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Validating the bespoke model for the social and economic impact of Carbon farming and developing a theoretical model for the impact of Paludiculture

REPORT

Validating the bespoke model for the social and economic impact of Carbon farming and developing a theoretical model for the impact of Paludiculture

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Executive Summary

Peatlands account for only 3% (circa 4 million km2) of the total global land area while they contain more than 30% of all global soil carbon weighing in at roughly 500 Gigatonnes (Gt). When drained or burned for agriculture, peatlands release centuries of stored carbon into the atmosphere, turning from being a carbon sink to a carbon source. CO_2 emissions from drained and burned peatlands equate to circa 10% of all annual fossil fuel emissions.

About 15% of the world's peatlands have been drained for agricultural conversion, burned or mined for fuel or horticultural products and globally the EU is the second largest emitter of GHG from damaged peatlands (0.22 Gt CO_2e/year or 15% of total global peatland emissions). This is equivalent to circa 5% of the official EU greenhouse gas emissions total of 4.483 Gt CO_2e/year in 2017 (including UK). Sustainable management of peat soils, with higher water tables, could deliver significant emission savings and enable areas to be farmed for longer.

Carbon farming is an alternative land management practice that could provide financial incentives to the actors of the bioeconomy for climate-friendly activities resulting in carbon removals and storage, thus creating a new source of income, and helping them adapt their businesses to withstand the effects of climate change. It involves raising the water table and practicing wet agriculture.
As part of the Care-Peat project a carbon farm pilot was established in the UK and a preliminary financial feasibility model has been built. The model highlights that carbon farming, peatland restoration and rewetting can be financed through carbon credits that may be exchanged in the markets, or bought directly from project developers (for example, land managers, NGOs, trust funds or public bodies) or from intermediaries.

The development of the financial feasibility and pricing model also revealed specific socio-economic parameters in trading ecosystem services that need further defining and validation during the next stage of this work. The specific socio-economic parameters are presented under the headings of modelling, capacity, and social. During validation these specific socio-economic parameters are discussed within the framework of the theoretical implications listed above.
Initiating, implementing, maintaining, and managing a peatland restoration scheme would require significant capacity inputs initially and over a fifty-year period. These capacity inputs would either be provided by the farmer, or the farmer would need to access these inputs from specialist support.

Carbon farming initiatives should encourage the development of a range of locally or regionally tailored result-based pilot schemes for carbon farming, and meanwhile promote the more widespread adoption of well-designed, action-based or hybrid schemes to make the initial step towards a real shift in the agriculture sector's contribution to EU climate targets. The experience gathered through pilot schemes will be essential to upscale result-based carbon farming, by improving design elements and expanding farmers' knowledge and understanding of the potential benefits to them. In addition to the specific examination of carbon farming primarily based on specific experiences derived from work carried out on the Winmarleigh carbon farm, we also discuss as part of this deliverable a number of possible paludiculture (wetland farming) practices based on research carried out by other projects.

Introduction and scope

In the UK pilot a carbon farm has been established on existing farmland. A bespoke model for the social and economic impacts of the farm has been developed based on reviewing related carbon standards and case studies of payments for ecosystem services. Parallel to this a theoretical model for the social and economic impact of paludiculture is examined to analyse the business case for crops, products, or services to be sold from wet or rewetted peatlands. This is also informed by related work being carried out by the other partners involved in the consortium in Ireland, Belgium, the Netherlands and France.

The aim of this document is to outline and define Carbon Farming and paludiculture in Europe to support wet peatlands and to minimise carbon emissions from degraded peatlands. This report aims to provide the basis for developing measures to adopt and to enhance peatland restoration.
Therefore, the following topics are presented and discussed:

- Carbon farming and paludiculture
- Economic aspects of rewetting and peatland restoration
- Social impacts of rewetting and peatland restoration

This document is part of a draft toolkit of different socio-economic models and use cases to promote the roll-out of peatland restoration based on literature, theoretical models, Care-Peat pilots, our Decision Support Tool and other investigations. We include input from existing models and cases and from other EU projects.

A companion spreadsheet for this document is provided as an economic forecasting and pricing tool entitled:

Care-Peat - Carbon Farming - Financial Feasibility and Pricing Tool

Context

It is important to understand the significance of peatlands in the context of global Greenhouse Gas (GHG) emissions in order to fully appreciate the need for developing socio-economic models to finance their restoration and preservation on a sustainable basis.

According to the MoorFutures®[1] policy document, peatlands account for only 3% (circa 4 million km2) of the total global land area while they contain more than 30% of all global soil carbon weighing in at roughly 500 Gigatonnes (Gt). To put this in context, that is more than 1,000 times the weight of every single human being currently living on planet Earth or 100 billion African bull elephants or twice the total amount of carbon held in the biomass of all the world's forests.

Peat-forming lands are particularly rich in organic matter. Peat accumulates in areas where the decomposition of plants is slowed due to wet conditions, which results in a large store of carbon accumulated over thousands of years. **Fully functional, healthy peatlands are the most space efficient long-term carbon store and sink in our planet's biosphere.** This carbon-storing organic matter (peat) is derived from dead and decaying plant material under conditions of permanent water saturation. Peatlands are characterised by an incomplete cycling of matter, resulting in a positive carbon balance.

However, many peatlands are degraded and emit rather than store carbon. Global annual GHG emissions from drained organic soils are roughly 1.6 Gigatonnes CO_2e/year, at least twice that emitted directly from aviation. About 15% of the world's peatlands have been drained for agricultural conversion, burned or mined for fuel and horticultural products and **globally the EU is the second largest emitter** of GHG from drained peatlands (0.22 Gt CO_2e/year or 15% of total global peatland emissions). This is equivalent to circa 5% of the official EU greenhouse gas emissions total of 4.483 Gt CO_2eq/year in 2017. Peatland emissions are reported by EU countries in their National Inventory submissions to UNFCCC but are not yet fully accounted for in the National Inventories [from January 2021, the UK National Inventory does incorporate peatland emissions].

Europe is the continent with the largest peatland losses, where peat has ceased to accumulate in over 50% of former peat areas and few of our peatlands are in a near-natural or rewetted condition. When drained or burned, peatlands release centuries of stored carbon into the atmosphere, turning from being a carbon sink to a carbon source. CO_2 emissions from drained and burned peatlands equate to circa 10% of all annual fossil fuel emissions.

The largest peatland emitters in the EU are Germany, Finland, United Kingdom (in the EU pre-Brexit), Poland, Ireland, Romania, Sweden, Latvia, Lithuania, and the Netherlands. In most of these countries, drained peatlands contribute to more than 25% of total emissions from agriculture and agricultural land use while **99% of EU peatland emissions** are caused by **16 of the 28 EU Member States**. These emissions can be significantly reduced by raising water levels near to the surface (e.g. by drain blocking or by stopping pumping), which reduces emissions and protects the remaining peat carbon store.

[1] www.moorfutures.de

Afforestation on drained peatlands is an inappropriate mitigation measure and can result in increased net carbon emissions. In the long term, a complete cessation of peatland drainage and reversal of the effects of existing drainage is unavoidable if we want to reach the core goal of the Paris Agreement - zero net emissions by 2050. The EU and all its Member States have unanimously affirmed this goal.

The negative consequences of this type of land use are becoming increasingly obvious. Drainage allows oxygen to enter the soil, leading to microbial decomposition of the peat and thereby breakdown of the stored carbon leading to emission of substantial amounts of greenhouse gases. Further negative consequences of drainage are a reduction in water quality through the discharge of dissolved and particulate organic carbon to ground and surface water and land subsidence (1-2 cm yearly). This results in increasing drainage costs, higher flooding risks, reduced water quality and - ultimately - loss of productive land. Peatlands occur in almost all EU Member States, with a concentration in North-Western, Nordic and Eastern European countries.

Maintenance and sustainable use of peatlands is of importance for reducing GHG emissions and for climate change mitigation. Beside their role as a natural carbon sink, healthy peatlands provide many additional ecological services including contributions to water depuration, flood prevention and biodiversity conservation. Therefore, by preserving, protecting and restoring peatlands, we can reduce emissions and revive an essential ecosystem with high values for biodiversity conservation, climate regulation and human welfare.

In the EU NWE region emissions amount to 150 Mt CO_2e/year, which is greater than Belgium's total emissions from all sources. Yet emission estimates from degraded peatlands are inadequate and we currently lack effective strategies and methods to combat degradation and promote recovery. Regional differences in land ownership complicate the situation and limit the replicability and transferability of effective alternative management of peatlands. All relevant EU policies need to reflect this.

Within Care-Peat, nature organisations have worked together with landowner groups to demonstrate carbon savings potential by using pilots ranging from 2 to 250 ha. with five knowledge institutes from four countries working alongside to develop and test new techniques for improved peatland carbon assessment and accounting to highlight the region's natural potential for significant carbon reduction. The project also worked with innovative companies in the field of restoration and developed partnerships with local and regional stakeholders to increase the impact of pilots and maximise socio-economic benefits. Methods tested and validated will be transferred and replicated to users across the EU to determine the most appropriate management measures. Partners, who manage additional peatlands, will facilitate further restorations after the project ends to benefit both biodiversity and carbon reduction policies. The project continuously liaised with stakeholders and continued to build relationships with other projects to maximise exchange, cooperation, and dissemination.

Carbon Farming

4.1 Overview of Carbon Farming

The LULUCF sector (Land Use Land Use Change and Forestry) is crucial to reaching a climate-neutral economy, because it can capture CO_2 from the atmosphere. However, to encourage the agriculture and forestry sectors to deliver on climate action and contribute to the European Green Deal, it is necessary to create direct incentives for the adoption of climate-friendly practices, as currently there is no targeted policy tool to significantly incentivise the increase and protection of carbon sinks for individual land managers.

For this reason, the European Commission announced in the Farm to Fork Strategy [2] that in 2021 it would launch a Carbon Farming initiative[3] to promote a new green business model that rewards climate–friendly practices by land managers, based on the climate benefits they provide. In addition, as announced in the Circular Economy Action Plan[4], the Commission will develop a regulatory framework for certifying carbon removals based on robust and transparent carbon accounting to monitor and verify the authenticity of carbon removals.

Carbon farming will provide financial incentives to the actors of the bioeconomy for climate-friendly activities resulting in carbon removals and storage, thus creating a new source of income and helping them adapt their businesses to withstand the effects of climate change.
Examples of effective carbon farming practices include:

- Enhancing soil organic carbon in depleted arable land, which also improves the productivity and resilience of farming activities.
- Planting new forests, restoring degraded forests, and improving the management of existing forests.
- Supplying biomass for the production of long-lasting bio-based products.
- Protecting carbon-rich soils, such as grasslands and peatlands, thanks to appropriate management techniques.

The European Commission has already promoted carbon farming in its recommendations[5] on the Member States' CAP Strategic Plans and will continue outlining carbon farming possibilities.

[2] https://ec.europa.eu/food/farm2fork_en
[3] https://ec.europa.eu/clima/news/commission-sets-carbon-farming-initiative-motion_en
[4] https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en
[5] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-strategic-plans_en#cap-strategic-plans-recommendations

4.2 Outline of the UK Carbon Farm Pilot

The site of the UK carbon farm pilot for Care-Peat is a former lowland raised bog that was drained in the 1970s and converted to agricultural land used for livestock and winter feed crops. It borders Winmarleigh and Cockerham Moss Site of Special Scientific Interest (SSSI) which is a lowland raised bog. A large drain between the sites removed water from the farmland and, despite piling and other water retention measures, previously caused water loss on the SSSI raised bog. Lancashire Wildlife Trust (LWT) has owned most of the SSSI since 2012 and in 2019, LWT purchased the remaining part of the SSSI along with 20 ha of the neighbouring farmland, part of which is being used for the current pilot. The carbon farm pilot is a collaboration between Lancashire Wildlife Trust, BeadaMoss® and Manchester Metropolitan University.

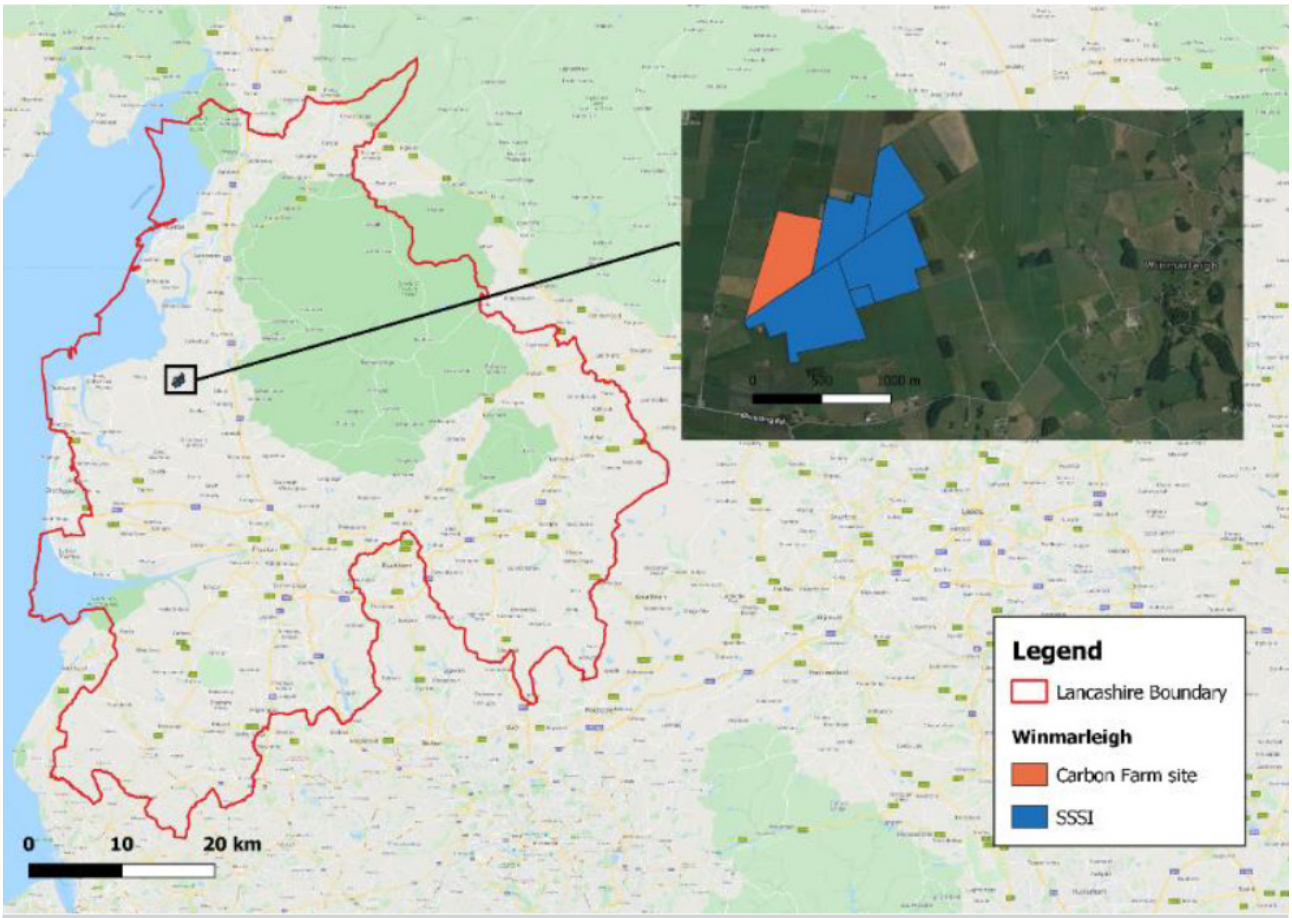

Figure 1. Location of Winmarleigh carbon farm pilot site, adjacent to Winmarleigh Moss SSSI.

The main objective for this pilot is the change in management of 3 ha of farmland to a 'Carbon Farm' planted with *Sphagnum* moss, designed to rapidly turn the site from a carbon source to a carbon sink. Methods involved raising the water table through blocking drains and ditches, the removal (and re-use on site) of the nutrient and seed-rich organic topsoil and planting of a permanent, non-harvested cover crop of specialised bog species (*Sphagnum*).

The 'product' of the farm is carbon captured through photosynthesis into vegetation which, in the longer term, will form peat. This contributes to reduction of carbon dioxide in the atmosphere and lowering of emissions compared to the former land use, protecting existing carbon stored in the peat.

The intention of the pilot is to demonstrate land management options for farmland on peat soils that are climate friendly and financially viable. Financing could be provided by corporate carbon offsetting or blended finance with government subsidies and payments for ecosystem services (PES) schemes.

