Royal Society for the Protection of Birds

Economic costs and benefits of nature-based solutions to mitigate climate change

cambridge econometrics

clarity from complexity

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Contents

Executive Summary

Nature-based solutions?

Nature-based climate solutions are nature-based processes which have the potential to remove carbon from the atmosphere and store it for a long time, thereby providing a 'natural' way to mitigate climate change. Forests, mangroves, swamps, peat bogs, salt marshes and seagrass beds are all examples of nature-based solutions which have the ability to sequester carbon.

Despite their potential to reduce global greenhouse gas emissions (GHGs), Nature-based climate solutions are not being created, monitored and protected in sufficient volumes, and indeed many of these habitats are in degraded condition and being allowed to worsen. Insufficient funding for Nature-based climate solutions in the UK is preventing natural habitats from achieving their ecological potential, therefore diminishing their ability to remove carbon from the atmosphere.

Natural habitats help mitigate climate change, while creating job opportunities and economic benefits for people and businesses

Restoration and improved management of natural habitats can enhance their carbon sequestration potential. Investing in the restoration of natural habitats can be expected to deliver further benefits in terms of creating jobs and economic output, helping to meet commitments for biodiversity, and delivering vital ecosystem services for people and businesses.

This report provides an analysis of the costs and benefits of restoring three habitats of interest in the UK, namely peatlands, salt marshes and woodlands. A cost benefit analysis approach is used to compare the monetary value of costs and benefits. When monetisation of benefits is not feasible, a qualitative assessment is adopted, and considered alongside the quantitative cost benefit analysis.

Three habitats are analysed to determine the costs and benefits of restoration

Peatlands are the largest natural terrestrial carbon store. The preservation of peatlands can reduce the amount of carbon being emitted from damaged habitats, while as the habitat is restored, it can begin to sequester and store carbon. This analysis shows that for every £1 invested in restoration, the average expected quantified returns are estimated to be £4.62 in terms of economic and social benefits. Alongside the monetary benefits, peatland restoration can contribute to improved water quality, reduced flood risk, enhanced biodiversity and the preservation of ecological and archaeological sites. Restoration projects can also boost employment and gross value added (GVA) in the economy. This analysis estimates that the upfront capital investments in restoration could be expected to create around 3 temporary jobs for every 100 hectares of habitat (during the restoration phase) and generate £156k in GVA over the same period. In addition, the ongoing activities to maintain the restored peatland are estimated to create 7 job-years for every 100 hectares of habitat and generate £321k in GVA per 100 hectares of habitat, over a period of 100 years.

Vegetation in **salt marshes** capture large amounts of carbon dioxide, after which the sequestered carbon is incorporated in trapped in the marsh soil and layers of deposited sediment for long periods of time. Therefore, salt marsh restoration represents a Nature-based solution, which can contribute to both climate change mitigation and adaptation. However, the condition of salt marshes in the UK is being threatened by climate change. This analysis shows that for every £1 spent on salt marsh restoration, up to £1.31 can be expected to be returned in quantified economic and social benefits, depending on whether a low, medium and high cost of restoration scenario is assumed. Although the upfront restoration costs can be high for some sites, restoration of salt marshes can also deliver improved water quality, fish nursery areas, enhanced biodiversity and reduced flood risk. Depending on the nature of the restoration projects, 14 to 74 temporary jobs for every 100 hectares of restored habitat can be created during the restoration phase as a result of the capital investment. In addition, the upfront capital investment in the restoration of the habitat is estimated to generate between £880,000 and £4.8m in GVA per 100 hectares of restored habitat.

Woodland represents 13% of the land cover in the UK. Woodlands are a Nature-based solution due to their ability to act as a natural carbon sink. This analysis shows that for every £1 spent on afforestation, an average of £2.79 is estimated to be returned in quantified economic and social benefits. In addition, woodlands can deliver further valuable ecosystem services such as improved water quality, noise mitigation, temperature regulation, reduced flood risk and enhanced biodiversity. This study also shows that the capital investments attributed to afforestation can create approximately 25 temporary jobs and generate £1.2m for every 100 hectares of habitat during the tree-planting stage. In addition, the ongoing maintenance of woodlands are expected to secure 6 job-years and generate £314,000 in GVA per 100 hectares of habitat, over a period of 100 years.

Investing in Nature-based solutions help to achieve carbon reduction targets, while providing an opportunity for a green economic recovery

This analysis estimates positive benefit-cost ratios of restoration in all cases, and for all habitats substantial further benefits are identified. Although we are unable to monetise these further benefits, and therefore are unable to include them in the quantitative cost benefit analysis, their contribution must not be discounted. Although the initial up-front costs can be high for each of the three habitats, benefits from restoration arise during the entire period of 100 years considered in this analysis.

Nature-based solutions can play an integral role in helping to deliver a Net Zero economy, as they provide a way of removing emissions on an ongoing basis. Beyond this, Nature-based solutions can also deliver noteworthy economic and social benefits and could therefore also form part of a green recovery strategy in the short term as Government seeks ways of boosting economic growth following the impacts of COVID-19.

