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The basis of a carbon credits certification for restoration & low carbon farming on peatlands in Northwest Europe

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Abstract

This report outlines the basis and methodology for a carbon crediting scheme that could be applied to peatlands sites in Northwest Europe to facilitate the contracting of payments for ecosystem services through peatland restoration, potentially integrated with low impact "carbon friendly" commercial farming. The aim of this methodology is to unlock new private sector funds through carbon credits for rewetting, restoration, and sustainable management projects through the adoption of complementary farming approaches in drained and degraded peatlands. This report is aimed mainly at policymakers, national or regional authorities, associations or NGOs interested in setting up and certifying credits for peatlands but can also be accessible for potential investors.

At a global level, peatlands store at least 550 Gigatonnes of carbon which corresponds to more than twice the carbon stored in all forests or 75% of all the carbon contained in the atmosphere. When degraded, these peatlands are emitting the stored carbon in the atmosphere. Globally, degraded peatlands emissions of carbon are estimated to account for 6% of all CO_2 emissions from anthropogenic activities *(C-toolbox, 2022)*. Restoration works on degraded peatlands stop these emissions but are costly projects which then restrain or require the modification of the agricultural activities undertaken on the peatland. To make these restoration projects and sustainable peatland farming activities economically viable, external funding is needed. Elsewhere, restoration may be required on non-cultivated land which may encounter fewer barriers but will still require a workable financial model.

This report further outlines the scope of applicable peatlands sites for carbon credits, and current situation for peatlands in Northwest Europe. This methodology also shares references and guidelines needed at each step of a peatland restoration project and/or alternative reduced GHG farming systems funded by carbon credits from the mounting to the certification of the credits. It allows identification of the different checks needed to ensure that the emitted carbon credits are science-based and additional. It provides validation, greenhouse gases and other co-benefits calculations, monitoring and verification methods while also considering their limits. This methodology offers all specifications needed for a verification standard that could be set up a national or regional level. As a report developed by the Carbon Connects partnership on behalf of the Interreg NWE programme, it focuses on references adapted to Northwest European countries (Ireland, UK, France, Belgium, the Netherlands, and Germany).

Summary

Glossary

Wetland: An area where water covers or is present at or near the surface of the soil all year or during a certain period during the year.

Peatland: An area defined by the constitution of its soil that is storing high concentration of dead organic matter. This organic matter originates from the decomposition of different wetland plants (sphagnum, other mosses, typha, cattail…). (Joosten, H. & Clarke, 2002)

Mire: A peatland where peat is actively being formed which mean that the synthesis of organic matter is more important than its degradation due to water saturation. (Joosten, H. & Clarke, 2002)

Bog: A peatland that is raised above the surrounding landscape and that receives water only from precipitation. (Joosten, H. & Clarke, 2002)

Fen: A peatland that is situated in a depression and receives water that has been in contact with mineral bedrock or soil. (Joosten, H. & Clarke, 2002)

Carbon crediting contract: agreement between a project proponent (mostly landowners and farmers) and an investor (mostly companies) which commits the project proponent to the proper implementation of levers that would allow a calculated gain in greenhouse gas reduction (in this case, restoration, and sustainable management of peatland) in exchange for a payment. This contract applies to a specific period and site.

Peatland restoration project: a list of concrete actions implemented by the project proponent that would enable a reduction of greenhouse gases emissions and an overall improvement of the environmental quality of a peatland.

Paludiculture: The CAP defines paludiculture as a productive land use of wet and rewetted peatlands that preserves the peat soil and thereby minimizes CO_2 emissions and subsidence.

Maximum Sustainable Output: A management approach matching natural grass availability to livestock numbers and types, working toward the minimisation and gradual elimination of most off-farm inputs, working with, not against natural cycles and processes.

Introduction on the importance of peatlands

Mismanaged, drained peatlands have massive greenhouse gases emissions – more than the shipping and aviation industries combined – and cost €400 billion in climate damage annually. However, they are often overlooked and underrepresented. Peatlands, a type of wetland, are one of the most valuable ecosystems in Europe for biodiversity, water quality, flood protection and carbon storage. Rewetting peatlands is a key step to reducing CO_2 emissions and mitigating climate change.

Despite only covering 3% of land surface, globally, peatlands contain at least 550 gigatons of carbon - more than twice that stored in all forest biomass and equivalent to 75% of all carbon in the atmosphere. This makes peatlands the world's largest land-based carbon store, despite their relatively small surface coverage. Beyond their vital role in carbon storage, peatlands also provide further crucial ecosystem services. In their natural wet state, they mitigate flooding and drought, reduce the risk of fire, and help ensure clean drinking water. In the UK, 43% of the population receives drinking water sourced from peatlands, with the number climbing to 68% in Ireland. Peatlands are also incredibly important for biodiversity, home to rare birds, throngs of insects, and unusual plants.

I- Description of the type of projects that can be funded

General aim of the methodology

A methodology is required to unlock new private sector funds for restoration projects in drained and degraded peatlands. Restoration projects mainly aim at raising the water table to maintain the peat wet to limit its mineralization which is a great source of atmospheric CO_2. In this methodology, the avoided emissions of carbon dioxide from the peat resulting from restoration can be sold on a voluntary carbon credit market.

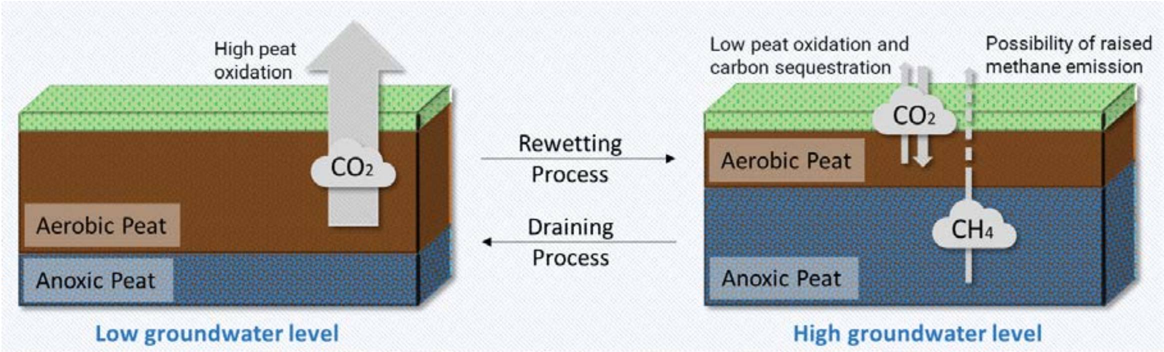


Figure 1: The effect of water level raising on greenhouse gases fluxes

Restoration may be combined with modified agricultural practices. There is also great potential value in the adoption of low input, low cost farming methods, improving soil health and carbon storage capacity, not necessarily associated with ecological restoration projects.

Applicable emission reduction levers

There are therefore two distinct approaches which may be combined.

- The ecological restoration of peatlands to their best possible condition, which may or may not include commercial agriculture.
- The alternative farming approach where land management and farm business plans actively seek to store carbon through improved soil and vegetative health whilst very significantly reducing or eliminating aspects of their own GHG emissions.

Restoration approach

Drain blocking, the filling of ditches, leaky sediment traps or the construction of dams or bunds are the most common ways to mechanically raise water tables and stop erosion of peat, but other techniques can be used to influence hydrology. For example, the cessation of pumping activities on a peatland can also be a simple lever for rewetting in some projects.

Tree cutting can also help to raise the water table as trees are draining the land quite heavily. This is a counter-intuitive lever because tree planting is frequently associated with additional carbon storage. However, it has been stated that in most cases, the peatland will have better overall environmental quality with a mire-specific vegetation that is storing long-term carbon rather than trees. In fact, even though trees store carbon, they will also dry out the peat and cause its mineralisation into CO_2. The scientific evidence suggests that removing plantation forests from peatlands during restoration deliver net reduction in greenhouse gases while also improving water quality and biodiversity. (IUCN UK Committee, 2014)

Another challenge that these rewetting projects face is to restrict the erosion of the peat. The use of covers and revegetation can help but in the most extreme scenario, peatland top layer removal and reprofiling can be used. The reintroduction of native peatland vegetation (Sphagnum implantation) and removal of invasive species (Ludwigia peploides, Reynoutria japonica…) can also enrich and stabilise the biodiversity of the peatland and allow long new term carbon sequestration in the soil.

Alternative Farming Approach: the regenerative farming

The rewetting projects are also heavily influencing the possible economic models on the peatlands. For example, turf cutting is completely banned as it's a practice that heavily deteriorates peatlands and causes indirect greenhouse gas emissions. Some of these new economic models can also allow for further carbon emission reductions that are considered in this methodology:

- The promotion of a more extensive grazing (sometimes with longer flooded periods) perhaps utilising the Maximum Sustainable Output (MSO) concept where livestock numbers and types, and farm operations, are matched to natural grass production, minimising Variable and Fixed costs, concentrating on profitability not production.

- Carbon farming through paludiculture (that can create long term carbon storage materials and substitutes to fossil fuels and fossil peat as growing media)

- The use of fewer inputs on peatland farms (mainly fertilisers, electricity, and fuel).

- The continuation of arable agriculture but under a raised water table may result in a greater area of peatland rewetted compared to paludiculture, since it doesn't require the marked change of the latter but allows the farmer to continue with more traditional crops whilst reducing emissions. But this option results in continued but maybe lower GHG emissions.

Perimeter of applicability

Peat definition:

Peat is defined as sedentary accumulated material consisting of more than 30% of its dry mass composed of incompletely decomposed plant remains and humic substances *(C. Schulz, 2019)*. This definition is not universal so other parameters and numbers can be used depending on the country.

Eligible peatlands:

A minimum depth of peat is needed so that it has not been entirely degraded/mineralised at the end of the carbon crediting contract. This thickness can be easily verified on site with a corer or auger. Different approaches are then possible:

- **Specific approach:** peat carbon content is calculated using on site peat depth and peat carbon concentration measures. No more carbon credits can be claimed than the amount of carbon that is locked in the peat layer at the start of the rewetting project.

- **Generic approach:** a minimum of 50cm of peat can be generally taken for a peatland area to be eligible for carbon crediting. This security margin is notably used in the Peatland Code which limit itself to a relatively homogeneous typology of peatlands. This approach, generally sufficient to ensure no overclaiming of credits, is less time consuming (less calculations and on-site measures needed) but can prevent the applicability of some sites.

Contract duration:

To have a significant and more permanent carbon emission reduction, it's recommended to define a contract duration of 25 to 50years. These are therefore long-term contracts compared to other carbon credits schemes (for example, in the Label Bas Carbone, hedges plantation and sustainable management contracts are 5 years, renewable once).

- **Finding a minimum duration for the contract:** Contracts of less than 10years don't deliver enough permanent emissions reductions setting up a minimum for the contract duration. That's first because the carbon flux impacts become clearer after a few years following the re-adaptation of the vegetation and re-balancing of bio-chemical cycles. That's also because these restoration projects have continuing positive long-term impacts on greenhouse gases emissions which must be valued to enable more competitive peatland carbon credits. Longer contracts also reduce the risks of non-permanence, for example the risk of disruptions to the new hydrological equilibrium following rewetting that can greatly limit the impacts of restoration on carbon fluxes. Longer contracts also mitigates the impact of the methane spike following rewetting and the site preparation emissions on the overall calculation of carbon emission reduction.

- **Finding a maximum duration for the contract:** For contracts longer than 50years, the project shall demonstrate that the carbon store of the peatland site would not have been depleted in the baseline scenario at the end of the contract. Up to 100years contracts can be used but the longer the contract, the greater the risk that the regulatory framework will change during the contract. This could cause some missed opportunities for the landowner/farmer or remove the additionality of its rewetting project before the end of the contract.

- **Contract Deliverables:** Specification of the actions to be taken to store carbon in the soil and of the alternative farm management techniques to be utilised to reduce GHG emissions arising from alternative farm operations.

II- The additionality demonstration

An investment can be classified as additional if it allows a project with positive social or environmental impacts to happen. This additionality is valid if the project wouldn't have been carried out spontaneously without the funding unlocked through the investment. This generally means that there is a lack of incentives (legal, economic…) and/or existing barriers (technical, social…) that make an unfavourable cost-benefit balance for the implementation of this type of projects. Types of projects that happen spontaneously because they are attractive from an economic point of view or regulated cannot be classified as additional even if they have positive social of environmental impacts.

The additionality concept is applicable to peatland restoration and to the alternative farming "GHG friendly" practices, (paludiculture or extensive agriculture) which could be integrated with, or deployed separately to, ecological restoration.

Voluntary carbon credits markets are schemes that unlock:

- New economic incentives for project proponents to carry out projects with positive impacts on the environment through greenhouse gases emission reduction.
- New investments opportunities for the private sector that could allow investors to claim quantified positive impacts on environment like greenhouse gases emission reduction.

As such, carbon credits schemes need to be classified as additional investments. It is therefore necessary to demonstrate that the context is unfavourable to the spontaneous setting up of peatland restoration and sustainable management projects through the following process:

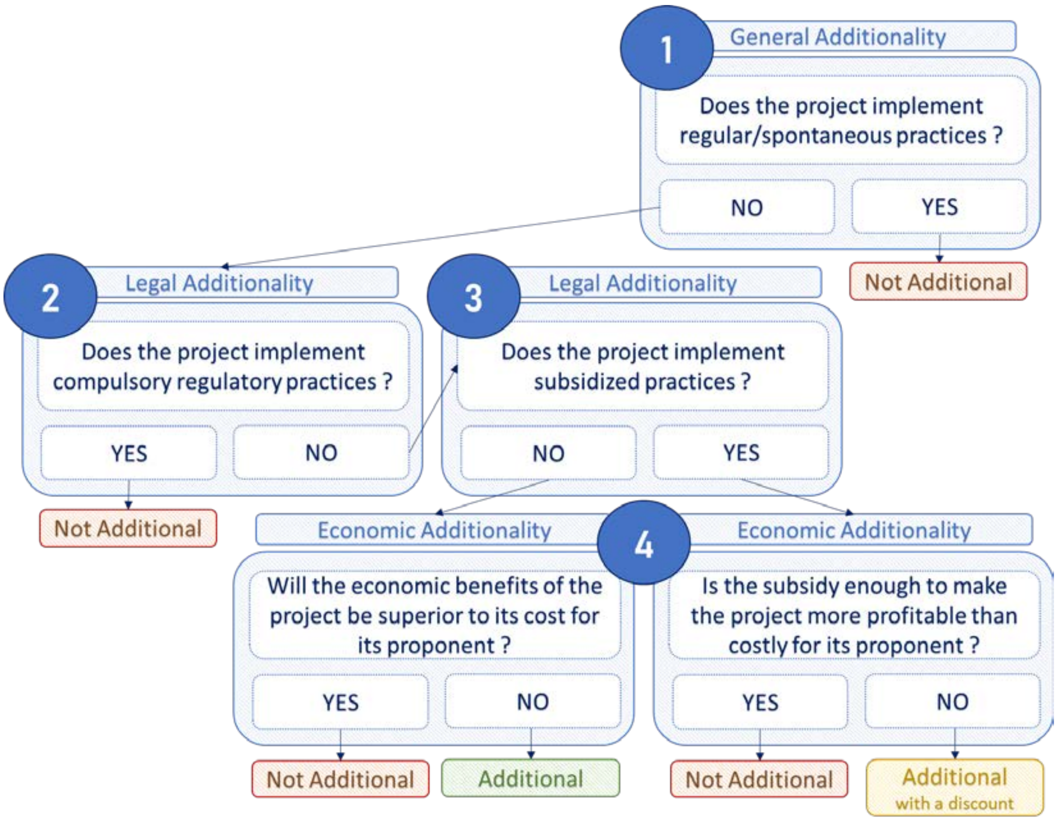


Figure 2: Decision tree to define the additionality of an investment on a project

A) Analysis of usual practices

State of play of peatland degradation

Europe:

A first entry on the additionality demonstration of our peatland rewetting levers is to observe the scarcity of rewetting projects that happen spontaneously compared to the high number of degraded peatlands in Europe. The Greifswald mire centre observed that less than 1% of the degraded peatland of Europe have been rewetted which demonstrates that spontaneous rewetting is a very rare case. The dominance of degraded peatlands is a second argument which shows that without incentives and regulations, territorial actors will tend to degrade the peatlands (mainly for economic reasons).