4.3 Defining Carbon Farming

4.3.1 What is Carbon Farming?

Carbon farming[6] involves practices that improve the rate at which CO_2 is removed from the atmosphere and converted to plant material and/or soil organic matter. Carbon farming is successful when carbon gains, resulting from enhanced land management and/or conservation practices, exceed carbon losses. Emerging funding options include "carbon credits." Basic considerations for generating carbon credits from peatland rewetting were summarised in 2011 and the first carbon credits from peatland rewetting were sold in 2011 (from the German regional Moorfutures scheme), a first national scheme followed in 2017 (the UK Peatland Code), and in 2017 a methodology for rewetting drained temperate peatlands was launched under the Verified Carbon Standard. Carbon farming includes peatland restoration and most forms of paludiculture, i.e., carbon farming on organic soils is, if combined with productive use of the plant biomass, paludiculture. Since then, additional carbon credit schemes have been launched in the UK and EU.

Carbon farming refers to the management of carbon pools, flows and GHG fluxes at farm level, with the purpose of mitigating climate change.[7]

Farm-level payments for carbon farming can be action-based or result-based. Action-based schemes reward land managers for putting in place climate-friendly agricultural practices. In result-based schemes the payment to land managers is directly linked to measurable indicators of the climate benefits they provide. The advantage of this latter approach is that the use of public or private funds is more directly linked to the intended climate objective. In addition, farmers enjoy a greater degree of flexibility, as they are free to choose their management strategies to achieve the desired results, rather than following a set of rules. Hybrid schemes combine elements of action- and result-based schemes, typically offering a payment to carry out a set of management actions, which is 'topped up' if farmers can demonstrate that they have delivered additional climate benefits.

[6] Tanneberger, F., Appulo, L., Ewert, S., Lakner, S., Ó Brolcháin, N., Peters, J. and Wichtmann, W., 2021. The Power of NatureBased Solutions: How Peatlands Can Help Us to Achieve Key EU Sustainability Objectives. Advanced Sustainable Systems, 5(1), p.2000146.
[7] COWI, Ecologic Institute and IEEP (2021) Technical Guidance Handbook - setting up and implementing result-based carbon farming mechanisms in the EU Report to the European Commission, DG Climate Action, under Contract No. CLIMA/C.3/ETU/2018/007. COWI, Kongens Lyngby.

4.3.2 Result-based carbon farming

Result-based carbon farming in peatlands is a promising option because of the high level of potential climate benefits per hectare and it mitigates against the **paradox of additionality** identified in the Care-Peat and CConnects White Paper: Towards a Carbon Credit and Blue Credit scheme for Peatlands where damaging practices can potentially be rewarded to a greater extent than good environmental and agricultural practices. Peatland restoration and rewetting can be financed through carbon credits that may be exchanged in the markets, or bought directly from project developers (for example, land managers, NGOs, trust funds or public bodies) or from intermediaries. The choice among these options will depend on the specific characteristics of the peatland, including the institutional setting.

GHG fluxes from peatlands and emission factors in peatlands are well correlated to water table levels, land use and vegetation type. In many peatlands, the water level and thus land use are determined by drainage, either in below ground piping or open ditches, sometimes with active pumping. Reducing or ending drainage will be a prerequisite for rewetting and restoration. Therefore, payments can rely on monitoring of proxy indicators such as vegetation for GHG fluxes or water table depth rather than on direct measuring. This feature makes monitoring, reporting and verification (MRV) simpler and more cost efficient.

The initiatives reviewed for this study base the payment on avoided emissions, but buyers are generally willing to pay a higher price to secure co-benefits. In fact, the carbon credit prices of the ongoing carbon farming initiatives are generally higher than those traded in the international voluntary carbon markets. Design options to measure and reward co-benefits beyond climate change mitigation, particularly related to water quality and biodiversity, should be considered in future schemes. Linking credits and payments to the slower process of sequestration of carbon in peatlands, rather than only to avoided emissions, should be further explored.

In the 2014-2020 CAP programming period peatland managers faced a trade-off between CAP payments and carbon farming. In fact, although Member States may offer support for peatland restoration and rewetting under their Rural Development Programmes (RDPs), the resulting rewetted peatlands may no longer be eligible for CAP Pillar 1 direct payments. This barrier to uptake could be overcome if rewetted peatlands were made eligible for both Pillar 1 direct payments and rural development interventions in the 2021-27 programming period.

The nations of the UK will set their own regimes for agricultural support after Brexit. In England ministers are moving to a system of 'payment for public goods', with a higher tier Landscape Recovery Scheme aimed at blending public funds with private income from ecosystem services such as GHG reductions.

4.4 The case for Carbon Farming

Despite the predominance of agriculture on lowland peat soils, it is arguably not as valuable as some of the other services provided by those peat soils. Initial assessment of the natural capital account for the lowland peat soils in NW England shows it to effectively be in the negative because the value of the other ecosystem services currently being supplied by them cannot make up for that lost from carbon emissions being emitted through current, drainage-based land practices. Lowland peat soil areas in the UK under cropland are the most productive but produce the most emissions. Once environmental externalities are valued, current agricultural practices deliver considerable costs to society that could be ameliorated by conversion to land management systems that work with higher water table levels, such as wetter farming.

The productivity and profitability of drainage-based peatland agriculture come at the expense of other ecosystem services. Peat is an organic material that is around 90% water by volume when waterlogged.[10] Cultivation of peat soils (for food and fibre crops that require dry conditions) requires drainage; it is estimated that 90% of UK lowland peat area has been drained for agriculture.[6] Whilst this drainage has provided some of the UK's most fertile agricultural land, it is a key driver in peatland degradation and loss of associated ecosystem functions and habitats for unique peatland wildlife. Ongoing drainage and lowering of the peat water table leads to the decomposition of plant material in the peat and significant peat loss and shrinkage with subsequent peat subsidence, lowering of the land surface and large-scale CO_2 emissions.[10,8]

Changes in water level management will likely play a key part in that change in the management of lowland peatlands, since raising and stabilising the peatlands' water level can address many of the problems caused by peatland drainage. The rate of peat subsidence could be reduced or even stopped by raising water levels;[10,12] among other benefits this would crucially reduce greenhouse gas emissions.

Sustainable management of lowland peat soils, with higher water tables, could deliver significant emission savings and enable areas to be farmed for longer. Research by Evans et al (2021) indicates that halving the drainage depth across all peatlands under intensive agricultural use in the UK, most of which is in England, could reduce emissions by around 70%. However, peatlands, once restored and/or rewetted, can no longer be used for conventional drainage-based agriculture and will not be suitable and feasible in all areas. Since much lowland peat has been converted to prime arable land, restoring it to a natural or semi-natural state has a high opportunity cost associated with lost agricultural production - there are concerns that it could impact on food security, have implications for livelihoods and regional economies, and simply displace agricultural emissions to further afield.[9,10]

Emissions from UK farms presently amount to 45.6 million tonnes of carbon dioxide (CO_2) equivalent a year – about one tenth of UK GHG emissions.

The NFU's Achieving Net Zero: Farming's 2040 goal states that the sector will need a range of measures to achieve its goal, including those that improve land management and change land use to capture more carbon. As part of this, peatland and wetland restoration might deliver GHG savings of up to 3 Mt CO_2e per year.

There is a need to develop a new sustainable agricultural model with new solutions to sustainably manage lowland peatlands currently in agricultural use. Raising the water table and converting to wet agriculture production represents one potential solution that balances the need to mitigate the large GHG emissions and soil carbon losses associated with drainage-based peatland agriculture whilst continuing agricultural output and supporting rural livelihoods. In the UK context the 6th carbon budget[9] considers two watertable management options for the area of lowland cropland peat that remains in conventional agriculture:

- Dynamic watertable management (seasonal rewetting) involves raising the water-table up to 10 cm below the peat surface during the winter months when there are no crops in the ground, which is then drained to between 40-100 cm below the surface during the growing season. Assuming an average water table depth of 50 cm for the year, they estimate that emissions could fall by less than half to around 18 tCO_2e / hectare / year.
- A permanent increase of the watertable to an average of 40 cm below the peat surface all year round could deliver higher savings, with annual emissions falling further to 16 tCO_2e / hectare.

The UK Carbon Farm Pilot focuses on the second option: a permanent increase of the water table. **Carbon Farming** does not provide a harvestable crop to sell but can be a vital part of a wetter farming system on lowland peat soils.

Carbon farming involves implementing practices that are known to improve the rate at which CO_2 is removed from the atmosphere and converted to plant material and soil organic matter. Specifically, to wetter farming of lowland peatlands it can involve growing a permanent, non-harvested cover crop of specialised bog species (*Sphagnum*), grown for the purpose of protecting soil carbon and sequestering further atmospheric carbon.

The 'product' of the farm is the carbon that is captured in the vegetation and soils, and the reduction of carbon emissions. It is not about harvesting a crop to sell, although 'selling' the carbon kept in the soil (carbon offsetting) would provide some income to "Carbon Farmers".

Why grow *Sphagnum*? Peat is formed in waterlogged, acidic, conditions, which are very low in nutrients, and only very specialised plants - like *Sphagnum* – can thrive in it, but more importantly for climate change, the carbon in these plants is trapped in perpetuity. As *Sphagnum* moss grows, underlying *Sphagnum* vegetation decays but decomposes very slowly, forming peat, the majority of which is carbon – effectively absorbing CO_2 from the atmosphere and burying it as peat below the *Sphagnum*.
Target areas: Any area of lowland peat under agriculture, but especially poor quality, marginal land, or degraded peatlands with shallow peat in need of replenishment or building up. Focus areas could be those adjacent to wetland conservation areas to provide a hydrological buffer between conservation areas and more intensive agriculture.

Wet agriculture has been described as an 'inclusive solution' since it allows continued productive use and sustainable economic assets whilst keeping water tables higher on peatlands that sustain other vital provisioning and regulating ecosystem services - including protection of peat soils and carbon storage, flood regulation and other regulating services. In addition, in certain locations restoring and reconnecting wetlands in a targeted way across a lowland agricultural catchment can potentially improve overall agricultural productivity by balancing water supply and buffering against soil loss. Wetter farming allows us to use provisioning capacity of peatlands without compromising regulating services.

It is important to bear in mind what wet agriculture is not – the primary activity is agriculture with a clear production goal, not nature conservation. Be that as it may, there are numerous examples that show that wetter ways of farming on peat soils support and enhance wetland conservation as well as generating a wider range of ecosystem benefits associated with wetland habitats such as water buffering, nutrient retention, local climate cooling and habitat provision for rare species, while allowing agricultural production simultaneously. Wet agriculture offers more synergies with peatland aims than conventional agriculture or other management practices (See table 1 below).

Table 1: Synergies between wet agriculture and peatland aims compared to conventional agriculture or other management practices. Adapted from FAO and Wetlands International, 2012).[10]

Aim/ Utilisation	Farming and Food Production	Biodiversity Conservation	Climate Change mitigation	Water storage / regulation	Water quality
Wet agriculture	Synergy	Synergy	Synergy	Synergy	Synergy
Conservation	Conflict	Synergy	Synergy	Synergy	Synergy
Rewetting	Conflict	Synergy	Synergy	Synergy	Synergy
Conventional Agriculture	Synergy	Conflict	Conflict	Conflict	Conflict
Abandonment	Conflict	Conflict	Conflict	Conflict	Conflict

[10] FAO and Wetlands International, Joosten, H., Tapio-Biström, M., Tol. S. (eds.) (2012) Peatlands - guidance for climate change mitigation through conservation, rehabilitation and sustainable use. Food and Agriculture Organization of the United Nations. Mitigation of Climate Change in Agriculture (MICCA) Programme.

4.5 Design, implementation & costings - UK Carbon Farm

This section outlines the design and installation costs of the Winmarleigh Carbon Farm, in NW England, which was introduced in section 4.2.

4.5.1 Carbon Farm design and implementation

Ground preparations were completed in 2020. A re-wetted area within the farm totalling 2 hectares has been planted with 150,000 plugs of *Sphagnum* moss. There is a further 1 ha as a water retention area. A further hectare acts as the control plot (land use mirroring the surrounding farmland).

The Carbon farm set up was achieved through a series of steps:

1. Removal and re-use on site of the 10 cm top layer of nutrient- and seed-enriched soil.
2. Raising of the water table to re-wet the former farmland through bund creation, drain removal and ditch blocking.
3. Bunding used to divide the area into 8 'cells' - 0.25 ha each in size.
4. Creation of water retention area, irrigation, and hydrology control system with solar powered pump.
5. Planting of 150,000 *Sphagnum* moss plugs in total, over 6 cells (the remaining two cells were planted with phragmites but unfortunately these did not thrive), sourced from sub-partner, BeadaMoss® (Micropropagation Services Ltd.), which were covered in a blanket of straw to protect them and reduce evaporation losses during establishment.
6. Low intensity management of site and ongoing monitoring.

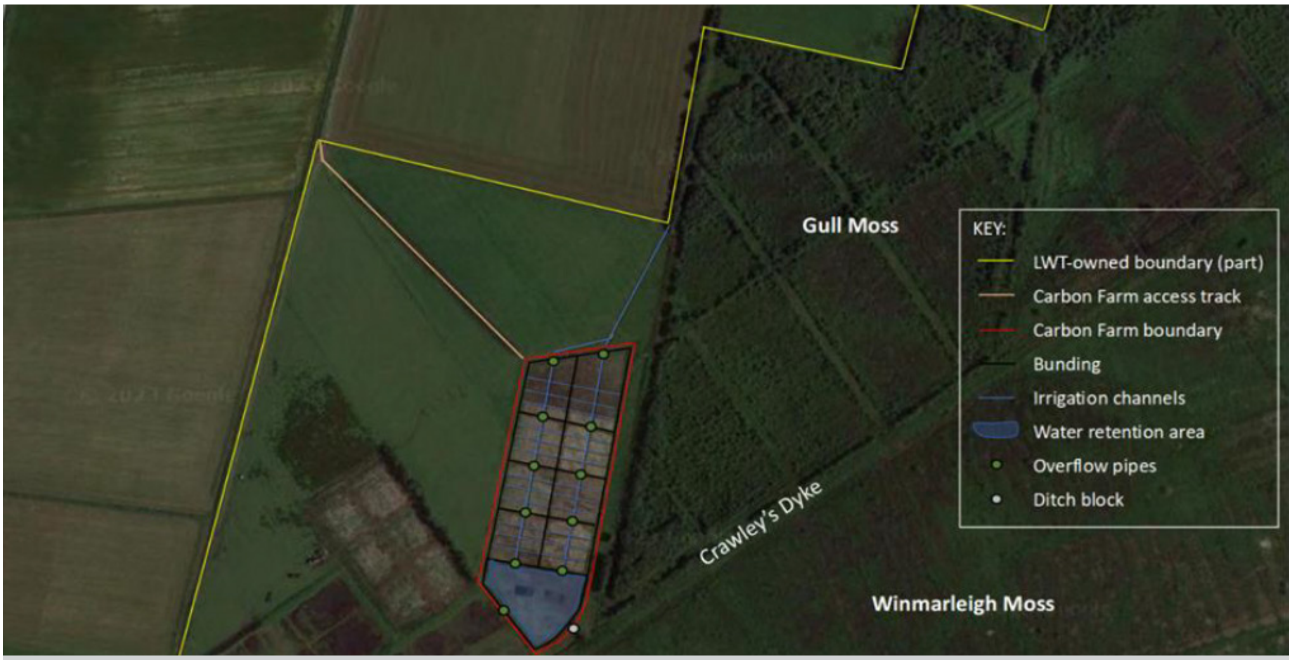

Figure 2: Layout of the Winmarleigh Carbon Farm.

Table 2: Establishment costs of the carbon farm pilot.

Item	Net costs (£)
Ground preparation capital works (topsoil removal, 2ha *Sphagnum* beds, irrigation ditch system, 1 ha water retention area / sump).	35,600
Supply & installation of low energy solar pumps used for the irrigation system (solar pump for a carbon farm, a float control system, a remote telemetry option, solar panels)	9,300
Provision of Beadahumok™ moss plug plants (budgeted figure)	82,500
Contractor planting of the *Sphagnum* plugs (150,000)	22,000

4.5.2 Establishment costs

An overview of the establishment costs is provided in Table 2. It is important to note that these costs have been incurred due to the nature and timescales of the project. Some of these costs were linked to limitations that this pilot project has had to work within and 'real life costs' for farmers could be significantly lower with certain activities adapted, removed, or carried out by the farmers themselves. For example:

- Using crop cycles / planting appropriate nurse crops to prepare the soil's chemistry for *Sphagnum* moss planting, instead of stripping the topsoil. This would also provide an additional income.
- Labour cost savings and mechanisation - making use of existing farm machinery and labour rather than engaging contractors, using machinery to plant the *Sphagnum* plugs.
- Use of overhead/surface water irrigation system, instead of installing sub-surface drainage pipes and irrigation ditches if appropriate (see case study 2 below). This might be easier for a farmer to achieve with pre-existing kit. It is also predicted that costs of the seed *Sphagnum* crop will reduce due to future economies of scale.

