factors for DOC from tropical organic soils ($CO_2\text{-}C_{DOC}$) are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used.

In our example, the proposed default value for 'Mixed dry agriculture' and 'Secondary swamp' is 0.82 tC ha^{-1} $yr^{-1.}$

10. Emission factors for CH_4 emissions from drainage ditches

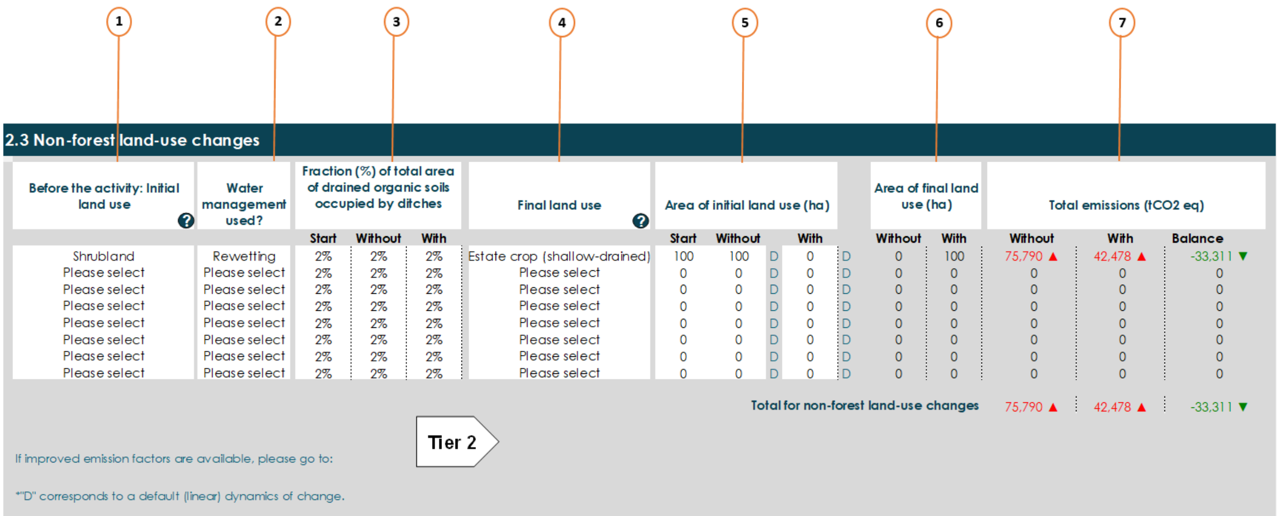
Emission factors for CH_4 emissions from drainage ditches ($\mathbf{EF_{CH_{4_{ditch}}}}$) are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used.

In our example, the proposed default value for 'Mixed dry agriculture' and 'Secondary swamp' is 2 259 kg CH_4 ha^{-1} $yr^{-1.}$

Module 2.3: Non-forest land-use changes

Module 2.3 Non-forest land-use changes (Figure 10) deals only with non-forested peatlands, where natural Indonesian peat swamp forests have been removed. By default, the land classes included in this module are considered drained (deep- or shallow-drained). Here users can assess the carbon balance of land uses that remain drained with or without undergoing a further land-use change. If, the following land classes: 'Mixed dry agriculture', 'Estate crops' and 'Paddy field' remain under the same land use, they should be accounted for using the Modules 3.1, 3.2.2 and 3.3 respectively.

Figure 10. Module 2.3: Non-forest land-use changes



Source: Peat-GHG tool screenshot.

1. Before the activity initial land use

Select from the dropdown list the land class which corresponds to the initial land use of the area of interest.

In our example, 'shrub land' is selected as the initial land use.

2. Water management used

Select from the dropdown list the water management practices that will be implemented.

In our example, 'rewetting' is selected

3. Fraction of total area of drained organic soils occupied by ditches

The default assumption is that the land remains drained and that drainage ditches are not blocked at the start, without and with-project scenarios. The default $\mathrm{Frac_{ditch}}$ of 2 percent is applied, but users can modify it. For more information about $\mathrm{Frac_{ditch}}$, see description in Module 2.1 Peatland deforestation.

In our example, $\mathrm{Frac_{ditch}}$ remains the same and is set to 2 percent at the start, without and with-project scenarios.

4. Final land use

Select from the dropdown list the land class which corresponds to the final land use with the project implementation.

In our example, estate crop (shallow-drained) is selected as the final land use.

5. Area of initial land use

Enter the extent of the initial land use in hectares at three points in time: at the start, without and with project scenarios.

In our example, the area of shrub land is set to 100 ha at the start and without –project scenario. With project scenario the area of shrub land is set to 0.

6. Area of final land use

Once you have indicated the name and size of the initial land use in hectares, the tool calculates automatically the area of final land use for the without and with-project scenario.

In our example, the area of 'estate crop (shallow-drained)' is 0 ha for the without project scenario. With the project, the whole area of shrub land is expected to be converted to 'estate crop (shallow-drained)'.

7. Total emissions

See description in Module 2.1 Peatland deforestation. The emissions will be given as tCO_2eq.

Tier 2

If you want to check the emission factors used or provide better ones click **Tier 2**. The following table in Figure 11 will appear.

Figure 11. Tier 2 section of Module 2.3: Non-forest land-use changes

2.3 Non-forest land-use changes

Use this part only if you want to refine the analysis with Tier 2 emission factors

IPCC default values are provided for your information only: The tool will use Tier 2 values automatically wherever specified.

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Initial land use	(1) Biomass Default	(1) Biomass Tier 2	Final land use	(2) Biomass (1st year) Default	(2) Biomass (1st year) Tier 2
	t C/ ha			t C/ ha	
Shrubland	7.6		Estate crop (shallow-drained)	2.4	
Please select	0.0		Please select	0.0	
Please select	0.0		Please select	0.0	
Please select	0.0		Please select	0.0	
Please select	0.0		Please select	0.0	
Please select	0.0		Please select	0.0	
Please select	0.0		Please select	0.0	
Please select	0.0		Please select	0.0	

Emission/removal factors from drained organic soils

Initial land use	(3) Mean annual Water table* Default	Tier 2	(4) CO_2-$C_{soil-onsite}$ Default	Tier 2	(5) $CH_{4\,land}$ Default	Tier 2	(6) N_2O-$N_{soil-onsite}$ Default	Tier 2	(7) CO_2-C_{DOC} Default	Tier 2	(8) $CH_{4\,ditch}$ Default	Tier 2
	cm/year		t CO_2-C/ ha/yr		kg CH_4/ha/yr		kg N_2O-N/ha/yr		t CO_2-C/ ha/yr		kg CH_4/ha/yr	
Shrubland	>30		5.3		4.9		2.4		0.82		2259	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	

Final land use	Mean annual Water table* Default	Tier 2	CO_2-$C_{soil-onsite}$ Default	Tier 2	$CH_{4\,land}$ Default	Tier 2	N_2O-$N_{soil-onsite}$ Default	Tier 2	CO_2-C_{DOC} Default	Tier 2	$CH_{4\,ditch}$ Default	Tier 2
	cm/year		t CO_2-C/ ha/yr		kg CH_4/ha/yr		kg N_2O-N/ha/yr		t CO_2-C/ ha/yr		kg CH_4/ha/yr	
Estate crop (shallow-drained)	<30		1.5		26.2		3.3		0.82		2259	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	
Please select	0		0		0		0		0		0	

Source: Peat-GHG tool screenshot.

1. Biomass

Corresponds to default biomass carbon stocks at the initial drained land use. Proposed default biomass in tC ha^{-1} before conversion are detailed in Table 13 above.

In our example, the biomass of shrub land is 7.6 tC ha^{-1}.

