User manual Site Emissions Tool v1.2

A user-friendly tool to estimate GHG-emission reductions from peat rewetting

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The Site Emissions Tool or SET was developed in the Interreg NWE-project Carbon Connects[1,2]. It aims to help interested farmers, other land owners, and policy makers to assess the effects of drainage, crop and management choices on Greenhouse Gas (GHG) emissions from peat soils. It is an attempt to find a working balance between user-friendliness (i.e. simplicity) and accuracy. The tool is meant to be robust enough to be used as a basis for payment of emission reduction. This payment can be through C-crediting, subsidies or other means.

Contents

1 Scope and limitations

The SET carries out several steps needed to estimate GHG-emission effects of changing (ground)water levels and land management in peatlands. The SET was developed explicitly for use in peatlands, not in mineral soils. It calculates GHG-effects in a sufficiently robust manner to base payment for emission reduction upon. However, several aspects are not included, which should be addressed for a full consequential LCA assessment (see Appendix B). These are:

- Leakage effects;
- Site preparation;
- Ecological developments following rewetting.

Leakage effects refer to leaks in the project boundaries. This covers negative effects that occur outside the project area, but as a result of the project. In the context of GHG emissions, leakage implies that emissions are displaced to areas outside the project boundary, which may partially or completely negate emission reductions in the project area. If, for example, a peat grassland used for pasturing or hay-making is rewetted, this results in emission reductions. But if the same farmer shifts his activities to a new, hitherto undrained peat area which is then drained for this purpose ('activity shifting'), the net gain may equal zero or even be negative. It is preferable to include leakage effects in total GHG-effect accounting of a project, but it was not feasible to include this in the SET because these effects are highly project specific.

Site preparation refers to all activities required for rewetting, such as removal of topsoil and vegetation or

[1] https://www.nweurope.eu/projects/project-search/cconnects-carbon-connects/#tab-1

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creating water management infrastructure. GHG-effects of such activities can be substantial, especially for small scale projects in a drained landscape. However, the range of activities and effects is very project-specific which is why it is not included in the SET.

Relevant ecological developments following rewetting result from the sudden change that rewetting brings, and the time the ecosystem needs to adjust to this. This adjustment time leads to two factors that are important in rewetting projects: firstly, vegetation does not change from one type to another overnight. It can take 10 years for vegetation to reach an more-or-less stable situation after strong rewetting, but the SET only allows users to specify vegetation at two moments. Still, gradual vegetation and management change can be simulated using repeated SET calculations. Secondly, heightened methane emissions in the first few years after rewetting (i.e. methane spikes) are reported in the scientific literature. Theoretically it seems plausible that these occur, as a result of large amounts of easily degradable organic matter that is present in the soil following years of drainage and fertilization. But currently it is not sufficiently clear what drives the magnitude of methane spikes, nor indeed if these always occur after rewetting. Although methane spikes are not included, structural methane emissions resulting from rising water levels are included.

2 General approach

The SET determines pre and post rewetting GHG emissions using a scenario approach. SET also determines how much emission reduction is eligible for claiming Carbon credits or other forms of payment.

Carbon emissions from soil are based upon the GEST system (Couwenberg et al., 2011), which includes both carbon dioxide (CO_2) and methane (CH_4) emissions. The GEST, or Greenhouse Gas Emission Site Types, consists of a list of typical emission factors for different combinations of vegetation and groundwater levels. These emissions are based upon annual emission budgets determined in various research projects. The number of studies the emission factors are based upon ranges from 1 up to 48, depending on the Site Type and the emission type (i.e. CO_2 vs CH_4). The SET uses the mean emission numbers from an as yet unpublished updated version of the GEST which contains 30 regular Site Types, plus an additional 9 highly specific types (Couwenberg, Reichelt, & Jurasinski, n.d.; Reichelt, 2015; Appendix A).

Standard IPCC Tier 1 calculations are applied to estimate emissions of nitrous oxide (N_2O) resulting from application of manure or fertilizer, cattle droppings and from crop residues left on the field (De Klein et al., 2006). Emissions from fossil fuel combustion are calculated by assuming the carbon content of the fuel is completely transformed in CO_2. Emission from electricity use is based upon average CO_2-emission per kW. Finally, application of the biomass produced for long rotation applications or to replace fossil fuel is treated as avoided emission of all the carbon in the biomass. Emissions of methane (CH_4) and nitrous oxide (N_2O) are transformed to CO_2 equivalents to enable comparison between the different gases. These transformations use the Global Warming Potential averaged over 100 years (GWP100) without climate carbon feedbacks (Myhre et al., 2013). CH_4 has a GWP100 of 28 CO_2-equivalents, N_2O has a GWP100 of 265 CO_2-equivalents.

The output pane provides the relevant raw numbers plus some graphic output to ease interpretation. Total emission savings are reported per ha and per site. The maximum amount of avoided carbon emission that is eligible for crediting, or other forms of payment, is the amount of carbon that is present in the soil at the start of rewetting. This means that emissions reductions from the soil are no longer eligible for payment after all the peat would have been lost in the business as usual scenario. SET determines the time until all the peat is lost by determining the amount of carbon in the soil at the start of the project, and subtracting the carbon emitted each year. The carbon content of the peat is based on an existing analysis of peat properties (Loisel et al., 2014). Table 1 shows the carbon content per peat type together with some other peat characteristics.