<u>Potential funding opportunities additional to carbon credits</u>

- ELMS - Environmental Land Management Scheme (UK only)
- Blended finance including contributions from Government and private businesses.
- Biodiversity Net Gain (BNG) - payments paid to offset biodiversity losses from developments (at present it is not possible to stack these funding streams with Carbon for the same activity).

The carbon farm pilot in the UK will contribute to the data needed to develop new funding schemes and also demonstrate to farmers what they can do with poor quality marginal land that could also bring greater revenue in the future. It can also help to bring in carbon-related revenue for land that may not fit with current carbon offsetting schemes. To be successful, however, carbon farming is likely to need support to cover set-up costs and ongoing management from subsidies or private finance carbon-offsetting schemes.

4.6 The economics of Carbon Farming

4.6.1 Economic overview

The 2019 UK Greenhouse Gas Emissions Inventory, published by the Department for Business, Energy, and Industrial Strategy (BEIS 2021), for the first time updated emissions from drained and rewetted inland peat soils in the UK to be consistent with the 2013 IPCC Wetlands Supplement.[11] The results showed that agricultural lowland peatlands used for cropland and grassland represent the largest net GHG source from UK peatlands; occupying around 15% of the total UK peatland area but contributing more than 50% of the total GHG emissions from UK peatlands (BEIS 2021). In the UK, arable cropland occupies just 7% of peat area, but has the highest GHG emissions per unit area of any land use of around 39.5 tCO_2e/hectare compared to 3 tCO_2e/hectare in the uplands.[12] [13] These GHG emissions will need to be mitigated if the UK is to achieve its target of net zero by 2050. In addition, the carbon benefits of restoring all lowland peatlands are estimated to far outweigh the costs (ONS, 2019). For example, the estimated cost of restoring all UK lowland peatland under horticultural and arable crops would be £2,861 million, but the present value of carbon benefits is £35,628 million.

Peat loss and shrinkage and costs of land-drainage

The current management of lowland peatlands in the UK is already responsible for losing peat carbon faster than from any other kind of peat. Approximately two thirds of lowland peatlands in the UK are classed as 'wasted' (deep peat that is substantially degraded). This peat also has a lower agricultural value than deep fen peat and the cost of pump drainage in these areas is likely to rise. Continued agricultural use will further degrade their productivity. But further consequences of drainage are peat soil loss and land surface subsidence (1-2 cm a year)[14] resulting in:

- Soil degradation and loss of carbon-rich soil from cropland which can reduce soil quality, crop yields and, ultimately, loss of productive capacity, so that their comparative advantage in drainage-based farming will decline. Eroded soil releases dissolved and particulate carbon, impacting water quality and aquatic ecosystems.
- Soils with reduced organic matter hold less water, exacerbating runoff and reducing their resistance to drought and erosion.
- Enhanced compaction and drainage of agricultural soils, increasing flood risk downstream.
- Higher flood risks and impacts on infrastructure, costs of land drainage and flood defences.

[11] 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands
[12] Committee on Climate Change (2020) The Sixth Carbon Budget, The UK's path to Net Zero
[13] Evans et (2017) Implementation of an Emissions Inventory for UK Peatlands: A report to the Department for Business, Energy & Industrial Strategy
[14] Peatlands in the EU, Common Agriculture Policy (CAP) after 2020. Position Paper (Version 4.8)

Holme Fen in Cambridgeshire, UK is a classic example of the loss and shrinkage of peat soils as a result of drainage: it is estimated that over 100 years of drainage has resulted in peat shrinkage of around 4 metres. The analysis of the 6th Carbon Budget report estimates that most of the remaining lowland peat under agriculture will become wasted over the next 30 to 100 years if the current rate of degradation continues. It is a common sight in areas of drained agricultural peat soils for the land levels of the fields to be sometimes several feet lower than the roads that transverse them. An additional cost of peat subsidence due to drainage can be the adverse impact on local road and rail infrastructure. Many lowland peatland areas across the EU are now below sea level and at increased flood risk. Significant investment in embankments and coastal flood defences, drainage pumps and sluices, have been needed to ensure protection from flood risk and maintain agricultural production. For example, in the UK flood protection is managed by a combination of Internal Drainage Boards (IDBs), the Environment Agency and local authorities, depending on the region. At field level, farmers typically use a combination of sub-surface drainage pipes and field ditches to manage water levels for conventional crops that require dry conditions which, because of ongoing peat subsidence, have to be deepened over time in order to be effective. In coming decades, it is anticipated that conventional farming could become increasingly difficult as peat soils disappear, and drainage costs increase.

The changing climate also poses new pressures for lowland peatlands – including more frequent and intense flooding events, and prolonged periods of summer drought. Drained peatlands are more vulnerable and will lose carbon at a much faster rate than wetter, more resilient peatlands, which could mean additional costs in the future for those responsible for land drainage and flood risk management. Even without climate change, many areas will only retain a significant covering of peat for the next fifty years or so, before the soils begin to be influenced by the mineral material underneath.[15]

4.6.2 Financial Feasibility and Pricing Tool

This tool is provided as a companion spreadsheet See Appendix A.
(Care-Peat - Carbon Farming - Financial Feasibility and Pricing Tool)
The instruction manual is provided in Appendix B.

[15] NE (2010) England's peatlands: carbon storage and greenhouse gases (NE257)

4.7 Social impacts of Carbon Farming

4.7.1 Survey and interview of farmers

A survey and follow-up interviews were conducted in 2023. The survey, conducted in collaboration with the National Farmers Union (NFU), aimed to gather information on the knowledge and attitudes of farmers and land managers regarding paludiculture. The objective was to inform guidance for those farming on peat. The survey specifically targeted participants who could potentially adopt new high-water-table farming practices and/or utilise paludiculture crops. Although the primary focus was on farmers operating on lowland peat, the survey included participants from upland areas and other farming practices to ensure a broader understanding. The survey was conducted using the Jisc online survey platform, accessed by participants via a provided link under specific conditions. The survey link was distributed through various channels, including the NFU newsletter, Water Resources Newsletter, the NIAB (National Institute of Agricultural Botany, UK) paludiculture network, and social media platforms. Despite reaching over 5,000 individuals, the response rate was low, which could be attributed to survey fatigue and the concurrent circulation of a similar Defra survey. Follow-up interviews were conducted through telephone calls and Microsoft Teams.

Out of the 19 participants, 15 were currently farming on peat, with 12 of them specifically operating on lowland peat. The survey primarily focused on assessing the knowledge base of land managers regarding paludiculture. Participants were asked to rate their current level of knowledge on paludiculture practices. 21% stated that they had no previous knowledge, while 26% claimed to possess a high level of knowledge. These findings suggest the existence of knowledge gaps that need to be addressed through further outreach and education.

Another objective was to gauge farmers' support for peat restoration as a climate change mitigation tool. 11% disagreed, and 5% strongly disagreed with the statement: "I believe that it is vital to protect peatlands due to the environmental benefit of their carbon sequestration properties." This highlights the need to counter misinformation about peatland restoration methods.

Regarding familiarity with paludiculture products related to carbon credits, 10% of land managers had never heard of them, while 47% had some level of awareness. This indicates a need for further education on how farm businesses can incorporate paludiculture as a viable option. Participants received information on paludiculture practices prior to the survey, which allowed them to address any concerns they might have about implementing these practices on their farms. 55% agreed that both unwanted effects on neighbouring land causing conflict and increased water use were issues, while 72% agreed that lack of knowledge and machinery availability were concerns.

The survey responses indicated that financial concerns were dominant. 55% strongly agreed that paludiculture crops' profit margins posed a barrier, and 35% strongly agreed, while 50% agreed, that the lack of business cases for paludiculture was also a barrier. These findings suggest the presence of knowledge gaps that ongoing trials can address by providing more information on business cases and viability. On a more positive note, 72% agreed and 22% strongly agreed that the positive effect of paludiculture on climate change would be a motivating factor for adopting these practices. Additionally, 66% agreed that diversifying their farm was a good reason to consider paludiculture. However, most participants disagreed that it would reduce the overall number of working hours on the farm, despite agreeing that it would require fewer inputs, which they considered a favourable aspect for adoption. During the follow-up interviews, the discussion focused on the participants' farms in more detail.

This revealed additional concerns regarding new agri-environmental schemes and whether carbon credits would be stackable payments. One land manager expressed apprehension about the profitability of implementing these practices due to the small scale of their farm.

Despite these concerns, the overall sentiment towards paludiculture methods was positive. Participants recognised the potential of paludiculture to make their farms Net Zero and, as a result, more attractive as suppliers. This aspect is likely to generate significant interest in implementing paludiculture in the future, especially as supermarkets increasingly prioritise their own Net Zero targets.

4.7.2 Wetter farming: the land manager's view

Separately, a small number of interviews were also conducted with farmers and landowners managing lowland peat soils in the Northwest for this study, to explore farmers' current soil management practices, challenges they face and their perspectives of potential wetter farming practices or higher water table management. All those interviewed could identify areas of land which were difficult to manage or less productive because of existing high water level or are 'getting wetter'; overall the interviewees were open to exploring the option to incorporate higher water table management for these targeted areas, although they were not actively seeking to do so, and would not welcome it across their entire existing farming system.

The interviewees were uncertain of wetter farming as a viable practice due to practical and financial implications; a key concern was how to manage higher water levels at a field level, how that could fit into a catchment based pump drainage system and the potential to negatively affect surrounding drained land through rewetting or raising the water table; another concern was how permanently raising the water level in one area would impact on existing due to tenancy agreements. There is clearly a need for further engagement with farming groups working in these lowland peat soils regions, to increase awareness of rotational cropping systems on the farm (or land rotated between farmers).

The financial uncertainty of transitioning areas to wetter farming was also a concern, especially for tenant farms, who are reliant on making an income to cover land rental and may be limited to what changes they could make to land management and developing a theoretical model for the impact of Paludiculture and knowledge of wetter farming options and examine the associated practicalities, costs and potential incomes at a farm level – tailored to the NW river basin or catchment context.

Table 3: Summaries of key concerns from conversations with farmers.

KEY CONCERNS	
Raising water levels	How would it be possible to permanently (re) wet a single field which is linked into a wider drainage system, without impacting surrounding land? Would it require water levels to be altered for an entire catchment area?
	Adverse impacts on neighbouring, highly productive fields / farms who would not welcome their land becoming wetter as a result.
Crop rotation & displacing production	How will it work for crop rotation if you need to keep one field e.g. wet all the time? If a field(s) is taken out of rotation (or out of production all together) could this put more pressure on land elsewhere which 'would need to be worked a lot harder'; by pushing the previous farm activity to other land? Could this also potentially impact on land availability/ values and rental prices?
Tenancy	It would be hard for tenant farmers, who need to ensure an income to fulfil their rental obligations, to make the switch without guarantee of whether it will bring enough contribution to fulfil rental obligations and continue to make a living - or without appropriate compensation.
	They are required, under their land rental agreement, to keep the land in good agricultural productivity; tenant farmers could be required to gain prior consent from the landlord before changing agricultural production. For owner occupiers it could be easier.
	Tenant farmers (who face rent reviews) may be put off from the financial outlay of major capital investments required to change to a wetter farming system.
Financial	What would the financial outlay/upfront costs be and also equipment required? Alternative machinery would be needed to cultivate and harvest, as existing farm machinery already struggles with wetter soils.
	Viability of wetter farming crops or that it would add any monetary value to existing business models; it would be a risk to transition away from a profitable business model without having certainty of yields / income from alternative crops and the potential financial support (esp. when required to pay land rental).
	Route to market for wetter farming crops is not clear. Carbon farming is the most understood option, but private financing opportunities from carbon / nature-based solutions markets is not well–understood, and how that could be applicable to their farm business – e.g Peatland Code – and farmers are awaiting clarity on the new ELMS.
No regionally specific examples	Farmers need evidence of it working. There are no regionally specific demonstrations relating to understanding of crops and how to manage higher water tables and that it can be done successfully (a lot of research is coming from the East of England).
Lack of confidence	It would require a major change in operational management, and substantial investment in adapted machinery. Will there be long term-support for it?
	Could the capital works required to raise water levels potentially release more greenhouse gas than is saved through rewetting?
	If climate is changing, how do we know that wetter farming will be appropriate for the region in the future?
Culture	Reluctant to switch from existing, long-standing land management practises and reversing land drainage whole scale. Reliance on pump drainage for current farm business.

4.8 Social impacts of Carbon Farming

Result-based carbon farming can potentially offer a significant contribution to climate change mitigation in Europe. Result-based carbon farming remains in its infancy, with some implementation issues still to be addressed before it reaches its full potential. In particular, it will be necessary to promote new technological and methodological developments to progressively reduce the uncertainties and costs of MRV, both through public research programmes and private investments. Developing a result-based scheme requires significant up-front investments and resources for the scheme's designers and for farmers. Increased support to farmers from the Common Agricultural Policy (CAP) in the EU or Environmental Land Management Scheme (ELMS) in the UK, and other public and private funds could facilitate farmers' uptake and upscaling by covering at least part of the costs.

If the wetter farming measures are to be adopted, it is imperative that these measures are practical, economically viable, legally compliant, acceptable to retailers and socially acceptable to consumers. There are a small number of trials in the UK but there is clearly a need for large scale demonstration pilots to investigate crop yields, carbon savings, harvest requirements and financial viability in regional contexts – also how forthcoming environmental and agricultural policies will support them.

Reducing risks for farmers will also be important to increase uptake. This could be done through different strategies, e.g. considering the use of hybrid schemes, where farmers receive a basic action-based payment for employing climate-friendly management practices and an additional result-based payment if climate benefits can be demonstrated. Engaging farmers in the scheme design will also be essential to progressively improve it and to increase farmers' uptake. Another key element to build trust, and thereby promote farmers' uptake, is the support of advisors, who can assist farmers in identifying the most appropriate solutions for their farm, including through the use of whole farm carbon audit tools.

Finally, it will be necessary to recognise and reward farmers for the co-benefits of well-designed carbon farming initiatives, as an effective means of helping the EU to achieve other important environmental objectives for farmland and helping farmers to adapt their businesses to withstand the effects of climate change. The next steps require farm-scale trials to quantify the economic value and viability under current market systems of paludiculture crops. There is also clearly a need for further engagement with farming groups working in these lowland peat soils regions, with communities in flood risk areas as well as those involved in water management and environmental conservation, to increase awareness and knowledge of wetter farming options and examine the associated practicalities, costs and potential incomes at a farm level. The future costs and management of water within complex and heavily modified landscapes are also a key factor that will need to be considered alongside any transition to a wetter way of farming on lowland peat soils. The EU Carbon Farming Initiative[16] should encourage the development of a range of locally or regionally tailored result-based pilot schemes for carbon farming, and meanwhile promote the more widespread adoption of well-designed, action-based or hybrid schemes, to make the initial step towards a real shift in the agriculture sector's contribution to EU climate targets. The experience gathered through pilot schemes will be essential to upscale result-based carbon farming, by improving design elements and expanding farmers' knowledge and understanding of the potential benefits to them.

[16] https://ec.europa.eu/clima/policies/forests/carbon-farming_en

Paludiculture

5.1 Overview of Paludiculture

Drainage-based agriculture on peatland causes enormous economic and environmental losses through GHG emissions (25% of EU agricultural emissions from 3% of EU agricultural land), loss of biodiversity, water pollution, soil degradation, and subsidence followed by an eventual loss of productive land. Rewetting (i.e. raising the water level near to the surface) is essential to minimise emissions and peat degradation, but also impedes drainage-based land use. Paludiculture has been recognized as "agricultural activity" and "eligible hectares" in the amendments to the CAP legislative text (Art. 4 §1) approved by the European Parliament and Council. CAP direct payments, together with a clear understanding of the term "paludiculture" are the key prerequisite to enable farmers to take up rewetted productive peatland use (Paludiculture).

5.2 Defining Paludiculture

5.2.1 Definition of Paludiculture

In February 2021, the following definition was proposed by the Greifswald Mire Centre in Germany to the European Commission on request. It was supported by a number of other organisations in the EU including NUI Galway representing the Care-Peat project as part of the informal EU CAP Network previously established.

Paludiculture is the productive land use of wet and rewetted peatlands that preserves peat soil and thereby minimises CO_2 emissions and subsidence.[17]

Paludiculture is a form of agriculture with clear production goals, that allows wet or rewetted peatlands to remain productively used and doesn't require habitats to be drained. It requires farming systems designed to generate a commercial crop from wetland conditions using species that thrive under (or are tolerant of) wet conditions, produce sufficient quantity and quality of biomass and (ideally) contribute to peat formation. It is designed so that above ground biomass (e.g. for food, fibre and energy) can be harvested without harming the peat below. It can also include the keeping of livestock suitable to wet grassland conditions. So is a wetter way of farming on peatlands that does not degrade the peat layer and may even add to peat accumulation.