Europe's peatland landscape is dominated by fens, which is estimated to cover roughly 600,000 km² of its land surface. This is followed by bogs, which are estimated at around 450,00 km² *(Tanneberger et al., 2021)*. In total, 25% of European peatlands are degraded. This number however changes drastically when excluding European Russia from the equation, which then lies at 48% *(Tanneberger et al., 2021)*. These statistics don't include former peatlands from which the peat has already been completely degraded. Thus, it can be stated that the degree of degradation is overall much higher than what these numbers make it out to be.

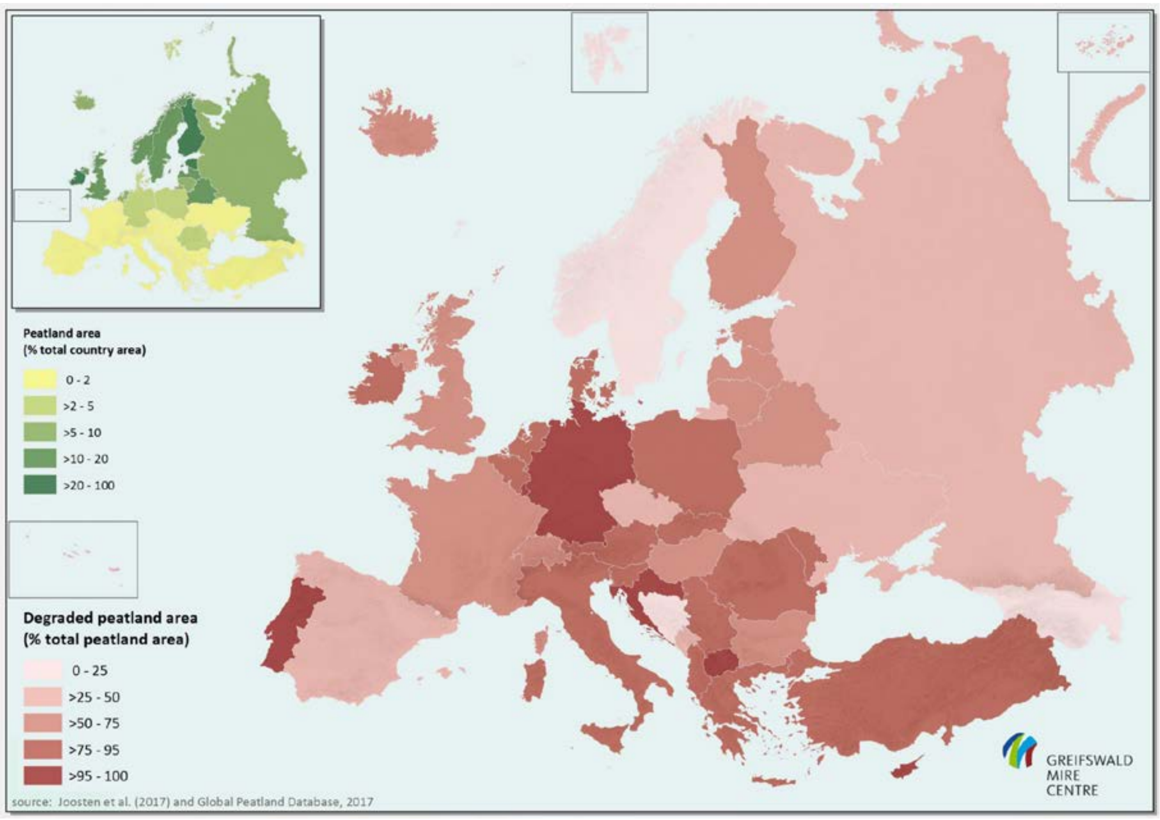


Figure 3: Current degraded peatland area per country in Europe in % of total peatland area (Greifswald Mire Centre, 2015)

Regarding the distribution of degraded peatlands in Europe, some clear disparities in their allocation exist. The degree of degradation increases in southern parts of Europe. Some examples for countries with a small degree of degradation are Andorra, Norway, and Faroe Islands, having less than 20% of their peatlands degraded. At the other end of the spectrum are countries such as Germany, Denmark, and Croatia, which have between 91% and 100% of their peatlands degraded *(Tanneberger et al., 2021)*. This trend is also found when examining the total area percentage of peatlands in European countries. The farther north you are, the higher the percentage of peatlands on the land surface *(Joosten et al., 2017)*.

Northwest Europe:

Northwest Europe countries have been subject to same activities that have led to peatland degradation such as the exploitation of peat for energy and horticulture, drainage for agriculture and forestry... The resulting overall high level of degradation of Northwest Europe creates a substantial of potential sites for restoration highlighting the need to create new sources of funding for these restoration like carbon credits. Here is a focus on the state of some of the Northwest Europe countries participating in the Carbon Connects project:

Table 1: State of the peatlands in Northwest Europe countries

Countries	Peatland coverage	Share of degraded peatland
Germany	3,6%	Very high (95-100%)
Ireland	21%	High (75-95%)
France	0,5%	Medium (50-75%)
The United Kingdoms	11%	Medium (50-75%)
The Netherlands	7,3%	High (75-95%)

Germany:

Originally, over 5% of Germany's land surface was covered in Peatlands. Due to anthropogenic processes, it has been reduced to 3.6% *(Joosten et al., 2017)*. Germany is one of Europe's countries with the highest degradation, having drained over 95% of its peatlands. The vast majority of the drained peatlands are being utilised for agriculture, sitting at around 72% of the land use. Due to climatic circumstances most of the German mires are located in northern Germany *(Joosten et al., 2017)*.

Ireland:

Overall, 21% of Ireland's country area consists of peatlands *(Tanneberger et al., 2017)*. Most of these peatlands are located in the western area of the country, extending from north to south. Ireland's peatland landscape is dominated by bogs, accompanied by a significantly smaller area covered in fens. In 1979, around 56% of bogs in Ireland were recognized as untouched by anthropogenic processes. Nowadays, however, all peatlands have been affected by cutting, fires, grazing, etc.

France:

If most French regions have a climate favourable to house peatlands, there are some major regional disparities both in terms of the surface area and the nature of these environments. As a whole, 0.52% of France's land area is covered in peatlands. The largest areas are found in the montane zones and in the valleys and depressions of the northern half of France. On the other hand, the Mediterranean region has very few peatlands because the climatic conditions are not very favourable to the accumulation of peat. Since the 1945s, the surface area of French peatlands has been halved because of a diversity of anthropogenic causes *(Malone & O'Connell, 2011)*.

The United Kingdom:

There are three main types of peatlands in the UK. These include blanket bogs, raised bogs and fenland. Most of these are situated in the north, 60% of them being in Scotland. 11.07% of the UK's country consists of peatlands *(Tanneberger et al., 2017)*. According to current estimations around 80% of UKs peatlands are in a damaged state or are deteriorating due to anthropogenic actions *(Office for National Statistics, 2019)*.

The Netherlands:

Peatlands make up 7.32 % of the Netherlands country area *(Tanneberger et al., 2017)*. Although peat soils cover less than 10% of dutch agricultural area, they are responsible for more than half of the greenhouse gas emissions from agricultural soils *(Fritz et al., 2014)*. There is no bog or fen in the Netherlands, which hasn't been influenced through anthropogenic processes. Albeit through draining, cutting, burning, farming, or building. The total area of peatlands has been reduced quite drastically throughout the years. A survey revealed that in the years 1960 and 1990 335,642 ha of peat >40cm peat were covering the land. This was accompanied by 191,417 shallow peat soils. This number has shrunken until 2017, where the peatland area was estimated to be at around 273,342 ha *(Joosten et al., 2017)*.

The development of paludiculture

Paludiculture is the active use of permanently wet conditions, adapting the way we look at common agriculture from the necessity to alter land types i.e., drying out land, and instead adapting the way we use the land and adapting agricultural practices to better adhere to the ecosystem requirements. Paludiculture allows for land to maintain a permanently wet condition which is vital to carbon sequestration and the regeneration of peatlands.

Some benefits to Paludiculture are the reduced management costs, it can be an intermediate stage between drained use and natural conservation due to its low impact use, buffer areas which is the use of Paludiculture as a buffer between areas of conservation and areas of normal agricultural practice and natural corridors connecting areas of conservation creating a safe passage for many species.

A full list of plants that could be considered suitable for Paludiculture practices can be found on the Database of Potential Paludiculture Plants (DPPP), however, some of the most common plants and their uses in Europe are listed in the following table *(Greifswald Mire Centre, 2020)*.

Table 2: The different business models of paludiculture (Greifswald Mire Centre, 2020)

	**Alder (*Alnus glutinosa*)** Central Europe, fen, oligo-eutrophic Timber, fuel
	**Cattails (*Typha* sp.)** Central Europe, North America, West Africa, fen, polytrophic Construction material (insulation), solid fuel, fibbers, potting soil, horticulture substrate
	**Common reed (*Phragmites australis*)** Europe, China, fen, polytrophic Construction material (thatching), paper, solid fuel
	***Sphagnum* sp.** Worldwide, bog, oligotrophic Growing substrate, revitalisation
	**Water buffaloes** Europe, Asia Cheese, meat, conservation grazing

Taking an example of a plant commonly used for paludiculture practices, Sphagnum Moss is found in wetlands worldwide and has many benefits including as a growing medium which can be used as an alternative to peat soil which is commonly used by gardeners. Sphagnum is a low impact material which can be grown as a peatland area is being rewetted, thus ensuring that an income stream will continue while rewetting occurs, it is also a vital part of peatland biodiversity.

A second example of the benefits of a plant commonly found in peatlands and wetlands is Typha, more commonly known as Cattails. This plant is an example of the many uses and possibilities that can be found through Paludiculture. Cattails are harvested for use in construction as insolation, they can be pressed into panels and plates, it can also be used for producing disposables from the fibers or making baskets and matts and some parts of the plant can even be harvested for food.

The cultivation of paludiculture crops can also enable more additional carbon credits to be claimed for farmers following rewetting. This is possible in two scenarios. The first is if the products of paludiculture are used as a substitute of fossil products (bioenergy instead of fossil fuel, sphagnum-based substrates for gardening instead of peat-based substrates). The second is if the products of paludiculture have a lifetime longer than 10 years allowing the claim of more carbon storage (building materials from cattails).

In the less than 1% of the total area of degraded peatland in Europe that has been rewetted, only a tiny fraction of these rewetting projects has been accompanied with the implementation of paludiculture. However, paludiculture should be promoted as it offers new revenue sources and carbon emission reductions opportunities for farmers while maintaining a good environmental quality of their land. Paludiculture implementation implies numerous additional investments for the farmer in addition to the cost of the rewetting of the peatland. It remains a rare practice which goes beyond the usual practices and as such, that can be subsidised in the framework of rewetting projects funded by carbon credits.

Extensive livestock farming on wetlands

Extensive livestock farmers are one of the most common managers of many wetlands and peatlands as these areas are not good lands for an easy cultivation of most common crops. In some countries like France, legislation on wetlands restricts or even prohibits any intervention in these environments for carbon, water and biodiversity protection reasons. As such, mowing and grazing remains one of the only business models possible in these areas. *(C. Deniaud, A. Lannuzel, E. Kernéïs, A. Bonis, F. Launay, et al., 2020)*

A study of soil-vegetation relationships carried out in the Haut-Doubs and the Swiss Jura massif *(Rion, 2015)* has shown that the cessation of mowing and grazing is leading to a proliferation of woody plants and a litter accumulation that decrease the aboveground light and consequently increase the release of nutrients. It can therefore be stated that extensive farming activities are helping to keep peatland areas open and as such are responsible for preserving their specific biodiversity, carbon storage and functionality:

- **Extensive livestock farming for a more sustainable carbon storage:** Extensive livestock farming has positive effects on the intensity of waterlogging through its impact on the settlement of the surface layers of the soil as well as on the proliferation of ligneous plants which can have draining effects. These agricultural practices are therefore allowing better moistening of the peat limiting its mineralisation and so reducing the carbon dioxide emissions.

- **Extensive livestock farming for the maintenance of a peatland specific biodiversity:** Peatlands are widely recognised for their high environmental value and most of them are classified in the framework of the Birds and Habitats directives of Natura 2000. A well-managed grazing is necessary for the conservation, diversity, and mosaic distribution of the vegetation. Some more ambitious practices of extensive farming are encouraged by agri-environmental and climatic measures (deferred mowing, reduction of inputs, management of water levels, etc.) as they have positive impacts on the expression of a diversified flora and the reception of birds, amphibians and mammals attached to these environments.

- **The adoption of Maximum Sustainable Output concept: Less can be More:** that is less activity at lower cost can generates more profit, usually requiring very significant business re-structuring at significant cost. The central MSO concept is that a livestock farm is not a conventional business in that the basic means of production, natural grass, is free. The standard economic theory of the firm shows that as fixed costs are spread more widely across rising production levels marginal revenues can rise more quickly than marginal costs, creating larger profits in the hatched area beyond the break-even point.