Table 1. Peat soil characteristics per peat type. Bulk Density and Carbon content of peat from Loisel et al. (2014).

Peat type	Bulk Density (g/cm^3)	Carbon content of peat (%)	Carbon content of soil (kg C/m^2/cm peat)
Sphagnum	0.076	46.0	0.35
Herbaceous	0.118	50.5	0.60
Woody	0.108	50.9	0.55
Brown moss	0.177	47.9	0.85
Unknown	0.118	46.8	0.55
Humified	0.192	47.4	0.91

After all the carbon in the peat has been emitted to the air in the business as usual scenario avoided emissions from the soil are no longer eligible for payment, but carbon sequestration still is[3], as is the carbon in the harvested biomass if it is used in long rotation applications or to replace fossil fuel use. A timeline graph shows how the emissions develop over time and which of these are eligible for payment systems, i.e. which of these are creditable.

[3] Note that even GESTs with a positive net GHG emission (expressed in CO_2-equivalents) can be sequestering carbon, because emissions of CH_4 have a Global Warming Potential of 28 CO_2-equivalents.

3 The input tab

The inputs SET requires are described and explained below. Each section starts with a screenshot of the relevant input tab, with possible entries. This is followed by a brief description of the input and its usage in the SET.

3.1 General site data

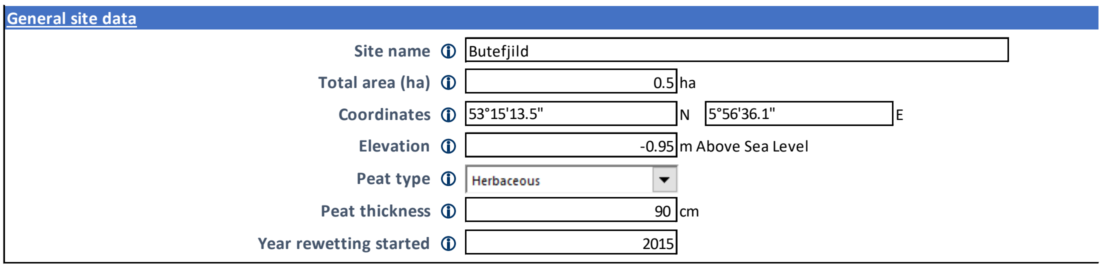


Figure 1. Input pane for general site data.

Site name is the name used to identify the site. No calculations are performed on this, instead it is included to ease the user's administration.

Total area is the rewetted site's area in ha's. This is needed for calculations.

Coordinates are latitude / longitude coordinates of the centre of the site. No calculations are performed on this, instead it is included to ease the user's administration, and to help comparison between sites.

Elevation is measured in m above sea level, or a countries standard ordinance level if that is more relevant. No calculations are performed on this, instead it is included to ease the user's administration, and to help comparison between sites.

Peat type is dropdown menu offering a choice between peat types: Sphagnum, herbaceous, woody, brown moss, unknown or humified (Table 1).The peat type is used to determine the carbon content of the soil.

Peat thickness is the average thickness of the layer of peat in cm. Peat thickness is used to determine carbon content of the soil.

Year rewetting started is the first year in which water levels were raised. This affects the timeline output effects on emissions and creditable emissions savings.

3.2 Groundwater and vegetation

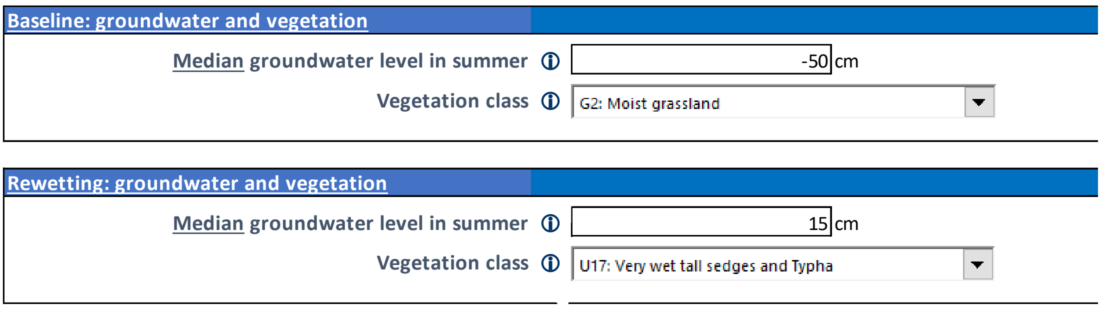


Figure 2. The input pane for groundwater and vegetation.

Groundwater levels and vegetation classes need to be specified twice, once for the business as usual scenario, and once for the changed conditions after rewetting.

Median groundwater level in summer is the middle number when all groundwater level recordings between 1 April and 30 September are put in increasing order[4]. Enter this value in cm relative to the surface, i.e. + is above the soil surface and – is below the soil surface. This metric stems from the use of the GEST, which uses median groundwater levels to indicate groundwater conditions. The groundwater level entered here limits the number of vegetation classes (next step).

Vegetation class is the type of vegetation present in the site. After the groundwater level has been filled in the drop down menu lists all the vegetation types that can be present with these groundwater level conditions. Select the best fit. If the best fit is not immediately clear, use the list of GESTs and associated moisture classes in Appendix A. This includes winter groundwater levels, plus the range of conditions that each GEST can occur in.