2. Biomass the first year after conversion

Corresponds to default biomass carbon stocks at the final drained land use one year after the conversion. Proposed default biomass in tC ha^{-1} after conversion is detailed in Table 7 above.

In our example, the proposed biomass of 'Estate crop- shallow drained' (e.g. sago palm) for the first year after the conversion is 2.4 tC $ha^{-1.}$ Users can modify this data by entering site-specific information in the Tier 2 section.

3. Mean annual water table

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used.

In our example, by default shrub land has a mean annual water table depth of 30 cm below the surface whereas the mean annual water table of estate-crop (shallow-drained) is typically less than 30 cm.

4. Emission factors for CO_2 for tropical organic soils

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used. Abbreviated as $CO_2\text{-}C_{soil\text{-}onsite}$

In our example, the default emission factors for shrub land and Estate crop (shallow-drained) are 5.3 tC ha^{-1} yr^{-1} and 1.5 tC ha^{-1} yr^{-1} respectively.

5. Emission factors for CH_4 from tropical organic soils

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used. Abbreviated as $\boldsymbol{EF_{CH_{4_{land}}}}$

In our example, the default emission factors for shrub land and Estate crop (shallow-drained) are 4.9 kg Ch_4 ha^{-1} yr^{-1} and 26.2 kg Ch_4 ha^{-1} yr^{-1} respectively.

6. Emission factors for N_2O from tropical organic soils

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used. Abbreviated as $N_2O\text{-}N_{soil\text{-}onsite}$

In our example, the default emission factors for shrub land and Estate crop (shallow-drained) are 2.4 kg N ha^{-1} yr^{-1} and 3.3 kg N ha^{-1} yr^{-1} respectively.

7. Emission factors for DOC from tropical organic soils

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used. Abbreviated as CO_2-C_{DOC}

In our example, the default emission factor for 'shrub land and Estate crop (shallow-drained) is 0.82 tC ha^{-1} yr^{-1}.

8. Emission factors for CH_4 emissions from drainage ditches

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used. Abbreviated as $\mathbf{EF_{CH_{4_{ditch}}}}$

In our example, the default emission factor for shrub land and Estate crop (shallow-drained) is 2259 kgCH_4 ha^{-1} yr^{-1}.

3.3 Module 3: Managed agricultural peatlands

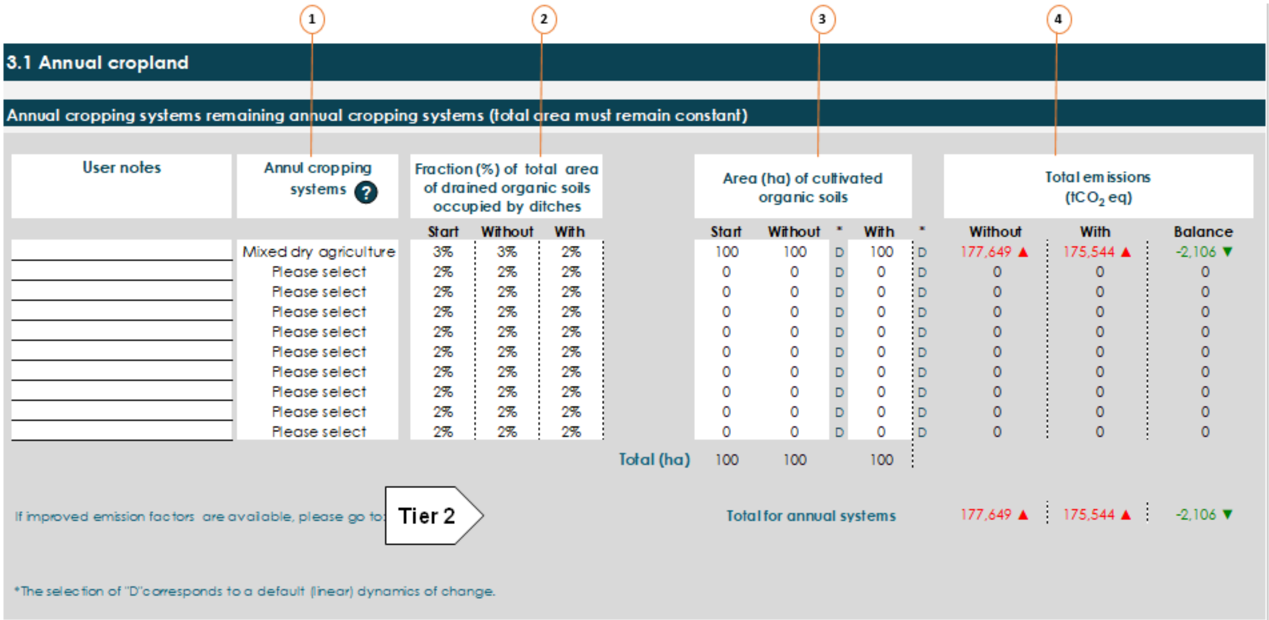
This section describes the steps required for calculating GHG emissions associated with managed agricultural peatlands. This excel sheet includes three modules:

- Module 3.1: Annual cropland
- Module 3.2: Estate crops (perennial tree crops such as oil palm, rubber, sago palm etc.)
- Module 3.3: Paddy field on drained organic soils

Module 3.1: Annual cropland

Module 3.1 Annual cropland (Figure 12) allows users to estimate peat-related emissions/removals associated with drained annual cropland that have not undergone any land-use conversion. In this module, a (drained) annual cropland remains a (drained) annual cropland under different land use intensity (e.g., fertilizer application) and fraction of areas covered by ditches. At present, CO_2 and non-CO_2 emissions from fires on drained organic soils and biomass or residue burning are not covered in this module.

Figure 12. Module 3.1: Annual cropland on tropical organic soils



Source: Peat-GHG tool screenshot.

1. Annual cropping systems

Select from the dropdown list the annual cropping system.

> In our example, 'Mixed dry agriculture' is selected. Users have also the possibility to select ' Other' crop but need to enter in Tier 2 section the emission factors that are associated with the ' Other' crop.

2. Fraction of total area of drained organic soils occupied by ditches

See description in Module 2.1 Peatland deforestation.

> For our example, $\mathrm{Frac}_{\mathrm{ditch}}$ is set to 3 percent at the start and without -project scenario. With the project scenario, the $\mathrm{Frac}_{\mathrm{ditch}}$ is set to 2 percent.

3. Area of cultivated organic soils

Enter the extent of this specific land use in hectares at the start, without and with-project scenarios. The total area of annual cropping system must remain constant.

> For our example, the area at the start, without and with -project scenario is set to 100 ha.

4. Total emissions

See description in Module 2.1 Peatland deforestation.

Tier 2

If you want to check the emission factors used or provide better ones click Tier 2. The following table in Figure 13 will appear.

Figure 13. Tier 2 section of Module 3.1: Annual cropland on tropical organic soils

1 2 3 4 5 6

3.1 Annual cropping systems remaining annual cropping systems (total area must remain constant)

Annual cropping system	Mean annual Water table* Default	Tier 2	CO_2-$C_{soil\text{-}onsite}$ Default	Tier 2	$CH_{4\,land}$ Default	Tier 2	N_2O-$N_{soil\text{-}onsite}$ Default	Tier 2	CO_2-C_{DOC} Default	Tier 2	$CH_{4\,ditch}$ Default	Tier 2
	cm/year		t CO_2-C/ ha/yr		kg CH_4/ha/yr		kg N_2O-N/ha/yr		t CO_2-C/ ha/yr		kg CH_4/ha/yr	
Mixed dry agriculture	> 30		14.0		7.0		5.0		0.82		2259	
Other	> 30		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	
Please select	0		0.0		0.0		0.0		0.00		0	

Source: Peat-GHG tool screenshot.