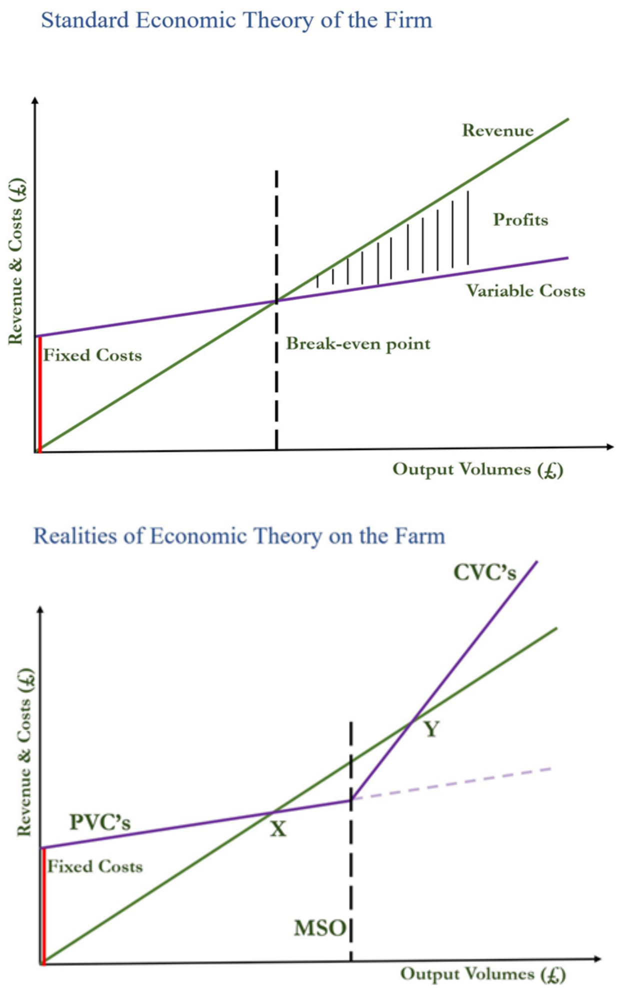


Figure 4: The Maximum Sustainable Output concept

> The availability of "free" grass means that livestock farms are not "standard" businesses. Livestock production beyond the availability of natural grass, the point of Maximum Sustainable Output, means farmers are potentially working harder to lose money because variable costs are "kinked" beyond MSO, rising much more quickly and ahead of marginal revenues. Some costs are fixed, and some variable costs (Productive Variable Costs or PVCs) are unavoidable. Other variable costs incurred to increase livestock production beyond that which can be supported by natural grass, for example artificial fertilisers and hard rations, rise very sharply, producing the "kink" in the variable costs line. These are known as Corrective Variable Costs or CVCs. Reduced production and the avoidance of these costs means more profit for less effort, known as the "less is more" approach.

However, extensive grazing has been in decline over the last 20 years and especially in marshland areas where many farmers are retiring without finding a new owner. In 2016, average livestock density in the EU reached 0.8 livestock units per hectare (LU/ha) of agricultural area. Northwest Europe countries have an average livestock density higher than this EU average. A low livestock density is between 0.6 LU/ha and 1 LU/ha. However, even lower livestock densities are common in extensive livestock production.

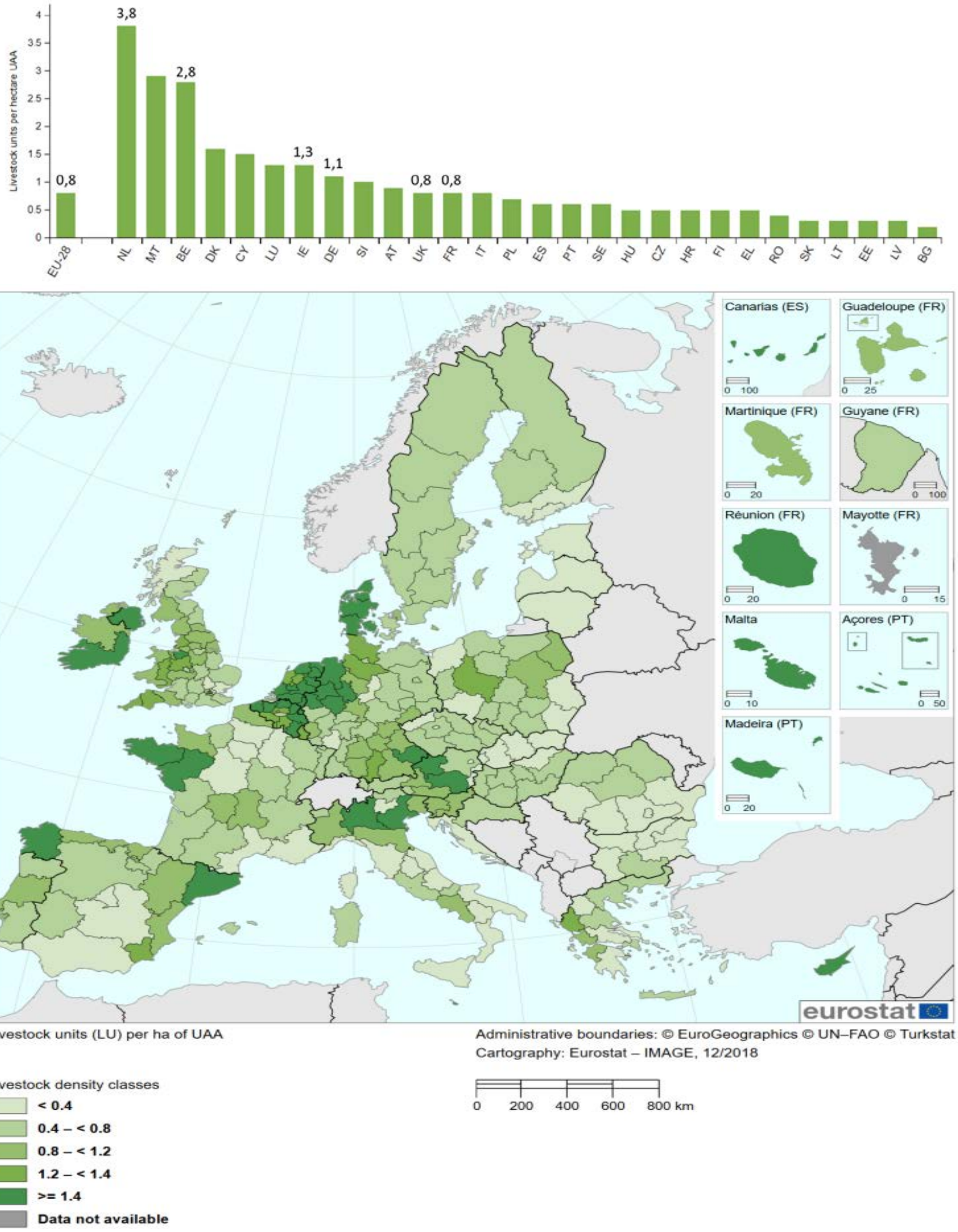


Figure 5: Figure: Livestock density per hectare in Europe per countries and regions (Eurostat, 2018)

Considering the environmental importance of extensive livestock practices and their decline (because of economic and technical difficulties), these practices may appear as additional. However, it is important to consider the emissions inherent to a livestock activity (direct emissions, manure…) in the calculation of the carbon credits.

B) Inventory of barriers

Different barriers are preventing the spontaneous rewetting of peatlands by farmers and other landowners. These barriers are both technical, economic, and social:

The cost of restoration

The first economic barrier is the cost of the rewetting itself. The process of restoration involves staffing, materials, equipment, and expertise that can be quite costly.

Before any restoration works, an assessment must be carried out to understand the hydrology and state of mineralization of the bog. The assessments are a long and relatively costly operation with at least 10 days of surveying, a complete assessment is therefore estimated at around 10,000€/peatland of fixed cost.

In several cases, raising groundwater tables is more affordable than continuation of drainage, but restoration itself can also be expensive due to the scale and complexity of the work involved. Estimating costs is difficult as sites vary greatly in their situation and position in the landscape.

A comparison of several dataset coming from capitalised restoration operations, across the UK, Switzerland, and France (*Peatland Code, Life Anthropofens et Tourbières du Jura project, Gubler et al.*), has brought into light that several expenditure items are quite independent from one another in such fieldwork. Each one can be related to ground variables through a cost-function and contribute for a certain part of the total cost of the related project. Costs range from 5 000 to 150 000€/ha. In France, a more likely cost is of 10 000 to 40 000€/ha. Reported figures from Switzerland are closer to the upper bound of 150 000€/ha, and the information coming from the UK costs vary from 5 000 to 15 000£/ha.

Another source of data is the Carbon Connects white paper that made a review of peatland restoration costs from planning, actions, and monitoring. In Germany and the Netherlands, the observed cost range between 1 500 to 3 500 € per ha (Van Belle et al., 2012, SKP 2020). The EU-LIFE nature programme has invested 167,6 million of euros in 80 projects between 1993 and 2015 with the aim of restoring over 91 300 hectares of peatlands (equivalent to 1 836 € per ha) in Western European countries, mostly Natura 2000 sites (Anderson et al. 2017). The Living Bog EU-LIFE project (NPWS); started in 2016 targeted the restoration of 2 600 ha of raised bog across 12 sites in Ireland with an overall budget of €5.4 million (equivalent to 2 076 € per ha). However, costs of restoration by farmers on farmland would be significantly reduced if they do the work themselves with existing equipment.

This cost depends highly on peat's depth and degradation level. Three scenarios can be considered that represent the various degradation steps of a peatland. First a reopening of forested bog, that mainly consists of woodworking, does not exceed a few thousand euros per hectare. In case of hydrological disturbances observed, a remandering operation can be conducted. That kind of engineering is directly bound to the linear metres of drain to re-naturalized and can barely exceed 30.000€/ha. Finally, a complete ecological restoration of a former extraction pit involves all items of expenditure, from hydraulic engineering to waste treatment, and can reach cost ceilings in this area. The following infographic summarises the cost structure of the hydraulic restoration work. It contains the main variables which determine each item of expenditure.

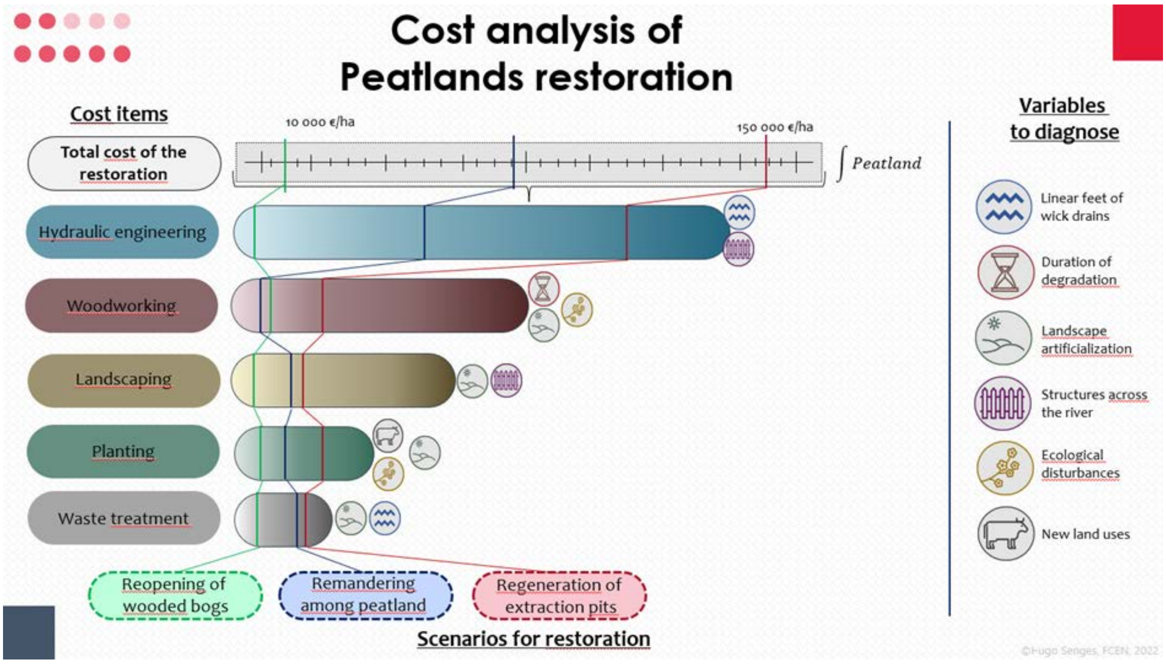


Figure 6: Cost analysis of Peatlands restoration (Hugo Senges, FCEN, 2022)

The review of the literature on the subject has also made it possible to update the following items:

- Low elevation peatlands are cheaper to restore than higher peatlands because they are less difficult to access.
- "There are also opportunity costs that arise from modifying the use of land as part of restoration" *(Okumah, M., Walker, C., Martin-Ortega, J., Ferré, M., Glenk, K. and Novo, P., 2019)*. These opportunity costs are notably related to the loss of economic opportunities for farmers as dry agriculture products are, as of right now, more profitable than products of the wet agriculture. It's notably because the wet agriculture value chain is not really developed compared to the dry agriculture one in North West Europe.
- "Data gathered through a survey with peatland programme officers and other existing evidence, damming drains with rock appears as one of the most expensive techniques (reported at £5,883/ha); and damming drains with peat as the least expensive (reported at £105/ha)."
- The table of costs from the Life Program 'Tourbières du Jura" in the eastern mountains of France, identified an indicator that could more precisely estimate the cost of restoration/rewetting of a peatland area: the linear metres of drain to plug over the associated peat area in its watershed. It is measurable through spatial/aerial imagery via radar or lidar acquisition instruments.

Effects of rewetting on farm practices and profitability

In wetlands, drainage was for a long time encouraged by agronomic experts and even subsidised with public money *(E. Frejefond, D. Zimmeril, P. Vaquié, M. Lagoutte, 1996)*. It was recognised for *(Y. Pons, A. Capillon, L. Damour, E. Lafon, 1989)*:

- Extending the periods of access to the grazed or mown grasslands. Also, Bog Asphodel, a bog indicator species can appear, It is harmful to livestock welfare. Therefore, rewetting creates a technical barrier.

- Allowing yield gains (from 2-3tDM/ha to 7-8tDM/ha) in grasslands. Therefore, rewetting creates an economic barrier. In this extreme scenario, if all this yield loss from grazing is compensated with the purchase of hay for feeding herds, rewetting will create a loss of 500€/ha (if we consider a middle price of 100€/t for hay).

- Opening these fields for crop cultivation. Therefore, rewetting creates a technical barrier.