1 Introduction

1.1 Policy background

Climate change mitigation

Nature-based climate solutions (NBS) are approaches to climate change mitigation based on the natural ability of ecosystems to remove carbon from the atmosphere (carbon sequestration) and store it. The ecological restoration of environments such as woodland, mangrove swamps, peat bogs, salt marshes and seagrass beds and the improved maintenance of natural habitats and ecosystem services, are all examples of NBS. NBS provide an alternative to other carbon sequestration techniques such as carbon capture and storage (CCS).

Further benefits of habitat restoration

As well as offering environmental benefits through carbon sequestration, the restoration of habitats such as peatlands, woodland and salt marshes offer further environmental benefits such as increased biodiversity, improved water quality, reduced flood risk and reduced air pollution. Restored habitats also offer recreational and tourism opportunities and potential employment creation through restoration and ongoing operation and maintenance activities.

A note on definitions

Nature-based climate solutions are also sometimes referred to as natural climate solutions. Box 1 below explains the subtle differences in the two definitions.

Box 1 Natural climate solutions vs nature-based solutions

Natural climate solutions (NCS) are actions taken for the conservation, restoration, and management of natural habitats, which aim to increase carbon storage and reduce greenhouse gas emissions in the atmosphere. Natural habitats like wetlands, grasslands and forests can capture carbon from the atmosphere and store it for long periods of time. By doing so, NCS improve resilience of the ecosystem, enhance biodiversity, and help communities adapting to climate change.

Nature-based solutions (NBS) are defined by the International Union for Conservation of Nature (IUCN) as actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN 2020). Nature based solutions can differ from NCS, as the former can result in invasive and harmful interventions for biodiversity, when not implemented effectively. For instance, plantation of non-native trees can provide benefits for carbon sequestration, while displacing native animal species (Seddon et al. 2020).

Nature-based solutions are given little attention…

Despite great potential to aid the transition to net zero, to date, little public funding has been available for NBS in the UK. And while targets exist for reducing emissions, there are few comparable targets for nature recovery. Targets for nature recovery, when combined with other policies for decarbonization, are indeed essential to achieve Net Zero goals. Targets exist for reforestation; however, the most recent woodland statistics indicate that tree-planting targets have been missed (Forestry Commission 2019). Furthermore, the Committee on Climate Change's Net Zero report called for an increase in UK woodland cover to 17% by 2050, if net zero is to be achieved (Committee on Climate Change 2019). This would require 30,000 hectares a year to be planted every year to 2050 (compared to 13,000 hectares planted in 2019).

NBS are however, rising up the agenda. Following and supporting the recommendations put forth by the CCC mentioned above, in April 2020, the Natural Capital Committee, who until November 2020, advised the UK government on the economic value of the natural environment, published recommendations for using nature based interventions to help reach net zero by 2050 (Natural Capital Committee 2020). The report recommends that the government should prioritise spatial planning for the following five nature-based interventions:

- maintaining and increasing tree cover
- maintaining and increasing soil carbon (including peatland restoration)
- improving biodiversity
- managing freshwaters and wetlands
- sea use changes.

The report highlights that NBS can deliver carbon reductions at a lower cost than other, engineered, solutions, such us Carbon Capture and Storage (CCS) technologies. Importantly, NBS need to be delivered effectively, for example by planting the right trees in the right places to avoid undermining other environmental priorities. When carried out effectively, NBS have the added benefit of enhancing biodiversity, the stocks of natural capital in the UK and the consequent delivery of a broad range of other valued ecosystem benefits.

Although the UK Budget 2020 includes a Nature for Climate Fund of £640m for tree planting and peatland restoration, more, ongoing, funding will be required to enable substantive change.

Nature-based climate solutions as part of a green stimulus package

Following the 2020 COVID-19 pandemic and associated economic shutdown, there are many calls for the UK government to place strong sustainability and green principles at the heart of a recovery plan. Increased investment in NBS is one such measure which could form part of a wider green stimulus package. Furthermore, as well as providing economic benefits, natural habitats have demonstrated their wider environmental and social benefits during the pandemic. Having access to nature and wildlife can improve individuals' well-being and happiness, and these benefits should be recognised and explicitly considered when delivering future funding.

The Committee on Climate Change set out its recovery package recommendations in a letter to the Prime Minister in May 2020 (Committee on Climate Change 2020b). The letter states that there are 'clear economic, social, and environmental benefits from immediate expansion' of measures including 'tree planting, peatland restoration, green spaces and other green infrastructure'. The letter highlights that changes to the way the UK's landscape is used can deliver substantial benefits for the climate, biodiversity, air quality and flood prevention and that additional tree planting and peatland restoration should form a key part of changes to land use.

A further letter to the Prime Minister in June 2020 from more than 200 leading UK businesses, investors and business networks calls for the economic recovery plan to align with the UK's wider clean growth goals[1]. The letter recommends that recovery plans should ensure support for sectors and activities that can deliver sustainable growth, including natural environmental improvements.

There is growing traction for a more sustainable economy following the COVID-19 crisis, and NBS can play a substantial role in the path to recovery.

Summary

NBS and the potential benefits they could provide are rising up the political agenda and could form part of a post-COVID-19 green recovery package. However, these solutions need to be implemented carefully if the full environmental, economic and social benefits are to be achieved. This report aims to show that there are some clear economic, social, and environmental benefits from investment in the restoration of natural habitats as NBS.

