German Environment Agency

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Approaches to measure greenhouse gas emissions from peatlands

1 Greenhouse gas emissions from peatlands

1.1 Relevance

Near-natural peatlands are ecosystems sequestering more carbon than they release. They also contribute to biodiversity preservation and the landscape water balance regulation (Joosten et al., 2012). Germany's peatlands have largely lost these functions, as they have been drained since the 18th century due to a growing demand for food and energy (Jeschke & Joosten, 2003).

From a climate mitigation perspective, drainage is highly problematic because it leads to the depletion of carbon that has been accumulated over thousands of years in the form of peat. It turns peatlands from carbon sinks into sources of greenhouse gases (GHG). In 2022, peatlands in Germany were responsible for approximately 7% of the country's GHG emissions (UBA, 2024a).

Preserving carbon stocks in peatlands is therefore of great importance for achieving national and international climate targets. Raising the water level to surface level is the only viable measure that can be implemented on the required scale. This process is called rewetting. The cost of rewetting peatlands is high (Wichmann et al., 2022). However, even simple calculations show that rewetting the vast majority of agricultural peatlands is economically beneficial (Grethe et al., 2021).

Rewetting can be financed either by the public sector or by private actors. In both cases, it is necessary to estimate the expected emission reductions as accurately as possible. This justifies public funding of climate protection measures in peatlands and enables private actors to transparently communicate their climate protection commitment.

Depending on the purpose, different approaches are used to assess GHG emissions from peatlands and to estimate the emission reduction potential, which are compared below.

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1.2 Processes of emission and sequestration of greenhouse gases

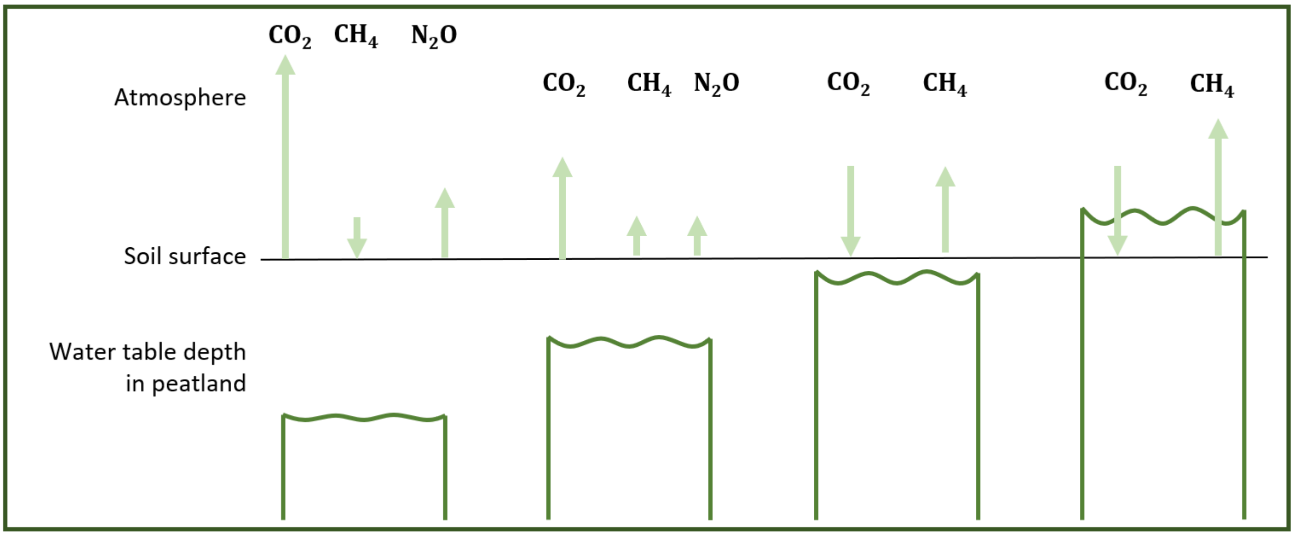
It is technically possible to measure the GHG emissions of a peatland directly, like those of a factory or a vehicle. However, as direct measurements are expensive, indicators such as certain site factors and land use activities are used to record GHG emissions from peatlands over a wide area. Their relationship to the emissions is determined in advance through targeted research.