Whilste the devastating effects of this drainage on the environment are now recognised, some of its agronomic benefits are also in question. As proven in a study carried out in the Cotentin Bessin peatlands *(E. Bouillon, 2007)*, the extension of the winter flooding period could be beneficial for the yield of wetland grasslands. It could limit the cessation of summer growth and the hydric stress of the grass in a context of water rarefaction. Rewetting could also open access to new business models like paludiculture and/or carbon farming *(C-toolbox, 2022)*.

Even with this new evidence, drainage remains associated for farmers with a gain of economic margin and better technical convenience creating a big social barrier for the emergence of rewetting projects.

There are also a lot of territorial barriers to rewetting as different local stakeholders (like water boards, anglers, farmers, hunters, tourists, environmental associations, local authorities…) will have different views regarding what the water table level should be. There is a diversity of issues (economic, environmental, risk management…) which have conflicting requirements related to the water table and can make it a political decision. The regulations can also block the emergence of restoration projects and the will of farmers/landowners to rewet their lands.

Barriers to the Adoption of Maximum Sustainable Output

The absolute minimisation of Fixed Costs for example the elimination of heavy tractors, grass cutters, balers, and the elimination of Corrective Variable Costs, for example artificial fertiliser means that the transition from conventional farming will require complete restructuring of the farm business, from breeding and sales cycles to grassland management and the type and number of livestock units on farm.

The transition will require the commitment to a multiple year journey from production-centred business to a profit-centred business, with significant transitional risk and cost. The farmer may not have the financial capital, or the expertise required to manage that transition unsupported.

Outside investment could provide the financial capital and fund the expert support required to bridge the transition gap. This may base on Corporate Social Responsibility, being seen to support the transition to regenerative agriculture, or it could be based on a share in a more profitable farm enterprise.

C) Analysis of the reglementary framework and public subsidies

Historically, the CAP has been largely subsidising agricultural activities that require peatlands to be drained. With the incoming CAP starting in 2023, a major step forward has been taken with a protection of high carbon storage plots from drainage which prevents access to subsidies in case of non-compliance by a farmer. The European framework of this CAP also open new opportunities to support good peatland practices like paludiculture or rewetting with the eco-schemes. However, there is still a lack of eligibility and subsidies for best wet agriculture practices in most national strategic plans.

Peatlands are delivering several ecosystem services so maintaining them in a good condition is a matter of common interest. As such, peatlands can be reglementary protected and the rewetting of peatlands can be publicly funded. The additionality of carbon credit schemes to this different public levers need to be ensured to avoid the potential double funding:

Table 3: Synthesis of the levers of the methodology funded by the CAP 2023-2027

Countries	Eco-schemes	The agri-environment-climate measures
Germany	Extensive grazing only	Restoration projects
Ireland	Extensive grazing only	Wet agriculture
Belgium	Extensive grazing only	Restoration projects
France	Extensive grazing only	Extensive grazing only
The Netherlands	Paludiculture	Wet agriculture

The conditionality

To be eligible for the basic payments of the first pillars of the CAP, farmers need to respect different Good Agricultural and Environmental Conditions. In the CAP 2023-2027, a new Good Agricultural and Environmental Condition named GAEC 2 ensures the preservation of carbon rich soils and as such protects wetlands/peatlands *(European Parliament, 2020)*. This reglementary framework makes peatland drainage prohibited for all EU members.

As proven in the analysis of usual practices, a lot of peatlands are already damaged/drained. Even if no further degradation is allowed, investments are needed for the restoration of a big number of degraded peatlands that are emitting CO_2. As such, this carbon crediting methodology is additional to the conditionality of the CAP.

The eco-schemes

Introduced in the European framework of the CAP 2023-2027, those eco-schemes are some bonus direct payments that will be conditioned by the environmental quality of farm practices. This conditionality must go beyond that of the basic payments that already protect wetlands/peatlands in the framework of the GAEC 2. The European Commission identified the rewetting of wetlands/peatlands and paludiculture as potential agricultural practices that these new eco-schemes could support *(European Commission, 2021)*. It is up to each state/region to include those practices or not in their national/regional strategic plan:

- In France, Belgium and Ireland, there is no specificities about peatland in the eco-schemes (however extensive grazing is subsidised).
- In Germany, there is no specific mention of peatland in the eco-schemes, but good management of Natura 2000 sites and extensive grazing can be subsidised.
- In the Netherlands, paludiculture is supported by the new eco-schemes.

There are no examples of direct funding for peatland rewetting in the eco-schemes of Northwest Europe countries. As such, this carbon crediting methodology is additional to the eco-schemes of Northwest Europe countries. In the framework of the eco-schemes of the Netherlands which support paludiculture, we should not take in account fossil fuel substitution carbon sequestration in materials resulting from paludiculture crops.

The agri-environment-climate measures

These measures are one of the major territorial development tools of the 2nd pillar of the Common Agricultural Policy. They allow farmers to receive financial assistance under a one to five-year contract in return for environmentally friendly practices *(European Parliament, 2021)*. In some countries, complementary contracting mechanisms are also used in the framework of the Natura 2000 network that are targeting other types of landowners that are not eligible for the CAP. All those payment schemes can be result-based (respect of a good outcome regarding environmental quality) or prescription-based (respect of a set of practice specifications):

- In France, the contracting is only possible in restricted zones where territorial agri-environment-climate projects exist. Numerous agri-environment-climate projects have been carried out in peatlands but most often with a view to improving water quality. Those projects support farmers' practices which sustainably maintain some of the ecosystem services delivered by peatlands, but they are not promoting direct peatland restoration. For example, in the "Marshes of Grand Lieu" site, the syndicate of the Grand-Lieu watershed animate an agri-environment-climate project. This project allows local farmers to access payments if they practice extensive grazing, maintain the vegetation cover, and limit their fertilisation and mowing. The subsidies range from 120€/ha to 265€/ha depending on the level of commitment of the farmer. *(DRAAF Pays de la Loire, 2020)*.

- In Ireland, the Green Low-Carbon Agri-Environment Scheme (GLAS) was also promoting sustainable farmer practices but there was no direct support for peatland restoration *(Adas, 2020)*. This will change in the CAP 2023-2027 as GLAS will be replaced by Agri-Environment Climate Measures (AECM). In this AECM, a new results-based scheme is proposed with the aim of reducing greenhouse gas emissions from drained peatland by promoting an agricultural management that raises the water table levels. *(Departement of Agriculture, Food, and the Marine, 2021)*.

- In Germany, the Environmental, climate-related, and other management commitments can subsidise peatland restoration projects. *(Ministry of food and agriculture, 2021)*

- In the Netherlands, with the Agricultural Nature and Landscape Management (ANLb), only farmers' groups can be funded for their good management of peatland areas. *(Ministry of Agriculture, Nature, and Food Quality, 2021)*

- In Wallonia, subsidies to restore the hydrological functioning of peatlands/wetlands can be provided in the future CAP. However, these funds are part of the aid for non-productive investments in agricultural and forestry holding, not from the agri-environment-climate measures *(Wallonia agriculture SPW, 2021)*.

In countries where AECM only supports environmentally friendly practices this carbon crediting methodology is additional (Netherland, France). In countries where AECM supports peatland rewetting, carbon credits can be additional if the AECM doesn't support the full cost of rewetting and its economic impacts. In this case, the additionality needs to be proven by calculation considering both the costs and sources of income for the restoration project. In case of a farmer already applying for this AECM, a discount rate could also be applied to the amount of carbon sold (for example with the case of Ireland).

The LIFE programs

This LIFE program is a financial instrument of the European Commission, dedicated to the support of innovative projects that protect the environment and climate. Project owners can be both public and private (associations, local and regional authorities, citizens, companies, NGOs…). It can fund pilot projects with the aim of developing the knowledge around new potential beneficial practices for the environment. Demonstration projects can also be funded to test the relevance of these practices in a new specific context. The LIFE program can also fund best practice projects and communicate on practices that are already well known for their positive impacts to disseminate them at a larger scale *(Ministry of Ecological Transition and Territorial Cohesion, 2022)*.

LIFE-Nature and Biodiversity funds the Natura 2000 network of European ecological sites and other actions to preserve and study biodiversity in Europe. An example in France can be the project LIFE "Tourbière du Jura" which funded the hydro-ecological restoration of 55 peatlands of the Franc-Comtois Jura massif, within 14 Natura 2000 sites in 32 communes *(DREAL Bourgogne Franche-Comté,* *2022)*. Another example in UK, is the Pennine PeatLIFE project that have delivered 1,353 hectares of peatland restoration in the North Pennines, Yorkshire Dales and Forest of Bowland.

If LIFE funds already subsidise a rewetting project, the economic additionality of carbon credits is not ensured. As such, it must be proven by a calculation considering both the costs of restoration and the public funding provided to the rewetting project. A discount rate could also be applied to the amount of carbon sold.

Specific national regulations

In addition to this European framework mainly linked to the CAP, other national or even regional/local regerminations can exist and impact on the potential additionality of restoration projects. For example, in the Netherlands, the water table can be enforced locally by water boards. As such, rewetting projects that do not raise the water table beyond this regulatory framework cannot be considered as additional.

It is also important to note that the United Kingdoms is no longer eligible for the CAP and is developing its own agriculture bill that is deeply different in its aim. There will be no direct payment in it and the main idea is to “give public money for public goods”. As such, subsidies will most certainly be aimed at funding peatland restorations *(Department for environment, food, and rural affairs, 2020)*. There can be a risk of double payment so economic additionality should be verified in case a project is already funded by public money.

III- Quantification of greenhouse gases emissions reduction

A) Scenarios and greenhouse gases considered

For each peatland area considered, the general approach for calculating the creditable emission reduction is to make the difference between a baseline scenario which is a continuation of current practices with a scenario in which ecological restoration has been achieved perhaps combined with changes of farming practices. The amount of creditable emission also depends on the number of years considered in the contract.

Equation 1: Carbon credits quantification

$$\boldsymbol{GHG_{CRDTS}} = \sum_t \sum_a \boldsymbol{A_a} * \left(\boldsymbol{GHG_{BSL,a,t}} - \boldsymbol{GHG_{RWT,a,t}}\right)$$

$$with\ a\epsilon[1, \dots, Number\ of\ homogeneous\ areas]\ and\ t\epsilon[1, \dots, Contract\ Duration]$$

In tonnes of CO_2-equivalent:

GHG_{CRDTS} : *amount of total creditable emission reductions*

In tonnes of CO_2-equivalent per hectare:

$GHG_{BSL,a,t}$: *greenhouse gases flux in the baseline scenario on area a and year t*

$GHG_{RWT,a,t}$: *greenhouse gases flux in the rewetted scenario on area a and year t*

In hectares:

A_a : *surface of the area a*

As different types of greenhouse gas are considered, each of them is converted in CO_2-equivalent following their Global Warming Potential averaged on 100 years:

Table 4: Global Warming Potential of various greenhouse gases

Greenhouse gases (GHG)	Global Warming Potential averaged on 100 years (GWP_{100})
Carbon Dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous Oxide (N_2O)	265

For each the baseline and rewetted scenario, two main type of GHG flux are considered: GHG flux from the peat and GHG flux from farming practices:

Equation 2: Calculation of the baseline and project scenario

$$\boldsymbol{GHG_{BSL,a,t} = GHG_{BSL_{PEAT},a,t} + GHG_{BSL_{PRACT},a,t}}$$

$$\boldsymbol{GHG_{RWT,a,t} = GHG_{RWT_{PEAT},a,t} + GHG_{RWT_{PRACT},a,t}}$$

In tonnes of CO_2-equivalent per hectare:

$GHG_{BSL_{PEAT},a,t}$: $GHG\ flux\ of\ the\ peat\ in\ the\ baseline\ scenario\ on\ area\ a\ and\ year\ t$

$GHG_{RWT_{PEAT},a,t}$: $GHG\ flux\ of\ the\ peat\ in\ the\ rewetted\ scenario\ on\ area\ a\ and\ year\ t$

$GHG_{BSL_{PRACT},a,t}$: $GHG\ flux\ of\ the\ practices\ in\ the\ baseline\ scenario\ on\ area\ a\ and\ year\ t$

$GHG_{RWT_{PRACT},a,t}$: $GHG\ flux\ of\ the\ practices\ in\ the\ rewetted\ scenario\ on\ area\ a\ and\ year\ t$

Farming practices will form part of the contract, detailed in a technical specification between the investor and the farmer. For example, no application of artificial N, specific grassland management techniques etc.

B) Greenhouse gases flux from peat

The direct monitoring of the greenhouse gases flux from the peat is a costly and time-consuming process. That's why different approaches have identified proxies which are indicatives of the state of the peat and its emission of greenhouse gases. A first proxy that drive these greenhouse gases emissions is the level of the water table. A linear relationship has been demonstrated that shows that higher water table causes smaller emissions of CO_2 from the peat and in some cases, higher emissions of CH_4. Overall, this relationship shows a positive net climate impact when raising the tables:

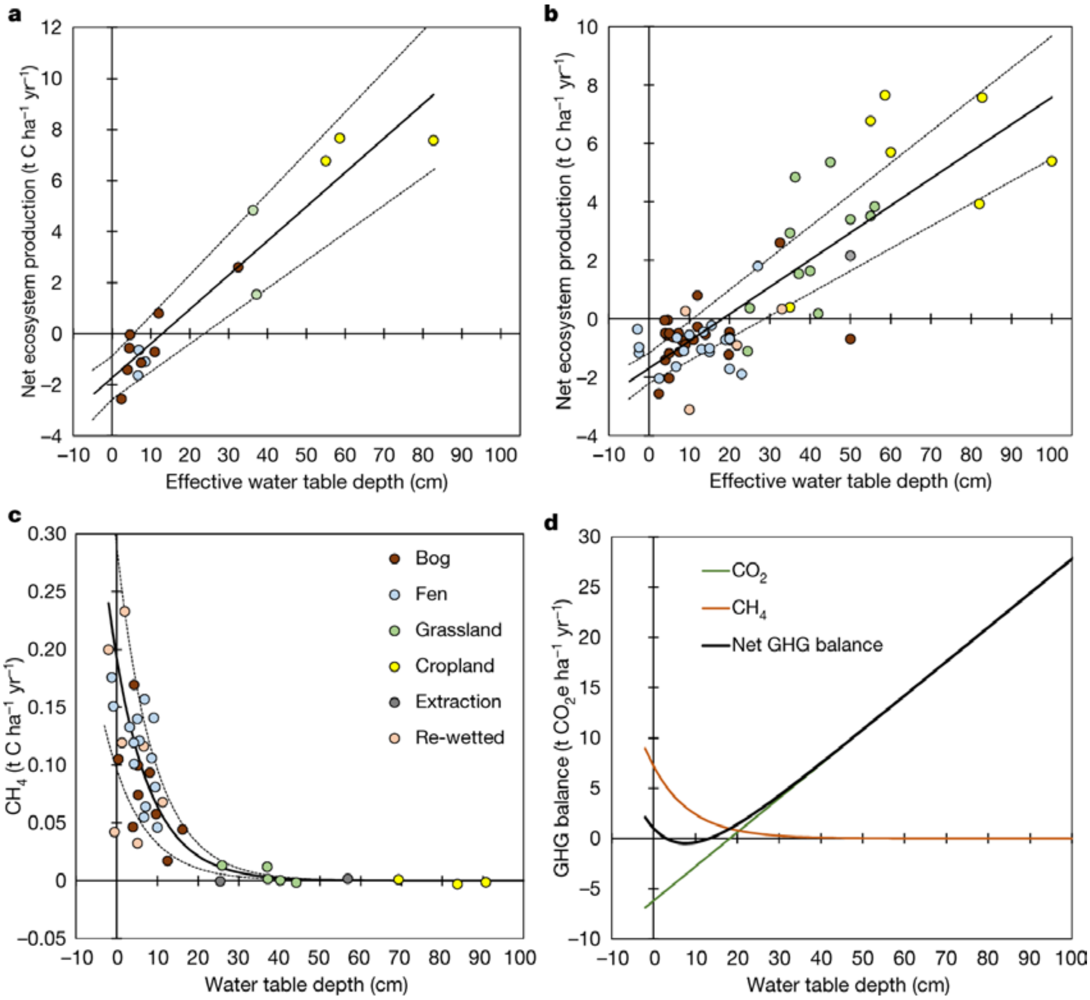


Figure 7: Annual mean values of carbon dioxide and methane flux versus mean water table depth. (C. D. Evans et al.,2021)

(a) CO_2 on UK and Irish eddy covariance studies.
(b) CO_2 on all published eddy covariance studies on boreal and temperate peatlands.
(c) CH_4 on UK and Irish static chamber studies.
(d) Regressions from b and c converted to tCO_2e ha−1 yr−1 to show net climate impact of CO_2 and CH_4 versus water table.