1.2 RSPB work on nature-based climate solutions

A study conducted by the RSPB in 2019 mapped nature rich areas in the UK and calculated how much carbon is contained in the vegetation and top 30cm of soil (RSPB 2020a). The research finds that 66% of the carbon in nature-rich areas lies outside protected areas. Many of these habitats are not being looked after properly and are in poor condition. The study highlights that if natural habitats were managed effectively, nature could be sequestering and storing more carbon from the atmosphere. Similarly, the UK has seen a decrease in the area of Sites of Special Scientific Interest (SSSI) in favourable condition from 44% in 2003 to 38.9% in 2019 (Natural England 2019). Restoration and improved land management of natural habitats therefore provide a significant natural solution to aid the fight against climate change. The study recommends that Government policies should prioritise an improvement in the ecological condition of the carbon and nature-rich areas across the UK.

The mapping study forms Phase 1 of the RSPB's work in investigating the potential of NBS in the UK. In Phase 2, the RSPB is seeking to understand the physical climate mitigation potential available through increased afforestation, peatland restoration and managed realignment. A final phase will take a wider look at land use and examine various scenarios associated with tree planting and other NBS.

1.3 The purpose of this report

Within the broader aims of Phase 2, this report outlines the economic and social costs and benefits of NBS in three habitats of interest - peatlands, salt marshes and woodland. The report compares the use of these three habitats for NBS with the next best alternative use of the land, to determine the economic and social costs and benefits of using the land for NBS. Although benefits and costs of NBS vary largely depending on the site of the habitat and on the restoration activities required, this analysis does not provide any site-specific estimates. This analysis prioritises the adoption of central estimates

[1] https://www.corporateleadersgroup.com/reports-evidence-and-insights/pdfs/final-290520-business-groups-ceo-resilient.pdf

and average values over the use of wide ranges of costs and benefits based on site specific factors.

The RSPB will use the research detailed in this report to inform the debate around future public expenditure on environmental land management programmes and demonstrate the benefits of NBS, including the ability of NBS to achieve nature and climate goals and to deliver a variety of public goods and private economic opportunities.

1.4 Overview of approach

To assess the potential economic and social costs and benefits of NBS in this study, a cost benefit analysis (CBA) approach is used. The CBA approach involved estimating the monetary, non-monetary and wider macroeconomic costs and benefits of alternative uses for the three habitats of interest - peatlands, salt marshes and woodland, i.e. the costs and benefits of restoring the habitat as a NBS, and the opportunity cost of not continuing to use the land for its current purpose. The first step in the analysis was to identify economic and social costs and benefits for the alternative uses of the natural habitat, as well as identifying existing methods for quantifying these costs and benefits.

A range of literature sources have been reviewed, including reports by public and private organisations, academic and ‘grey’ literature, and existing relevant data from official sources such as the ONS. These are used to identify the known or suggested costs and benefits are of each alternative use of the land, and what methods are commonly applied for quantifying the identified costs and benefits. Private and external, as well as monetary and non-monetary, costs and benefits were considered in the review. It is important to highlight that costs and benefits of NBS are expected to vary widely depending on the location of the habitat and the nature of the restoration activities required. However, due to data availability this analysis provides representative estimates of costs and benefits of NBS and does not account for site-specific factors. When the data presented wide ranges of costs and benefits, averages values and central estimates are usually adopted.

1.5 The cost benefit analysis approach

The quantification stage of the CBA uses a net present value (NPV) approach, as adopted by the ONS UK Natural Capital Accounting and recommended by the System of Environmental-Economic Accounts (SEEA).

The NPV approach estimates the value of the stream of benefits that are expected to be generated over the lifetime of an asset, in this case the restored natural habitat. These values are then discounted back to the present accounting period. This provides a single estimate of the capital value of the asset at a given point in time[2].

There are three main aspects of the NPV approach:

- Expected future flows of values – in this case the future annual monetised value of each benefit, calculated using the methods set

[2] All monetary values referred to in the CBA analyses have been converted to a 2019 price base, unless stated otherwise.

out in Chapters 2-4. All costs and benefits in the analysis are expressed on a per hectare basis.

- The asset lifetime, i.e. the period over which the flows of values are expected to be generated – in this CBA the lifetime of the natural habitat is assumed to be 100 years, as suggested by the ONS guidance on Natural Capital Accounting (ONS 2019).
- The choice of discount rate – in this CBA benefits are discounted at the HMT social discount rate (3.5%), also suggested by the ONS guidance on Natural Capital Accounting.

For consistency with the HM Treasury guidance on natural capital accounting, the monetary value of the gross value added (GVA) of restoration projects is not included in the CBA analysis. However, GVA resulting from the recovered habitats should be considered alongside the CBA analysis, as it represents an important benefit to the economy.

Once NPVs are obtained for each benefit, the total value of each restored habitat is calculated by summing up the costs and the benefits, and a benefit-cost ratio is calculated to assess the total trade-off between the two. A benefit-cost ratio greater than 1.0 implies the restoration of the natural habitat will deliver a positive net present value to society.