1. Mean annual water table

Mean annual water table is treated in this module exactly in the same way as in previous modules.

In our example, the default mean annual water table for 'Mixed dry agriculture' is set to 30 cm below the soil surface.

2. Emission factors for CO_2 for tropical organic soils

On site CO_2 emissions from drained tropical croplands is treated in this module exactly in the same way as in previous modules. Refer to Module 2.1 for emission factors used. Abbreviated as CO_2-$C_{soil\text{-}onsite}$

In our example, the default value is 14 tC ha^{-1} yr^{-1} for mixed dry agriculture. All emission factors associated with ' other' crop is set to 0. For the ' other' crop, users should enter their own data.

3. Emission factors for CH_4 from tropical organic soils

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used. Abbreviated as $\boldsymbol{EF_{CH_{4_{land}}}}$

In our example, the default emission factor for 'Mixed dry agriculture' is 7 kg Ch_4 ha^{-1} yr^{-1}.

4. Emission factors for N_2O from tropical organic soils

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used. Abbreviated as $N_2O\text{-}N_{soil\text{-}onsite}$

In our example, the default emission factor for 'Mixed dry agriculture' is 5 kg N ha^{-1} yr^{-1}.

5. Emission factors for DOC from tropical organic soils

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used. Abbreviated as $CO_2\text{-}C_{DOC}$

In our example, the default emission factor for 'Mixed dry agriculture' is 0.82 tC ha^{-1} $yr^{-1.}$

6. Emission factors for CH_4 emissions from drainage ditches

They are treated in this module exactly in the same way as in Module 2.1: Peatland deforestation. Refer to Module 2.1 for emission factors used. Abbreviated as $\mathbf{EF_{CH_{4_{ditch}}}}$

In our example, the default emission factor for 'Mixed dry agriculture' is 2259 $kgCH_4$ ha^{-1} $yr^{-1.}$

Module 3.2: Estate crops: perennial tree crops such as oil palm and rubber

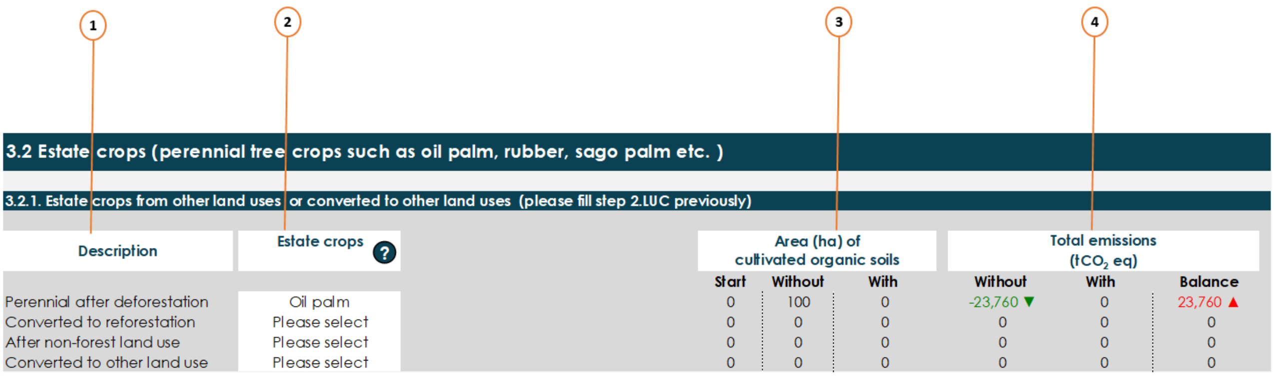
This module is divided in two components:

- Section 3.2.1 Estate crops from other land uses or converted to other land uses (please fill step 2. LUC previously)
- Section 3.2.2 Estate crops remaining estate crops (total area must remain constant)

Estate crops from other land uses or converted to other land uses

Sub-module 3.2.1 (Figure 14) allows users to calculate the biomass stock changes on estate crops (perennial tree crops) due to land-use conversions which have been specified in Module 2 previously. At present, CO_2 and non-CO_2 emissions from fires on drained organic soils and biomass or residue burning are not covered in this module.

Figure 14. Sub-module 3.2.1: Estate crops from other land uses or converted to other land uses (please fill step 2.LUC previously)



3.2 Estate crops (perennial tree crops such as oil palm, rubber, sago palm etc.)

3.2.1. Estate crops from other land uses or converted to other land uses (please fill step 2.LUC previously)

Description	Estate crops	Area (ha) of cultivated organic soils			Total emissions (tCO_2 eq)		
		Start	Without	With	Without	With	Balance
Perennial after deforestation	Oil palm	0	100	0	-23,760 ▼	0	23,760 ▲
Converted to reforestation	Please select	0	0	0	0	0	0
After non-forest land use	Please select	0	0	0	0	0	0
Converted to other land use	Please select	0	0	0	0	0	0

Source: Peat-GHG tool screenshot.

1. **Description**

- **Estate after deforestation:** Refers to newly established estate crops after deforestation in conjunction with Module 2.1
- **Converted to reforestation:** Refers to estate crops that are converted to forest land (e.g. plantations) in conjunction with Module 2.2
- **Estate after non-forest land use:** Refers to newly established estate crops from conversion of other non-forest land use systems in conjunction with Module 2.3
- **Converted to other land use:** Refers to estate crops that are converted to other non-forest land uses in conjunction with Module 2.2

For our example, the line referring to 'Estate after deforestation' is used. In our example, in the absence of the project estate crops is expected to be established on a previously forested land (without-project scenario).

2. Estate crops

Select from the dropdown list the estate crop type.

For our example, 'Oil palm' is selected.

3. Area of cultivated organic soils

The areas of estate crop at the start, without and with the project scenarios are automatically filled by the tool.

For our example, 100 ha of oil palm is shown in the without project scenario. The area of oil palm at the start and with the project is 0, as no deforestation takes place at the start or with the project scenario.

4. Total emissions

See description in Module 2.1 Peatland deforestation.

Estate crops remaining estate crops

Sub-module 3.2.2 (Figure 15) allows you to estimate peat-related emissions/removals associated with estate crops (perennial tree crops) that have not undergone any land-use conversion. In this module, an estate crop (deep or shallow drained) remains an estate crop under different land use intensity (e.g., fertilizer application) deep drainage and fraction of areas covered by ditches. At present, CO_2 and non-CO_2 emissions from fires on drained organic soils and biomass or residue burning are not covered in this module.