3.3 Fertilizer use, grazing animals and crop residues

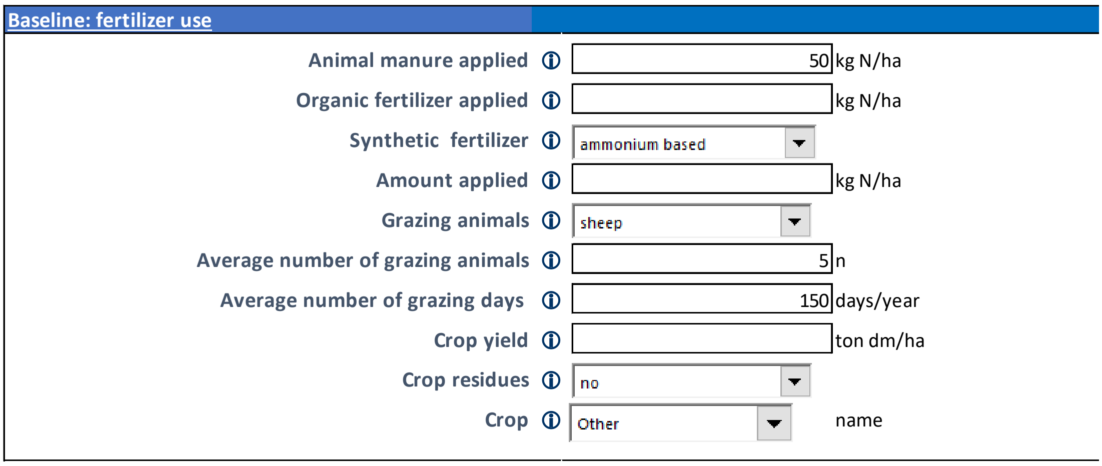


Figure 3. Fertilizer use inputs, only for the baseline scenario. An identical input pane needs to be filled out for the rewetting scenario.

Animal manure applied is the amount of manure applied yearly, measured as kg N/ha. If no manure is applied leave this field empty, or put in 0 (zero).

Organic fertilizer applied is the amount of compost or other organic fertilizer applied yearly, measure as kg N/ha. If no organic fertilizer is applied leave this field empty, or put in 0 (zero).

Synthetic fertilizer can distinguished in ammonium based or nitrate based fertilizers. Select the correct type first, then put in the amount applied measured as kg N/ha per year. If no synthetic fertilizer is applied leave this field empty, or put in 0 (zero).

Grazing animals is a drop down box offering a list of animal types. Select the best fit.

Average number of animals is the average amount of animals simultaneously present at the site (not per ha).

Average number of grazing days is the number of days the animals are present at the site, per year.

[4] This is a different measure than the average lowest groundwater level or the yearly average groundwater levels used in some countries!

Crop yield is the yield harvested per year, expressed in ton dry matter per hectare (ton dm/ha). If no harvest takes place (aside from feeding the grazing animals) leave this empty of fill in zero.

Crop residues are relevant only if a crop is harvested. If this is the case, crop residues are stubbles or other left over parts of the crop left on the field.

Crop is the type of plant harvested. Select the best fit, or if nothing similar to the crop grown at your site is available select ‘other’. If no crop is harvested, leave this empty.

3.4 Activity data

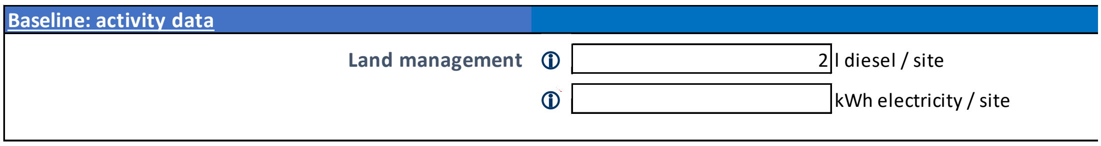


Figure 4 Activity inputs, only for the baseline scenario. An identical input pane needs to be filled out for the rewetting scenario.

Energy consumption to run machines, pumps etc. used to manage the land needs to be filled in here. Fill in the yearly diesel and / or electricity use for management of the site, for the baseline scenario and for the rewetting scenario. If the equipment used runs on renewable energy, leave the relevant box empty, or fill in zero.

3.5 Crop use

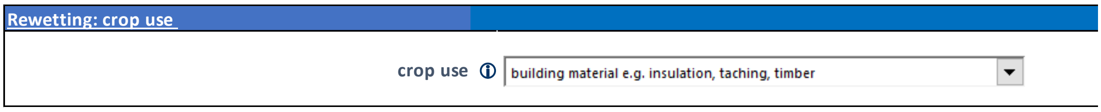


Figure 5 Select what the harvested crop is used for. This pane is only available for the rewetting scenario.

Crop use has to be specified for the rewetting scenario alone, because the SET assumes the crop grown before rewetting was not used for long rotation products or to replace fossil fuels. Select the category the harvested biomass will be used for, or select ‘other uses/unknown’ if the categories do not fit your site’s biomass use. Note SET also needs inputs for productivity and crop type, which need to be entered under ‘Fertilizer use’.