As indicated in Chapters 2-4, there are many social benefits which it is not feasible to monetise within the scope of this study, and which are to be assessed qualitatively. For decision making purposes, these additional benefits, which could be substantial, should be considered alongside the final benefit-cost ratio as further considerations of the positive impacts investment in Nature-based solutions can generate.

Assumptions and limitations to the approach

While Cost Benefit Analysis, conducted in a manner consistent with the Green Book, is typically used for project evaluation by the UK Government, there are substantive questions about its suitability for evaluating investment decisions, both in relation to its methodological approach and its relevance given the current economic and policy environment.

Frank Ackerman wrote extensively on the limitations to cost benefit analysis (Ackerman 2008; Ackerman and Heinzerling 2002). His primary criticisms included;

- It requires all costs and benefits to be monetised; anything which cannot be monetised cannot be included in the calculation;
- The process of monetisation implies that all costs and benefits can be traded off against each other;
- It struggles to deal with uncertainty; there is uncertainty both of outcome and in terms of monetisation methodology, and the sum effect of this across all costs and benefits would introduce such large ranges across the CBA as to make it uninformative;
- The use of particular discount rate strongly affects the trade-off within a cost-benefit analysis between short- and long-term impact.

Moreover, there are fundamental questions in current times about the ‘status quo’ which is implicit in any such cost-benefit calculation. To highlight two key considerations;

- The UK Government is committed to achieving a net zero emission economy by 2050. The relevant question when evaluating different low-, zero- or negative-carbon technologies is therefore not whether the measure carries a net positive impact relative to doing nothing, but whether it does so relative to other measures which achieve the same emissions reduction.
- CBA assumes full use of resources; it is on this basis that economic impacts (i.e. employment and GVA impacts) are removed from the calculation, because the assumption is that these activities simply take place instead of an alternative use of these resources. In CBA, there are no spare resources in the economy in either the short- or the long-term, and therefore there can be no net additions to the economy in either timeframe. However, given the short-term economic downturn caused by COVID-19, and the absence of full employment of resources in recent history either in the UK or elsewhere in the world, such assumptions seem rather unfavourable.

Table 1.1 below summarises how these and other assumptions/limitations of the adopted methodology apply in particular to the cost benefit analysis carried out in this report.

Table 1.1 Assumptions and limitations of the methodology

Habitat type	Assumptions & Limitations
General assumptions & limitations	• The CBA provides an overview of some of the benefits and costs of restoring peatlands, salt marshes and woodlands, which we are able to monetise. Monetised benefits and costs presented in this report should be interpreted as indicative estimates, as these are not based on the analysis of specific sites or locations. In reality, costs and benefits (and the resultant benefit-cost ratio) may vary substantially depending on the location of the habitat. • The benefit-cost ratio which is calculated through the CBA does not account for *all* the various benefits associated with these deployments, a number of which we are unable to monetise and have instead acknowledged qualitatively. The benefit-cost ratio should therefore be considered as an estimate, and should be considered alongside the other supporting analysis. On balance, we expect that the benefit cost ratios derived in this analysis tend to underestimate the overall benefits of restoration projects. • When data provides wide ranges of costs and benefits depending on site-specific factors, the adoption of averages and central estimates was prioritized over the use of extensive range values.
Peatlands	• The CBA analysis focuses exclusively on upland peatlands, as these are more likely to be restored to their natural state than lowland peatlands. Upland peat is also the most common peatland habitat in UK, accounting for 65% of the total peatland extent (IUCN UK 2010). • Opportunity costs of restoring peatland are included in operational costs. These costs refer to the payment required to compensate former owners/users of the land for potential income losses. • Land acquisition costs are not counted, as peatland restoration is assumed to take place without a change in land ownership. • Due to data availability, it is not possible to separate operational costs from opportunity costs. This limitation may lead to overestimate the impacts of restoration on the creation of employment opportunities and on the generation of gross value added (GVA).
Salt marshes	• Due to data availability, recurring costs and operational expenditures are not counted in the costs of restoring salt marshes. • Opportunity costs are expressed as the expenses required to purchase the land. • Due to data availability, it is not possible to separate capital costs from opportunity costs. This limitation may lead to overestimate the impacts of restoration on the creation of employment opportunities and on the generation of gross value added (GVA).
Woodlands	• Due to data availability, it was not always possible to estimate costs and benefits by type of woodlands (i.e. broadleaved and coniferous). When data presented both values for coniferous and broadleaved woodland, an average of the two values was considered to carry out the analysis. • Opportunity costs are expressed as the expenses required to acquire the land. • The full carbon sequestration potential may not be reached for many years after afforestation. However, due to data availability this analysis assumes that the carbon sequestration potential is constant over a period of 100 years. This implies that the carbon sequestration full potential is achieved from plantation onwards.

Source: Cambridge Econometrics

1.6 Report structure

The rest of this report is structured as follows:

- Chapters 2 - 4 presents the findings of a literature review, in which the economic and social costs and benefits for alternative uses of each natural habitat, and existing methods for quantifying these costs and benefits, are identified. Each chapter then presents the results of a cost benefit analysis, in which the net costs and benefits of restoring each of the three habitats. Costs and benefits are presented per hectare of restored habitat.
- In Chapter 5, conclusions are set out.