1. Estate crops

Select from the dropdown list the type(s) of estate crop associated with the area of interest

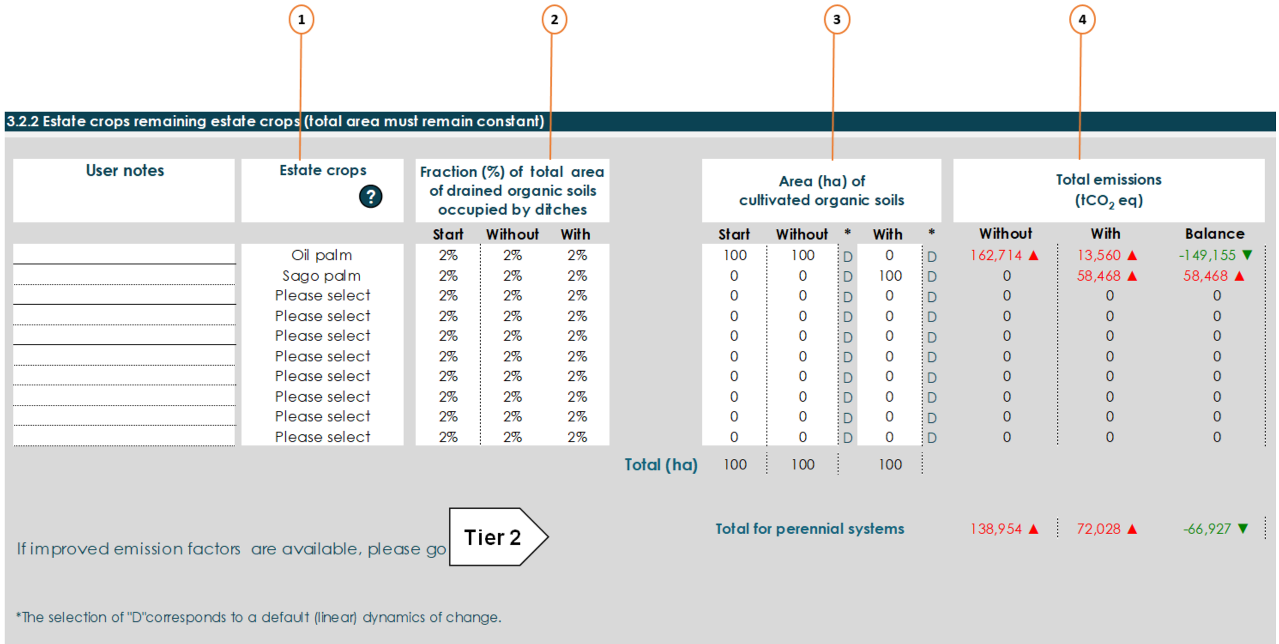
In our example, oil palm (deep-drained) and sago palm (shallow drained) are selected.

2. Fraction of total area of drained organic soils occupied by ditches

The default assumption is that the land remains drained (deep or shallow) and that the drainage ditches are not blocked at the start, without and with the project scenarios. For more information about $\mathrm{Frac}_{\mathrm{ditch}}$, see description in Module 2.1 Peatland deforestation.

In our example, $\mathrm{Frac}_{\mathrm{ditch}}$ is set to 2 percent at the start, without and with project scenarios.

Figure 15. Sub-module 3.2.2: Estate crops remaining estate crops keeping the total area constant



3.2.2 Estate crops remaining estate crops (total area must remain constant)

User notes	Estate crops	Fraction (%) of total area of drained organic soils occupied by ditches			Area (ha) of cultivated organic soils					Total emissions (tCO_2 eq)		
		Start	Without	With	Start	Without	*	With	*	Without	With	Balance
	Oil palm	2%	2%	2%	100	100	D	0	D	162,714 ▲	13,560 ▲	-149,155 ▼
	Sago palm	2%	2%	2%	0	0	D	100	D	0	58,468 ▲	58,468 ▲
	Please select	2%	2%	2%	0	0	D	0	D	0	0	0
	Please select	2%	2%	2%	0	0	D	0	D	0	0	0
	Please select	2%	2%	2%	0	0	D	0	D	0	0	0
	Please select	2%	2%	2%	0	0	D	0	D	0	0	0
	Please select	2%	2%	2%	0	0	D	0	D	0	0	0
	Please select	2%	2%	2%	0	0	D	0	D	0	0	0
	Please select	2%	2%	2%	0	0	D	0	D	0	0	0
	Please select	2%	2%	2%	0	0	D	0	D	0	0	0
				Total (ha)	100	100		100				
					Total for perennial systems					138,954 ▲	72,028 ▲	-66,927 ▼

If improved emission factors are available, please go [Tier 2]

*The selection of "D"corresponds to a default (linear) dynamics of change.

Source: Peat-GHG tool screenshot.

3. Area of cultivated organic soils

Enter the extent of the specific estate crop in hectares at three points in time: at the start, baseline and new scenarios. Note that the total areas of estate crops must be the same at the beginning and at the end (baseline or new-scenario).

In our example, the area is set to 100 ha.

4. Total emissions

See description in module 2.1 Peatland deforestation and drainage.

Tier 2

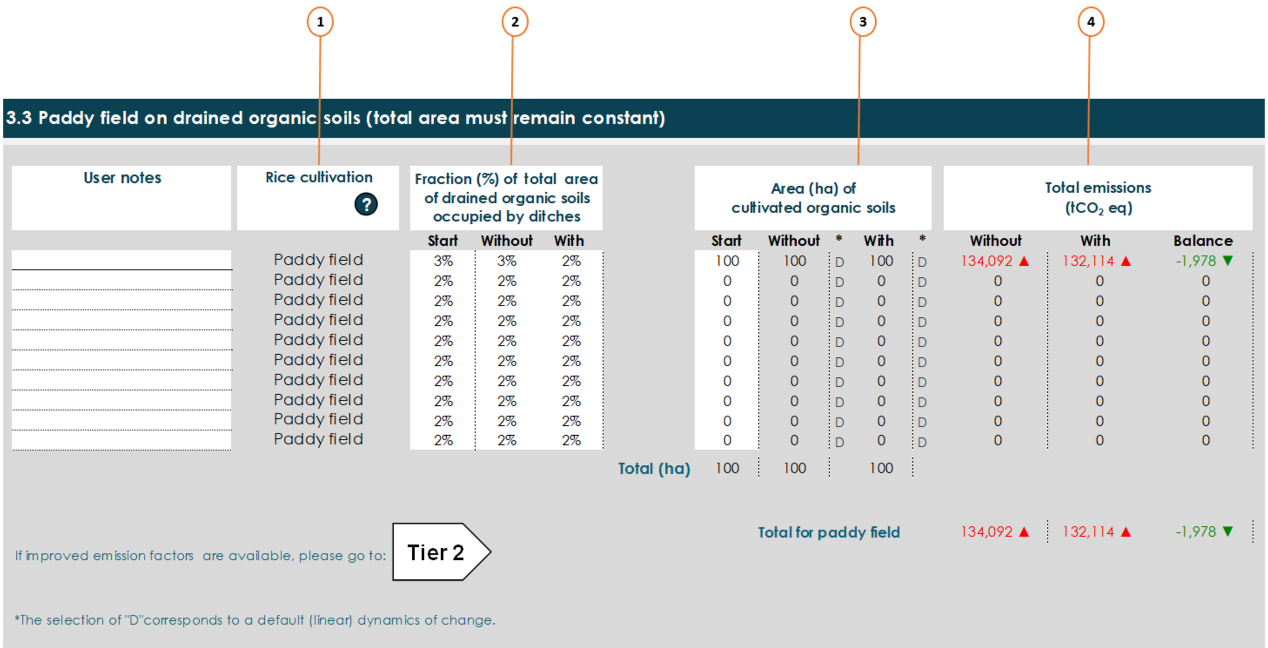
If you want to check the emission factors used or provide better ones click [Tier 2]. Emission factors are treated in this module exactly in the same way as in in other modules described above.

Module 3.3: Paddy field on drained organic soils

Module 3.3 (Figure 16) focuses on rice cultivation on tropical organic soils. In this module paddy field remains paddy field under different land use intensity (e.g., fertilizer application), drainage and fraction of areas covered by ditches. At present, CO_2 and non-CO_2 emissions from fires on drained organic soils and biomass or residue burning are not covered in this module.

Rice cultivation on peat is largely restricted to shallower peat areas (< 100 cm) at the edges of peat domes. Shallow peat may have higher fertility and relatively lower environmental risk than deeper and more acid peat for rice cultivation. However, it is good to remember that as long as the peatland remains drained, for example in alternating drying and wetting of paddy fields, there is a risk of fire during the dry period. Rice farming can be somewhat profitable also in degraded peatland, and thanks to wet management, its emissions can be lower compared to deep-drained management of oil palm or rubber plantations (Surahmana et al. 2018).