4 The output tab

The outputs SET generates are described and explained below. Each section starts with a screenshot of the relevant output pane. This is followed by a brief description of the output.

4.1 Site characteristics

Site characteristics

Site name	Butefjild	Coordinates	53°15'13.5" N	5°56'36.1" E
Total area (ha)	0.5 ha			
Peat type	Herbaceous			
Peat thickness	90 cm			
Rewetting started	2015			
	Baseline	**After rewetting**		
Moisture class	2+: Moderate moist	6+: Flooded (lower eulittoral)		
Vegetation class	G2: Moist grassland	U17: Very wet tall sedges and Typha		

Figure 6 Site characteristics on the SET output tab.

The top part of this pane shows some characteristics the user specified in the input tab. This is intended to help the user, by collecting all the relevant data on the output tab.

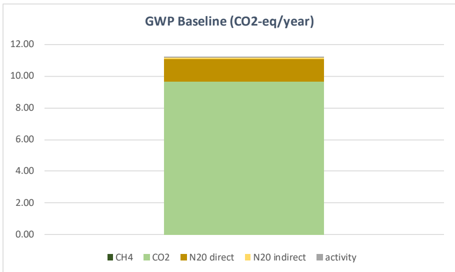
The moisture classes for the baseline scenario (i.e. business as usual) and after rewetting are determined from the groundwater level the user entered. This is the moisture class used by the GEST-methodology.

Vegetation class is the Greenhouse gas Emission Site Type (GEST) the user selected.

4.2 Baseline outcome and Rewetting outcome

Baseline outcome

GEST			
	CH4	0.0	tCO2-eq
	CO2	9.7	tCO2-eq
	GWP subtotal	9.7	tCO2-eq
N2O			
	N20 direct	1	tCO2-eq
	N20 indirect	0	tCO2-eq
	GWP subtotal	1	tCO2-eq
Activity			
	GWP subtotal	0.0	tCO2-eq
TOTAL			
	GWP total	11.2	tCO2-eq



Rewetting outcomes

GEST			
	CH4	3.4	tCO2-eq
	CO2	-0.5	tCO2-eq
	GWP subtotal	2.9	tCO2-eq
N2O			
	N20 direct	1	tCO2-eq
	N20 indirect	0	tCO2-eq
	GWP subtotal	1	tCO2-eq
Activity			
	GWP subtotal	0.0	tCO2-eq
Product			
	GWP subtotal	-4.4	tCO2-eq
TOTAL			
	GWP total	-0.4	tCO2-eq

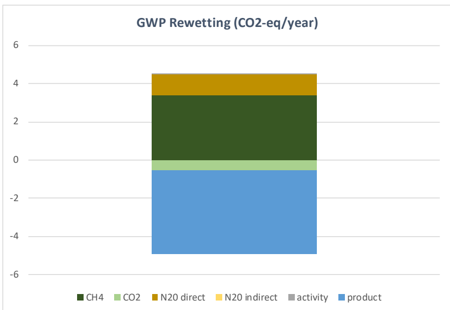


Figure 7 Calculated emissions from land, from fertilizers, grazing animals and crop residues, from fossil fuel use, and – only for the rewetting scenario – savings from product use. Numerical output is on the left and the right shows a graphical representation of the same numbers.

These two panes show the calculation results, first for the baseline (business as usual) scenario, and next for the rewetting scenario.

GEST shows the carbon flows according to the GEST, for the entire site. It reports the CO_2 and the CH_4-flows expressed in CO_2-equivalents. Positive values indicate emissions, i.e. carbon flows from the soil to the air. Negative values indicate immisions, i.e. carbon flows from the air to the soil, which in is carbon sequestration.

N2O shows the calculated flows of N_2O, divided into direct and indirect flows, for the entire site. Direct N_2O emission results from breakdown of nitrogen-containing biomass in the site. Indirect N_2O emission results from nitrogen leaking from the site, via water or the air, which gives rise to N_2O-emissions elsewhere.

Activity shows the GHG emissions resulting from fossil fuel use, for the entire site.

Product shows the GHG emission reduction eligible for payment schemes that results from use of the harvested crop for biobased applications, for the entire site. Emission reductions can only be claimed if the biomass is used for long rotation products, such as building materials, or to replace fossil fuels. If the application is eligible for emission reduction payments, all the carbon in the biomass is transformed to CO_2-equivalents.

The graphical output shows all the numerical output per category in one graph. Different colours show different types of emissions. The axes scale automatically, therefore direct comparison of the height of the different coloured bars is not possible.

The example in Figure 7 shows that in the drained state the site's emissions were dominated by CO_2-emission, with a total flux of 11.2 ton CO_2-eq/yr. Rewetting and shifting to Typha culture decreased the CO_2-flux to a negative value, showing that CO_2-uptake by the plants is larger than CO_2-emission from the soil. However, rewetting has increased CH_4-emissions from 0 to 3.4 ton CO_2-equivalents. This limits the GHG-benefit of rewetting, but still the carbon flows from the soil have been reduced from a total of 9.7 tCO_2-eq. to a total of 2.9 tCO_2-eq. Effect of changes in land management are very small. The biomass harvested is used to produce building materials, specifically for blow-in insulation. This is expected to remain in the building for at least 25 years, therefore it is treated as carbon storage. The graph shows savings due to product use equal the total emissions from land management. With negative emission of CO_2 from the soil, the total GHG-balance of this site has become negative. This means rewetting has changed the site from a GHG source to a GHG sink.