Water table depth has been identified as a key site factor influencing a peatland's greenhouse gas emissions (Evans et al., 2021; Tiemeyer et al., 2020). The water table depth is the distance between the water saturated area (water table) of the soil and the soil surface. Oxygen is available to microorganisms at this depth. This enables microbial decomposition of organic matter and the release of the greenhouse gases CO_2 and nitrous oxide (N_2O). The depth of the water table, and therefore the size of the oxygenated zone of a soil, is directly related to the depth of drainage. The deeper a soil is drained, the larger the oxygen-filled zone becomes, and the higher the CO_2 and N_2O emissions are. Conversely, in the case of complete water saturation of the soil, i.e., in the absence of oxygen, specialized microorganisms release methane (CH_4).

As well as emitting greenhouse gases, peatlands remove CO_2 from the atmosphere through photosynthesis as plants grow. However, the vast majority of the carbon bound in the growing biomass is – as in other ecosystems – rapidly decomposed and oxidized to CO_2, even in fully waterlogged peatlands. Only a fraction of the biomass (~10% of net annual production) remains as peat in living peatlands in the long term due to water saturation and oxygen exclusion.

Figure 1 shows the relationship between net GHG emissions and the water table depth. When the water table is close to the soil surface, long-term carbon sequestration (peat formation) exceeds microbial carbon decomposition, thereby overcompensating for the increase in CH4 emissions, at least in the medium and long term (Günther et al., 2020). In addition to water table depth, there are other factors that influence the level of GHG emissions from peatlands, such as temperature, nutrient availability and acidity. These are not discussed further here.

Figure 1: Relationship between net greenhouse gas emissions and water table depth



Annotation: Green boxes represent the water-saturated zone of the soil. The length of the arrows symbolizes the magnitude of net emissions or sequestration of the respective greenhouse gas.

Source: own illustration.

1.3 Assessment of site characteristics and land use activities

National and international datasets showing the distribution of peatlands, or the predominant land use and land cover can be used to map site characteristics over large areas to indicate GHG fluxes in peatlands. The recording of land cover, in particular, is becoming increasingly accurate thanks to the continuous improvement of remote sensing and automated methods for analyzing satellite images (Thünen Earth Observation, 2023).

Water table depth or soil properties such as nutrient content are less accurately measured by remote sensing. On-site assessments are carried out to determine these site factors, particularly in small areas. To estimate GHG emissions over a large area, data collected at sampling points must be extrapolated. This can be done by dividing the area into homogeneous sub-areas, for example by vegetation, which are assumed to have the same site conditions.

In addition, spontaneous vegetation (in semi-natural or extensively farmed peatlands) can be a direct indicator of long-term site conditions (Ellenberg et al., 2010; Koska et al., 2001). This is because each species only occurs under certain site conditions. Individual site characteristics can be assessed most accurately when all species occurring in an area are considered together. If a species occurs alone, i.e. without competition, it can often cover a wide range of site conditions, but if it has to compete with other species, the range is much narrower („ecological amplitude", Kotowski et al., 1998).

1.4 Estimation of greenhouse gas emissions

There are two ways of estimating GHG emissions based on recorded site characteristics and land use activities:

- A (homogeneous) area is assigned to an **emission class** with a certain spectrum of site characteristics, which represents a fixed quantity of emissions per unit area and year (emission factor) for each GHG (CO_2, CH_4, N_2O).
- Alternatively, emission factors can be calculated seamlessly for each individual site using **statistical equations or process-based models**. In this case, selected measured site characteristics are used as input parameters to determine the area specific emission factors using the equations or models.

Once the emission factors have been determined, they are multiplied by the size of a subarea. To calculate total emissions, CH_4 and N_2O emissions are converted into carbon dioxide equivalents (CO_2eq). The global warming potential (GWP) indicates how many times stronger a non-CO_2 GHG molecule affects global warming compared to a CO_2 molecule. By standard convention, the impact over 100 years is used, referred to as the 100-year global warming potential (GWP_{100}) (GWP_{100}: CH_4 = 28, N_2O = 265, Myhre et al., 2013).