Figure 16. Module 3.3: Paddy field on drained organic soils keeping the total area constant



Source: Peat-GHG tool screenshot.

1. Rice cultivation

By default, paddy field is shown in the tool.

2. Fraction of total area of drained organic soils occupied by ditches

The default assumption is that the land remains drained and that the drainage ditches are not blocked at the start, without- and with-intervention scenarios. $\mathrm{Frac}_{\mathrm{ditch}}$ of 2 percent is applied, by you can modify it. See description in Module 2.1 Peatland deforestation.

In our example, $\mathrm{Frac}_{\mathrm{ditch}}$ is set to 3 percent at the start and without the project scenario. With the project scenario $\mathrm{Frac}_{\mathrm{ditch}}$ is set to 2 percent.

3. Area of cultivated organic soils

Enter the area in hectares of drained paddy field at the initial stage (start). The total area of drained paddy field must remain constant. The areas associated without and with the project scenarios are automatically filled in by the tool.

In our example, the area of drained paddy field is 100 ha.

4. Total emissions

See description in Module 2.1 Peatland deforestation.

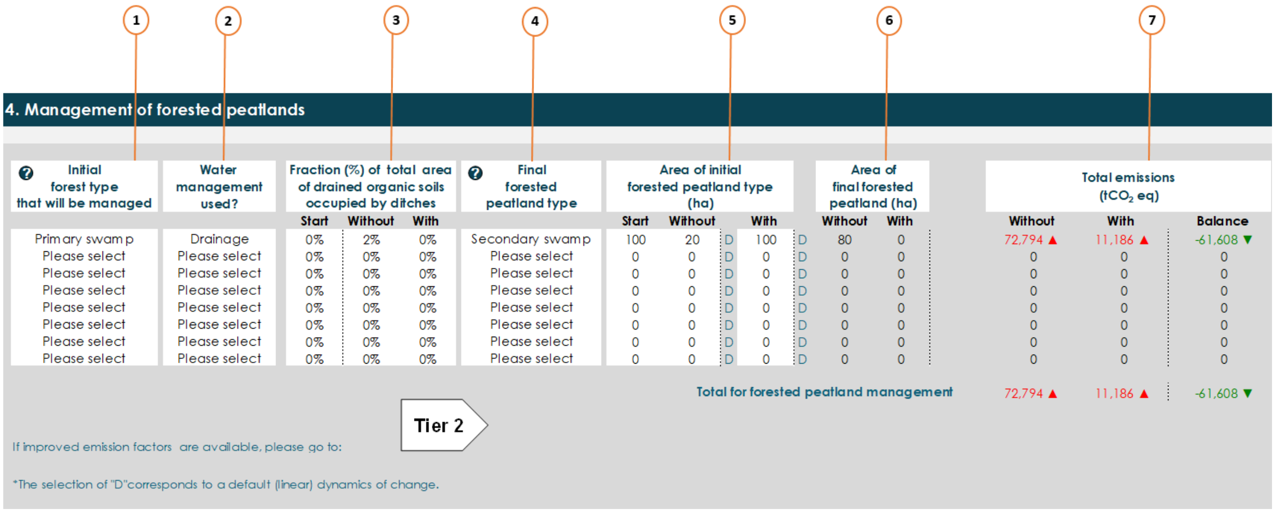
Tier 2

If you want to check the emission factors used or provide better ones click Tier 2. Emission factors are treated in this module exactly in the same way as in in other modules described above.

3.4 Module 4: Management of forested peatlands

Module 4 'Management of forested peatlands' (Figure 17) accounts for emissions or removals associated with drained and/or undrained tropical peatlands covered by forests (natural or plantations). This module can be used to assess (avoided) emissions from forest degradation or removals due to forest restoration.

Figure 17. Module 4: Management of forested peatlands



Initial forest type that will be managed	Water management used?	Fraction (%) of total area of drained organic soils occupied by ditches			Final forested peatland type	Area of initial forested peatland type (ha)			Area of final forested peatland (ha)		Total emissions (tCO_2 eq)		
		Start	Without	With		Start	Without	With	Without	With	Without	With	Balance
Primary swamp	Drainage	0%	2%	0%	Secondary swamp	100	20 D	100 D	80	0	72,794 ▲	11,186 ▲	-61,608 ▼
Please select	Please select	0%	0%	0%	Please select	0	0 D	0 D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0 D	0 D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0 D	0 D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0 D	0 D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0 D	0 D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0 D	0 D	0	0	0	0	0
Please select	Please select	0%	0%	0%	Please select	0	0 D	0 D	0	0	0	0	0
						Total for forested peatland management					72,794 ▲	11,186 ▲	-61,608 ▼

Source: Peat-GHG tool screenshot.

1. Initial forest type that will be managed

Select from the dropdown list the forest type that will be managed.

In our example, 'Primary swamp' is selected.

2. Water management used

Select from the dropdown list the water management practices that will be implemented.

For our example, drainage is selected.

3. Fraction of total area of drained organic soils occupied by ditches

See description in Module 2.1 Peatland deforestation.

In our example, $\mathrm{Frac}_{\mathrm{ditch}}$ at the start is 0 percent. Without the project is set to 2 percent while with the project scenario is set to 0 percent.

4. Final forested peatland type

Select from the dropdown list the forest type after forest management changes.

In our example, 'Secondary swamp''Secondary swamp' is selected.

5. Area of initial forested peatland type

Enter the extent of the initial forest type (in hectares) at three points in time: at the initial situation, without and with-project scenario.

In our example, the area of 'Primary swamp' forest is set to 100 ha at the initial situation (start). Without the project, it is assumed that 20 ha of primary forest will be present. With the project, it is expected that the whole area of primary forest will be preserved.

6. Area of final forested peatland

Once users have indicated the name and size of the initial forest type, the tool calculates automatically the area of final forest type for without and with-project scenarios

In our example, the areas of 'Secondary swamp' forest for without and with -project scenarios are 100 ha and 0 ha respectively.

7. Total emissions

See description in Module 2.1 Peatland deforestation.

Tier 2

If you want to check the emission factors used or provide better ones click: **Tier 2**. Emission factors are treated in this module exactly in the same way as in in other modules described above.

3.5 Module 5: Inputs of liming and fertilizers

Liming corresponds to the addition of carbonates to soils in the form of either calcic limestone or dolomite. Those additions lead to CO_2 emissions when carbonates dissolve. CO_2 emissions are calculated using default emissions factors provided by IPCC guidelines, i.e., 0.12 tC per tonne lime for limestone and 0.13 tC per tonne lime for dolomite (Chapter 11, IPCC 2006). These default emission factors are equivalent to carbonate carbon contents of the materials (12 percent for $CaCO_3$, 13 percent for $CaMg(CO_3)_2$).

CO_2 emissions are obtained by multiplying the emission factor with the quantities of each type of carbonates applied. When the user does not know the type of lime used, it can select the third line of the table, “not-specified”, that uses an average emission factor. User may also specify her/his own emissions factor that must, by definition, be less than the default emission factor, because that default factor corresponds to the carbonate carbon content of the materials. Calculations are then done for the quantities’ information concerning the beginning, and the two scenarios (without and with-project scenarios) and the dynamics chosen. Results provide the corresponding emissions in tCO_2eq (Figure 18).