4.3 Carbon savings

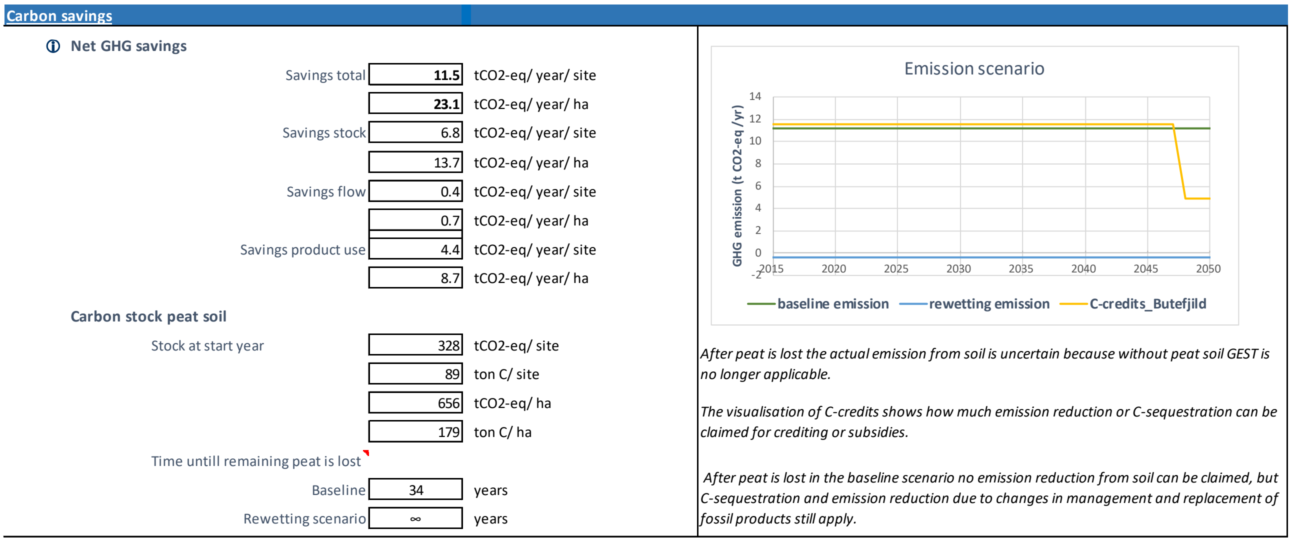


Figure 8. The Carbon savings output pane shows the net effect of the project. The left side shows several key numbers. The graph shows how emissions and creditable emissions develop over time, for both the baseline scenario and the rewetting scenario.

The Carbon savings pane show the net results of the rewetting project[5]. It has a section listing the net GHG-savings, a section showing what happens to the carbon in the soil. It has a graphical output that compares the net emissions of the baseline scenario and the rewetting scenario, and shows how much emission saving is eligible for payments and how this develops over time.

The Net GHG savings section is separated into

- Savings total: this is the total reduction of GHG-emission due to rewetting, expressed in tCO_2-eq. The numbers are given for the entire site, and as an average per ha;
- Savings stock: this is the reduction of GHG-emission from the soil. This is referred to as stock, because the total amount of carbon in the soil is the stock from which carbon flows to the air are fed. The numbers are given for the entire site, and as an average per ha;
- Savings flow: this is the emission reduction from turnover of nitrogen inputs (fertilizers, livestock, stubble) and from fossil fuel use. The numbers are given for the entire site, and as an average per ha;
- Savings product use: this is the reduction of carbon emissions due to the application of the biomass harvested. The numbers are given for the entire site, and as an average per ha.

The Carbon stock peat soil section is separated into

- The stock at start year: this shows how much carbon is in the peat soil at the start of rewetting. This is the maximum amount of carbon reduction that can be claimed for payment schemes. The numbers are given as ton C and as ton CO_2-eq., and for the entire site and as an average per ha.
- The Time until peat is lost: this shows how many years it will take for the peat to disappear in the baseline scenario and in the rewetting scenario. Carbon flows from the soil originate from the carbon stored in the peat (i.e. the stock), so net emission of carbon slowly eats up the peat;
  - Baseline shows the expected remaining lifetime of the peat layer without rewetting. In this example a 30 cm layer of peat is estimated to disappear over 34 years;
  - Rewetting scenario shows the expected lifetime of the peat layer with rewetting. In this example the expected lifetime is ∞, or infinite. This shows that the GEST chosen for the situation after rewetting has net carbon sequestration: it locks more carbon in the soil than is emitted to the air. This means that new peat is being formed, even though the net GHG emission from soil is 2.9 tCO_2-eq. after rewetting (Figure 7 – GEST). This results from the high Global Warming Potential of CH_4.

The graphical output shows how the net emissions develop in the baseline scenario and in the rewetting scenario, and how the emission savings which are eligible for payment develop over time. The timeline extends to 2050 because the current policy goal is to be carbon neutral by 2050. That means C-crediting systems run up to 2050, as the additionality criterion prohibits issuing of C-credits after the existing policies have changed society to generate no net emissions. See Appendix B for more details. Because in the baseline scenario all the peat will be lost after 34 years, emission reductions from the soil are no longer eligible for payment after 34 years. After 2048 only the flow savings, savings from product use, and net carbon accumulation in the soil (peat build up) are still eligible for payment.