This approach is directly used in the Dutch peatland carbon credits scheme Valuta Voor Veen that uses the water table as a proxy to quantify the greenhouse gases flux from targeted specific types of peatland. Other carbon credits schemes such as the German MoorFutures (which is using the GEST approach) and British Peatland Code are identifying site types linked to more diversified factors as proxies to identify the carbon emission of the peat. This methodology focuses on these approaches by site types as they allow for better flexibility in considering the diversity of peatland situations and types.

The Greenhouse Gas Emission Site Types methodology

The Greenhouse Gas Emission Site Types (GEST) approach can be used to model the effects of drainage and rewetting on carbon dioxide (CO_2) and methane (CH_4) fluxes from the soil *(Couwenberg et al., 2011)*. This approach consists of a list of typical emission factors for different combinations of vegetation and groundwater levels (with moisture classes). These different emission factors are based on monitored annual emission budgets determined in various research projects. These emission factors can be both positive or negative and so represent both emission and sequestration. The Site Emission Tool (SET) developed under Carbon Connects collates the key information from the GEST approach and allows a streamlined use of this approach particularly in the context of quantifying carbon credits.

Vegetation is a more complete proxy for indicating greenhouse gas fluxes because *(Couwenberg et al., 2011)*:

- It is, by itself a good indicator of water table depth, which as stated earlier, is strongly correlated with the greenhouse gases flux of the peat.
- It is determined by long-term local water table conditions and thus provides indication of average greenhouse gases fluxes on a longer time scale (annual) and on finer spatial scale.
- It is also determined by other site factors that determine the emissions of the peatland such as the nutrient availability, acidity, and historic land use.
- It is itself directly and indirectly responsible for a part of the greenhouse gases emissions by regulating CO_2 exchange (supplying organic matter for CO_2 and CH_4 formation, influencing peat moisture, possibly providing possible bypasses for methane emission).

Equation 3: Peat greenhouse gases emissions

$$\boldsymbol{GHG_{PEAT,s,a,t} = GHG_{PEAT\_CO2,s,a,t} + 28 * GHG_{PEAT\_CH4,s,a,t}}$$

In tonnes of CO_2-equivalent per hectare:

$$GHG_{PEAT,s,a,t} : GHG\ flux\ of\ the\ peat\ in\ the\ scenario\ s\ on\ area\ a\ and\ year\ t$$

$$GHG_{PEAT\_CO2,s,a,t} : CO_2\ flux\ of\ the\ peat\ in\ the\ scenario\ s\ on\ area\ a\ and\ year\ t$$

In tonnes of CH_4 per hectare:

$$GHG_{PEAT\_CH4,s,a,t} : CH_4\ flux\ of\ the\ peat\ in\ the\ scenario\ s\ on\ area\ a\ and\ year\ t$$

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 (which could emit CO_2 or CH_4). The data source is mean emission numbers from a 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)*.

Table 5: Greenhouse gases emission (CO2 and CH4) of different peatland vegetation types (Couwenberg, Reichelt, & Jurasinski, n.d.; Reichelt, 2015)

Type of possible Vegetations in Drained Scenarios	CH4		CO2		Total C-flux
	GWP	n	GWP	n	GWP
G1: Dry to moderately moist grassland	-0,01	24	31,44	16	31,5
G2: Moist grassland	0,01	48	19,37	38	19,5
G3f: Periodically flooded grasslands	-0,05	3	13,46	-	13
G3s: Moist to very moist grassland with shunt species	0,75	7	13,46	-	14
A1: Dry to moderately moist arable land	0,08	11	41,69	10	42
A2: Moist arable land	0,17	6	23,44	4	23,5
U1: Moist bare peat	0,03	2	8,99	2	9
U3: Moist Reeds	0,04	1	2,77	2	3
S1: Dry to moderately moist grassland on peaty soils (Anmoor)	-0,05	9	46,09	14	46
S2: Dry to moderately moist arable land on peaty soils (Anmoor)	0,07	8	35,11	12	35
Type of possible Vegetations in Rewetted Scenarios	CH4		CO2		Total C-flux
	GWP	n	GWP	n	GWP
G5s: Wet grassland with shunt species	2,93	4	-3,89	-	-1
U11: Wet meadows and forbs	7,35	2	-3,89	-	3,5
U12: Wet small sedges with mosses	4,72	23	-1,99	15	2,5
U13: Wet sphagnum lawn	5,25	6	-3,02	6	2
U14: Wet tall reeds	6,47	10	0,21	2	6,5
U15: Wet tall sedges	9,49	3	1,03	2	10,5
U16: Wet bog heath	17,8	1	-0,01	7	18
U17: Very wet tall sedges and Typha	6,81	8	-1,08	8	5,5
U18: Very wet Phragmites reeds	12,44	12	-12,38	8	0
U19: Wet to very wet Sphagnum hollows	11,81	8	-4,58	8	7

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. We determine 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)*. This table shows the carbon content per peat type together with some other peat characteristics:

Table 6: Peat soil characteristics per peat type. Bulk Density and Carbon content of peat from Loisel et al. (2014).

Peat type	Bulk Density (g/cm3)	Carbon content of peat (%)	Carbon content of soil (kg C/m2/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, as is the carbon in the harvested biomass if it is used in long rotation applications or to replace fossil fuel use.

The GHG emission factor is directly linked to the identified site type both for the baseline scenario and rewetted scenario. Most of the time, the baseline scenario will be a continuation of the pre-rewetting site type that can be directly identified in the project site by peat vegetation. If there is a doubt between several types of vegetation for the baseline scenario, it will be necessary to choose the one with the lowest GHG emission to ensure a conversative assessment.

For the rewetted scenario, it's the other way around: if there are doubts about the resulting type of vegetation and moisture class, it will be necessary to choose the one with the biggest GHG emission to ensure a conservative assessment. The initial planned rewetted scenario should mobilise experts and modelling tools in hydrology (ground elevation models such as waterwijzer) to measure the potential effects of the rewetting project.

Regular updates on the evolution of the project site can also help to ensure that the initial planned rewetted scenario is valid. Expected trajectory changes can be considered in the calculation of the emission reduction if the hydrology or vegetation of the site does not react as expected.

The UK Peatland Code methodology

The UK peatland code is using the same principle to assess the number of carbon credits associated with a restoration project. It makes a difference between a baseline scenario which is a continuation of current practices with a scenario in which a restoration project has been implemented (with revegetation and/or rewetting and a shift of the management practices). The specificity of the peatland code is that it only focuses on specific types of peatlands: either blanket bogs or raised bogs on sites that are actively eroding or drained. It responds very well to the needs of the United Kingdom, which has great surfaces of peatlands that are predominantly of these 2 types.

This focus allowed peatland code to develop specific emission factors linked to site types that are different from the GEST approach. Unlike the GEST approach, which is using descriptions of vegetation and moisture, the different site types of the peatland code are describing levels of degradation of the peatland thanks to specific features that are mapped initially using aerial imagery and confirmed through field surveys.

Table 7: Identification key for different Peatland Code Site Types and associated Emission Factors (IUCN, 2022)

Pre-Restoration (Baseline) Condition Categories

Pre-Restoration Condition Category	Description	Emission Factor ($tCO_2e/ha/yr$)
Actively Eroding: Hagg/Gully	• Extensive bare peat within hagg/gully system (e.g. steep bare peat cliffs and/or bare gully bottoms)	23.84
Actively Eroding: Flat Bare	• Extensive continuous bare peat (e.g. peat pan or former cutting site)	23.84
Drained: Artificial	• Within 30m of an active artificial drain (grip)	4.54
Drained: Hagg/Gully	• Within 30m of hagg/gully drainage system	4.54
Modified*	Highly Degraded: • No/little *Sphagnum* • *Calluna vulgaris* extensive • Small discrete patches of bare peat frequent (micro-erosion) Moderately Degraded: • *Sphagnum* in parts • Scattered patches of *Calluna vulgaris* • Extent of bare peat limited to small patches	2.54
Near Natural*	• *Sphagnum* dominated • *Calluna vulgaris* absent or scarce • Little or no bare peat	1.08

**Ineligible for Peatland Code Restoration - these condition categories may be present within the project site and can be included within the restoration plan but any claims of emissions reduction as a result of their restoration cannot be validated/verified under the Peatland Code.*

Post-Restoration Condition Categories

Pre-Restoration Condition Category	Description	Emission Fact (tCO$_2$e/ha/yr)
Actively Eroding: Hagg/Gully	• Extensive bare peat within hagg/gully system (e.g. steep bare peat cliffs and bare gully bottoms)	23.84
Actively Eroding: Flat Bare	• Extensive continuous bare peat (e.g. peat pan or Former cutting site)	23.84
Drained: Artificial	• Within 30m of an active artificial drain (grip)	4.54
Drained: Hagg/Gully	• Within 30m of hagg/gully drainage system	4.54
Drained: Re-vegetated Actively Eroding	• Bare peat no longer extensive and continuous	4.54
Modified	• Within 30m of a re-wetted artificial drainage syste (active flow interrupted by restoration activities) **OR** Highly Degraded: • No/little *Sphagnum* • *Calluna vulgaris* extensive • Small discrete patches of bare peat frequent (micro-erosion) Moderately Degraded: • *Sphagnum* in parts • Scattered patches of *Calluna vulgaris* • Extent of bare peat limited to small patches	2.54
Near Natural	• *Sphagnum* dominated • *Calluna vulgaris* absent or scarce • Little or no bare peat	1.08

In addition to the Peatland Code which only covers upland peat, the UK Centre for Ecology & Hydrology (UKCEH) have developed a range of emissions factors for other peatland types in UK.

C) Greenhouse gases flux from farming practices

A lot of changes in farming practices could come with restoration projects as the rewetting of the land requires technical adaptations. Most of the commonly used crops like maize, straw cereals but also oilseeds, protein and vegetable crops are adapted to dry conditions and will not be profitable after a significant rewetting. However, the farmer will then have the possibility to go towards wet adapted crops through paludiculture. In a livestock context, the farmer will also have to adapt his pasture management (especially grazing-management) since the grass will not be productive at the same time of the year. To avoid potential leakages of greenhouse gases emissions caused by these changes of farming practices, major carbon emissions/sequestrations factors are calculated as a complement to emission changes from the peat.

For the farmer, the project can also generally be a good opportunity to set up more sustainable practices which can be economically valued in carbon credits if these practices decrease the carbon footprint of the farm. For example, farmers can change their animal loading, crop rotation, quantity of used fertilisers (both organic and synthetic) and mechanisation of the farm. These practices shift then impact the carbon footprint of the farm. As such, this calculation can also lead to the consideration of more claimed emissions reduction for the project proponent.

It is not, however, the most complete, accurate and therefore suitable method for carbon credits based only on emission reductions from farming practices. In fact, other methods exist in each countries that are specialised on different agriculture levers of mitigation. For example, in France, the Label Bas Carbone national certification recognise different methods such as:

- the FIELD CROPS methodology to assess emission reductions of field crops farms (fuel and fertilizers reduction, carbon sequestration through conservation agriculture…),
- the CARBON AGRI methodology to assess emission reductions of livestock farms (herd management and feeding, manure management, grassland carbon sequestration…),
- the HEDGES methodology to assess emission reductions from hedges plantation and sustainable management.

In this methodology, Standard IPCC Tier 1 calculations are applied to estimate emissions of nitrous oxide (N_2O) resulting from application of manure or fertiliser, cattle droppings and from crop residues of paludiculture left on the field *(De Klein et al., 2006)*. We're also calculating the carbon emission from the use of fuel and electricity. The carbon emission reduction resulting from the use of paludiculture crops as a substitute for fossil-based fuel and materials is also considered.

Equation 4: Greenhouse gases emission calculation for farming practices

$$GHG_{PRACT,s,a,t} = GHG_{FERTI,s,a,t} + GHG_{ANIM,s,a,t} + GHG_{CR,s,a,t}$$
$$+GHG_{IND,s,a,t} + GHG_{NRJ,s,a,t} - GHG_{SUBST,s,a,t}$$

Direct emission from fertilisers

The use of too much fertiliser generally has both an environmental cost (greenhouse gas emissions, impact on water quality) and an economic cost for the farmer. Using less fertiliser reduces input costs but can also limit the yield potential of crops so the farmer needs to match his fertiliser use to the needs of his crops. The primary determinant of a farm's plot nutrient need is the choice of its crop rotation as different crops will have different needs and a more diverse and long rotation generally reduces the need for external nutrient inputs. Certain cultivation techniques make it possible to reduce the overall need of the crops for fertiliser spreading such as the use of plant covers in intercropping or the use of Fabaceae in the rotation. In the case of a substantial rewetting project, these practices are rarely relevant. It is often the case that dry crops are simply abandoned and the land is returned to grass (for grazing-management) or to a natural areas who doesn't need as much or any fertilisation. Another output can be the implementation of paludiculture with crops which may have fertilisation needs.