[17] https://europe.wetlands.org/download/4943/?tmstv=1687731822

5.2.2 Paludiculture plants and utilisation options

Paludiculture comprises various agricultural production systems that target the production of plant or animal-based commodities from harvesting vegetation on semi-natural sites to establishing specific permanent crops.

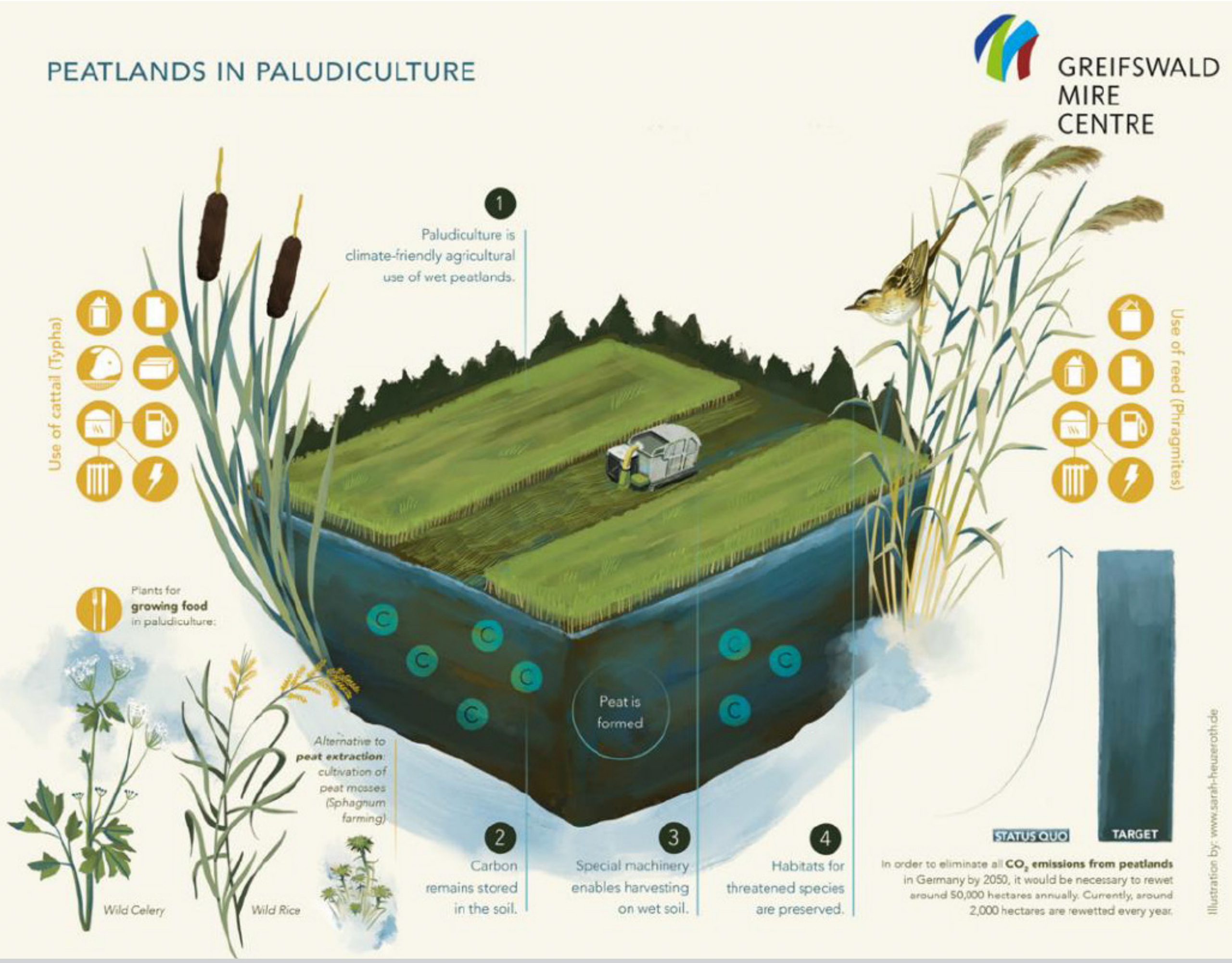

Figure 3: The prefix "Paludi" comes from the Latin "palus" meaning "swamp, morass".

Paludiculture uses above ground biomass, while below ground biomass, i.e. a major part of the net primary production, remains for peat formation. After establishing high water tables near the soil surface throughout the year, wet grasslands may develop a succession of vegetation or permanent crops with specific peatland species that can be cultivated. The harvested biomass can be used as food, feed, fibres for industrial biochemistry, for production of construction materials, high quality liquid or gaseous biofuels, for heat production through direct combustion or for further purposes such as extracting and synthesising pharmaceuticals and cosmetics. These diverse options for biomass from paludiculture show its great potential for future circular bioeconomy applications.

Table 4: Examples of paludiculture utilisation options for European Peatlands

Species	Region & sites	Utilisation	GHG Emissions
Alder (*Alnus glutinosa*)	Central Europe, Fen, oligo-uterotrophic	Timber for carpentry, interior fittings & furniture, Veneer, Combustion	
Canadian Poplar (*Populus canadensis*)	Northern Peatlands	Biofuel	Found to reduce CH_4 emissions, with a negligible effect on N_2O
Cattail, Bulrush (*Typha angustifolia, Typha latifolia*)	Central Europe, North America, West Africa Fen, polytropic	Insulation material, Filling material (seed hairs), Construction material, Packaging, Disposable tableware, Fodder, Horticultural growing media	
Chokeberries (*Aronia melanocarpa*)	Northern peatlands	Food, Medicinal use	
Cloudberries (*Rubus chamaemorus*)	Northern peatlands	Food	
Common Reed (*Phragmites australis*)	Europe, China, Fen, polytropic	Thatching material, Insulation material, Construction material, Packaging, Fodder, Combustion, Silicon	
Cranberries (*Vaccinium oxycoccos*)	Northern peatlands	Food	
Giant Reed (*Arundo donax*)	Northern peatlands	Biofuel	
Lingonberries (*Vaccinium vitis-idaea*)	Northern peatlands	Food, Medicinal uses	
Reed Canary Grass (*Phalaris arundinacea*)	Northern peatlands	Biofuel	Shown to reduce N_2O emissions, but substantially increase CH_4 [4]
Round-leaved sundew (*Drosera rotundifolia*)	Raised bog	Herbal medicine for cough diseases, Vegetarian rennet for cheese making	
Sphagnum spp.	Worldwide Raised bog, oligotrophic	Founder material for restoration and *Sphagnum* farming, Orchid cultivation, Horticultural growing media replacing peat, Substrates, Insulation and packaging material, Food preservation, Medical uses, Natural sunscreen	Demonstrated to reduce CH_4 emissions, negligible effect on N_2O
Water buffaloes (*Bubalus bubalis*)	Europe, Asia	Cheese (mozzarella), Meat, Conservation grazing	
Willow (*Salix spp.*)	Northern Peatlands	Biofuel, Fodder, Weaving material (e.g. baskets)	

5.3 Examples of Paludiculture

5.3.1 *Sphagnum* Farming

Sphagnum farming focuses on the cultivation of *Sphagnum* moss, commonly known as peat moss or bog moss. *Sphagnum* moss is a unique type of moss that thrives in wetland environments and plays a crucial role in the formation of peat. It has several valuable characteristics that make it useful for various applications. While revenue from the sale of *Sphagnum* farming can potentially be combined with revenue from carbon credits the issue of additionality has to be resolved. While *Sphagnum* is a hugely valuable product, markets for it are not well developed.

Figure 5: *Sphagnum* Farming in Germany near Oldenburg
(Photos courtesy of Niall Ó Brolcháin - Paludiculture Study Tour - Germany - September 2022)

Overview of *Sphagnum* farming and its key aspects:

Cultivation: *Sphagnum* moss is cultivated by creating suitable conditions for its growth in wetland areas. This involves maintaining appropriate moisture levels and controlling factors like temperature and light. The cultivation process can be conducted in wetlands, hydroponically or in specially designed plots or containers that mimic the natural wetland environment.

Environmental Benefits: *Sphagnum* farming offers numerous environmental advantages. By cultivating *Sphagnum* moss, the degradation of natural peatlands can be minimized. Peatlands are crucial carbon sinks, and preventing their destruction helps reduce greenhouse gas emissions. *Sphagnum* moss also filters water, improves water quality, and provides habitat for various plant and animal species.

Economic Applications: *Sphagnum* moss has multiple commercial applications, which makes its cultivation economically viable. Some common uses include horticulture (as a component of potting mixes), floristry (for flower arrangements), and as a soil amendment in agricultural practices. It is highly absorbent, retains water, and has antiseptic properties, making it valuable in the production of gardening and personal care products.

Restoration and Conservation: *Sphagnum* farming can contribute to the restoration and conservation of degraded peatlands. By actively cultivating *Sphagnum* moss, degraded areas can be rejuvenated, allowing the natural ecosystem to recover. This helps preserve biodiversity and protects the valuable ecosystem services provided by peatlands.

Sustainable Alternative: *Sphagnum* farming provides a sustainable alternative to traditional peat extraction for commercial purposes. Peat extraction involves draining and degrading peatlands, which leads to carbon emissions and loss of valuable habitats. By cultivating *Sphagnum* moss, the demand for harvested peat can be reduced, promoting more sustainable land use practices.

5.3.2 *Sphagnum* Farming UK - A Sustainable Alternative to Peat in Growing Media.

Organisations involved: Manchester Metropolitan University, Micropropagation services/BeadaMoss®, The University of East London, Natural England, Melcourt Industries.
Project funding: Innovate UK -AGRI-TECH CATALYST.
Location: Little Woolden Moss, Greater Manchester, a site which has previously been used for commercial peat extraction but is now owned and being restored by Lancashire Wildlife Trust (since 2018).

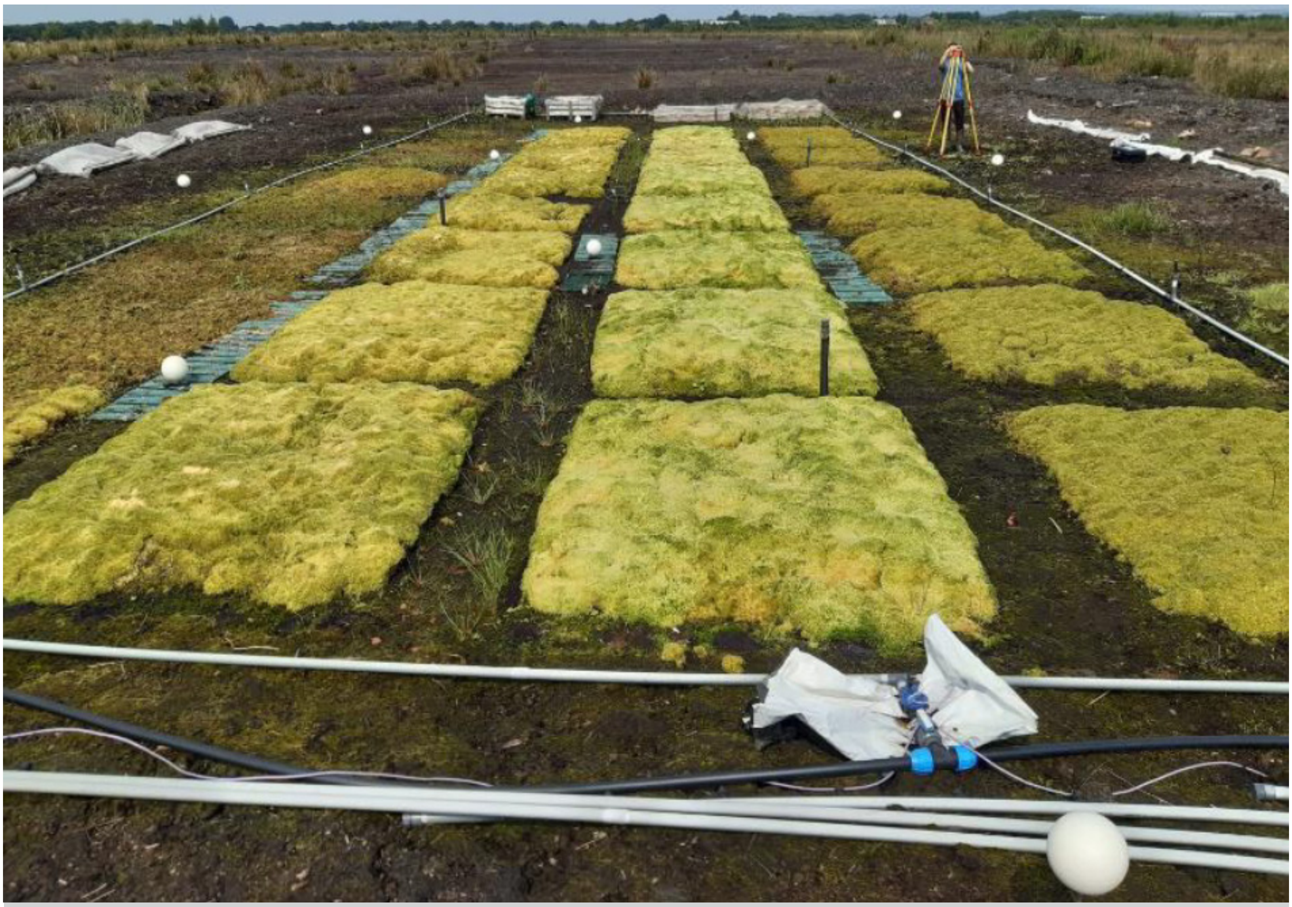

Figure 4: *Sphagnum* Farming UK – Innovate UK. Little Woolden Moss trial site, Greater Manchester, showing good *Sphagnum* growth across all treatments

Design and Installation

The *Sphagnum* Farming UK project trialled BeadaMoss®26 (BeadaGel™ and BeadaHumok™) *Sphagnum* palustre growth under a range of cover treatments (perforated plastic, nylon mesh, straw, no cover) typically used in conventional agriculture. These were laid over the *Sphagnum* in order to maintain high humidity (see Figure 4). The seeding material is sustainably produced *Sphagnum*, obtained through a process of micropropagation, grown in solar powered facilities by BeadaMoss®. *Sphagnum* palustre was chosen since it is fast-growing, resilient and a growing media choice. Instead of raising the water table close to the ground surface, as with the Winmarleigh Carbon Farm, irrigation was from above (drip or spray irrigation) to simulate rain, while the water table below was unregulated. Trials were conducted on: Little Woolden Moss (LWM), an ex-milled Greater Manchester peatland.

Monitoring and outputs

A detailed digital terrain model (DTM) of the various field plots was obtained using terrestrial laser scanning (TLS) on the prepared ground, and a series of 'peat anchors' providing fixed reference points to measure subsequent swelling of the peat following rewetting and *Sphagnum* crop growth and saleable volume over the project. GHG (CO_2, CH_4) flux rates and water chemistry were monitored to understand the effect of different treatments on carbon balance, nutrient use and global warming potential. Water relations of the various plots both in terms of the water table in the peat and the pore-water pressure in the *Sphagnum* were also monitored. *Sphagnum* establishment and growth was good, after teething problems caused some damage, on both peatland and farmland sites. The spray irrigation produced faster growth than drip and all three cover types were better than no cover.

The successful production of BeadaMoss® *Sphagnum* biomass using surface irrigation techniques and could simplify the expansion to commercial scale by avoiding problems of raising water tables in adjoining agricultural crops. The high productivity should make *Sphagnum* Farming viable at a larger scale, even with the relatively high set-up costs. Large field trials are currently underway. Melcourt Industries incorporated micropropagated Sphagnum into a peat-free growing media and used it to run plant growth trials, with favourable results. Various commercial growers have compared the *Sphagnum* growing media product with other growing media available today, with comparable results.

In the UK trials, GHG fluxes measured in the *Sphagnum* farming plots were measured monthly for one year, and seasonally thereafter, using a closed chamber system and Los Gatos UGGA. There was a greater uptake of CGHG in plots with *Sphagnum* than bare plots, in *Sphagnum* under cover than with no cover, and uptake increased with increasing *Sphagnum* ground cover (Figure 12). All covers kept the soil temperature warmer in winter. Water-table depth (measured at LWM only) was higher in spray- than drip irrigated areas (-11.2 ± 7.9 and -15.3 ± 9.2 cm respectively). No treatment changed methane fluxes at either site, which were minimal across the monitoring period (mean of <0.4 mg CH4 m^{-2} h^{-1} across treatments) with random emission or uptake of methane, so negligible values are assumed, showing the benefits of controlled surface irrigation.

5.3.3 Biomass to fuel District Heating Schemes

District heating schemes utilizing biomass from paludiculture involve the use of wetland biomass, as a renewable energy source for heating purposes in a local district or community.

Figure 6: Biomass for district heating schemes
(Photos courtesy of Niall Ó Brolcháin - Paludiculture Study Tour - Germany - September 2022)

Biomass Production: Wetland plants, such as reeds, cattails, or other suitable species, are cultivated in specially designed wetland areas or peatlands. These plants are chosen for their high biomass production.