[5] Note that Figure 8 was generated with a more shallow peat layer than that shown in Figure 1.

5 Literature cited

Couwenberg, J., Reichelt, K. F., & Jurasinski, G. (in prep.). Vegetation as a proxy for greenhouse gas emissions from peatlands: an update.

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Appendix A. The GEST system

The GEST system was developed by Couwenberg et al. (2011), and was subsequently extended with more types and data (Couwenberg et al. n.d.; Reichelt 2015). Table A-2 below shows the Greenhouse gas Emission Site Types and associated soil moisture classes from the extended version. This is the version used by the Site Emission Tool. When the user is unsure which GEST to choose in the input tab, look up the full moisture class in Table A-1 and use this to select the best matching GEST in Table A-2.

Table A-1. Soil moisture classes used in the GEST-system (source: Koska et al. 2001[6]). Soil moisture classes and water tables are characterized by WLw (long termed, median water table in Oct - Mar), WLd (long termed, median water table in Apr - Sep) and WD (deficit of water supply). The dry types (2- and lower) are characterized by the water shortage plants experience during the growing season. The SET only requires the user to specify the median summer groundwater level, this is WLd.

Soil moisture class		Water tables in relation to surface (+ above, - below) WLw	WLd
7+	Upper sublitoral	+250 to +140 cm	+250 to +140 cm
6+	Flooded (lower eulittoral)	+150 to +10 cm	+140 to 0 cm
5+	Wet (upper eulittoral)	+10 to -5 cm	0 to -10 cm
4+	Semi wet (very moist)	-5 to -15 cm	-10 to -20 cm
3+	Moist	-15 to -35 cm	-20 to -45 cm
2+	Moderate moist	-35 to -70 cm	-45 to -85 cm
2-	Moderate dry	< 60 l / m^2	
3-	Dry	60 – 100 l / m^2	
4-	Very dry	100 – 140 l / m^2	

Table A-2. Overview of the GESTypes and associated groundwater levels. Seasonal fluctuations of moisture are indicated by a combination of different moisture classes (e.g. 5+/4+ reflects a WLw of 5+ and a WLd of 4+). Strongly fluctuating moisture is indicated by a tilde (e.g. 3~ reflects a WLw in the range of 4+ and a WLd in the range of 2+).

Nr.	GESType	Soil Moisture Classes
	Grasslands	
G1	Dry to moderately moist grassland	(2~), 2+, 2-
G2	Moist grassland	3+, 3+/2+
G3	Moist to very moist grassland	4+/3+
G3f	Periodically flooded grasslands	4~, 3~
G3s	Moist to very moist grassland with shunt species	4+/3+, 3~, (3+, 3+/2+)
G3m	Moist to very moist acidic *Molinia* meadows	4+/3+

[6] Koska, I, Succow, M, Clausnitzer, U., Timmermann, T., Roth, S. (2001): *Vegetationskundliche Kennzeichnung von Mooren (topische Betrachtung)*. In: Succow, M., Joosten, H. (eds.): *Landschaftsökologische Moorkunde.* Schweizerbarth, Stuttgart. Pp. 112 – 184.

Nr.	GESType	Soil Moisture Classes
G4	Very moist grassland	4+, 4~
G4s	Very moist grassland with shunt species	4+
G5	Wet grassland	5+/4+
G5s	Wet grassland with shunt species	5+, 5+/4+, (4~)
	Croplands	
A1	Dry to moderately moist arable land	2+, 2-
A2	Moist arable land	3+, 3+/2+
	Unmanaged	
U1	Moist bare peat	3~, 3+
U2	Moist bog heath	3+
U3	Moist Reeds	3+, (3~)
U6	Very moist bog heath	(5+/4+), 4+
U7	Very moist forbs and sedges	(5+/4+), 4+, (4+/3+)
U8	Very moist *Sphagnum* lawn	(5+/4+), 4+
U9	Very moist tall sedges	(5+/4+), 4~, 4+, (4+/3+)
U10	Wet bare peat	5+/4+
U11	Wet meadows and forbs	5+
U12	Wet small sedges with mosses	5+ (4+)
U13	Wet sphagnum lawn	5+, (5+/4+)
U14	Wet tall reeds	(5~), 5+, (5+/4+)
U15	Wet tall sedges	5~, 5+, (5+/4+)
U16	Wet bog heath	6+/5+, 5+, (5+/4+)
U17	Very wet tall sedges and Typha	6+, 6+/5+
U18	Very wet *Phragmites* reeds	6+, (6+/5+, 5~)
U19	Wet to very wet *Sphagnum* hollows	6+, (5+)
U20	Flooded tall reeds (> 20 cm above surface)	6+
	Special GESTs	
S1	Dry to moderately moist grassland on peaty soils (Anmoor)	2-, 2+/2-, 2+
S2	Dry to moderately moist arable land on peaty soils(Anmoor)	2+, 2-
S3	Cropland (2+) flooded in summer (wet year)	3+
S4	Grassland (2+/3+) flooded in summer (wet year)	(5+), 5+/4+, (4+)
S5	Simulated harvest (Paludiculture)	(5+), 5+/4+
S6	Wet tall reeds (dry year)	(5+/4+), 4~, 4+
S8	Very wet reeds with lateral import of organic matter	6+, 6+/5+, (5~, 5+)
S9	Ditches in low intensity grassland	6+