2 Comparative analysis of approaches for assessing greenhouse gas emissions from peatlands

2.1 Field of application and purpose

GHG emissions from peatlands are recorded in different contexts and for different purposes. Here, three common types of GHG measurement approaches are compared.

- At the national level, GHG emissions are recorded in the **national GHG inventory** reports under the Framework Convention on Climate Change. These document and report progress towards national GHG emission reduction targets to the international community (UNFCCC, 1997). The guidelines of the IPCC (2006, 2014), which apply to all 195 reporting countries, are also used for this purpose in Germany (UBA, 2024b).
- **Peatland climate protection projects** are designed to reduce greenhouse gas emissions. A transparent quantification of the achieved emission reductions is essential for such projects, as it provides the necessary basis for raising public and private funds. Among the many standards for peatland carbon offset projects, the German regional standards „MoorFutures“[1] and „Moorbenefits 2.0“[2], the „Peatland Carbon Code“ (PCC)[3] widely used in the UK and the VM0036 methodology of the international „Verified Carbon Standard“ (VCS)[4] are discussed here as examples.
- **Companies** report their GHG emissions, among other reasons, to publicly communicate their climate change efforts and to meet legal obligations. The Greenhouse Gas Protocol (GHG Protocol)[5] is the most widely used private, transnational standard for GHG reporting by companies and, increasingly, by public entities. GHG emissions from peatlands can already be reported under the GHG Protocol. A detailed reporting guideline is being developed (WRI & WBCSD, 2022).

The different purposes of the GHG reporting approaches result in **different time perspectives.** Both national and corporate GHG reporting compare current emission levels with those of the past and record them in regularly published reports. In contrast, project-based reporting is forward-looking. It compares the GHG emissions planned or realized in the climate project with those that would have occurred in a business-as-usual scenario.

To determine GHG emission reductions in corporate and national GHG reporting, the emissions of a current period are compared with those of a previous period. In contrast, for peatland carbon offset projects, two forward-looking scenarios are used to estimate GHG emission reductions. In the reference scenario, GHG emissions are projected without the implementation of peatland carbon offset measures. In the project scenario, GHG emissions are estimated with the implementation of measures. The GHG emission reductions are then quantified by comparing the two scenarios.

Both GHG reporting and the GHG Protocol are **applied globally**. In contrast, the project standards analyzed, and their methodologies are limited to a climate zone (VCS methodology VM0036), a country (PCC) or a region within a country (MoorFutures, Moorbenefits 2.0).

[1] https://www.moorfutures.de/

[2] https://www.hswt.de/forschung/projekt/1795-moorbenefits-2-0

[3] https://www.iucn-uk-peatlandprogramme.org/peatland-code-0

[4] https://verra.org/methodologies/vm0036-methodology-for-rewetting-drained-temperate-peatlands-v1-0/

[5] https://ghgprotocol.org/

The scope of the reports also differs. While the national GHG inventory covers the entire peatland area of a country, corporate GHG reporting only covers the areas directly and indirectly affected by the reporting company. Peatland climate protection projects cover specifically defined project areas, which can vary in size.

If the same area is analyzed by two GHG reporting approaches, the area covered may differ due to **different peatland definitions**. For national GHG reporting, the IPCC has adapted the FAO definition of organic soils (IPCC, 2006, Annex 3A.5). This adaptation is also used in the standards of the GHG Protocol. In addition, there are numerous national definitions of peatland soils that, according to the IPCC (2006), can also be used to delimit the peatland areas analyzed. The standards for peatland climate protection projects do not refer to a specific peatland definition.

2.2 Accounting methods

Each GHG assessment approach has its own set of rules that define the **methodological requirements** for assessing GHG emissions from peatlands. The degree of differentiation of the requirements varies according to the scope and purpose of each approach.