Harvesting and Processing: Once the wetland plants have reached maturity, they are harvested and processed to extract the biomass. The biomass can include the stems, leaves, and other plant components, depending on the specific plant species and cultivation methods used.

Biomass Conversion: The harvested biomass is then converted into a usable form of energy, typically through combustion. In this process, the biomass is burned in a controlled environment, such as a biomass boiler or furnace, to generate heat.

Heat Distribution: The heat generated from biomass combustion is used to produce hot water or steam. This heat is then distributed through a network of insulated pipes, known as a district heating network, to supply heat to various buildings and facilities within the local district or community.

Heat Utilization: The hot water or steam from the district heating network is used for space heating, water heating, and other heating applications in residential, commercial, and industrial buildings. The heat can be utilized through radiators, underfloor heating systems, or other heat transfer mechanisms, depending on the building's infrastructure.

Environmental Benefits: Biomass from paludiculture is considered a renewable energy source because wetland plants can be sustainably harvested and regrown. Additionally, the use of biomass as an alternative to fossil fuels reduces greenhouse gas emissions and contributes to mitigating climate change.

Economic and Social Benefits: District heating schemes utilizing biomass from paludiculture can have positive economic and social impacts. They create local employment opportunities in biomass production, harvesting, and processing. Moreover, they enhance energy independence, reduce dependence on imported fossil fuels, and contribute to the development of a local, sustainable energy infrastructure.

5.3.4 Reeds for thatching

Reeds are widely used in thatching, which is the practice of using plant materials to create roofs, walls, and other structures. Thatching with reeds can be considered a form of paludiculture when the reeds are cultivated in wetland or marshy areas.

Figure 7: Reeds for thatching
(Photos courtesy of Niall Ó Brolcháin - Paludiculture Study Tour - Germany - September 2022)

Reed Cultivation: Wetland areas are usually flooded or have a high water table, creating suitable conditions for reed growth. Reed beds are established and managed to ensure a sustainable supply of reeds for thatching.

Harvesting: Once the reeds have reached the appropriate maturity, they are harvested. This is typically done by cutting the stems close to the ground. Harvesting practices should be carefully managed to avoid damaging the wetland ecosystem.

Processing: After harvesting, the reeds undergo processing to prepare them for thatching. The leaves and excess foliage are removed, leaving behind the long, flexible stems that will be used for thatching.

Thatching Installation: Thatching is a skilled craft that involves layering the prepared reed stems in an overlapping pattern to create a waterproof and durable roof or wall covering. The thatch is usually attached to a supporting framework of timber or other materials.

Benefits of Reed Thatching as Paludiculture:

Ecosystem Preservation: Cultivating and harvesting reeds in wetland areas promotes the preservation and restoration of valuable wetland ecosystems. By utilizing these areas sustainably, it helps protect biodiversity, prevent soil erosion, and maintain water quality.

Carbon Sequestration: Wetlands have high carbon sequestration potential. By cultivating reeds in paludiculture sites, carbon dioxide can be captured from the atmosphere and stored in the wetland ecosystem, contributing to climate change mitigation.

Local Economy and Employment: Thatching with reeds can provide economic opportunities for local communities. It can create jobs related to reed cultivation, harvesting, processing, and thatching itself. This can contribute to the development of rural areas and support sustainable livelihoods.

Cultural Heritage: Thatching has a long history and cultural significance in many regions. By promoting reed thatching as a form of paludiculture, traditional building techniques and cultural practices can be preserved and passed down through generations.

5.3.5 Black Alder

Black Alder (*Alnus glutinosa*) is a species of tree that is well-adapted to wetland environments. Black Alder trees can be grown as a crop as a form of paludiculture.

Figure 8: Black Alder trees growing on a wetland
(Photos courtesy of Niall Ó Brolcháin - Paludiculture Study Tour - Germany - September 2022)

Wetland Adaptation: Black Alder trees are particularly suited for wetland conditions due to their ability to tolerate waterlogged soils. They have adapted to thrive in areas with poor drainage and high water tables, making them suitable for wetland cultivation.

Ecosystem Services: Black Alder trees offer numerous ecological benefits in wetland environments. They stabilize soil, prevent erosion, and improve water quality by absorbing excess nutrients and pollutants. They also provide habitat and food for various wildlife species.

Timber Production: One of the main economic benefits of cultivating Black Alder trees in paludiculture is the production of timber. Black Alder wood is known for its durability, resistance to water, and suitability for construction, furniture, and other wood products. Although the quality of the timber can vary depending on the height of the water table.

Biomass Production: Black Alder trees can also be grown for biomass production in paludiculture. The trees have fast growth rates and high biomass yields, making them suitable for renewable energy purposes, such as bioenergy or biogas production. However, the cost of harvesting Black Alder trees grown for biomass can be prohibitive if the ground is too wet.

Carbon Sequestration: Wetlands, including those cultivated with Black Alder trees, play a crucial role in carbon sequestration. They have the ability to store significant amounts of carbon in their soils, contributing to climate change mitigation.

Biodiversity Conservation: Paludiculture with Black Alder trees can help preserve and restore biodiversity in wetland ecosystems. The trees provide habitat for various plant and animal species, contributing to the overall ecological richness of the area.

5.3.6 Using *Typha* as a building material

Growing *Typha*, commonly known as cattails, as a form of paludiculture for use as a building material can offer several benefits.

Figure 9: Using *Typha* grown on wetlands as a building material
(Photos courtesy of Niall Ó Brolcháin - Paludiculture Study Tour - Germany - September 2022)

Suitable Growing Conditions: Cattails thrive in wetland environments, particularly in areas with shallow water, marshes, or along the edges of ponds and lakes. They have a high tolerance for waterlogged conditions and can grow in a variety of soil types.

Sustainable Harvesting: Cattails are a renewable resource as they can be harvested without damaging the plant or the wetland ecosystem. Harvesting involves cutting the mature seed heads or stems, leaving the rhizomes (underground stems) intact for future growth.

Building Material Properties: Cattails have unique properties that make them suitable for various building applications. The outer layers of cattail stems contain strong, fibrous strands that can be used for weaving, thatching, or as a reinforcement in composite materials. The inner pith can be utilized as a lightweight filler material.

Processing and Preparation: After harvesting, cattail stems can be processed and prepared for use as a building material. The stems can be dried and split into long, thin strips, which can then be woven into mats, screens, or panels. The strips can also be used as a thatching material for roofs or walls. The pith can be removed and used as insulation or mixed with other binders to create composite materials.

Sustainability and Environmental Benefits: Using cattails as a building material promotes sustainability and environmental conservation. By cultivating and harvesting cattails, wetland ecosystems are preserved and can continue to provide essential ecosystem services, such as water purification, flood control, and habitat for wildlife. Additionally, cattails absorb carbon dioxide and help mitigate climate change.

Local Economic Opportunities: Growing cattails for building materials can create local economic opportunities, particularly in areas with abundant wetland resources. This form of paludiculture can support small-scale enterprises, such as artisans specializing in weaving or construction using cattail-based materials, thereby contributing to local employment and income generation.

Figure 10: A 'Tiny House' made largely from paludiculture products
(Photos courtesy of Niall Ó Brolcháin - Paludiculture Study Tour - Germany - September 2022)

A multi-purpose Paludi(culture) tiny house was built, by the Greifswald Mire Centre in partnership with a company called More and More. This was designed to serve as a holiday home, a temporary office or an artists' residence. The tiny format stands for a conscious way of living with reduced space, costs, consumption of energy and other resources – and reduced emissions. The building materials are visible on and in the inner walls, floor and furniture the Paludi tiny house shows the Paludi-Plus: building materials produced by a handful of paludiculture pioneering manufacturers. Reeds can be found on the roof and walls and in the walls for sound and heat insulation. Cattail is used in boards and as blow-in insulation. There is alder in the wall and floor panels as well in the kitchen furniture. Last but not least, wet meadow grass fibres also serve as insulation.

5.3.7 Water buffalo replacing more traditional cattle on wetlands

Farming water buffalo on wetlands as a form of paludiculture involves utilizing wetland areas to raise water buffalo for agricultural purposes. Water buffalo, also known as Bubalus bubalis, are well-suited for wetland environments due to their ability to thrive in waterlogged areas and their natural affinity for grazing on marshy vegetation.

Figure 11: Farming water buffalo on wetlands
(Photos courtesy of Niall Ó Brolcháin - Paludiculture Study Tour - Germany - September 2022)

Wetland Selection: Suitable wetland areas are identified and assessed for their ecological conditions, including water quality, soil composition, and vegetation cover. It's important to choose wetlands that have the potential to support water buffalo farming without compromising the overall health of the ecosystem.

Habitat Management: Wetlands are managed and modified to create an optimal habitat for water buffalo. This may involve the construction of fences, water control structures (e.g., dikes, ponds, or channels), and grazing areas within the wetland. These modifications should be designed to minimize negative impacts on the wetland ecosystem and maximize the well-being of the water buffalo.

Grazing and Forage: Water buffalo are allowed to graze on the vegetation within the wetland. They feed on a variety of wetland plants, including grasses, sedges, reeds, and aquatic plants. The wetland vegetation provides a natural and nutritious diet for water buffalo.

Environmental Benefits: Farming water buffalo on wetlands as a form of paludiculture offers several environmental benefits. The water buffalo help control the growth of invasive plant species and maintain the ecological balance within the wetland. Their grazing activities can improve vegetation structure, increase plant diversity, and promote habitat for various wetland species.

Livestock Management: Water buffalo need to be managed appropriately to ensure their health and welfare. This includes providing adequate shelter, veterinary care, and monitoring their behavior and overall condition. Access to clean drinking water is essential, and appropriate measures should be taken to prevent water pollution and maintain water quality within the wetland.

Productive Uses: Water buffalo farming on wetlands can generate various products and income streams. These may include milk production (including mozzarella cheese), meat production, hide and leather products, as well as other by-products such as fertilizer. Additionally, the wetland itself may offer opportunities for sustainable aquaculture, agroforestry, or ecotourism activities.

5.4 The case for Paludiculture

The case for paludiculture on peatlands is very similar to the case for carbon farming on peatlands, with similar benefits to carbon storage, biodiversity and other ecosystem services.

Sphagnum farming on wetland soils could offer landowners a new, innovative high value crop. Typical UK farming sites proposed initially would include bare areas of harvested peat, areas of poor scrub grazing and later also peat soil agricultural areas subject to flood risk and inundation. It may also play a role in supporting regional nature conservation interests since peatland vegetation has high conservation value and *Sphagnum* farms with rotational cropping could provide ecological corridors and buffer land to extend designated conservation wetlands.

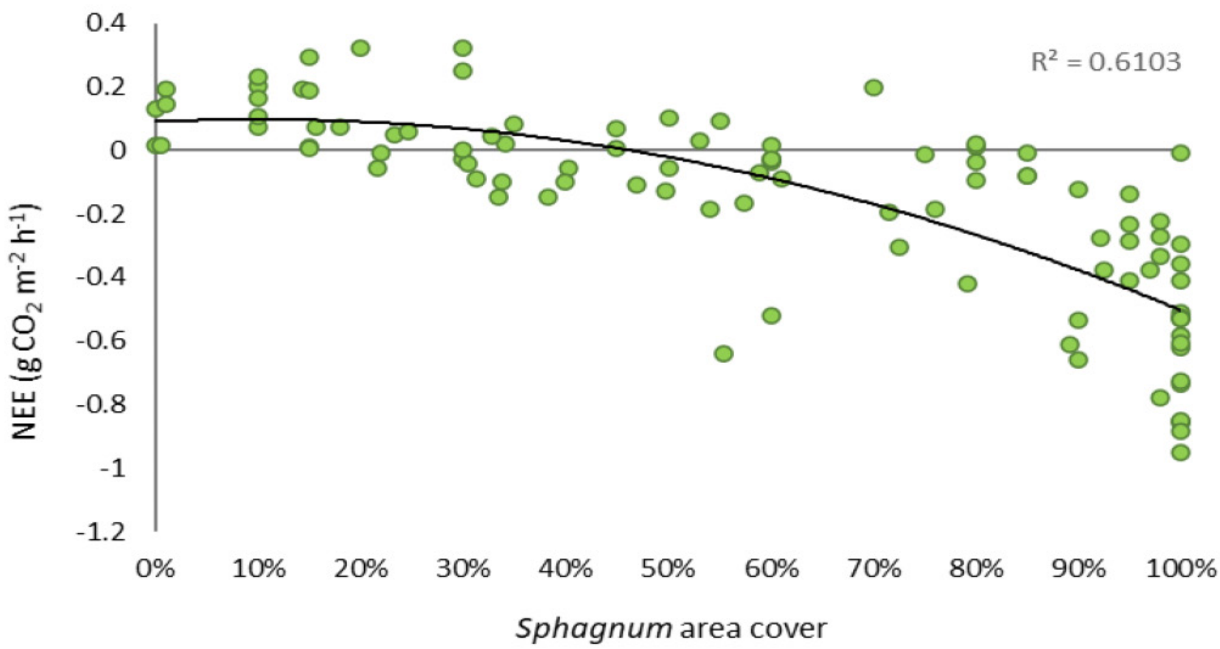

Figure 12: NEE (Net CO_2 uptake) increases with *Sphagnum* cover: Little Woolden Moss site, May to September 2019 data, Middle of day measurements. Data source: Dr Anna Keightley.

5.5 The economics of Paludiculture

The ecosystem services aspects to the economics of paludiculture are similar to those of carbon farming on peat. The differences lie in that, in addition to ecosystem services benefits, there is a tangible crop taken from the site which has a market value. *Sphagnum* volume and biomass production rates in the UK farming trials were good. After nearly two years, biomass production by volume was up to 1600 m^3 ha-1 (standard industry bulk density), and by dry matter to 14,800 kg ha-1. The Productivity (average) expected to increase but at just 1600 m3 the crop value would be £56,000/Ha - based on £35/m3 – showing the potential commercial viability. This would be in addition to the benefits to GHG emissions reduction, biodiversity and other ecosystem services.

5.6 Social impacts of Paludiculture

These are also similar to carbon farming on peat, however, farmers may feel more comfortable dealing with a crop that is harvested and sold as it more closely fits with their existing experiences and cultural histories. *Sphagnum* farming could affect the public in several ways to benefit their well-being. The success of *Sphagnum* farming will increase rural employment in areas of wet, marginal land. However, it is clear that to achieve this impact that supportive infrastructure will need to be systematically and strategically put in place.

5.7 Conclusions and next steps for Paludiculture

Paludiculture as defined in a European context "the productive land use of wet and rewetted peatlands that preserves peat soil and thereby minimises CO_2 emissions and subsidence", is far from a mature science or discipline in 2023, yet it is necessary if farmers and other landowners wish to continue to productively use land that is coming under ever increasing pressure to re-wet and decarbonise. Peatlands produce the highest level of GHG emissions from one of the least favourable land types for productive farming. While it does not provide the optimal use of peatlands for reducing GHG emissions, it is near optimal while allowing productive use of the land to continue.

It will be necessary to recognise and reward farmers for the co-benefits of well-designed paludiculture initiatives, as an effective means of helping to achieve other important environmental objectives for farmland and helping farmers to adapt their businesses to withstand the effects of climate change. The next steps require farm-scale trials to quantify the economic value and viability under current market systems of paludiculture crops. There is also clearly a need for further engagement with farming groups and other stakeholders working in lowland peat soils regions, with communities in flood risk areas as well as those involved in water management and environmental conservation, to increase awareness and knowledge of wetter farming options and examine the associated practicalities, costs and potential incomes at a farm level. The future costs and management of water within complex and heavily modified landscapes are also a key factor that will need to be considered alongside any transition to a wetter way of farming.

5.8 Blended Finance Model

Types of finance to pay for the restoration and maintenance of wet peatlands including paludiculture :

1. Carbon Credits
2. Ecosystem services
3. Paludiculture
4. Co-location with renewable energy
5. Government and EU Subsidies & Grants
6. Environmental Funds and Foundations
7. Loans

The traditional uses of drained peat as a fuel or as a substrate for compost are not included in this list. Only types of finance that relate to wet peat are included.
Theoretically it is possible for all 7 types of finance to be used for one project. However, in the context of the global Carbon Crediting system, the main goal is to reduce CO_2e emissions and therefore additionality (i.e., the concentration reduced by buying the Carbon Credit) is central. Whereas the main goal for paludiculture is to provide a product for sale.