Appendix B. GHG assessment for land management

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1 Introduction

This document gives guidelines for monitoring greenhouse gas (GHG) emissions from managed peatlands. In contrast to unmanaged peatlands, managed peatlands have vegetation that is planted and cultivated. Therefore using only plant species and vegetation as an indicator of site conditions is less reliable in managed peatlands than it is in unmanaged peatlands. Furthermore, in managed peatlands the nitrogen balance is affected by fertilization, which leads to nitrous oxide (N2O) emissions. For unmanaged peatlands nitrous oxide emissions are negligible. The GEST- method (see below and the appendix) does not take nitrous oxide emission into account, but is a good approach to determine CO2 emissions. For managed peatlands we add an estimate of N2O emissions, which we term a GEST+ approach.

Before we go in depth in the monitoring scheme for managed peatlands, some basic background information is given to comprehend the reasoning behind the monitoring scheme.

1.1 Delimitation

The guidelines in this document are not suited for:

Unmanaged peatlands

Peatland managed for peat extraction/harvesting of peat (however, peatlands for sphagnum/paludiculture are included)

Saline peatlands

Constructed peat-/wetlands for wastewater treatment

Permanently flooded peatlands

2 Background

2.1 Carbon in peatlands

Wetlands (peatlands and other lands with organic and wet soils) are crucial in maintaining the Earth's carbon balance as they contain soils with high organic carbon content. Although peatlands only occupy 3% of the land area of the world, they contain 500 - 700 gigatonnes of carbon in their peat. This is twice the total amount of carbon in the biomass of all the world's tropical rainforests (Paige & Baird 2016). The enormous soil carbon stock is the most important characteristic of peatlands. Consequently, peatlands are the most space-effective carbon store of all terrestrial ecosystems. In the boreal zone, peatlands contain on average seven times more

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carbon than other ecosystems.

Peat is preserved by water saturation. As long as peatlands are water logged, the carbon remains stored virtually forever. This carbon store grows slowly but steadily by the addition of fresh plant material, which is converted into peat. In this way, thick layers of peat are deposited over time.

2.2 Effects of human activities

Human activities on peatlands (e.g. drainage, agriculture, forestry, peat extraction, aquaculture) and their effects (e.g. oxidation of soil organic matter) significantly affect the carbon and nitrogen balance and, thus, the GHG emissions and nutrient removal from these lands. The actual magnitude of human-induced emissions and nutrient removal from peatlands depends on numerous variables, including soil and peat type, type of land use of land use conversion, peatland size, management practice, vegetation composition, water table depth, growing season length, salinity, precipitation, and temperature.

2.3 GHG effects of draining

Draining peatlands lowers the water table and increases the oxygen content of the soil, and therefore increasing carbon dioxide (CO2) emissions. Methane (CH4) emissions from drained peatlands are generally negligible because the soil carbon is then preferentially oxidized to CO2. However, methanogenesis (the forming of methane) may take place in drainage ditches with a higher water table causing significant emissions of CH4 to the atmosphere. Drained peatlands can also emit significant amounts of N2O from nitrogen in the organic matter in the soil, or from nitrogen added by fertilization. Losses of particulate and dissolved organic carbon in drainage waters from peatlands can also be significant. From a GHG perspective this is important, as this is a potential source of CH4 emissions.

2.4 GHG effects of rewetting

Rewetting peatlands raises the water table again, decreases CO_2 emissions, and rapidly decreases N_2O emissions to almost zero. But rewetting increases CH_4 emissions compared to the drained state, as the oxygen level in the soil drops and methanogenesis starts again. Rewetting can also restore peatlands to a state where net CO_2 emissions are greatly reduced or even become negative, causing peatlands to function as a net remover of greenhouse gases from the atmosphere.

2.5 Agricultural management/use of peatlands

Change in peatland management can have both direct and indirect effects on GHG emissions. For instance, increasing the water table can reduce crop production, or it can reduce the amount of livestock can be fed off the peatland area. This reduces agricultural production.

If agricultural production is reduced because the peat area is rewetted for CO_2 emission reduction or storage, extra agricultural production elsewhere may be required to keep up total agricultural production. This can lead to conversion of unused land to agricultural land, or it can lead to increased production on land that is already used for agriculture. Conversion to agricultural land can lead to drainage of peatlands (outside the rewetted area), leading to GHG emissions. If agricultural intensification takes place on peat soil by further lowering groundwater levels GHG emissions may increase. If rewetting leads to changes in GHG emissions elsewhere (through land use change or land use intensification) this should be corrected for in the calculation of the CO_2 emission reduction through the rewetting project.

For livestock, the starting point in most countries is that farmers will keep their original number of livestock after rewetting and possibly import roughage from elsewhere to substitute reduced feed production. If this happens there is no impact on emissions from livestock. However, there will be extra CO_2 emission due to the supply of roughage, which may offset the CO_2 reduction achieved by rewetting. If the amount of livestock is reduced, this will reduce total livestock emissions of the project.