Figure 18. Module 5: Inputs of liming

5. Inputs (liming and fertilizers)

Description and unit to report (1)	Amount applied annually (2)					Total emissions at field level (tCO_2 eq) (3)				Total emissions (tCO_2 eq) (4)		
						CO_2 emissions		N_2O emissions				
Lime	**Start**	**Without**	*****	**With**	*****	**Without**	**With**	**Without**	**With**	**Without**	**With**	**Balance**
Calcic limestone ($CaCO_3$) (tonnes per year)	50	50	D	200	D	660	2,475	-	-	660 ▲	2,475 ▲	1,815 ▲
Dolomite ($CaMg(CO_3)_2$) (tonnes per year)	0	0	D	0	D	0	0	-	-	0	0	0
not-specified (tonnes per year)	0	0	D	0	D	0	0	-	-	0	0	0
Fertilizers												
Synthetic fertilizer (tonnes of N per year)	0	0	D	0	D	-	-	0	0	0	0	0
N-fertilizer in irrigated rice (tonnes of N per year)	0	0	D	0	D	-	-	0	0	0	0	0
Sewage (tonnes of N per year)	0	0	D	0	D	-	-	0	0	0	0	0
Compost (tonnes of N per year)	0	0	D	0	D	-	-	0	0	0	0	0

If improved emission factors are available, please go to: **Tier 2**

*The selection of "D"corresponds to a default (linear) dynamics of change.

Source: Peat-GHG tool screenshot.

In our example, 50 tonnes per year of limestone is applied at the start and without the project. With the project scenario the application rate will be increased to 200 tonnes per year.

Nitrous oxide emissions from N application to managed soils

The following sources are covered: synthetic fertilizers, N fertilizer in non-upland rice single and multiple drainage, sewage and organic fertilizers (Table 15). Emissions are calculated based on amount of N applied and an emission factor associated with the type of input. The emission factors are obtained from Table 11.1, IPCC 2019.

Table 15. Default emission factors to estimate nitrous oxide emissions from managed soils

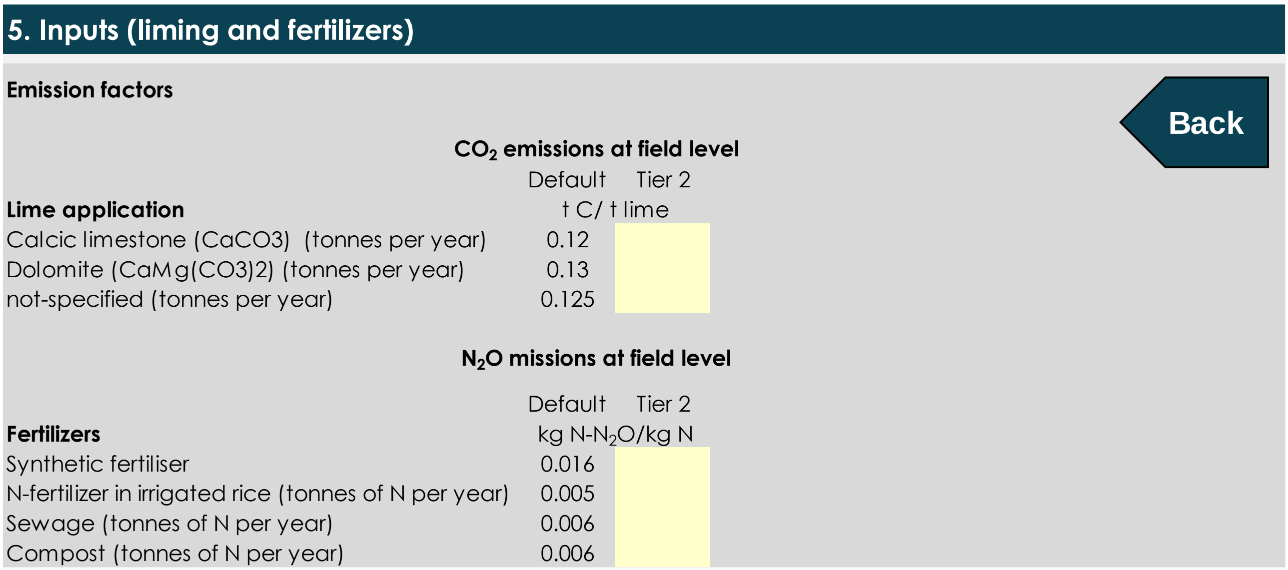
Type of input	Default emission factor kg $N\text{-}N_2O$/kg N
Synthetic fertilizer	0.016
N fertilizer in non-upland rice single and multiple drainage	0.005
Sewage	0.006
Compost	0.006

Source: IPCC, 2019.

Tier 2

If you want to check the emission factors used or provide better ones click Tier 2. The following table in Figure 19 appears.

Figure 19. Tier 2 section of Module 5.1: Inputs of liming and fertilizers



5. Inputs (liming and fertilizers)

Emission factors

Back

CO_2 emissions at field level

Lime application	Default	Tier 2
	t C/ t lime	
Calcic limestone (CaCO3) (tonnes per year)	0.12	
Dolomite (CaMg(CO3)2) (tonnes per year)	0.13	
not-specified (tonnes per year)	0.125	

N_2O missions at field level

Fertilizers	Default	Tier 2
	kg $N\text{-}N_2O$/kg N	
Synthetic fertiliser	0.016	
N-fertilizer in irrigated rice (tonnes of N per year)	0.005	
Sewage (tonnes of N per year)	0.006	
Compost (tonnes of N per year)	0.006	

Source: Peat-GHG tool screenshot.

3.6 Module 6: Detailed results

This module allows users to visualize the expected climate change mitigation benefits for peatland management interventions. Figure 20 shows a summary table that includes the two scenarios so users can compare them. The balance is the difference of GHG gross fluxes between 'without- and with-project scenarios. Results are reported in tCO_2eq. Positive numbers represent sources of CO_2eq emissions while negative numbers represent carbon sinks or CO_2eq emissions reductions.

Figure 20. Module 6: Detailed results

1 2 3

Islands of Indone Kalimantan — **Climate:** Tropical Wet — **Soil type:** Organic (peat) — **Duration of interventions (in years)** 20 — **Total area (ha)** 400

Peatland interventions	Gross fluxes (in tCO_2eq)			Total balance disaggregated by C pool and GHG — All GHGs in tCO_2eq					Gross fluxes per year (in tCO_2eq/year)		
	Baseline	New-Scenario	Balance	CO_2	CO_2		N_2O	CH_4	Baseline	New-Scenario	Balance
	Positive (+): source of GHGs Negative (-): sink of GHGs			Biomass	Soil	Other	Soil	Soil			
Land use chang											
Deforestation	141,610	7,457	-134,153	-63,850	-72,573		-983	3,253	7,081	373	-6,708
Affo/reforestatio	111,321	108,680	-2,641	37,987	-38,500		-1,967	-161	5,566	5,434	-132
Other LU change	87,956	113,283	25,327	0	29,517		3,770	-7,959	4,398	5,664	1,266
Agricultural peatlands											
Annual crops	0	0	0	0	0		0	0	0	0	0
Estate crops	0	0	0	0	0		0	0	0	0	0
Rice	0	0	0	0	0		0	0	0	0	0
Forested peatlan	7,457	7,457	0	0	0		0	0	373	373	0
Inputs (lime, fertil	0	0	0			0	0	0	0	0	0
Total	**348,345**	**236,878**	**-111,467**	-25,863	-81,556	0	819	-4,867	17,417	11,844	-5,573
Per hectare	871	592	-279	-65	-204	0	2	-12			
Per hectare per	44	30	-14	-3	-10	0	0	-1	44	30	-14

Source: Peat-GHG tool screenshot.

1. **Gross fluxes**

It shows the estimated gross fluxes and CO_2eq emissions and removals in tCO_2eq. from the without- and with project scenarios as well as the total balance disaggregated by module over a total period of accounting.