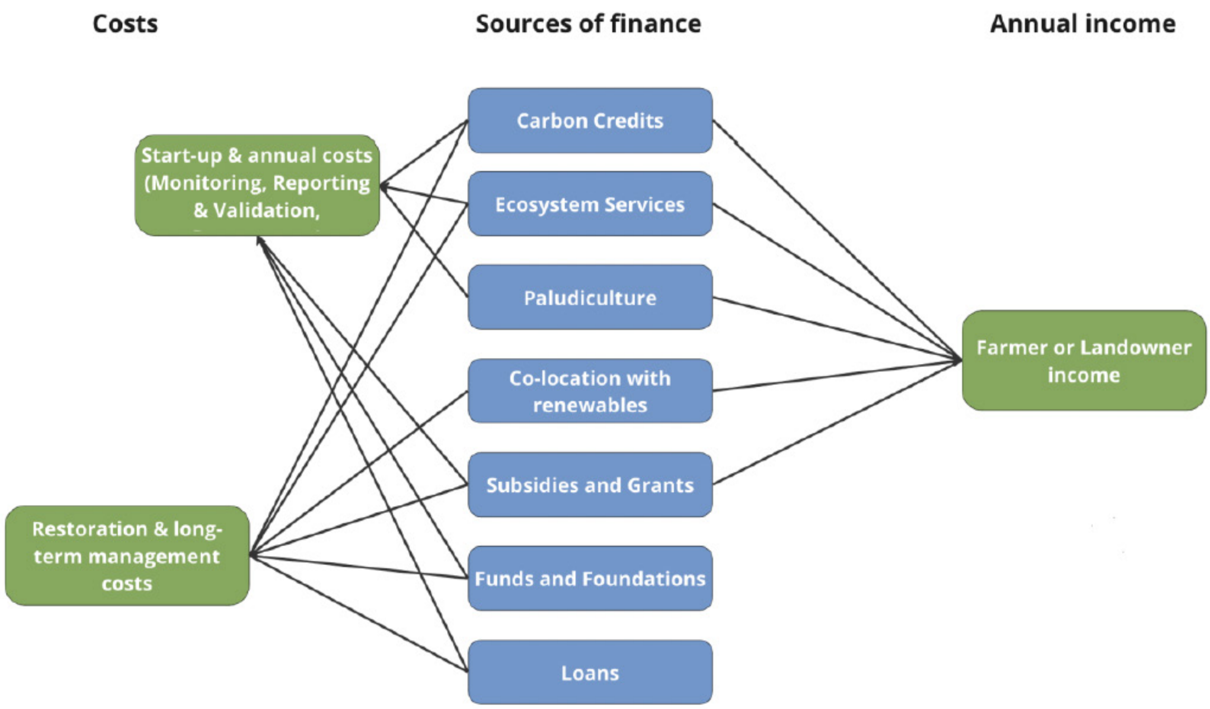

Figure 13: Blended Finance model for Peatland Restoration & Rewetting.

Appendix A
Carbon Farming Tool

Companion Spreadsheet for the Carbon Farming Tool
Care-Peat - Carbon Farming - Financial Feasibility and Pricing Tool

The need for the tool
A financial feasibility and pricing tool for carbon credits is presented here. The tool estimates the feasible profit from selling carbon credits as part of peatland restoration projects. It has been developed to inform discussions between advisers, brokers, accrediting bodies, farmers, landowners, and investors in carbon farming and other peatland restoration practices.
Emerging regulated, voluntary, and unregulated carbon markets create a complex patchwork of financial feasibility for investing in carbon farming. The variation on pricing carbon credits creates the need for a pricing tool that cuts across different emerging markets and locations. The financial feasibility and pricing tool presented here contributes to addressing this need.
The tool presented here is transferable across situations. It can be used in different countries, restoration projects, accreditation schemes, and carbon markets. The £ symbol is only used to show monetary information. The UK currency does not underpin the calculations. Any currency could be inserted in the cells that show £ symbol.
All inbuild assumptions to the tool can be amended to reflect site and project specific details. Information on average credits per hectare per year, cost of money, carbon registry costs, and investment arrangements are amendable. The tool works for future time scales from the calendar year 2020. The duration of the project affects the calculations, but the calendar years per se do not.

Summary of the tool
The tool estimates the financial feasibility of peatland restoration projects and the expected profit from different selling prices of carbon credits. The required input information is the project duration in years, average credits generated per hectares per year, hectares restored, investment amount, whether registry and investment costs are included, and a selling price of carbon credits.

Four indicators for financial feasibility are calculated. They are the rate of return, compound annualised rate of growth, gross present value, and net present value (**Figure 1**). Financial feasibility is indicated when all four indicators, and the profit per carbon credit and per hectare per year, return positive values. The expected profit per carbon credit and profit per hectare per year are based on the resulting net present value (**Figure 2**).

The financial feasibility and pricing tool comprises twenty-seven equations. The equations are grouped into six sets each informing the next. The financial feasibility and pricing tool has been organised and presented in Microsoft Excel file. The tool is outlined in detail including instructions on how to it in the accompanying instructions manual document and presentation slides. **Figure 1 and Figure 2** are summary overviews of financial feasibility and pricing tool.
The outcomes of the financial feasibility and pricing tool are illustrative examples. They illustrate potential profits or losses from selling carbon credits at different prices over a period of years. The outcomes of this tool are not financial forecasts. Specialist advice should be sought by farmers, landowners, or investors planning a change in land management.
The tool presented here has been validated in collaboration with farmers, policy makers and other stakeholders from the UK, and other partners involved in the Care-Peat consortium.

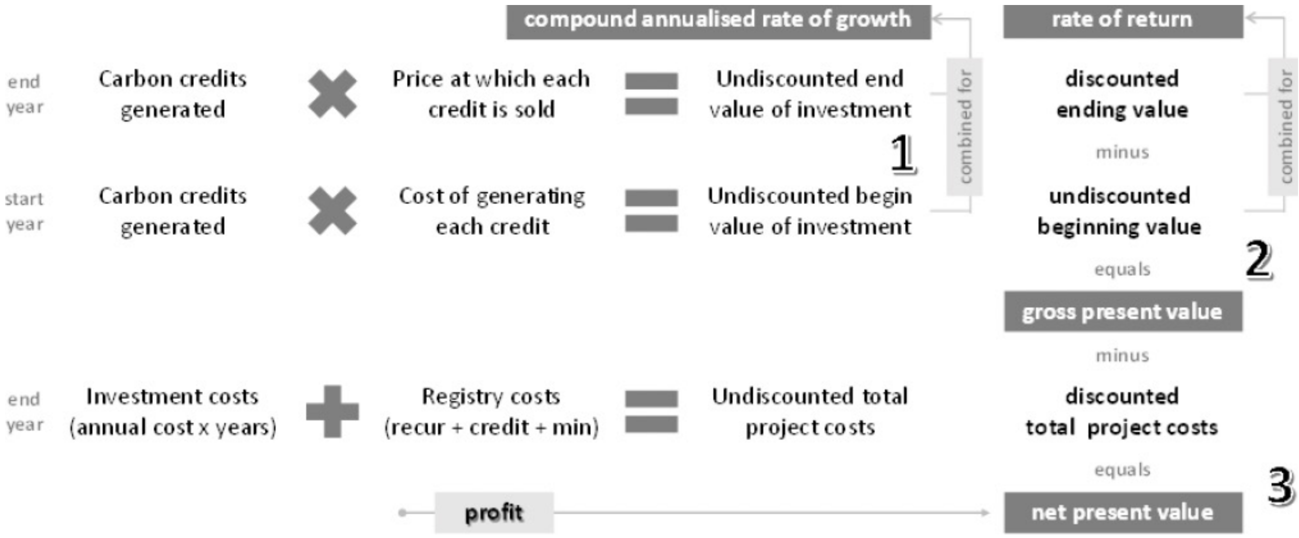

Figure 1: the four profitability indicators incorporated in the tool, dark grey boxes, there is potential profit when all four indicators are positive values

note: undiscounted values refer to present day value of money; discounted values refer to the value of money in the future converted to present day value of money; the undiscounted beginning and ending values of the investment are used in calculating the compound annualised rate of growth (1); the discounted ending and undiscounted beginning values of the investment are used in calculating the rate of return and the gross present value (2); the discounted ending and the undiscounted beginning values of the investment as well as the discounted total project costs are used in calculating the net present value (3); there is profit when all four profitability indicators are positive.

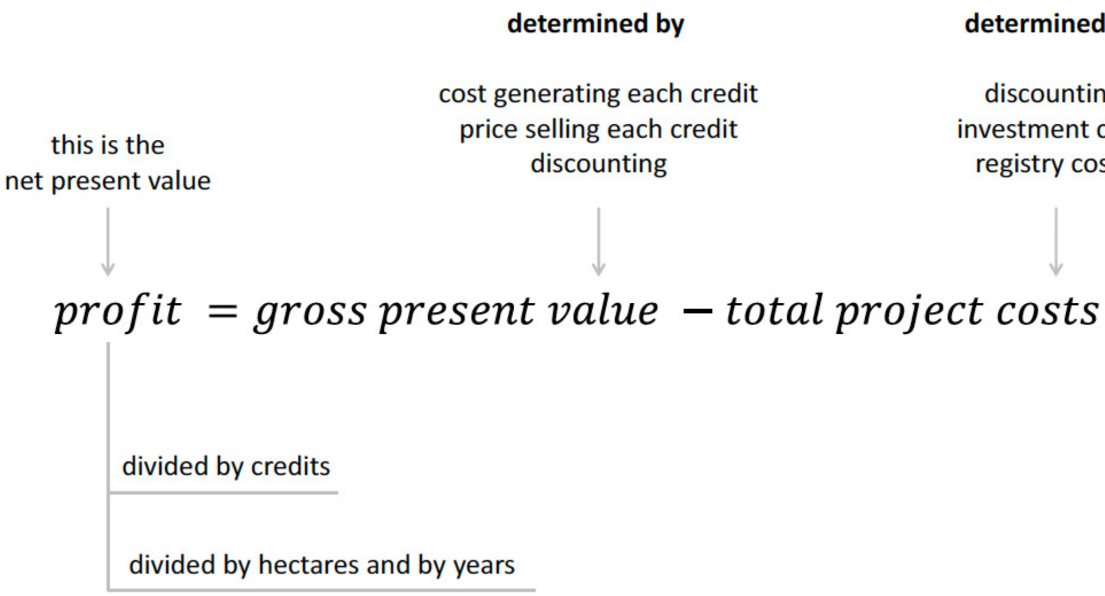

Figure 2: the profit per credit and per hectare per year, based on net present value, and determined by costs, selling price, and discounting

note: there is profit when the compound annualised rate of growth, the rate of return, the gross present value, and the net present value are positive; when there is profit the net present value is divided by credits generated, and by hectares and years of restoration, to show profit over the duration of the project.

Example application of the tool

An example application of the financial feasibility and pricing tool is presented here. This example application has been demonstrated to inform initial discussions between stakeholders interested in carbon farming and other peatland restoration practices.

The example application of the tool demonstrates potential financial feasibility of selling carbon credits for a fifty-year period from an initial investment in restoring one hectare of peatland and generating an average 20 credits per year. The inbuilt assumptions of the tool were not changed (**Figure 3**). All monetary values are shown in pounds sterling (£) but this represents a unit only. There is no link to the UK currency.

	Inbuild assumptions, **do not amend** values in this column	User assumptions, **amend values in this column**	Set up for calcaltions, **do not amend** values in this column
financial feasibility and pricing tool inbuild assumptions			
Credits per hectare per year			
Carbon Connects site emission tool			
Peatland Code emission calculators	20		20
Value of money			
Nominal interest rate (%)	2.35		0.024
Inflation rate (%)	2.10		0.021
Carbon registry costs			
Registry account opening fee, one-off, (£)	0		0
Registry listing cost per credit (£)	0.05		0.05
Registry conversion cost fee per inspection* (£)	100		100
Registry conversion cost per credit above min threshold of credits ** (£)	0.05		0.05
Registry levy cost per credit (£)	0.05		0.05
Validation and verification application cost per inspection* (£)	600		600
Validation and verification statement cost per inspection* (£)	800		800
Validation and verification inspector travel costs per inspection* (£)	500		500
* Cycle duration in years (one inspection per cycle) (years)	5		5
** Min threshold of credits above which registry conversion costs incur (credits)	2000		2000
Investment servicing arrangements			
constant payments and interest rate			
at interest rate (%)	5.00		0.050
over period of years (years)	50		50
number of payments per year (12 means one per month)	12		12

Figure 3: the inbuilt assumptions of the tool, these assumptions were used to demonstrate the outcomes under four investment scenariosa

The example application of the tool demonstrates potential financial feasibility of selling carbon credits from an initial investment in a major restoration of one hectare of peatland. A major peatland restoration assumes restoring drained, to either re-vegetated or to modified peatland, with an emission factor 20 tCO_2e per hectare per year (i.e. reduction in greenhouse gasses).

The emission factor 20 tCO_2e represents the changes in emission factors from a baseline grazed pasture condition (intensive drained grassland, emission factor 21.45 tCO_2e) to the carbon farm pilot condition (approximated to rewetted modified bog, emission factor 1.42 tCO_2e).

Monitoring measurements of greenhouse gasses reduction from the carbon farm pilot are similar to these values albeit with insignificant variations. Other peatland types have different emissions factors. For example, cropland on peat >40cm deep has an emission factor 37.17 tCO_2e. Emission factors mentioned here are taken from the UK Peatland Carbon Code.

Three initial investment amounts under four investment scenarios are demonstrated in the example. The three amounts were the carbon farm pilot (£74,700), a typical (£15,000), and a small (£6,000) initial investment per hectare of peatland restoration.

The £74,700 per hectare initial investment in peatland restoration is based on the costs incurred in establishing the carbon farm pilot. The carbon farm pilot covered two hectares, it was established over a short research project period, and it included a water storage area and a control site (one hectare each). These requirements increased the implementation cost for the two-hectare carbon farm pilot to £149,400.

The £15,000 and £6,000 used to illustrate respectively a typical and a small initial investment per hectare is based on the literature. The former reflects the typical investment per hectare in establishing lowland peatland restoration. The latter reflects investment per hectare at sites that require minimal initial modification and input.

The £74,700, £15,000, and £6,000 are very high compared to other initial investment per hectare of peatland restoration reported in the literature (Okumah et al 2019). Initial investment amounts reported in the literature include £74 per hectare of damming drains with plastic, £5,883 per hectare of damming drains with stone, and a median £1,009 per hectare across all restoration methods (Okumah et al 2019).

However, such very low initial investment amounts may not include ongoing management costs and typically result in low reduction in greenhouse gas emissions (i.e. emission factors between 0.14 and 5.44 tCO_2e per hectare per year). For these reasons, a typical £15,000, and a small £6,000 investment per hectare were appropriate for demonstrating in the example application of the tool.

For the carbon farm pilot, a typical, and a small initial investment the example application of the tool demonstrates potential financial feasibility of selling carbon credits under four investment scenarios. Each investment scenario is a configuration of investment servicing and carbon registry costs. The four investment scenarios for pricing carbon credits for the duration of the restoration are:

1. with investment servicing and carbon registry costs i.e. there are either loan repayments or return payments to an investor and payments to a formal registry for processing carbon credits; profit in this scenario appears after both types of costs have been covered
2. with only investment servicing costs i.e. there are only either loan repayments or return payments to an investor but no payments to a formal registry for processing carbon credits; profit in this scenario appears after just one type of costs has been covered
3. with only carbon registry costs i.e. there are no loan repayments or return payments to an investor but only payments to a formal registry for processing carbon credits; profit in this scenario appears after just one type of costs has been covered

4. without investment service or carbon registry costs i.e. there are no loan repayments or return payments to an investor and no payments to a formal registry for processing carbon credits; profit in this scenario appears after overing the cost of generating each credit

First, for each initial investment under each investment scenario, the cost of generating each credit, and the break-even carbon price are shown (**Table 1**). The break-even carbon price is the minimum each credit must be sold to cover all costs over the investment period. There is profit above the break-even carbon price. The profit per credit and the profit per hectare per year are demonstrated (**Table 2**). **Table 1 and Table 2** demonstrate the minimum profit that could be expected if the seller is able to decide the carbon credit price.

Second, for each initial investment under each investment scenario, the profit or loss made per hectare per year by selling carbon credits at existing market prices were demonstrated. Potential profit or loss made by selling carbon credits at £20 per tCO_2e (mid-point IUCN pending issuance unit prices; REF) and at £40 per tCO_2e (low forecasted short-term trading prices in UK, REF) are shown on **Table 3**. Profit or loss made by selling carbon credits at £80 per tCO_2e and at £120 per tCO_2e (central and high forecasted short-term trading prices in the UK, REF) are shown on **Table 4**. **Table 3 and Table 4** demonstrate profits or losses that could be expected if the seller sells at existing and forecasted carbon credit prices.

Outputs of the application of the tool

An initial investment in a major restoration from drained to re-vegetated or modified one hectare of peatland, over fifty-years period, generates for the investor 1,000 carbon credits. The initial investment affects the cost of generating each credit, which in turn affects the price each credit must be sold to break-even. In the UK current and forecasted carbon prices range between £20 to £120 per tCO_2e (IUCN, DEFRA).