- The GHG Protocol provides a very broadly applicable standard for corporate GHG reporting. The methodological requirements for reporting GHG emissions from peatlands are therefore formulated in general terms. Accuracy will depend on the complexity of the value chain under consideration, the information available and the intention of the company.
- In national GHG reporting, the requirements for methodological accuracy depend on the relevance of GHG emissions from peatlands in the overall GHG inventory - the higher the relevance, the higher the requirements.
- The peatland climate protection project standards define the most accurate GHG measurement method to be used. This includes both the defined requirements for data collection, which is mainly done in the field, and the emission classes and statistical models to be used.

The estimation of GHG emissions from a peatland site is based on **site characteristics and land use activities** in all GHG reporting approaches analyzed. Both the peatland carbon offset project standards and the national GHG reporting standards specify what information needs to be collected, and how emissions are estimated on this basis. Only the GHG Protocol is not specific about which site characteristics and activity data should be included and how it should be evaluated.

- The estimation of GHG emissions is based under both, the minimum standard formulated by the IPCC (2006, 2014) and the German configuration of national GHG reporting on basic land use categories (e.g. arable land, grassland), on the groundwater table depth and the climate zone. While the IPCC minimum standard only distinguishes between deeply and shallowly drained peatlands and provides corresponding emission classes (see Chapter 1.4), the groundwater table depths for German GHG reporting are estimated with precise resolution (100*100 m grid) (Bechtold et al., 2014). The estimated values are used in statistical models to assess CO_2 and CH_4 emissions (Tiemeyer et al., 2020). The estimation of N_2O and DOC (leaching of organic carbon) emissions is based on emission classes.
- The peatland climate protection project standards Moorbenefits 2.0 and PCC also provide statistical models for estimating CO_2 and CH_4 emissions. These are partly specific to land use categories and, in the case of PCC, largely limited to bogs. The only variable (value to be entered into the equation of the respective model) is the depth of the groundwater table depth, as in the German GHG reporting.

- In the peatland climate protection project standard MoorFutures and the VCS methodology VM0036, the estimation of GHG emissions is based on the GEST approach of Couwenberg et al. (2008, 2011). GESTs (Greenhouse Gas Emission Site Types) are emission classes differentiated by the plant communities ('vegetation types') found on a peatland. Other site characteristics (in particular the distance to the groundwater table depth) only need to be recorded to estimate GHG emissions if no vegetation is present, or the existing vegetation is too depleted due to intensive land use.
- The GHG Protocol provides a wide range of options for selecting an appropriate GHG measurement method.

2.3 Conclusion

Drained peatlands account for about 7% of total greenhouse gas (GHG) emissions in Germany. Raising the water table to surface level can preserve the remaining carbon stocks and restore their natural function as carbon sinks. An accurate yet practical estimation of GHG emissions from peatlands is essential for the planning, implementation, and evaluation of peatland conservation measures and for GHG reporting. Different methods can be used for this purpose. The following summarizes conclusions from a comparison of methods for estimating GHG emissions from peatlands:

- **Influence of site characteristics and land use.**
  GHG emissions from peatlands are significantly influenced by site characteristics and land use.
- **Efficient data collection is possible.**
  Precise field surveys are time consuming and costly. Combined approaches, integrating remote sensing with field data collection and indicators such as plant species, can achieve similar accuracy with less effort.
- **Challenge of defining peatland soils.**
  The lack of an internationally standardized definition makes it difficult to compare data and methods. Harmonizing definitions could strengthen cooperation on peatland climate change mitigation.
- **Different objectives – different methodologies.**
  Emissions assessments serve different purposes, such as national greenhouse gas inventory reports, climate change projects or corporate reporting. Different objectives require specific methodologies with results that are not directly comparable.
- **Potential for methodological synergies.**
  Individual methodological elements could be transferred between approaches to improve accuracy or reduce effort.
- **Need for action despite uncertainties.**
  There is scientific consensus that drained peatlands produce high greenhouse gas emissions, which can be significantly reduced by rewetting. Action should not be delayed because of the current lack of highly accurate GHG accounting methods.

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