In our example, the total emissions without- and with project scenarios are 575,747 tCO_2eq and 311,456 tCO_2eq respectively. The net difference of these two scenarios is estimated at -264,291 tCO_2eq (total balance).

2. Total balance disaggregated by C pool and GHG

A summary of the total balance disaggregated by module, carbon pool and GHG.

For example, the total balance of 'Deforestation' is estimated at -136,841 tCO_2eq. CO_2 removals from the soil pool are 53 percent (-72,573 tCO_2eq) of the total balance (-136,841 tCO_2eq) while CO_2 removals from the biomass pool are 47 percent (-63,850 tCO_2eq).

3. Gross fluxes per year

It shows the estimated annual gross fluxes and CO_2-e emissions and removals from the without- and with interventions scenarios as well as the total balance disaggregated by module.

Figure 21. Graphs from the results module

Source: Peat-GHG tool screenshot.

Also, the tool shows additional graphs (Figure 21) and matrices (Figure 22) associated with:

1. Total fluxes for without- and with-intervention scenarios in tCO_2eq;
2. Total balance disaggregated by C pool and GHG in tCO_2eq;
3. Fluxes per component in tCO_2eq;
4. Balance per component in tCO_2eq; and
5. Percentage of drained and natural/undrained areas without- and with- interventions scenarios.
6. Land-use changes without- and with- project scenarios (Figure 22)

Figure 22. Detailed matrices of land-use changes without- and with- project scenarios

Detailed matrices of land-use changes without- and with- project scenarios

Area (in ha)		Final land uses (Without-project scenario)							
		Natural / Plantation forest	**Annual**	**Perennial**	**Rice**	**Grassland**	**Settlement**	**Other land**	**Total**
Iinitial land uses (Start)	Natural or Planted forest	100	0	100	0	0	0	0	200
	Annual	0	100	0	0	0	0	0	100
	Perennial	0	0	0	0	0	0	0	0
	Rice	0	0	0	0	0	0	0	0
	Grassland	0	0	0	0	100	0	0	100
	Settlements	0	0	0	0	0	0	0	0
	Other land	0	0	0	0	0	0	0	0
Total area (in ha)		**100**	**100**	**100**	**0**	**100**	**0**	**0**	**400**

Area (in ha)		Final land uses (With-project scenario)							
		Natural / Plantation forest	**Annual**	**Perennial**	**Rice**	**Grassland**	**Settlement**	**Other land**	**Total**
Iinitial land uses (Start)	Natural or Planted forest	200	0	0	0	0	0	0	200
	Annual	100	0	0	0	0	0	0	100
	Perennial	0	0	0	0	0	0	0	0
	Rice	0	0	0	0	0	0	0	0
	Grassland	0	0	100	0	0	0	0	100
	Settlements	0	0	0	0	0	0	0	0
	Other land	0	0	0	0	0	0	0	0
Total area (in ha)		**300**	**0**	**100**	**0**	**0**	**0**	**0**	**400**

Source: Peat-GHG tool screenshot.

3.7 Level of uncertainty

The results are accompanied by rough estimate of uncertainty (rounded up to the nearest 10 percent), which is calculated using the method given in the IPCC 2006 Guidance (IPCC 2006). When using the tool, calculations may be based solely on default coefficients (Tier 1 approach) or values provided by users (Tier 2 approach) or a combination of Tier 1 and Tier 2 emission factors. Therefore, it is difficult to provide uncertainties associated with the final values.

Figure 23 below provides indications of the minimum level of uncertainty that the user may expect, based on expert opinion. Different categories have been created, in order to reflect the level of uncertainties (low uncertainty 10 percent, moderate uncertainties 20 percent, high uncertainties 30 percent, and very high uncertainties of over 50 percent). Going from Tier 1 to Tier 2 decreases the category of uncertainties, as Tier 2 uses more precise values. At the end of the 'Results' module a final estimation of the total level of uncertainty is given expressed as a percentage (Bernoux *et al.* 2010).

Figure 23. Estimations of uncertainty level

Level of uncertainty

Total (in tCO_2eq)	Gross fluxes	% of uncertainty
Without	499,962 ▲	47.0
With	127,624 ▲	45.3
Net balance	-372,338 ▼	45.8

Uncertainty level	%
Low uncertainty	10.0
Moderate uncertainties	20.0
High uncertainties	30.0
Very high uncertainty	50.0

Source: Peat-GHG tool screenshot.

4. Key recommendations

The team and reviewers of this report want to give some recommendations and further notes that the user should be aware of when using the tool and interpreting the results. The FAO team remains available and would be grateful for any suggestions for further improvements both to the tool and to this manual.

The first and foremost gap in the current version of the tool remains that fire-related emissions cannot be calculated with it. A future version of the tool, depending on the availability of further resources, should prioritize the inclusion of emissions from fires. At the time of writing, further data is being collected to cover some major data gaps that will hopefully allow the tool to be further developed. While challenging to capture given the inherent unpredictability of fire occurrence and severity, some land-use classes (degraded forest, shrubland) are at far higher risk of fires than others (primary forest, cropland, estate crops and forest plantations). For example, any apparent emissions savings from land conversion to shrubland are unlikely to be achieved (unless the land is protected from fire and succession to forest is permitted to occur) due to the increased fire risk. Therefore, apparent emission savings associated with some land-use changes could, as noted above, be negated, or even outweighed by fire emissions due to the increased susceptibility of the new land-use to fire. Avoiding such a perverse outcome is a high priority for FAO for the next version of the tool, and resources are sought to cover this gap.

The design of the without-project scenario has a major influence on the calculated emission savings that result from the with-project scenario. The more high-emitting the without-project scenario is, the larger the calculated emissions reduction benefits will be, even if the without-project scenario involves conserving the same forest that was there at the start of the period. This approach carries a risk that the baseline scenario could be inflated to generate artificial emissions savings. Therefore, the without-project scenario needs to be strongly evidenced and validated to demonstrate that this scenario really would have occurred in the absence of the restoration or conservation measures undertaken with the project.

At present, the tool provides a single estimate of the emission saving based on the difference between the without-project and with-project scenarios. This calculation is highly sensitive to the selection of a without-project scenario and generates apparent emission savings even if no changes in land-use or management occurred, on the basis that the baseline scenario did not occur. While this is consistent with Indonesian emissions reporting it is good to note that the atmosphere would not ‘see’ any change in emissions as a result of this avoided activity.

On the other hand, active restoration of drained or degraded peatland would generate a real emissions reduction, i.e. one which the atmosphere will ‘see’, and which has a real impact mitigating climate change. This real emissions reduction is the difference between the ‘start’ emissions and the with-project scenario when activities include restoration. At present, the real emissions reduction is not included in the tool as an additional output. This output may (for example) be relevant for users or investors seeking to support active restoration measures to reduce emissions, rather than conservation measures aimed at avoiding a future emissions increase. In situations where actual GHG removal is achieved (i.e., the recreation of a CO_2-sequestering peatland), then this could also be reported, but at present none of the default emission factors used in the tool would generate net CO_2 uptake.

Future refinements of the tool will seek to include more highly resolved emissions estimates for different land-management options within a land use/cover class. Specifically, raising water-table levels within agriculture, estate crops, degraded forests or forest plantations has the potential to generate substantial emissions reductions, even without a land-use change. Published empirical relationships between CO_2 emissions and water table depth could be used to derive emission factors for different drainage depth increments and embedded in the tool. This approach would require that users know (and can verify) water table depths in their study areas for the different scenarios, to avoid spurious reporting of emissions reductions.