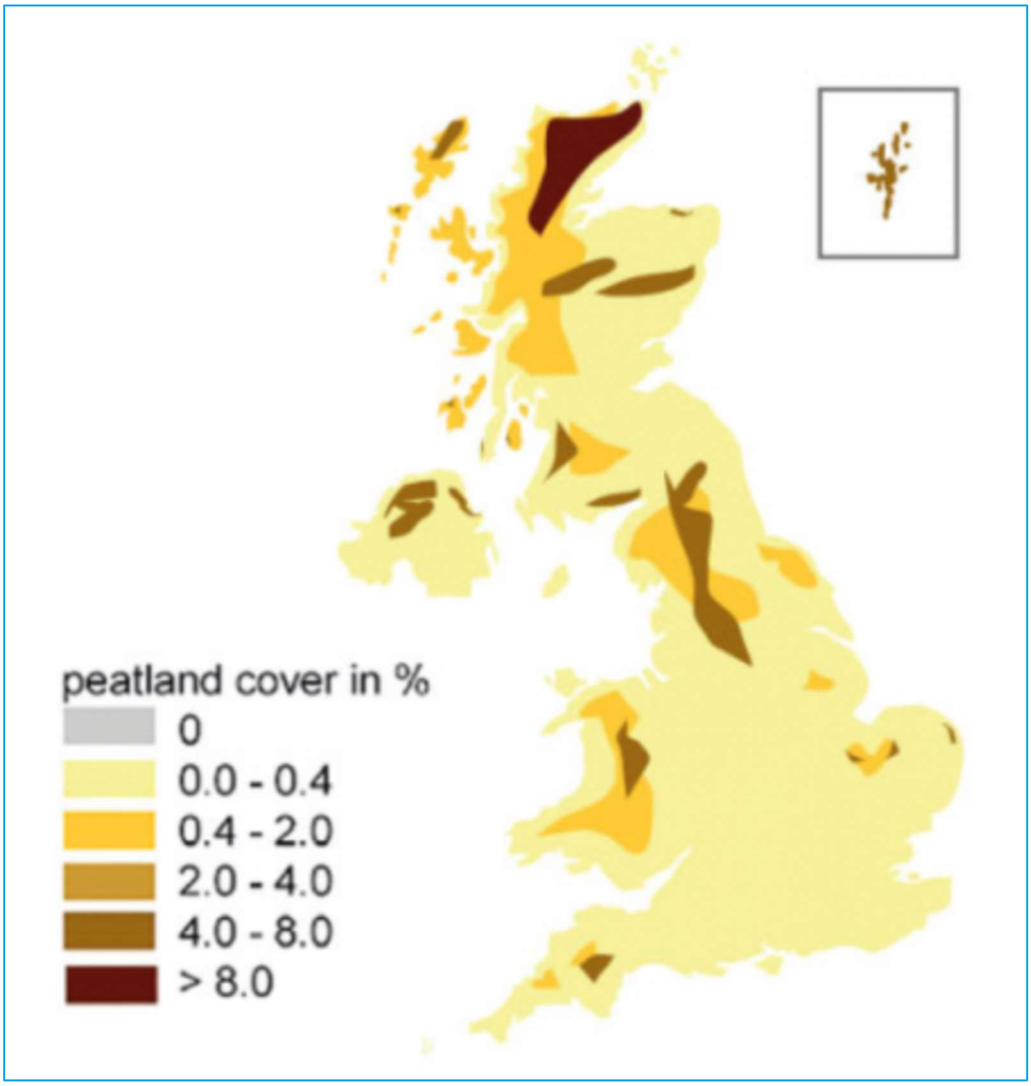
2 Peatlands

2.1 Peatlands as a Nature-based solution

UK peatlands

Peatlands are areas of land with a naturally accumulated layer of dead plant material (peat), which is formed because the waterlogged conditions prevent plant material from fully decomposing (Cris et al. 2012). The peat soil builds up slowly over time, storing vast amounts of carbon, making peatlands one of the most carbon-rich ecosystems on Earth. In the UK, peatlands account for around 10% of total land area, with 60% of UK peatlands located in Scotland (see Figure 2.1) (IUCN UK 2020).

Figure 2.1 The location of UK peatlands



Source: (IUCN UK 2020)

Three types of peatland exist in the UK; blanket bog, raised bog and fens. Peatland areas in the UK are typically used for farming, hunting sports or, in their natural state, as nature reserves. Use of peatlands historically for farming or hunting has left them in a poor state due to unsustainable land management practices, with an estimated 80% of UK peatlands in some way damaged. Much of the UK's peatland is no longer sequestering and storing carbon, and is conversely a substantial source of carbon emissions, emitting around 4% of the UK's total annual greenhouse gas (GHG) emissions (Evans et al. 2017). This analysis focuses exclusively on upland blanket bogs in the UK, as these are more likely to be restored to their natural state than lowland peatlands. This is because lowland peatland is primarily used as valuable agricultural land, for which the opportunity cost of using the land as a NBS would be substantially higher than converting upland peatlands to NBS. Upland blanket bogs are also the most common peatland habitat in UK, accounting for 65% of the total peatland extent (ONS 2019).

The carbon reduction benefits of restoring peatlands to a more natural state are twofold. Preventing further damage to peatlands reduces the amount of carbon being emitted from the habitat, while as the habitat is restored, it can begin to sequester and store carbon. Peatland restoration can therefore deliver substantial emissions reductions in the long term, making it an ideal nature-based solution.