A wetter peatland has a different management than a conventional deeply drained area. At a higher water table in spring and autumn, a farmer can usually not access the land. It is also assumed that crop production is lower so less mowing is needed. This reduces CO_2 emissions from agricultural machinery. On the other hand, during the months that a farmer can access the land management may be intensified.

3 Guidelines for the generation of credits for the carbon market

When monitoring GHG emissions for carbon credits it is important to understand some basic guidelines of voluntary carbon markets. MoorFutures has given an extensive overview of this, so most of this paragraph is adapted from Joosten et al. 2015[9].

Guidelines or criteria for credits on the voluntary carbon market were developed to ensure that projects indeed achieve their planned reduction of GHG emissions in a verifiable manner (quality assurance). The most important criteria are:

- Additionality
- Measurability
- Verifiability
- Conservativeness
- Reliability
- Sustainability
- Permanence

In light of these criteria, consideration must be given to:

- Reference scenario (baseline)
- Project period
- Leakage

A standard (e.g. VCS Standard 3.7, June 2017) defines all the specific requirements for developing projects and methodologies, as well as for the validation, monitoring and verification of projects. A methodology encompasses a set of methods and rules for measuring, reporting and verifying (MRV) the effects and outcomes of the project. Next, a concrete project is presented in a Project Description (PD for VCS projects; Project Design Document, PDD for CDM/JI and CCB projects). Such a document specifies the actions undertaken for the project and a monitoring plan for a defined project area. GHG emission reductions are assessed against a baseline scenario, i.e. continuation of the situation before the project is carried out. A PD (or PDD) is used for project validation and provides the basis for the issuing of credits generated by a project.

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[9] Joosten, H., K. Brust, J. Couwenberg, A. Gerner, B. Holsten, Th. Permien, A. Schäfer, F. Tanneberger, M. Trepel & A. Wahren (2015). MoorFutures. Integration of additional ecosystem services (including biodiversity) into carbon credits – standard, methodology and transferability to other regions. BfN-Skripten 407, Federal Agency for Nature Conservation, Bonn.

4 GHG accounting methodologies

4.1 Attributional vs consequential Life Cycle Assessment

GHG accounting describes how to inventorize and audit greenhouse gas emissions. A large number of different GHG accounting methods have been developed. Given the array of different methods it is not always clear which method(s) are the most appropriate for a given purpose. A helpful distinction between types of method, which has developed specifically within the field of life cycle assessment (LCA), is that between what are called 'attributional' and 'consequential' approaches.

Attributional methods can be broadly defined as inventories of anthropogenic emissions and removals for a given inventory boundary. Consequential methods aim to quantify the total change in emissions that occur as a result of a given decision or action. The LCA literature suggests that consequential methods are more appropriate for decision making on mitigation actions. The reason for this is that they capture the total consequences of the decision at hand, while empirical studies show that basing decisions on attributional LCA can result in mitigation actions that unintentionally increase rather than decrease emissions.

For CO_2 monitoring of land management the consequential approach is preferred. The consequential approach includes so called leakage effects (see also appendix 1 'leakage effects'). The effects of leakage on GHG-emissions are determined and the GHG accounting is corrected accordingly.

4.2 Determining the baseline

To determine the relative GHG impact of a change in peat management, the GHG-effect of the change needs to be compared to a no-change baseline. This baseline can either be based upon the current situation or on a reference situation. Preferably the current situation (i.e. the situation before the start of the project) is monitored and translated to a baseline scenario (see also the paragraph 'Reference' in the appendix). The baseline scenario describes what the future development of the area would be if the project were not carried out, for the project crediting period. The baseline levels are then used to compare with carbon emissions generated from changes by the project due to change in peatland management, i.e. drainage, rewetting, extraction, and restoration.

4.3 Setting system boundaries

The system or project boundaries determine which processes or emissions are included in the GHG accounting. System boundaries are generally specified for various dimensions:

- the geographical area
- boundaries between the technological system and nature
- production of capital goods
- time horizon

4.4 The geographical area

A (carbon credit) project must somehow be geographically restricted, this is the geographical area. It is proposed to restrict the geographical area to the agricultural or natural area in which peatland oxidation is reduced (i.e. the water level is raised).

4.4.1 Boundary between the technological system and nature

This boundary makes a distinction between natural occurring emissions (sometimes called background emissions) and human induced emission. For peatland management, emissions from soils (peatland oxidation) and above soil activity are included. For instance, the harvest should be included as well as the activities needed to produce the harvest, such as ploughing, planting, fertilizing and use of pesticides. For flowing resources, e.g. running water, the activities (i.e. pumping) needed to bring the resources into the geographical area should be included.

The emissions of CO_2, N_2O and CH_4 are included. In the calculation, all emissions of greenhouse gases are discounted in the unit of ton CO_2 equivalents (GWP100) per hectare per year.

4.4.2 Production of capital goods

Production of capital goods (e.g. machines, buildings) can potentially contribute significantly (>5% of total GHG) to the total emissions. Especially when investments are clearly and significantly different in the former situation and/or compared alternatives. However due to lack of precise data and effort required, production of capital goods is not included in the C-Connects methodology.

4.4.3 Time horizon

The time horizon is the length of time over which a project runs. Land Use and Land Cover Change (LULUC) projects have a duration of at least 10 years and preferably longer, up to 30-50 years.