The use of nitrogen fertilizer is the most important source of direct emissions of nitrous oxide (N_2O), a very potent greenhouse gas, from agricultural soils. These emissions are both direct during the spreading of fertilizer on the soil and indirect after a transfer of the nitrogen to water (in the form of nitrate) and via the atmosphere (in the form of ammonia). It's also possible to add the greenhouse gas emissions linked to the production and even the transport of nitrogenous of the fertilizers. The Maximum Sustainable Output approach involves the elimination of artificial fertiliser products from grassland management livestock production operations and therefore the complete elimination of the emissions described above and calculated below. This formula allows the calculation of greenhouse gas emissions directly related to spreading:

Equation 5: Greenhouse gases emission calculation from fertilization

$$\boldsymbol{GHG_{FERTI,s,a,t} = 265 * \frac{44}{28} * \sum_i \left(EF_{FERTI,i} * F_{FERTI,i,s,a,t}\right)}$$

Table 8: Emission Factor of different fertilisers

Type of fertilisation	EF
Animal manure	0,02
Organic fertiliser	0,02
Nitrate based fertiliser	0,02
Ammonium based fertiliser	0,01

In kilograms of CO_2-equivalent per hectare:

$GHG_{FERTI,s,a,t}$: $GHG\ direct\ emission\ from\ fertiliser\ in\ scenario\ s\ on\ area\ a, year\ t$

In kilograms of N_2O per kilograms of nitrogen:

$EF_{FERTI,i}$: $Emission\ Factor\ of\ the\ fertiliser\ i$

In kilogram of nitrogen year:

$F_{FERTI,i,s,a,t}$: $Quantity\ of\ fertiliser\ i\ used\ by\ hectare\ on\ scenario\ s,\ area\ a\ and\ year\ t$

Direct emission from grazing animals

Livestock farming is one of the only business models allowing the economic valorisation of wetlands through agriculture (with paludiculture which is currently a niche sector). As stated in the additionality part, livestock farmers are the most common peatland managers, and their activity can have good impacts on biodiversity and carbon storing by maintaining the peatland open. However, grazing animals can have a negative impacts locally on water quality and more globally with the emission of greenhouse gases notably because of their emission of excrement into the environment. More extensive grazing systems generally emit less greenhouse gases per hectare. Firstly, because the animals are fewer in number compared to their feeding area of grasslands and grasslands are storing carbon. Secondly, because more extensive system generally means more autonomy in feeding the herd. It should be remembered that animals are fed with foods that has its own impact on the environment. For example, a cow fed on imported soya meal and maize (with emissions from transport, mechanisation, and crop fertilisation) in an intensive system will have a greater impact on the climate than a cow fed on grass in an extensive system. On this methodology, we only target the direct emissions of the animals on the project site that result from a change in plot animal loading following a peatland restoration. For a more complete and systemic analysis of livestock emissions, specialised tools exist such as the CAP'2ER® (associated with the CARBON AGRI carbon credits methodology from Label Bas Carbone) and the Cool Farm Tool (CFT).

Animal breeding is the biggest source of greenhouse gases of the agricultural sector. Enteric fermentation (only from cattle/cows) and manure production are producing a great quantity of methane (CH_4) with manure production being also a source of N_2O. Different animals will have different climate footprints. This formula allows the calculation of greenhouse gas emissions directly related to the excretions of grazing animals:

Equation 6: Greenhouse gases emission calculation from animals

$$\boldsymbol{GHG_{ANIM,s,a,t} = 265 * \frac{44}{28} * Q_{ANIM,i,s,a,t} * N_{ANIM,i,s,a,t} * EF_{ANIM,i,s,a,t}}$$

Table 9: Emission Factor and yearly Nitrogen excretion of different grazing animals

Grazing animals	EF	N (excretion/head/year)
dairy cows	0,02	130,1
beef cattle	0,02	28,2
sheep	0,01	9,9
goat	0,01	7,4
water buffalo	0,02	76,5

In kilograms of CO_2-equivalent per hectare:
$GHG_{ANIM,s,a,t}$: $GHG\ direct\ emission\ from\ animals\ in\ the\ scenario\ s, area\ a\ and\ year\ t$

In kilograms of N_2O per kilograms of nitrogen:
$EF_{ANIM,i}$: $Emission\ Factor\ of\ the\ animal\ i$

In kilograms of nitrogen excretion per head per year:
$N_{ANIM,i,s,a,t}$: $Quantity\ of\ nitrogen\ emitted\ by\ animal\ i\ on\ scenario\ s,\ area\ a\ and\ year\ t$

In number of heads:
$Q_{ANIM,i,s,a,t}$: $Number\ of\ animals\ i\ on\ scenario\ s, area\ a\ and\ year\ t$

Direct emission from crop residues

Crop residues are parts of the cultivated plants that are not harvested and so remain of the field. Crop residues are emitting N_2O both directly and indirectly due to the microbial processes of nitrification and de-nitrification. Some peatland restoration projects are accompanied by the introduction of paludiculture as a new business model. This formula is used to calculate the amount of greenhouse gases emitted by residues of paludiculture crops that would have been left of the field:

Equation 7: Greenhouse gases emission calculation from crop residues

$$GHG_{CR,s,a,t} = 265 * \frac{44}{28} * FR_{CR,i,s,a,t} * Y_{i,s,a,t} * EF_{CR,i,s,a,t}$$

Table 10: Emission Factor and Residue Fraction of different paludiculture crops

Paludiculture Crop	Crop residue fraction of total yield (FR)	EF
Catail	0,11627907	0,02
Reed	0,046511628	0,02

In kilograms of CO_2-equivalent per hectare:

$GHG_{CR,s,a,t}$: $GHG\ direct\ emission\ from\ crop\ residues\ in\ the\ scenario\ s, area\ a, year\ t$

In kilograms of N_2O per kilograms of nitrogen:

$EF_{CR,i}$: $Emission\ Factor\ of\ the\ crop\ residue\ i$

In kilograms per kilograms per hectares of yield:

$FR_{CR,i,s,a,t}$: $Crop\ residue\ fraction\ of\ total\ yield\ of\ crop\ i\ on\ scenario\ s,$
$area\ a\ and\ year\ t$

In kilograms per hectares:

$Y_{i,s,a,t}$: $Yield\ of\ crop\ i\ on\ scenario\ s, area\ a\ and\ year\ t$

Indirect emissions of N_2O

All those agricultural practices (animal grazing and fertilisation) provide an additional source of nitrogen in the environment. This has an impact on the global nitrogen cycle indirectly enhancing the biogenic production of nitrous oxide (N_2O). This formula makes it clear that reducing any source of nitrogen in the environment will generally reduce indirect N_2O emissions:

Equation 8: Indirect greenhouse gases emission calculation linked to farming practices

$$\boldsymbol{GHG_{IND,s,a,t} = 265 * \frac{44}{28} * (GHG_{IND\_AM,s,a,t} + GHG_{IND\_NO,s,a,t} + GHG_{IND\_NIT,s,a,t})}$$

In kilograms of CO_2-equivalent per hectare:

$$GHG_{IND,s,a,t} : GHG\ indirect\ emission\ in\ the\ scenario\ s, area\ a\ and\ year\ t$$

In kilograms of N_2O per hectare:

$$GHG_{IND\_AM,s,a,t} : N_2O\ indirect\ emission\ of\ ammonia\ in\ scenario\ s, area\ a\ and\ year\ t$$

$$GHG_{IND_{NO},s,a,t} : N_2O\ indirect\ emission\ of\ nitrous\ oxide\ in\ scenario\ s, area\ a\ and\ year\ t$$

$$GHG_{IND\_NIT,s,a,t} :: N_2O\ indirect\ emission\ of\ nitrate\ in\ scenario\ s, area\ a\ and\ year\ t$$

$$GHG_{IND\_AM,s,a,t} = (Q_{ANIM,i,s,a,t} * N_{ANIM,i,s,a,t} + F_{FERTI,ANIMAL\ MANURE,s,a,t} + F_{FERTI,SYNTHTETIC,s,a,t}) * 0{,}1 * 0{,}01$$

$$GHG_{IND\_NO,s,a,t} = (Q_{ANIM,i,s,a,t} * N_{ANIM,i,s,a,t} + F_{FERTI,ANIMAL\ MANURE,s,a,t} + F_{FERTI,SYNTHTETIC,s,a,t}) * 0{,}15 * 0{,}01$$

$$GHG_{IND\_NO,s,a,t} = (F_{FERTI,ANIMAL\ MANURE,s,a,t} + F_{FERTI,ORGANIC,s,a,t} + FR_{CR,i,s,a,t} * Y_{CR,i,s,a,t} + F_{FERTI,SYNTHTETIC,s,a,t}) * 0{,}3 * 0{,}03$$

Emissions from energy

Modern agriculture is generally highly mechanised and therefore a consumer of energy both in the form of fuel and electricity. Reducing the number of machine passages on the fields allows to limit the need for fuel which is directly emitting carbon dioxide. Each tractor pass has a cost in fuel, equipment maintenance but also in time for the farmer. As such, a farmer will gain both economically and on working time if he chooses technical itineraries that are more conservative in tractor time. For a livestock farmer, preferring pastures instead of croplands to feed the herd can limit the needs for tractor use. Generally, favouring the planting of crops that require little movement in the most remote plots can be a strategic solution. Simplified cultivation techniques (with reduced or zero tillage for example) can also be used to reduce the need for fuel and machines. In most case, the electricity consumption of peatland farmers will be negligeable compared to the fuel consumption. In fact, the biggest consumption source of electricity in agriculture are greenhouses and livestock building heating and air conditioning. These are practices that do not concern peatland farmers.

MSO critically examines farm operations to absolutely minimize the need for heavy equipment, generating fixed costs, and to eliminate activity which does not contribute to profitability, reducing variable costs, particularly fuel and labor. For example, the gradual elimination of mowing and storage grass for winter feed with the replacement of in situ deferred grazing would significantly reduce both fixed and variable costs. In order to achieve these farmers would need to cover potentially significant transitional or conversion costs, remodeling livestock types, numbers and management policies.

Emissions from fossil fuel combustion are calculated by assuming the carbon content of the fuel is completely transformed into CO_2. Emission from electricity use is based upon average CO_2-emission per kW. It highly depends on the energy mix of the country where the electricity is used. This formula is used to calculate the amount of greenhouse gases emitted through the energy consumption of the farmer:

Equation 9: Greenhouse gases emission calculation from energy

$$\boldsymbol{GHG_{NRJ,s,a,t} = Q_{diesel,s,a,t} * 3,35 + Q_{electricity,s,a,t} * 0,581}$$

Table 11: Greenhouse gases emissions from energy (in CO2-equivalent)

diesel	3,35	kg CO2/liter
electricity	0,581	kg CO2/kWh

In kilograms of CO_2-equivalent per hectare:

$GHG_{NRJ,s,a,t}$: $GHG\ emission\ from\ energy\ in\ the\ scenario\ s, area\ a\ and\ year\ t$

In litters per hectare:

$Q_{diesel,s,a,t}$: $Volume\ of\ diesel\ used\ per\ hectare\ in\ scenario\ s, area\ a\ and\ year\ t$

In kilowatt-hours per hectare:

$Q_{electricity,s,a,t}$: $Electrical\ power\ used\ per\ hectare\ in\ scenario\ s, area\ a\ and\ year\ t$

Substitution of emissions and material sequestration

The implementation of paludiculture following a peatland restoration can also be a great source of greenhouse gases emissions through two processes. The first is the substitution which describe the fact that some paludiculture crops can be used to replace fossil resources that have bad carbon footprint. The second is material sequestration which describe the fact that some paludiculture harvests can be used as carbon stores.

So, application of the biomass produced for long rotation applications (such as building materials) or to replace fossil fuel is treated as avoided emission of all the carbon in the biomass. If the application is eligible for emission reduction payments, all the carbon in the biomass is transformed to CO_2-equivalents (with a factor 3,66). We set a carbon content of 0,475kg per kilogram of yield for paludiculture crops that are eligible for emission reduction. These formula and table are used to identify use of paludiculture harvests that are suitable to calculate an amount of greenhouse gases saved through substitution and/or material sequestration:

Equation 10: Greenhouse gases reduction calculation from substitution and material sequestration

$$\boldsymbol{GHG_{SUBST,s,a,t} = Y_{i,s,a,t} * 0,475 * 3,66}$$

In kilograms of CO_2-equivalent per hectare:

$$GHG_{SUBST,s,a,t} : \ GHG\ emission\ reduction\ from\ avoided\ emission$$

$$or\ long\ term\ stockagein\ the\ scenario\ s, area\ a\ and\ year\ t$$

In kilograms per hectares:

$$Y_{i,s,a,t} : Yield\ of\ crop\ i\ on\ scenario\ s, area\ a\ and\ year\ t$$

Table 12: Accountability of emission reduction per type of product use

Product use	Lifetime longer than 10 year (carbon storage)	Substitution of fossil products
building material (insulation, thatching, timber)	yes	no
bedding material	no	no
food application	no	no
fodder/ feed application	no	no
energy use: biogas, combustion, wood etc	no	yes
paper	yes	no
extraction of ingredients/building blocks: protein, fibres, cellulose	no	yes
high quality substrate in horticulture	no	yes

IV- Identification of limits, uncertainties, and risk of non-permanence

A) Data collection and uncertainties

Determination of the carbon store

The maximum carbon pool that can be credited is the amount of carbon in the peat on the project area. This amount of carbon is linked to two parameters: peat type/condition and peat thickness.

The **peat type** defines the carbon content per volume of peat. A corer/auger allows recovery of a known volume of peat. It is then necessary to determine the bulk density of this peat sample by dividing the oven dry weight (at 70°C for at least 48 hours) by the total volume of the sample. Direct analysis of a peat carbon content sample can be done in the laboratory using a dry combustion method with correction for inorganic carbon using a calcimeter. This method allows results with low uncertainties as they are specific for one analysed peatland area. However, the intervention of laboratory analysis can be costly.

A more low-cost solution would be to use existing references on peat types and their carbon contents. Extensive portraits for all types of peatland deposits have already been identified in the field and analysed in the laboratory. With this method, there is no laboratory analysis. Peat type can be identified in site with respect to both recognizable macrofossils from plant remains and the texture of the matrix in which they are embedded *(C. Schulz, 2019)*.