Generating each carbon credit at a cost and selling each credit at break-even prices that fall within the current market price range is possible in four instances (**Table 1**). All three initial investments but without any investment servicing or carbon registry costs, and a small initial investment under all investment scenarios, could be profitable within the current market price range of £20 to £120 per tCO_2e. Also, potentially profitable within the current market price range could be a typical investment amount but with either only investment servicing costs or only carbon registry costs. The carbon farm pilot initial investment with only carbon registry costs would need a break-even selling price of £128 per tCO_2e.

Selling carbon credits at break-even prices may be profitable but the profit may be too small to incentivise investment in carbon farming. At break-even prices, across all three initial investments and all investment scenarios, the highest potential profit per carbon credit is £0.88 and the highest profit per hectare per year is £17.65 (**Table 2**). However, the profit from farm produce excluding subsidies and miscellaneous income, from grazing livestock in least favoured areas in the UK, is £83 per hectare per year (UK Farm Business Survey). If carbon farming returns less profit per hectare per year than current farming practices, it will not provide enough incentive to farmers for changing land management.

For each initial investment under each investment scenario, the profit or loss made per hectare per year by selling carbon credits at four existing market prices were calculated. The mid-point of the IUCN pending issuance unit prices of £20 per tCO_2e (IUCN), and the low £40 per tCO_2e, central £80 per tCO_2e, and hight £120 per tCO_2e forecasted short-term trading prices in the UK (DEFRA) were used. The £20 and £40 per tCO_2e reflect the low, and the £80 and £120 per tCO_2e reflect the high, end of current carbon market prices.

Selling carbon credits at the low end of current market prices at £20 and at £40 per tCO_2e results in profit in four occasions only. A typical initial investment and a small initial investment, both without investment servicing and carbon registry costs, return profits per hectare per year (**Table 3**). Selling carbon credits at £20 each, under typical investment without investment servicing or carbon registry costs, results in a lower profit per hectare per year (£53.94) than from grazing livestock in least favoured areas (£84). However, selling carbon credits at £40 each result in significantly higher profits per hectare per year compared to livestock grazing. Selling carbon credits at the low end of current market prices results in significant losses per hectare per year under all investment scenarios of the carbon farm pilot initial investment.

Selling carbon credits at the high end of current market prices at £80 and at £120 per tCO_2e may result in significant profit per hectare per year. For example, selling carbon credits at £120 each, under a small initial investment and including investment servicing and carbon registry cost could result in £629.61 profit per hectare per year. However, a £629.62 profit per hectare per year under the carbon farm pilot initial investment could only be achieved if there are no investment servicing or carbon registry costs and still selling carbon credits at £120 each (**Table 4**).

Selling carbon credits at £80 each result in significant profit per hectare per year under small initial investment and typical initial investment with either investment servicing costs only, or with carbon registry costs only, or without either of these costs. Selling carbon credits at £80 each result in significant losses per hectare per year for the carbon farm pilot initial investment under all investment scenarios.

Overall, the outputs demonstrate that investment servicing costs and carbon registry costs have a significant effect on the potential profitability and carbon pricing from an initial investment. The inbuilt cost for servicing the investment is 5%, interest rate on a loan or return payment to an investor, which may be too high. A low-rate investment servicing will be important in motivating investing in land management changes for some landowners. Carbon registry costs are particularly important for small restoration schemes, such as 2-hectare carbon farm pilot, which proportionally may pay more to these costs than large schemes. Neighbouring small hold landowners may wish to form carbon cooperatives to share carbon registry costs.

Table 1: Cost of generating each carbon credit and break-even selling price per carbon credit under different investment scenarios

	With investment servicing and carbon registry costs		With only investment servicing costs		With only carbon registry costs		Without investment service or carbon registry costs	
	Cost of each credit	**Break-even credit price**	**Cost of each credit**	**Break-even credit price**	**Cost of each credit**	**Break-even credit price**	**Cost of each credit**	**Break-even credit price**
Carbon farm pilot investment £74,700 per hectare	£298.34	£561.00	£278.24	£519.00	£94.80	£128.00	£74.70	£85.00
Typical initial investment £15,000 per hectare	£75.97	£147.00	£55.87	£105.00	£35.10	£60.00	£15.00	£17.00
Small initial investment £6,000 per hectare	£42.45	£85.00	£22.35	£42.00	£26.10	£50.00	£6.00	£7.00

Table 2: Profit per credit and profit per hectare per year from selling carbon credits at break-even price under different investment scenarios

	With investment servicing and carbon registry costs		With only investment servicing costs		With only carbon registry costs		Without investment service or carbon registry costs	
	Profit per credit	**Profit per ha per year**	**Profit per credit**	**Profit per ha per year**	**Profit per credit**	**Profit per ha per year**	**Profit per credit**	**Profit per ha per year**
Carbon farm pilot investment £74,700 per hectare	£0.16	£3.21	£0.88	£17.65	£0.67	£13.49	£0.51	£10.23
Typical initial investment £15,000 per hectare	£0.15	£2.96	£0.87	£17.40	£0.21	£4.10	£0.04	£0.85
Small initial investment £6,000 per hectare	£0.51	£10.22	£0.35	£6.96	£0.36	£7.14	£0.19	£3.88

Table 3: Profit or loss per hectare per year when selling carbon credits at IUCN mid-prices (£20) and at low forecasted short-term trading prices in UK (£40)

	With investment servicing and carbon registry costs		With only investment servicing costs		With only carbon registry costs		Without investment service or carbon registry costs	
	Price £20 per credit	**Price £40 per credit**	**Price £20 per credit**	**Price £40 per credit**	**Price £20 per credit**	**Price £40 per credit**	**Price £20 per credit**	**Price £40 per credit**
Carbon farm pilot investment £74,700 per hectare	-£9,570.77	-£9,216.83	-£8,813.06	-£8,459.13	-£1,897.77	-£1,543.83	-£1,140.06	-£786.13
Typical initial investment £15,000 per hectare	-£2,244.53	-£1,890.60	-£1,486.83	-£1,132.89	-£703.77	-£349.83	**£53.94**	**£407.87**
Small initial investment £6,000 per hectare	-£1,140.07	-£786.14	-£382.37	-£28.43	-£523.77	-£169.83	**£233.94**	**£587.87**

Table 4: Profit or loss per hectare per year when selling carbon credit at central (£80) and high (£120) forecasted short-term trading prices in UK

	With investment servicing and carbon registry costs		With only investment servicing costs		With only carbon registry costs		Without investment service or carbon registry costs	
	Price £80 per credit	**Price £120 per credit**	**Price £80 per credit**	**Price £120 per credit**	**Price £80 per credit**	**Price £120 per credit**	**Price £80 per credit**	**Price £120 per credit**
Carbon farm pilot investment £74,700 per hectare	-£8,508.96	-£7,801.09	-£7,751.25	-£7,043.38	-£835.96	£128.09	-£78.25	**£629.62**
Typical initial investment £15,000 per hectare	-£1,182.72	-£474.85	-£425.02	**£282.86**	**£358.04**	**£1,065.91**	**£1,115.75**	**£1,823.62**
Small initial investment £6,000 per hectare	-£78.27	**£629.61**	**£679.44**	**£1,387.31**	**£538.04**	**£1,245.91**	**£1,295.75**	**£2,003.62**

Validation and recommendations
The financial feasibility and pricing tool for carbon credits presented here has been validated in collaboration with farmers, policy makers and other stakeholders from the UK, and other partners involved in the Care-Peat consortium.

The pre-validation version of the financial feasibility and pricing tool comprised two components. The first component was projecting incomes and costs year by year for the duration of the project and then discounting the values. The second component was considering the snap shots of the start and end value of the investment and then discounting the latter. The pre-validation version of the tool combined the two approaches and a range of indicators to arrive at an overall financial feasibility outcome and carbon credit pricing.

During the validation process feedback from stakeholders indicated the combined approach was cumbersome, the complexity of the assumptions potentially limited transferability, and combined outcomes were not directly comparable with the current carbon market prices. In response to these feedback comments the pre-validation version of the tool was substantially changed by excluding its first component (discounting projected yearly values) and focusing on the second component (discounting start and end values).

This substantial change made the final version of the financial feasibility and pricing tool more user friendly, transferable, comparable with IUCN and similar pricing tools, and intuitive to understand than the pre-validation version. During validation discussions with stakeholders of both the pre-validation and the final versions of the tool several key implications emerged that require further attention from researchers, farmers, practitioners, and policy makers.
These implications are outlined here:

- Current voluntary UK and international markets for carbon credits are inconsistent. This makes direct comparisons between peatland restoration projects and carbon prices unclear. In addition, making direct comparisons between existing voluntary UK and international market prices creates the risk of undervaluing ecosystem services due to unregulated competition.

- The tool does not capture market distortions due to other contextual costs, forgone income, incommensurability, or incomparability between types of units used to measure the produce of one hectare of land (Figure 4). These market distortions affect profit and must be considered

- **Recommendation:** further wide consultation is needed on whether existing voluntary market prices are reasonable indicators or if they may be undermining the ecosystem restoration efforts and undervaluing ecosystem services.

- Initiating, implementing, maintaining, and managing a peatland restoration project requires significant capacity inputs initially and over the duration of the project. The farmer would have to either provide these capacity inputs or access them from specialist support (**Table 5**).

- In the UK a broad legal framework for buying and selling carbon credits is emerging that includes the environmental land management scheme introduced by the Agriculture Act 2020, the local nature recovery strategies introduced by the Environment Act 2021, the Woodland Carbon Code, and the IUCN Peatland Code.

- In the UK initiatives for buying and selling carbon credits are still embryonic, existing schemes are mostly demonstration projects, and further policy coherence and clarity are needed. Implementation practices and standards in the UK may differ between initiatives.

- Governments could fund directly, subsidise, provide tax incentives, facilitate financing options with low servicing rates, or any combination of these market mechanisms to support in full capital costs or ongoing costs of peatland restoration. Supporting piecemeal only part of capital or ongoing costs would limit the attractiveness of peatland restoration to farmers.

- **Recommendation:** further wide consultation is needed on the role of government in supporting the voluntary carbon market, without creating market distortion or prescriptive regulation.

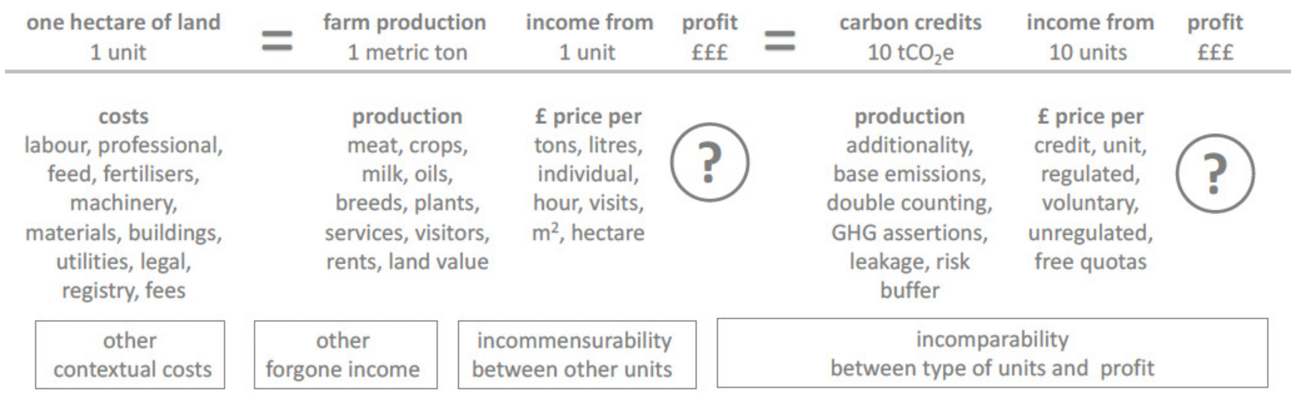

Figure 4: Market distortions that lead to incommensurability or incomparability between carbon credits and other produce from one hectare of land

Table 5: Capacity inputs and specialist support in peatland restoration projects

Requiring knowledge of	Requiring access to
peatland ecology habitat management emission factor calculators investment or loan servicing marketing ecosystem services management, reporting, verification systems negotiating contracts	accredited organisations brokers buyers consultants farmers farming organisations investors regulators

- The combination of investment servicing costs, carbon registry costs, and credits generated (i.e. tCO_2e reduction in greenhouse gasses per hectare per year) is more important in affecting the profit or loss from selling carbon credits than the initial amount invested in restoration per se.

- it may be possible to make significant profit per hectare per year from selling carbon credits within the current carbon market prices but that would require generating at least 20 credits per hectare per year of restoration, no investment servicing costs, and no carbon registry costs.

- High investment servicing costs and carbon registry costs, even with generating 20 credits per hectare per year, are likely to cause significant losses per hectare per year from selling carbon credits within the current carbon market prices.

- **Recommendation:** the risk of undervaluing carbon credits by overlooking hidden costs for the duration of the project must be considered at decision making.

- Selling carbon credits to a local buyer who could visit the peatland restoration site and see the benefits would be a suitable arrangement. This is clarified by international experience in mature pilot schemes in Germany and the Netherlands.

- Small to medium size enterprises willing to pay up to £1,500 per year, for certification of part of their social corporate responsibilities, would be suitable buyers of carbon credits from small carbon farms.

  Recommendation: further marketplaces are needed for local small to medium size enterprises to be matched with local small-hold carbon farmers.

- Inbuild assumptions in the financial feasibility and pricing tool affect the calculations. There are no fixed assumptions about investment servicing arrangements, carbon registry costs, emissions factors, nominal interest rate or inflation. These can be amended to reflect local situations.

- The tool is useful for making transparent the minimum financial considerations for pricing carbon credits. This transparency allows users to understand the financial and technical assumptions that affect profitability outcomes. These considerations are not exhaustive.

- Even after amending the assumptions to be site and project specific, the tool may not capture nuances of carbon credit schemes such as buffers, reserves, or time periods of selling credits. The outcomes of the tool are illustrative examples for discussion, they are not forecasts.

- Recommendation: further research is needed on modelling and forecasting carbon credit prices at the local, regional, and global levels.

- The tool considers carbon sequestration as a single ecosystem service provided from peatland restoration. Bundling additional ecosystem services of enhancing biodiversity, flood control, and cultural activities could promote mutual benefits and enhance the value of each single service.

- The potential for nature-based tourism, adventure tourism, natural exercise, school, health care, other residential and corporate awareness, and nature engagement events is significant from peatland restoration projects

- Recommendation: the potential for bundling ecosystem services rather than focussing on a single ecosystem service must be considered at decision making.

Appendix B Tool Instruction Manual

This is a financial feasibility and pricing tool for carbon credits from peatland restoration projects. It was developed by Manchester Metropolitan University and National University of Ireland Galway as part of Interreg North-West Europe Care-Peat project. This tool will be useful for advisers, brokers, accrediting bodies, farmers, landowners, and other investors in carbon credits.

Pricing of carbon credits varies widely under different markets. Emerging regulated, voluntary, and unregulated carbon markets create a complex patchwork of financial feasibility. This variation creates the need for a pricing tool that cuts across different emerging markets. The transferability of this financial feasibility and pricing tool contributes to addressing this need.

This financial feasibility and pricing tool for carbon credits is transferable across situations. It can be used in different countries, restoration projects, accreditation schemes, and carbon markets. The £ symbol is only used to show monetary information. The UK currency does not underpin any calculations. Any currency could be inserted in the cells that show £ symbol.

1.1 Outline of the tool

The tool uses non-technical input. It estimates the financial feasibility of peatland restoration projects and the expected profit from different sale prices of carbon credits. The input information is number of years, average credits generated per hectare per year, hectares restored, investment amount, whether registry and investment costs are included, and the selling price of carbon credits.

Four indicators are used for financial feasibility. They are the rate of return, compound annual rate of growth, gross present value, and net present value. Financial feasibility is indicated when all four indicators return positive values. The expected profit per carbon credit and per hectare per year are then based on the resulting net present value.

Inbuilt assumptions to the tool can be amended. Information on average credits per hectare per year can be amended by estimates from external calculators using site and project specific details. Cost of money, carbon registry costs, and investment arrangements are also amendable.

1.2 The organisation and presentation of the tool

The financial feasibility and pricing tool comprises twenty-seven equations. The equations are organised into six sets each informing the next. The tool has been organised in a Microsoft Excel file and presented in four tabs. The input tab is the main interface for the users to insert information and see the outcomes. The assumptions tab allows the users to amend the inbuilt assumptions that affect the calculations. There are no analytical equations in these two tabs.

The setup tab collates and arranges information for the calculations. There are sixteen equations in the setup tab arranged into three sets. The model tab performs the calculations for the profitability indicators. There are eleven equations in the model tab arranged into three sets. The last two tabs cannot be amended by the users.

The tabs of the financial feasibility and pricing tool are outlined in this document, including instructions on how to use each tab.