How might peatlands be restored?

The restoration of peatlands entails restoring the waterlogged conditions and the vegetation structure required for peat formation, to prevent the release of carbon stored in peat soil. Restoration activities can include re-vegetation of bare peat, rewetting peatlands by blocking drainage, removal of livestock grazing and burning management practices and the re-introduction of peat forming species where they are no longer present.

Identified benefits of peatland restoration and quantification

As well as providing a nature-based solution through their ability to sequester and store carbon, in their natural state, peatlands offer many other environmental, economic, and social benefits.

While some benefits are tangible and therefore relatively straightforward to monetise, such as increased economic output, in many cases the benefits are intangible. Assessing the monetary value of intangible costs and benefits is often very difficult. Where costs and benefits cannot be easily monetised, qualitative supporting arguments are formed and considered within the cost benefit analysis. In the sections that follow, we separate out the benefits which can be quantified in monetary terms (and are therefore included in the cost-benefit analysis), and those that cannot (and which are therefore considered qualitatively here).

2.2 Benefits that can be quantified in monetary terms

Carbon sequestration

Damaged peatlands in the UK release 10m tonnes of carbon emissions into the atmosphere every year (IUCN UK 2020), representing around 4% of total carbon emissions. Restoring at least 50% of upland peat and 25% of lowland peat by 2050 would lead to a reduction in emissions equivalent to five million tonnes of CO_2 (Committee on Climate Change 2020a). This potential reduction in the emissions being released by damaged peatlands is a key element to consider when evaluating the role peatlands play in helping to deliver net zero by 2050. Looking beyond 2050, restored peatlands offer further carbon sequestration benefits as the level of peat builds up over time (noting that it takes approximately 100 years to form 10cm of peat).

Quantifying carbon sequestration

Determining the monetary value of carbon sequestration requires an assessment of the net amount of carbon captured each year by peatlands. The latter is measured as tonnes of carbon dioxide equivalent removed each year for each hectare of habitat. Quantifying the benefits of carbon sequestration in monetary terms can be done in a simple fashion by multiplying the amount of carbon sequestered or emissions avoided by restored peatlands, by a price applied to carbon emissions. From the literature and current data sources it is possible to obtain data covering either the carbon emissions released by degraded peatlands (which could be avoided via restoration) or estimated annual sequestration rates of restored peatland. These estimates of carbon emissions either released or sequestered can be multiplied by a carbon price.

A near natural bog typically removes 3.54 tCO_2 per hectare per year (ONS 2020). In the CBA this carbon sequestration rate was used to estimate the total amount of carbon absorbed by UK upland peatlands each year. The quantity of sequestered carbon was then multiplied by projected non-traded prices of carbon (see Box 2 Carbon Valuation), as published by BEIS, to determine the monetary value of this benefit.

Box 2 Carbon Valuation

In 2009 the UK government agreed on a set of carbon values to be used in policy appraisal and evaluation. Every year, the UK government publishes updated projections of the price of carbon, including projections up to 2100. This approach distinguishes traded and non-traded carbon prices:

- **The traded carbon price** reflects the value of carbon emissions traded on the EU Emissions Trading System (ETS). The latter is the world's first major carbon market and works as a ‘cap and trade’ system, which sets a limit on the use of total greenhouse gas emissions and converts this amount into tradable emission allowances. Hence, the traded carbon price is typically used for appraising policies that affect the level of emissions in sectors covered by the EU ETS. The traded price of carbon was £14/tCO_{2e} in 2020.
- **The non-traded carbon price** is based on estimates of the **abatement costs** incurred in order to meet the emissions reduction target set in the Climate Change Act. This value is typically used for appraising policies that affect the level of emissions in sectors not covered by the EU ETS. In 2020, the non-traded price of carbon was £69/tCO_{2e}. Prior to 2009, the UK government based its valuation of the non-traded carbon value using the **shadow price of carbon**. The latter represents the lifetime damage costs associated with greenhouse gas emissions, known as the **social cost of carbon**.

Recreational benefits

Restored peatlands create new recreational benefits, as an area for walking, enjoying wildlife and educational visits. The recreational opportunities created by restoring peatlands, and the associated opportunities for improved health and well-being, are a substantial non-market benefit to be included in cost benefit analysis. It should be noted, however, that some recreational activities might be lost by re-wetting the landscape, including the ability to walk, horse ride or hunt on the land, and the opportunity cost of losing the ability to carry out these activities should also be taken into account. Nevertheless, restoration programs can bring wide benefits that outweigh these opportunity costs.

Quantifying recreational benefits

Since recreation is a non-traded public good, it is not easy to quantify or assign a monetary value to it. Quantifying the value of recreation at peatland habitats is made more difficult since individuals may not be aware they are visiting a peatland environment. These difficulties lead to the need for an approach to determine a proxy monetary value of recreation time spent at the natural habitat.

Various valuation methods are commonly used, including contingent valuation (also referred to as stated preference methods or choice experiments). This involves surveying individuals, asking them how much they would be willing to pay for a good or service or their willingness to accept compensation for the loss of a good or service. A further method is Value of Enjoyment per adult visit (VOE) which is different to willingness to pay, but also involves a survey. These methods are time-consuming and difficult to carry out and are not within the scope of this study.