Another method would be to look at the different soil inventories that have already been done on the project area. It is possible that existing data are already describing the carbon content of the soil.

The **peat thickness** can also be determined on site by taking a core sample with a simple steel probe/rod with a crossbar or a corer/auger. Another method would be to look at the different soil inventories that have already been done on the project area. It is possible that existing data are already describing the peat horizons and their depth. The older the inventory is, the bigger the uncertainty is on the remaining peat thickness.

Table 13: Uncertainties in different modes of peat type data collection

Data collection method	**Analysis on laboratory**	**Peat type references**	**Local references from inventories**
Level of uncertainty	Very small	Small	Variable (depends on the age of the data)
Costs and/or time required	High	Small	Small

Groundwater level monitoring

Raising the groundwater table is the main driver for reducing the greenhouse gases emissions from peatland. If the GEST approach does not require direct inputs on groundwater levels, they allow to verify the coherence of the vegetation class identified in the field and to quantify other environmental co-benefits. As such, there is no discount needed on carbon for groundwater level monitoring methods.
Shallow groundwater monitoring wells are used to monitor the groundwater levels in peatlands. Automated logger allows for easy monitoring but if not available, data needs to be collected at least every two weeks by hand.

Following the hydrological context, the level of the water table can be more or less dependent on the weather status which can have interannual variability. Therefore, one year of data is not robust enough to identify a clear median groundwater level.

To assess what will be the groundwater level after peatland restoration, ground elevation models can be used. An important input that can help in this regard is the drainage pattern of the project area and how the rewetting project will affect it.

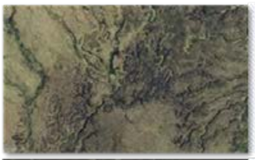
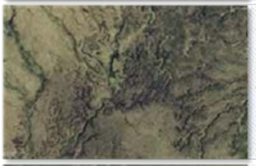
Vegetation/degradation class and associated greenhouse gases emissions

The assessment on the site type should be conservative as it will directly impact the GHG emission factor. If there's uncertainty about which site type to select, the one generating the smallest emissions reduction should be chosen. In the GEST approach, the vegetation class is the main parameter to evaluate the greenhouse gases emission of the peat. Regular vegetation survey on site is a good way to evaluate in which vegetation class an area is. The first annex of this methodology is sharing a vegetation identification table describing key species that could help determine the GES types on a site.

Using UAV surveys to collect aerial pictures can also help identify the areas of bare peat and erosion gullies. In fact, the Peatland Code approach uses maps/aerial pictures with descriptions of visible features to determine the emission of an area of peatland. This is making the process far more viable for bigger areas.

The spatial detail of the vegetation mapping investigation will determine the precision of the GHG emission reduction assessment. It is then necessary to differentiate between 1:2500, 1:5000 or 1:10000 scale maps. At the scale of mapping homogeneous patches of 1x1cm on the map/aerial photograph should be distinguished. So, for a 1:5000 mapping patches of 50 x 50m (i.e., 0.25 ha) in the field should be distinguished. 1:10:000 scale yields patch of 1ha in the field.

Table 14: Pre-restoration conditions categories of the Peatland Code and their description from sky pictures

	**Actively Eroding: Hagg/Gully** • Extensive bare peat within hagg/gully system e.g., steep bare peat cliffs and/or bare gully bottoms.
	**Actively Eroding: Flat bare** • Extensive continuous bare peat e.g., peat pan or former cutting site.
	**Drained: Artificial** • Within 30 m of an active artificial drain (grip).
	**Drained: Hagg/Gully** • Within 30 m of hagg/gully drainage system.
	**Modified** Highly degraded: • No/little Sphagnum spp. • Calluna vulgaris extensive • Frequent small discrete patches of bare peat. Moderately degraded: • Sphagnum in parts • Scattered patches of Calluna vulgaris • Extent of bare peat limited to small patches.
	**Near natural** • Sphagnum dominated • Calluna vulgaris absent or scarce • Little or no bare peat.

Finally, the last way of assessing the GHG emissions of the peat is to do in site monitoring. This method makes it hard to consider site heterogeneity and is costly. This monitoring cannot be used for ex ante funding of the carbon credits because it only gives historical data and so is not sufficient to assess what will be the GHG emissions in the rewetted scenario.

Table 15: Uncertainties in different modes of greenhouse gases emissions data collection

Data collection method	**In site vegetation and moisture survey**	**Satellite picture analysis**	**Greenhouse gases emission monitoring**
Level of uncertainty	Variable (depends on the expert and homogeneity of the site)	Variable (depends on the scale of mapping)	Small
Costs and/or time required	Medium	Small	High
Compatibility with ex ante calculation	Yes	Yes	No

Emissions from farming practices

The amount of **fertiliser** used by the farmer is the biggest emission factor linked to its practices after the emissions from animals. Most of the time, this data is easy to find because the amount of nitrogen added on the farmland is restricted by law in most European countries. In France, for example, the law requires the farmer to make a provisional nitrogen fertilisation plan. Some connected tractors allow direct collection of actual spreading data.

The emission from **animals** is the biggest emission factor linked to farming practices. This data is directly linked to the number and types of animals on the farm and their feeding regimes which are most definitely well known by the farmer.

The amount of **electricity/fuel** used by the farmer is a smaller emission factor linked to its practices. Some connected tractors allow direct collection of actual fuel consumption data. Looking at the bills of the farmer is also a way to quantify its historical consumption and then to make the follow up of the project.

There are no meaningful uncertainties linked to these different data collection methodologies for the emission of farming practices as it’s mostly a documentary survey.

B) Risk of non-permanence

The concept of non-permanence describes the risk that an expected beneficial effect on the environment, here a reduction in atmospheric greenhouse gases, can be easily reversed in the medium to long term and so be ephemeral. The risk is different according to the type of emission reduction:

- There is **no risk** of non-permanence when targeting **active greenhouse gases emissions reduction** levers. For example, if a change in farming practices lower the need for fuel use, a direct active emission is avoided. This reduction cannot be cancelled in the future. In this methodology, direct emission reductions have a low impact on the sum of claimable carbon credits.

- There is a **high risk** of non-permanence for levers of **carbon sequestration in biomass or soil** like afforestation because induced hazards or change of practices can provoke the re-emission of the stored carbon to the atmosphere. Peatland restoration can provide additional carbon storage through a capture of atmospheric CO_2 in the peat. Some changes in farming processes and land management can also directly benefit soil ability to hold carbon. However, in these contexts, change in the hydrological context, a reversal of the practices or a hazard (for example, a peatland fire) can cause the re-emission of this stored carbon. In this methodology, the carbon sequestration has a low impact on the sum of claimable carbon credits.

- There is a **lower risk** of non-permanence for levers of **indirect carbon emission reduction levers from biomass or soils** as the project reversal does not lead to a nullification of the past positive effects. An active lever (like drain blocking) will cause indirect effect, the raising of the water table, limiting the CO_2 emissions from peat. This effect is not totally controllable and subject to changes in the local context. Induced hazards or change of practices can cause a return of the CO_2 emissions from the peat. Here a risk can also be that the actions of rewetting are not successful enough compared to the projected scenario because of unanticipated factors (not enough water table elevation and vegetation changes and so less GHG-emission reduction). In this methodology, the indirect carbon emission reductions through different means of peat preservation have, by far, the biggest impact on the sum of claimable carbon credits.

We can deal with this non-permanence risk by adding a discount rate to the credits or by requiring a minimum duration of the project, which must be guaranteed at the start. The carbon credits should only be valid for the duration that the initially intended project is carried out unchanged. If changes are made or observed within this period: the project needs to be reassessed. Changes can lead to the continuation of carbon-credits, their increase or discard even with back casting/deleting of expected credits. So, there's a need to make provisions in the quantification and issuance of credits: being conservative and holding back a part of the credits until after periodic review has shown them to be delivered. However, not all the credits could be result-based and delivered ex-post as the project proponent needs a part of them ex ante to avoid a big economic risk by covering the cost of the restoration project.

C) Possible leakage sources

Leakage effects refer to leaks in the project boundaries. This covers negative effects that occur outside the project area, but because 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. Here are the potential leakage sources:

- A peat grassland used for pasturing or haymaking is rewetted, this results in emission reductions but can also reduce fodder production. To counter this, the same farmer can:
  - 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. This effect is normally prevented by the new reglementary framework of the CAP 2023-2027 that forbade drainage of further peatlands.
  - buy more fodder on the market which could also outsource some GHG-emission. Most of the time, this fodder will be bought locally, so still in the new reglementary framework of the CAP 2023-2027 that forbade drainage of further peatlands. However, the farmer should not import animal food from the international market to replace the reduction of its fodder production.
  - alternatively, the farmer could fundamental review the business livestock strategy running stock most appropriate to the new conditions at a minimum costs base. The MSO concept envisages working with natural processes and cycles, avoiding increasing costs by actively attempting to push against those natural processes.
- The cessation of fossil peat excavation activities is not considered on the project boundary to avoid leakages. In fact, to continue to answer the demand of peat (mainly for its organic substrate use), other peatland outside the project area could be excavated. Peat extraction is banned in most of northwest Europe countries, but emissions can be displaced to eastern European countries.

It is preferable to include leakage effects in total GHG-effect accounting of a project, but these effects are highly project specific and can be quite difficult to quantify (effects on the market, local hydrology, international outsourcing of the emissions…).

D) Other limits when assessing greenhouse gases emission reduction from the rewetting of peatlands

Site preparation

Site preparation refers to all activities required for rewetting, such as removal of topsoil, trees and other vegetation or creating water management infrastructure. GHG-effects of such activities can be substantial, especially for small scale projects in a drained landscape. Creation of further damage through use of vehicles (helicopters, excavators…) on sensitive peatland during restoration is also possible. However, the range of activities and effects is very project specific. An audit from the MoorLIFE project *(P. Titterton & J. Benson, 2022)* revealed that the CO2 emissions produced by site preparation were 37 times lower than the amount of CO2 emissions that were lost annually from the areas of bare peat one year after restoration was completed, with these benefits continuing to occur per year. So, the emissions from site preparation are quite negligible compared to the emission reduction allowed by rewetting. It's even more negligible the longer the contract is as emissions from site preparation are being increasingly diluted in each year's emission reductions. Therefore, it is important to guarantee a minimum contractual period.

Ecological developments following rewetting

The sudden change brought by rewetting result in significant ecological developments. However, the ecosystem need time to adjust to this new environment. 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 a more-or-less stable situation after strong rewetting. Secondly, during this period, the vegetation will take different transitional shapes that are each linked to different greenhouse gases emissions factors. Still, gradual vegetation and management change can be simulated using repeated GEST calculations. It's possible to do this calculation ex ante using predictions based on vegetation succession schemes done by experts and/or scientific literature. Ex post, it's also possible to do regular auditing every 5 to 10 years by monitoring water levels and vegetation on the project site. It allows to adjust in real time the greenhouse gases emission reduction assessment using the GEST.

Initial emission spikes

Heightened methane emissions in the first few years after rewetting (methane spikes) are reported in the scientific literature. Theoretically it seems plausible that these occur, because of large amounts of easily degradable organic matter that is present in the soil following years of drainage and fertilisation. 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. As emissions from the methane spikes are only occurring the first few years after rewetting, they are being increasingly diluted in each year's emission reductions. Therefore, it is important to guarantee a minimum contractual period as it makes the effects of this uncertainty more negligeable.

V- The validation and verification process

A third-party auditor is necessary to validate independently the different steps of the calculation and certification process of the carbon credits delivered from the implementation of a restoration project. They should be completely independent both from the buyers and sellers of carbon credits. The auditor should be external expert with a good understanding of how peatlands and their carbon emission reduction levers work (such as OF & G, Soil Association…). More precisely, they should be able to identify a non-compliance and understand its consequences. An expert on wetland vegetation is for example needed when using the GEST approach. There are two necessary steps where the auditor should be involved: first, there is the initial validation of the project and then, several verifications to ensure that the expected carbon emission reductions are realistic regarding the site evolution.

When more potential auditors are trained, the competition between verification companies increases. This could be a lever to make the price of the verification lower. However, to pull this lever effectively, there is a need for the peatland carbon credit market to be big enough to be attractive for these companies. As the validation and verification process contains fixed costs, the transaction costs can become prohibitive for projects that start with lower levels of degradation as they sell less carbon credits. Different levels of verification with simpler ones for projects that sell less carbon credits could be a solution to keep them attractive. Overall, keeping the methodologies and verifications process simple as much as possible is important to ensure that the greatest proportion of funds from credits ends up in project support and not in the technical and administrative process.

A) Before the project implementation: a validation of the suitability

As a first step, the auditor reviews the project proposition to ensure that it meets the objectives and requirements of the carbon credit methodology. A project document outlining the plan with restoration actions, expected results and longevity of the restoration will be registered by the project proponent. Then different check needs to be done by the auditor:

- The **conformity of the site** needs to be ensured: it needs to be a peatland with a minimum depth of peat with no activities forbidden by the methodology and a potential for carbon emission reduction.
- There is a need to verify the **eligibility of the project actions** both restoration and planned management as carbon emission reduction levers considered in the carbon credits methodology.
- The **economic additionality** of the project should be tested.
- Ensuring that the **expected carbon reduction emission calculation is realistic** given the initial conditions and actions planned.
- A good **assessment of the different risks** and their importance (uncertainties, non-permanence, leakage) should be validated. Discounts on carbon credits can be suggested if the risks are too high.

B) After the project implementation: a verification of the carbon reduction estimates

A **first verification** needs to be done a short time (around one year) after the restoration. This first step is to verify if all actions were carried out concretely as planned. It can be done only with a documentary verification which is a verification of the bills, accounting, and pictures of the projects. Additional verifications can be done directly on the ground. They can be systematic or random or not even required. The use of random more advanced verifications is a way to keep the overall cost of verification lower.

Then, **recurrent audits** need to be done at least every 5 to 10 years. These verifications need to be more frequent at the start of the project contract and less at the end because the first years are the most crucial to notice the success of a restoration project. The objective of these verifications is to ensure that the site is progressing as expected and so reducing the good amount of carbon emissions. On the ground, we can verify the effects of the project on groundwater levels and vegetation, for example using continuous monitoring of GW-levels. Bare peat reduction is also an example of a simple indicator to evaluate a project's success in some cases. Depending on the site development, climate and other environmental expected outcomes can be validated or not. If not, the initial plan needs to be adjusted to consider the real evolution of the site.

C) Monitoring of the project: ensuring a cost-effective follow-up

A follow up document and dataset could be updated more regularly by the project proponent to make the auditor gain time.