The input tab

The input tab is the main interface of the financial feasibility and pricing tool for the users (**Figure 1**). In the input tab users can (a) insert the minimum required information, (b) see how many carbon credits they could generate, and the cost for generating each credit, from investing in the restoration project, (c) insert and amend the price for selling carbon credits, and (d) see whether the selling prices are potentially profitable or not.

Non-technical input information is required as minimum. The required input information is the project duration in years, average credits per hectares per year, hectares restored, investment amount, whether registry and investment costs are included, and a selling price of carbon credits.

financial feasibility and pricing tool user interface			
Period of years	50	Credits generated by restored area	1,000
		Cost of generating each credit	£298.34
Average credits per hectare per year	20	Estimated credits per hectare per year	20
Hectares of restored area	1	Selling each credit for	£561.00
Investment	£74,700		
		Is the selling price profitable?	**YES**
Registry costs included?	Yes	Profit per credit	£0.16
		Profit per hectare per year	£3.21
Investment finance costs included?	Yes	Profit across project duration	£161
Start year	2023	End year	2072

Figure 1: the input tab, users input information in the underlined cells and see summary outcomes in the coloured cells

Average credits generated per hectares per year can be taken from the literature or similar projects and are only needed as an initial non-technical indicative input. Estimated credits generated per hectares per year can be calculated by using appropriate emission calculator tools and amended in the assumptions tab. There are no equations on the input tab.

Users adjust the selling price of carbon credits until they find the break-even point. The break-even point is the threshold between a profitable and not profitable sale price. Above the break-even point any pricing is potentially profitable and a profit per carbon credit and a profit per hectare per year are shown. These estimates are the expected profit from the selling price that has been entered.

Instructions for using the input tab

1. Insert the input information in the input tab on the left-hand side (underlined cells). On the right-hand side amend the selling price (underlined cell) until the profitable box shows Yes.

2. Use the cost of generating each credit as starting point (blue cell). Increase the selling price in large (tens, hundreds) or small increments to reach from not profitable to profitable pricing.

3. The break-even point is the threshold between a sale price that returns No, and the next small incremental increase of that sale price, which returns Yes in the profitable box.

4. For this reason, small incremental increases are necessary for identifying the break-even point. Above the break-even point any pricing is profitable, and the relevant cell shows Yes.

5. When the profitable box shows Yes, a profit per unit and a profit per hectare per year also appear (green cells). These estimates are the expected profit from the selling price that has been entered.

The assumptions tab

The assumptions tab shows the technical parameters that affect the outcomes of the financial feasibility and pricing tool (**Figure 2**). There are seventeen inbuild assumptions or technical requirements for the equations of the financial feasibility indicators. The inbuild assumptions cover the estimated carbon credits per hectare per year from the restoration project, the value of money, and any carbon registry costs and investment servicing costs. The assumptions tab is for using optionally to amend inbuilt assumptions as required by the users.

financial feasibility and pricing tool inbuild assumptions	Inbuild assumptions, **do not amend** values in this column	User assumptions, **amend values in this column**	Set up for calcaltions, **do not amend** values in this column
Credits per hectare per year			
Carbon Connects site emission tool			
Peatland Code emission calculators	20		20
Value of money			
Nominal interest rate (%)	2.35		0.024
Inflation rate (%)	2.10		0.021
Carbon registry costs			
Registry account opening fee, one-off, (£)	0		0
Registry listing cost per credit (£)	0.05		0.05
Registry conversion cost fee per inspection* (£)	100		100
Registry conversion cost per credit above min threshold of credits ** (£)	0.05		0.05
Registry levy cost per credit (£)	0.05		0.05
Validation and verification application cost per inspection* (£)	600		600
Validation and verification statement cost per inspection* (£)	800		800
Validation and verification inspector travel costs per inspection* (£)	500		500
* Cycle duration in years (one inspection per cycle) (years)	5		5
** Min threshold of credits above which registry conversion costs incur (credits)	2000		2000
Investment servicing arrangements			
constant payments and interest rate			
at interest rate (%)	5.00		0.050
over period of years (years)	50		50
number of payments per year (12 means one per month)	12		12

Figure 2: the assumptions tab, where users can amend, in the underlined cells, the inbuilt technical parameters that affect the calculations

In addition to the technical assumptions the financial feasibility and pricing tool is based on the following two broad assumptions. First, the restoration project successfully improves a year zero degraded peatland condition to a restored or carbon farm condition by the end of end of the project duration, generating all claimable carbon credits. Second, the buyer would be buying the credits ex-ante and post-ante throughout periods of time i.e. they would be paying for investment costs indirectly in the credit price, not directly at the start.

The equations in the column on the right set up the numbers in the correct decimal format for using in the subsequent calculations. There are no other equations on this tab.

Instructions for using the assumptions tab

1. Use the assumptions tab to amend the parameters that affect the background calculations.
2. The column on the left shows the inbuilt assumptions. The column on the right sets up the inbuilt or amended parameters for subsequent calculations.
3. Amend as required inbuilt assumptions by using the middle column (underlined cells). Amended parameters overwrite inbuilt assumptions in subsequent calculations.
4. Insert plain numbers with up to two decimal places. Do not use symbols in this column e.g. plus, minus, percentage, currency or other symbols.
5. Technical or specialist advice for using site emissions calculators and for amending carbon registry and investment servicing costs may be needed.
6. Use the Carbon Connects site emission tool, the Peatland Code emission calculators, or similar tools to estimate carbon credits per hectare per year based on site and project specific information.
7. Insert estimated carbon credits per hectare per year in cell G7. Estimated carbon credits are shown in the input tab, overwrite average credits, and are used in subsequent calculations.
8. Use long-term nominal interest rate and inflation rate for amending the value of money. Long-term fifty-year nominal interest rate and inflation rate are publicised by central banks.
9. Use the carbon registry costs associated with the specific certification organisation that is anticipated to process and verify the sale of carbon credits from the specific project.
10. Amend the interest rate, the number of years, and/ or the number of payments per year for servicing a loan or an investment.

The setup tab

The setup tab collates, sets up appropriately, and shows the detailed information used in calculating the financial feasibility indicators (**Figure 3**). There are sixteen equations in the setup tab (equations 01-16) arranged into three sets of equations. These are outlined below.

financial feasibility and pricing tool setup of parameters used in the model calculations

Calendar years and exponent			
Calendar year (start, year 0)			2023
Calendar year (end, year x)			2072
Final investment year (exponent)			49
Real interest rate (for discounting)			0.003
Years, credits, and hectares			
Period of years			50
Hectares restored			1
Average credits per hectare per year (input from literature)	20		
Estimated credits per hectare per year (amended or calculated)	0		20
Carbon credits			
Average credits used in calculations if initial input is not amended			20
Estimated credits used in calculations if initial input is amended			20
Carbon credits generated over period, hectares, and type of restoration			1000
Beginning and ending values of investment			
Beginning value (£ cost of generating each credit)			£298,345
Ending value (£ selling each credit for)			£561,000
Annual carbon investment costs			
Carbon investment			£74,700
Carbon investment cost per payment			-£339
Carbon investment cost per payment (for sum)			£339
Carbon investment annual costs (for sum)			£4,071
Registry costs			
Duration of inspection cycle (years)			5
Min units above which registry conversion costs incur			2000
	£ cost	times paid	sum cost
Registry account opening fee	0	1	0
Registry listing cost per credit	0.05	1000	50
Registry conversion cost minimum	100	10	1000
Registry conversion cost per credit (above min credits)	0.05	0	0
Registry levy cost per credit	0.05	1000	50
Validation and verification application cost (per inspection visit)	600	10	6000
Validation and verification statement cost (per inspection visit)	800	10	8000
Validation and verification inspector travel costs (per inspection visit)	500	10	5000
Type of costs included	registry	investement	
Registry costs included?	Yes	Yes	Yes
investment costs included?	No	No	Yes
Total costs over the duration of the project			
Total investment costs over project period			£203,545
Total carbon registry costs over project period			£20,100
Total project costs over project period			£223,645
Cost of generating each credit (i.e. investment divided by credits)			**£298.34**
Selling each credit for			**£561.00**

Figure 3: the setup tab, where users can see collated in one place all the information used in the calculations, users cannot amend this tab

Equations set 1 initial value of investment (**Figure 4**)

- equations 01-03 calculate the exponent and the real interest rate that are needed for the discounting equations. The project end year is calculated for illustrative purposes.

- equations 04-05 calculate the carbon credits generated and the cost for generating each credit. The latter is needed to inform the selling price and the former is used in equations relating to the monetary value of the investment and to carbon registry costs.

- equations 06-07 calculate the beginning value and the ending value of the carbon investment. These values are needed for subsequent equations in discounting and profitability indicators.

Eq. 01 $$Final\ investment\ year\ (exponent) = period\ of\ years\ -1$$

Eq. 02 $$Calendar\ year\ (project\ ends) = calendar\ year\ start + final\ investment\ year\ (exponent)$$

Eq. 03 $$Real\ interest\ rate\ (for\ discounting) = nominal\ interest\ rate\ -\ inflation\ rate$$

Eq. 04 $$Carbon\ credits\ generated = period\ of\ years\ \times\ hectares\ restored\ \times credits\ per\ hectare\ per\ year$$

Eq. 05 $$Cost\ generating\ each\ credit = \frac{investment\ amount + total\ project\ costs}{credits\ generated}$$

Eq. 06 $$Beginning\ value = carbon\ credits\ generated \times cost\ generating\ each\ credit$$

Eq. 07 $$Ending\ value = carbon\ credits\ generated \times\ price\ at\ which\ selling\ each\ credit$$

Figure 4: equations set 1, initial value of investment, in bold are equations that feed directly in multiple subsequent calculations

Equations set 2 investment costs (**Figure 5**)

- equations 08-10 calculate the total costs of servicing a loan or an investment for the restoration over the duration of the project. These costs contribute to the total project costs.

Eq. 08 $$Carbon\ investment\ cost\ per\ payment = PMT\left(\begin{matrix}\left(\frac{interest\ rate}{payments\ per\ year}\right), \\ (period\ of\ years \times payments\ per\ year), \\ (period\ of\ years)\end{matrix}\right) \times (-1)$$

Eq. 09 $$Carbon\ investment\ annual\ costs = carbon\ investment\ cost\ per\ payment \times payments\ per\ year$$

Eq. 10 $$Total\ investment\ costs\ over\ project = carbon\ investment\ annual\ costs \times period\ of\ years$$

Figure 5: equations set 2, investment costs, in bold is the equation that feed directly in multiple subsequent calculations

Equations set 3 carbon registry costs (**Figure 6**)

- equations 11-16 calculate the total carbon registry costs for administering the sale of carbon credits over the duration of the project. These costs contribute to the total project costs.

Eq. 11 $$Number\ of\ inspection\ visits = \frac{period\ years}{years\ per\ inspection\ cycle}$$

Eq. 12 $$Registry\ conversion\ cost\ per\ unit = cost \times (credits\ generated - minimum\ threshold)$$

Eq. 13 $$Registry\ costs\ recurring = \sum_{recuring} (cost \times inspection\ visits)$$

Eq. 14 $$Registry\ costs\ per\ credit = \sum_{per\ credit} (cost \times all\ credits)$$

Eq. 15 $$Registry\ costs\ per\ credit\ above\ threshold = \sum_{>threshold} (cost \times credits\ above\ threshold)$$

Eq. 16 $$Total\ registry\ costs\ over\ project = \sum recurring + \sum per\ credit + \sum per\ credit > threshold$$

Figure 6: equations set 3, carbon registry costs, in bold is the equation that feed directly ın multiple subsequent calculations

Instructions for using the set up tab

1. The setup tab is for reference only.
2. There is no option for the users to amend information in this tab.
3. Users can interrogate the information that feeds into the calculations on this tab.

The model tab

The model tab includes the calculations for the financial feasibility indicators and the overall profitability synthesis (**Figure 7**). Calculations include the discounting of start and end values of investment, the profitability indicators, and the profit per carbon credit and per hectare per year. There are eleven equations in the model tab (equations 17-27) arranged into three sets of equations. These are outlined below.

financial feasibility and pricing model discounting

discounting

	restored
hectares	1
credits generated over project duration	1000
	values
beginning value	£298,345
ending value (undiscounted)	£561,000
ending value (discounted)	£496,396
exponent year for discounting	49
real interest rate for discounting	0.003
exponent factor for CARG	0.020
total project costs (undiscounted)	£223,645
total project costs (discounted)	£197,890

financial feasibility and pricing model detailed output

profitability indicators

Income	£161
Credits	1000
Hectares	1
Years	50
Profit per credit	£0.16
Profit per hectare per year	£3.21
Rate of return (ROR) %	66.38
Compound annualised rate of growth (CAGR) %	1.30
Gross present value (GPV)	£198,051
Net present value (NPV)	£161
Profitable?	YES
Is the selling price profitable?	YES

Figure 7: the model tab, where users can see the profitability indicators and overall profitability synthesis, users cannot amend this tab

Equations set 4 discounting future value of investment (**Figure 8**)

- equations 17-18 calculate the exponent factor needed for the compound annualised growth rate, and the total project costs that are used for discounting and in the profitability indicators.
- equations 19-20 calculate the discounted ending value of the investment and the discounted total project costs. These values are then used in the profitability indicators.

Eq. 17 $$exponent\ factor\ for\ CARG = \frac{1}{exponent\ year}$$

Eq. 18 $$Total\ project\ costs = total\ investment\ costs + total\ registry\ costs$$

Eq. 19 $$ending\ value\ (discounted) = \frac{ending\ value\ undiscounted}{(1 + real\ interest\ rate)^{exponent\ year}}$$

Eq. 20 $$total\ project\ costs\ (discounted) = \frac{total\ project\ costs\ undiscounted}{(1 + real\ interest\ rate)^{exponent\ year}}$$

Figure 8: equations set 4, discounting future value of investment, in bold is the equation that feed directly in multiple subsequent calculations

Discounting converts future values into the value of present money by adjusting for interest and inflation rates and the number of years in the future. For example, with an interest rate 2.35% and long-term inflation at 2.10% then £7,000 in the year 2072 would be equal to £6,194 in the year 2023.

Equations set 5 profitability indicators (**Figure 9**)

- equations 21-24 calculate the four profitability indicators. These are the rate of return, the compound annualised growth rate, the gross present value, and the net present value.
- The difference between the rate of return and the compound annualised growth rate is that the former calculates a snapshot of growth and the latter a smooth steady growth. The difference between the gross present value and the net present value is that the former only includes future incomes and the latter includes both future incomes and future payments.

Eq. 21 $$Rate\ of\ return = \left(\frac{(ending\ value\ discounted\ - beginning\ value)}{beginning\ value}\right) \times 100$$

Eq. 22 $$Compound\ annualised\ rate\ of\ growth = \left(\left(\frac{ending\ value\ undiscounted}{beginning\ value}\right)^{\left(\frac{1}{exponent\ year}-1\right)}\right) \times 100$$

Eq. 23 $$Gross\ present\ value = ending\ value\ discounted - beginning\ value$$

Eq. 24 $$Net\ present\ value = ending\ value\ discounted - beginning\ value - total\ project\ costs\ discounted$$

Figure 9: equations set 5, profitability indicators, in bold are the equations that feed directly in the overall profitability outcome

Equations set 6 overall outcome (**Figure 10**)

- equations 25-27 synthesise an overall profitability outcome and calculate potential profit.
- An investment is potentially profitable when all profitability indicators, and the profit per credit and profit per hectare per year, are positive values. For potentially profitable investments, the profit per credit and profit per hectare per year are calculated. These are shown as outcomes on the input tab. The losses per credit and losses per hectare per year from unprofitable investments are also calculated but are not shown on the input tab.

Eq. 25
$$Profitable? = Yes\ when\ \forall \begin{pmatrix} profit\ per\ credit, \\ profit\ per\ hectare\ per\ year, \\ rate\ of\ return, \\ compound\ annualised\ rate\ of\ growth, \\ gross\ present\ value, \\ net\ present\ value \end{pmatrix} > 0$$

Eq. 26
$$Profit\ per\ credit = \frac{net\ present\ value}{credits\ generated\ and\ sold}$$

Eq. 27
$$Profit\ per\ hecatre\ per\ year = \frac{(net\ present\ value \div hectares\ restored)}{period\ years}$$

Figure 10: equations set 6, overall outcome, when all four indicators are positive then profit per credit and per hectare per year are calculated

It is possible for gross present value to positive but net present value to be negative because the former does not consider the costs during the duration of the project. It is also possible for either the rate of return or the annualised rate of growth to be positive while the other being negative. For these reasons all four indicators must be positive to indicate an overall project profitability.

Instructions for using the model tab

1. The model tab is for reference only.

2. There is no option for the users to amend information in this tab.

3. Users may interrogate the model tab for additional insights on pricing and profitability.

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European Regional Development Fund

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