It may be difficult or impossible to establish current rates of lime or nitrogen fertilizer application in complex landscapes such as community-owned farmland and plantations, and for baseline and new scenarios, application rates will be unknown. However, for many crop types (notably industrial oil palm and acacia) there will be standard application rates, and it may also be possible to obtain typical input types and rates per hectare for other crops (chicken manure is widely used in cropland, for example). At the moment, the tool requires users either to undertake some detailed pre-analysis of input rates across their study area or to guess. Consideration is therefore given to developing an additional worksheet (or separate Excel file) that would enable users to estimate total application rates for their study area based on Tier 1 type default rates (in tonnes/ha) of lime and fertilizer application for the land-use categories present.

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6. GLOSSARY

Above-ground biomass: All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage. Note: In cases where forest understory is a relatively small component of the above-ground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series.

Accounting period: Length of time over which greenhouse gas emissions and removals are quantified.

Activity data: Data on the magnitude of a human activity resulting in emissions or removals taking place during a given period of time. Data on energy use, metal production, land areas, management systems, lime and fertilizer use and waste arisings are examples of activity data (IPCC, 2019).

Below-ground biomass: All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.

Biomass: (1) The total mass of living organisms in a given area or of a given species usually expressed as dry weight. Includes above and below ground living biomass. (2) Organic matter consisting of or recently derived from living organisms (especially regarded as fuel) excluding peat. Includes products, by-products and waste derived from such material.

Dead wood: Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country).

Ditch: A long, narrow excavation dug in the earth, typically unlined, often with a uniform cross-section. They are most often used to provide drainage alongside roadways and from agricultural fields and to convey water for irrigation (IPCC, 2019).

Drainage channel: A ditch used for drainage (IPCC, 2019).

Drainage: Drainage is the process of artificial lowering of the soil water table. In the 2013 IPCC Wetlands Supplement, the term is used to describe the act of changing a soil from wet into dry. A drained soil is a soil that has formerly been a wet soil, but as a result of human intervention has become a dry soil. All organic soils are assumed to have originally been wet, therefore a dry organic soil is always also a drained organic soil (IPCC, 2014).

Emission factors: A coefficient that quantifies the emissions or removals of a gas per unit activity. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions (IPCC, 2019).

Emissions: The release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time. (IPCC, 2019).

Intervention: Change in land use/management practice from without-project scenario.

Litter: Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g.e.g., 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.

Organic soil: An organic soil is a soil with a high concentration of organic matter. Every soil that is not an organic soil is classified as a mineral soil (IPCC, 2006). The Peat-GHG tool follows the definition of organic soils in the 2019 IPCC Guidelines and in the IPCC Wetlands Supplement. Therefore, organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below:

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

(IPCC, 2014.)

In the context of Indonesia, peatland is defined as an area with an accumulation of partly decomposed organic matter, water saturated with carbon content of at least 12 percent (usually 40–60 percent C content) and the thickness of the carbon rich layer of at least 50 cm (MoEF, 2016).

Peat and peatland: Peatlands are wetland ecosystems where soils are dominated by peat. Peatlands are a type of a wetland that occur in almost every country on Earth, currently covering 3 percent of the global land surface. The term 'peatland' refers to the peat soil, and the wetland habitat growing on its surface. In peatlands, net primary production exceeds organic matter decomposition as a result of waterlogged conditions, which leads to the accumulation of peat. There are no IPCC definitions for peat and peatland. Definitions of peatland and peat soil differ between countries in relation to the thickness of the peat layer required to be determined as a peatland or a peat soil.

Pool, carbon and nitrogen: A reservoir in the Earth system where elements, such as carbon and nitrogen, reside in various chemical forms for a period of time. An example is carbon and nitrogen pools in forest biomass, which are composed of various types of compounds synthesized by trees. A group of pools are linked in a cycle with flows among the pools influenced by both anthropogenic and non-anthropogenic processes.

An example is carbon and nitrogen pools in forest biomass, wood products, dead organic matter, soils and the atmosphere, in which flows are influenced by non-anthropogenic drivers such as plant production and microbial decomposition, as well as anthropogenic drivers such as fertilization, land use, tree harvest and product use.

Removals: Removal of greenhouse gases and/or their precursors from the atmosphere by a sink (IPCC, 2019).

Rewetting: Rewetting is the process of changing a drained soil into a wet soil. A rewetted soil is a soil that has formerly been a drained soil but as a result of human intervention has become a wet soil. Similarly, 'wetting' is the process of changing an originally dry soil into a wet soil as a result of human intervention, as in wetland creation. 'Restoration' (adjective restored) is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. In the case of drained former wetlands, restoration always has to include rewetting. (IPCC, 2014.)

Sink: Any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere (UNFCCC Article 1.8). Notation in the final stages of reporting is the negative (-) sign (IPCC, 2019).

Soil carbon pool: A pool of carbon comprised of soil organic matter that is smaller than 2 mm in size.

Source: Any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere (UNFCCC Article 1.9). Notation in the final stages of reporting is the positive (+) sign (IPCC, 2019).

Tier: A tier represents a level of methodological complexity. UsuallyUsually, three tiers are provided. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as higher tier methods and are generally considered to be more accurate (IPCC, 2019).

Tier 1: Tier 1 methods are designed to be the simplest to use, for which equations and default parameter values (e.g.e.g., emission and stock change factors) are provided in IPCC 2014. While users need to furnish project specific activity data, the IPCC based emission coefficients are mostly applicable globally or at a regional level. Tier 1 values used in the tool are summarized in the different ad-hoc modules described in the present manual.

Tier 2: Tier 2 method can use the same methodological approach as Tier 1 but applies emission and stock change factors that are based on country- or region-specific data. Country-defined emission factors are usually characterized by more specificity for the climatic regions, land-use categories, vegetation types, drainage depth. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialized land-use.

Tier 3: Tier 3 method refers instead to the use of more complex methodologies, including GHG modelling techniques. They are tailored to address national circumstances and are driven by high-resolution activity data and disaggregated at subnational level. Their strong data requirements make an application time and resource intensive.

Tropical, moist climate: Areas where mean annual temperature (MAT) is more than 18 ^{o}C, with no more than 7 days of frost, and mean annual precipitation greater than 1 000 mm and less than or equal to 2 000 mm (IPCC, 2014).

Tropical, wet climate: Areas where mean annual temperature (MAT) is more than 18 ^{o}C, with no more than 7 days of frost, and mean annual precipitation greater than 2 000mm (IPCC, 2014).

Wetlands: This category includes land that is covered or saturated by water for all or part of the year (including peatlands in their natural state) and that does not fall into the forest land, cropland, grassland or settlements categories under the reporting to the UNFCCC. NB: This can be confusing, as wetlands are used for all these purposes, however, the greenhouse gas reporting happens only under one selected category. The Wetlands category can be subdivided into managed and unmanaged wetlands according to national definitions.

Wetlands occur over all climate zones and include reservoirs and other constructed waterbodies (e.g.e.g., agriculture and aquaculture ponds, canals and ditches and wetlands constructed for wastewater treatment) as managed sub-divisions. Managed wetlands may also include peatlands, riparian wetlands, forested swamps, marshes, playas, pans, salt lakes, brackish wetlands, salinas, and sabkhas, in addition to coastal wetlands, which include mangroves, saltmarshes, tidal marshes and seagrass. Unmanaged wetlands include natural rivers, lakes and ponds and any wetlands that have not been directly modified by human activity based on the Managed Land Proxy. (IPCC, 2014.)

Without-project scenario: Land use/management practice(s) without any intervention(s) (i.e.i.e., “business as usual”)

Peat-GHG tool: A greenhouse gas calculator for peatland management in Indonesia

User manual

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