For **vegetation monitoring**, annual surveys can be done to monitor impacts of restoration on vegetation and bare peat reduction. However, most of the individual landowners and farmers don't have this vegetation expertise. Aerial mapping is a way to limit the need to go directly on the sites which can be an expensive process for verification however field visits are still necessary to confirm the findings. This is a method widely used in the Peatland Code, but we can also imagine an identification of GEST-units from aerial photos.

For **groundwater level-monitoring**, it's important to assess the good amount of dip wells needed to have a decent representation of GW-level developments following rewetting. This can be somewhat site-specific. The use of automated GW-level monitoring is a way to make the follow up less time and money consuming. On average, it costs 600€ for the sensor plus 50 to 100€ for the data portal which is more affordable than the staff costs of manual monitoring.

For **greenhouse gases emission monitoring**, it could only realistically be done on a tiny fraction of the projects as it's a very resource intensive process (need for equipment and regular manpower). However, it's important to keep this more intensive monitoring on some sites to improve the knowledge with new reference points. For example, it's necessary to refine the emission factors used on the different carbon credits methodologies for different site types.

VI- The co-benefits of the restoration of peatlands

As stated, peatland restoration projects have positive impacts on greenhouse gases emission reduction and can have mixed impacts on farm profitability. However other side effects of peatland restoration need to be considered. They can be both positive or negative, economic, social, or environmental.

In 2015, all United Nations Member States adopted the 2030 Agenda for Sustainable Development which share 17 Sustainable Development Goals (SDGs). These goals are a well-recognised framework to identify what type of positive impacts a project could have. The targeted actions of this carbon credits methodology make it possible to contribute to 4 of these positive 17 goals:

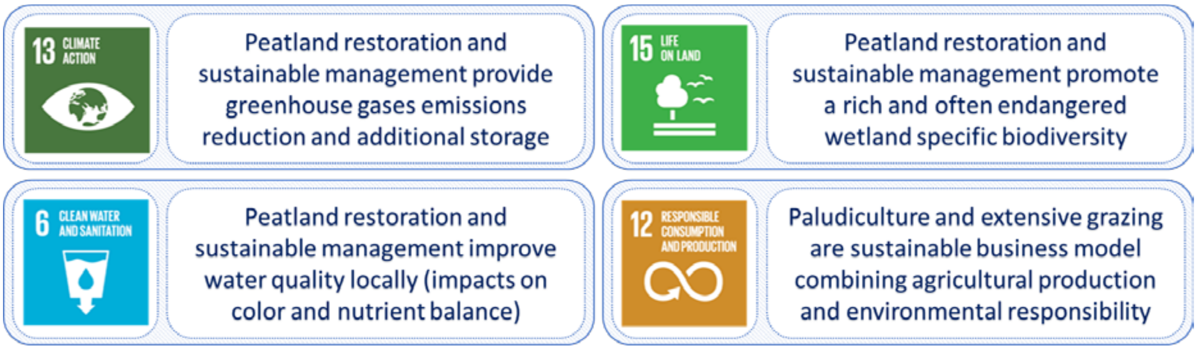


Figure 8: Peatland carbon credits targeted sustainable development goals

In a carbon credits methodology, the other environmental parameters affected by the restoration that are mostly positive and not related to greenhouse gases emission reductions are called environmental co-benefits. There are important because they can be a big added value for peatland restoration projects both when bundled with carbon credits or valorised separately in a layered scheme (monetize water for example). The German MoorFutures® 2.0 standard provides a framework to identify, quantify cost-effectively and possibly valorise these co-benefits in a bundle with carbon credits *(Hans Joosten, Kristina Brust, John Couwenberg & Al., 2015)*. It is a good first step towards the valorisation of these co-benefits, but it's still an area of potential further research.

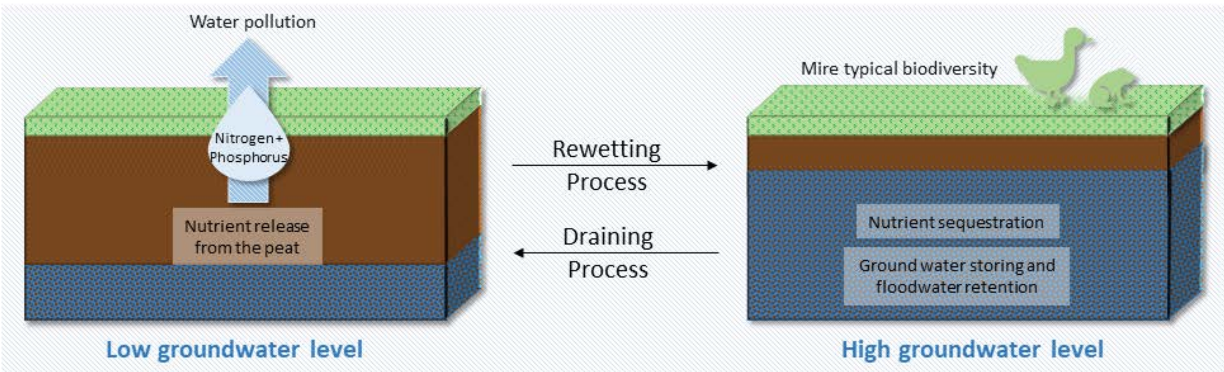


Figure 9: The effect of water level raising on other environmental co-benefits

A) Improvement of water quality

Functional peatlands are removing nutrients like nitrogen and phosphorus from the water of their environment. They are both fixed in the accumulating peat and transformed through biochemical reactions. In high concentration, these nutrients are polluting the water quality and promoting the eutrophication of the environment. In North German conditions, Gelbretch and al. (2001) have stated that a peatland can store 4.4-11.9 kg/ha/y of nitrogen.

Peatland drainage is causing the mineralisation of the peat releasing all of the fixed nutrients in the surrounding waters. This mineralisation can also have negative impacts on water colour because of dissolved organic carbon. Gerth and Matthey (1991) have calculated that a drained fen grassland can emit 27,5kg/ha of nitrogen every winter. As such, it's important to keep the peat wet to avoid nutrient releases in water due to peat mineralisation. Here too, peatland restoration through rewetting appears to be the best solution to limit these pollutions. Scheffer and Blankenburg (2002) have observed an average release of nitrogen from rewetted peat soils around 2kg/ha/y which is far less than in a degraded peatland. The amount of nitrogen and phosphorus emission reduction that we can expect can be quite varied from one site to another as it is directly linked to water depth evolutions, level of degradation and CNP ratio of the peat and so is also linked to the management history of the peatland (manure application, drain elevation, soil type…).

Some tools can help the quantification of the nitrogen and phosphorus emission reduction. For nitrogen, the MoorFutures 2.0 scheme suggests a variant of the GEST approach named the NEST (Nitrogen Emissions Site Type) approach. Like with the GEST approach, the identification of vegetation types allows an estimation of the water table level. Then, the nitrogen release is linearly correlated with the water depth *(Van Beek et al, 2007)*. It's necessary to be as conservative as possible when using this approach. For more robust quantification, modelling tools can be used but are more expensive and time consuming in data collection.

B) Flood mitigation

Functional wet peatlands act both as:

- a retention area that widens, slows down and stores a part of the water flow. If a single small, rewetted peatland will not have a big impact, the multiplication of these kinds of retention areas can have a great impact on flood mitigation. Therefore, the positive impact could only be observed at a territorial level on a specific watershed. It's possible to calculate the added retention volume following a peatland rewetting project by considering the topography of the terrain and the evolution of the water level.

- a buffer zone where floods do not cause significant economic damages. If dry agriculture is particularly sensitive to flooding, rewetted peatlands, and most of the activities on it will not be significantly damaged by periodical floodings. Moreover, as there are no significant risks on rewetted peatlands, the need for dykes is lowered, reducing the associated maintenance costs.

C) Increase in groundwater storing

As stated, functional peatlands slow down and store a proportion of the input water flow that takes more time to exit the peatland area. On the contrary, artificial drainage makes the input water go out of the peatland area faster. In some cases, it also causes a loss of stored water in the peatland causing an increased influx of water from its supplying aquifer. Degraded peatlands also have reduced infiltration that penalise the recharge of the underlying aquifer. All these hydrological mechanisms have a direct impact on the water table level that decreases with drainage and can potentially increase with rewetting.

With the monitoring of water level, the gain of groundwater stored on the area of the restoration site can be easily calculated. However, rewetting will probably have a wider impact by also increasing the water level and so groundwater storage of adjacent areas. Calculating the change of drained volume following rewetting can help to consider this wider and more complete calculation of gain in groundwater storing.

D) Increase of a wet-specific biodiversity

Degrading peatlands are not stable habitats with the most degraded sites being poor in biodiversity (some sites are even barren). As observed with the GEST approach, the type of vegetation of a peatland is directly linked to the level of the water table. Therefore, rewetting is a solution that promotes a shift of the flora and fauna toward a biodiversity which is both more resilient and specific to wetlands. Wetlands are wonderful environments for biodiversity as they provide habitat for 40% of the known species. This specific biodiversity is threatened at a global level. Indeed, 87% of the total surface of wetlands has been lost during the last 300 years. This decline of wetlands directly threatens the many species that depend on these environments. One fourth of the wetland specific species are nowadays threatened by extinction. *(IPBES, 2019)*

Figures:

Tables:

Equations:

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Annex:

Table: Identification key for different GES Site Types

N°	GEST	Soil Moisture	Vegetation type	Some indicative species
	Grassland			
G1	Dry to moderately moist grassland	(2~), 2+, 2-	Lolio-Potentillion anserinae;	Lolium pratense; L. sp.; Festuca syn. Schenodorus sp.; Dactylis glomerata;
G2	Moist grassland	3+, 3+/2+	Lolio-Potentillion anserinae; Cynosurion cristati	Lolium pratense; L. sp.; Festuca syn. Schenodorus sp.; Dactylis glomerata;
G3	Moist to very moist grassland	4+/3+	Ranuculo-Alopecuretum geniculati; Cynosurion cristati; Calthion palustris; Arrhenatheretum elatioris	Ranunculus repens/acris; Cynosurus cristatus; Holcus lanatus; Cardamine pratensis; Cirsium palustre
G3f	Periodically flooded grasslands	4~, 3~	Ranuculo-Alopecuretum geniculati; Cynosurion cristati; Calthion palustris; Alopecurion pratensis; Arrhenatheretum elatioris	Alopercurus pratensis; Holcus lanatus; Cardamine pratensis; Cirsium palustre
G3s	Moist to very moist grassland with shunt species	4+/3+, 3~, (3+, 3+/2+)	Calthion palustris;Alopecurion pratensis; Magnocaricion	Juncus effusus; other Jucus spp. / tall sedges (e.g. Cx. Riparia / acutiformis / acuta
G3m	Moist to very moist acidic *Molinia* meadows	4+/3+	Junco-Molinion	Molinia caerulea; Juncus conglomeratus; Cx. Nigra;
G4	Very moist grassland	4+, 4~	Calthion palustris; Magnocaricion	
G4s	Very moist grassland with shunt species	4+	Calthion palustris; Magnocaricion	Juncus effusus; other Jucus spp. / tall sedges (e.g. Cx. Riparia / acutiformis / acuta
G5	Wet grassland	5+/4+	Calthion palustris; Magnocaricion	
G5s	Wet grassland with shunt species	5+, 5+/4+, (4~)	Calthion palustris; Magnocaricion	Juncus effusus; other Jucus spp. / tall sedges (e.g. Cx. Riparia / acutiformis / acuta
	Cropland			
A1	Dry to moderately moist arable land	2+, 2-	N/A	
A2	Moist arable land	3+, 3+/2+	N/A	
	Unmanaged			
U1	Moist bare peat	3~, 3+	n/a	
U2	Moist bog heath	3+	Ericetum tetralicis typicum; only Erica tetralix	Erica tetralix
U3	Moist Reeds	3+, (3~)	Typho-Phragmitetum	
U6	Very moist bog heath	(5+/4+), 4+	Ericetum tetralicis	sphagna
U7	Very moist forbs and sedges	(5+/4+), 4+, (4+/3+)	Filipendulion / Caricion gracilis (Caricion elatae?)	
U8	Very moist *Sphagnum* lawn	(5+/4+), 4+	Sphagnetum cuspidati-obesi / Sphagno palustris ericetum	
U9	Very moist tall sedges	(5+/4+), 4~, 4+, (4+/3+)	Caricion gracilis	
U10	Wet bare peat	5+/4+	n/a	
U11	Wet meadows and forbs	5+	Caltion palustris	
U12	Wet small sedges with mosses	5+ (4+)	Caricion davallianae	
U13	Wet sphagnum lawn	5+, (5+/4+)	Sphagnetum cuspidati-obesi / Sphagno palustris ericetum	
U14	Wet tall reeds	(5~), 5+, (5+/4+)	Typho-Phragmitetum	
U15	Wet tall sedges	5~, 5+, (5+/4+)	Caricion gracilis; Caricion elatae	
U16	Wet bog heath	6+/5+, 5+, (5+/4+)	Ericetum tetralicis sphagnetosum	sphagnum >80%
U17	Very wet tall sedges and Typha	6+, 6+/5+	Typho-Phragmitetum; Caricion gracilis; Caricion elatae	Typha sp; Phragmites australis

U18	Very wet *Phragmites* reeds	6+, (6+/5+, 5~)	Phragmites mass vegetation	Phragmites australis
U19	Wet to very wet *Sphagnum* hollows	6+, (5+)	Rhynchosporion albae	Eriophorum angustifolium; Rhynchospora alba
U20	Flooded tall reeds (> 20 cm above surface)	6+	Typho-Phragmitetum	
	Special GESTs			
S1	Dry to moderately moist grassland on peaty soils (Anmoor)	2-, 2+/2-, 2+	Ranuculo-Alopecuretum geniculati; Cynosurion cristati; Calthion palustris; Arrhenatheretum elatioris	
S2	Dry to moderately moist arable land on peaty soils(Anmoor)	2+, 2-	n/a	
S3	Cropland (2+) flooded in summer (wet year)	3+	n/a	
S4	Grassland (2+/3+) flooded in summer (wet year)	(5+), 5+/4+, (4+)	Lolio-Potentillion anserinae; Cynosurion cristati	
S5	Simulated harvest (Paludiculture)	(5+), 5+/4+	Typha mass vegetation?	
S6	Wet tall reeds (dry year)	(5+/4+), 4~, 4+	Typho-Phragmitetum	
S7	*Sphagnum* lawn at former peat cut areas	5+, 5+/4+	Rhynchosporion albae	
S8	Very wet reeds with lateral import of organic matter	6+, 6+/5+, (5~, 5+)	Typho-Phragmitetum	
S9	Ditches in low intensity grassland	6+	open water	

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