Alternatively, methods for attaining revealed preferences are more relevant. Revealed preferences may be found where non-market goods and services are implicitly traded in secondary markets, e.g. the value of a place of recreation can be indirectly inferred from money spent on visiting those places (through entrance tickets, travel costs etc.). In the cost benefit analysis, the travel cost method was determined to be most suitable method for valuing recreation time at peatland habitats. This consisted of estimating the recreational value of visits to peatlands, using data on the expenditure incurred to travel to the peatland site and the spending during the visit (fuel, public transport costs, admission charges and parking fees). For this study, the ONS Peatlands Natural Capital Accounting database provided data on the number of visits to peatland sites and the related expenditure. The underlying data is based on the Monitor of Engagement with the Natural Environment survey (MENE) (Natural England 2020), which gathers self-reported information on outdoor recreational activities in England.

With all the aforementioned methods of valuing recreation, it should be noted that there is a problem of additionality; that is, visitors to a peatland may be choosing to visit there instead of somewhere else, so in reality it could be the case that no additional social benefit is created. This also implies that some peatland habitats attract more visitors than others, therefore retaining a higher recreational value.

2.3 Benefits which are difficult to monetise

Employment and economic opportunities of restoration

Peatland restoration projects have a positive effect on employment, through the creation of additional jobs both in the restoration phase itself, and in ongoing future operation and maintenance of the habitat. A restoration project increases output in sectors delivering the goods and services to carry out the restoration, and increased employment has a positive effect on household expenditure, creating further demand and output elsewhere in the economy.

Quantifying economic opportunities of restoration

In this study, an input-output (IO) analysis is carried out to determine the employment and gross value added (GVA) benefits that can be expected from a peatland restoration project, using capital expenditure (CAPEX) and operating expenditure (OPEX) costs as inputs to a UK-level input-output model developed by Cambridge Econometrics. This tool is based on the understanding that an initial investment or expenditure creates output, and associated jobs, in specific sectors. The IO tool is used to quantify the increase in purchases of goods and services required to deliver that output, and consequently additional impacts further up the supply chain. While GVA is expressed in monetary terms, it is not usually included in a CBA, hence its contribution to the overall benefits associated with peatland restoration is acknowledged in this section, alongside the employment benefits.

Employment opportunities of restoration

Peatland restoration projects have a positive effect on employment, through the creation of additional jobs both in the restoration phase itself, and in ongoing future operation and maintenance of the habitat. Furthermore, when considering upland peatland areas, jobs can be created in economically vulnerable and remote areas (Committee on Climate Change 2018). Conversely, due to restoration projects jobs can be lost in activities originally carried out on the land, such us animal raising and agriculture. However, job losses are typically small for restored upland peatlands, as these are not generally used for intensive and profitable economic activities (Committee on Climate Change 2018). The IO modelling carried out within this analysis estimates that, as a result of the capital investments in peatland restoration, around 3 temporary jobs for every 100 hectares of habitat can be created during the restoration phase. In addition, the investment for ongoing operation and maintenance of the restored habitat is expected to generate around 7 job-years for every 100 hectares of restored habitat during a period of 100 years[3]. These estimates include jobs, that are created as a direct result of the restoration project and ongoing operation and maintenance of the restored peatland, as well as within supporting industries (i.e. jobs within associated supply chains), and further jobs resulting from increased household incomes and consequent increased household spending.

As part of its recommendations on how to improve the UK's use of land to meet climate goals, the Committee on Climate Change recommends that at least 55% of peatland are restored to good status by 2050 (Committee on Climate Change 2020a). This 55% equates to approximately 1.6m hectares of peatlands across the UK (Glenk and Martin-Ortega 2018), thereby potentially generating approximately 48,000 temporary jobs in the restoration phase and 112,000 job-years during a period of 100 years. The value of the increased job opportunities should be considered alongside the benefit-cost ratio described above.

Increased gross value added (GVA) from restoration

Peatland restoration increases gross value added (GVA), through the investments in the conversion of the habitat to a nature-based solution. The IO modelling carried out within this analysis estimates that the upfront capital investment is expected to generate a total impact of £1,565 on GVA per hectare or restored habitat during the restoration phase. In addition, the investments in operation and maintenance of the restored habitat is estimated to generate a total impact of £3,213 on GVA per hectare of restored habitat, during a period of 100 years. These estimations include both the direct impact on GVA resulting from the restoration project and ongoing maintenance operations, as well as the indirect impact associated with supporting industries

[3] Job-years represent the cumulative years of full-time employment (FTE) jobs over a period of time, i.e. the total number of jobs for one person for one year. An FTE job represents one person's work for one year at regulated norms (e.g. 40 hours a week for 52 weeks a year, excluding holidays). Using this accounting, two separate, six-month jobs would therefore be counted as one FTE job.

in the supply chain and further value added from increased household incomes and household spending.

If the recommendation to restore 55% of UK peatlands were to be pursued (Committee on Climate Change 2020a), approximately £2.5bn can be generated in GVA during the restoration phase, as a result of capital investments. Similarly, the investments in operation and maintenance of the restored habitats are expected to generate around £5.1bn in GVA, over a period of 100 years.

Improvement of water quality

Peat soils have water regulating properties and up to 70% of UK drinking water is sourced from catchments dominated by peatland habitat (Natural England 2009). However, if the natural habitat is damaged, the water collected via peatlands becomes discoloured and there are both economic and environmental costs associated with removing the discolouration of water. The processes used for removing peat stain from water are environmentally damaging, since they are energy- and carbon-intensive and the process requires additional additives during the treatment, and generates additional waste to landfill (Scottish Forum on Natural Capital 2016). The escalated cost of water treatment associated with peatlands in poor condition ultimately raises consumers' water bills. Restoring peatland and improving water quality before it reaches water treatment facilities is more cost effective and environmentally friendly than removing discolouration later on.

Existing peatland restoration projects have demonstrated the potential for improved water quality resulting from the restoration of the habitat. For example, the United Utilities Sustainable Catchment Management Plans (SCaMP) project led to the restoration of 20,000 hectares of upland peatland (RSPB 2020b). Ongoing monitoring of these water catchment areas is beginning to show evidence that improved condition in the peatland habitats has reduced the discolouration of water.

Evaluating improved water quality

Improved water quality can be valued in monetary terms using the avoided cost method. This method is based on the principle that the benefit of naturally filtered water results in cost savings to water companies (and consumers) from not having to treat that water through other processes. The avoided cost method therefore values this benefit of peatland restoration by calculating how much it would cost to treat that water with an existing treatment system. However, the avoided cost approach is difficult, and therefore monetary estimates of reduced treatment costs of water associated with peatland restoration are scarce. Financial quantification is made difficult since the monetary relationships between increased water quality and decreased treatment costs are not yet well established, and it is also difficult for water utility companies to disentangle other factors such as treatment costs associated with pesticides (iCASP 2020). Beyond the lack of data, the valuation of this benefit remains difficult, as it is very challenging to quantify the exact contribution of restoration programmes to the improved quality of water. Hence, due to the lack of data and to methodological constraints, we do not attempt to monetise this benefit in this study.

There are, however, some indicative examples where the value of avoided water treatments can be used as a proxy for the valuation of improved water quality. For example, in 2010/2011 Severn Trent Water spent at least £2,000 per week during the summer, and as much as £4,000 per week in the winter months to remove peaty sediment from drinking water, equating to £160,000 over the course of a year (Scottish Forum on Natural Capital 2016). In addition, a report published by Natural England estimates the present value of two scenarios for the Keighley water catchment area over a 25 year period, an ‘improve’ scenario in which investments are made to deliver a greater range of ecosystem services through habitat restoration and more sympathetic land management interventions and ‘decline’ scenario in which there is future ecological decline in the catchment area habitat (Natural England 2012). In the ‘improve’ scenario, improved water quality is valued at £2.2m over 25 years, through reduced water treatment costs. Conversely, a decline in the ecological condition of the habitat led to increased water treatment costs of over £2.5m over the 25-year period.

While it is difficult to place monetary values on improved water quality benefits which can result from restored peatlands, the benefit should not be excluded from an overall evaluation of the costs and benefits of a restoration programme. Both environmental and economic benefits arise from reduced treatment requirement, and the value of these can be substantial over time.

Improved flood water management

Peatland vegetation slows the flow of rainfall, and the habitat’s natural ability to store water can play a role in regulating both peak flows during flooding and base flows during dry spells, preventing flooding in local towns and villages. Flooding can cause serious damage to agricultural land (leading to soil degradation or loss of crops for example), buildings and businesses, and can reduce property prices in the local area. Peatland which are restored to their more natural state can therefore offer substantial benefits for flood alleviation.

Evaluating reduced flood risk

The monetary value of reduced flood risk can be determined using the avoided cost method i.e. using the costs of damage to properties and possessions of flooding (for example, by using Weighted Annual Average Damage (AAD) figures) as a proxy. In this case, the avoided cost method is based on the principle that peatland restoration can increase the ability of the habitat to store water, resulting in a lower chance of flooding downstream. As a result, subsequent cost-savings occur, from not having to provide compensation for the losses and damages caused. However, to produce a robust estimate the number of homes, businesses and land which would benefit from reduced flood risk needs to be known, which is only possible when considering a particular site of restoration. Since this analysis does not focus on a specific site, producing a robust estimate of value is not possible, therefore, we do not attempt to monetise this benefit within this study.

However, some studies have attempted to estimate the monetary value of reduced flood risk resulting from specific peatland restoration projects, using the avoided cost method. For example, the restoration of the Wicken Fen National Nature Reserve in Cambridgeshire has led to the habitat acting as a natural flood storage area with the capacity to protect 2,000 hectares of farmland and ten homes in the local area. Of this area, 50 hectares would be flooded on average once every twenty years, while the remaining 1,950 hectares would be affected by higher water tables resulting in higher value crops being replaced with lower value crops (Peh et al. 2014). The value of the flood protection benefits to farmers and homeowners from restoring the Wicken Fen peatland (equivalent to avoided damage to crops and property) was estimated at £355,004 per flood event. Based on the assumption of a flood occurring every twenty years, this equates to £17,750 per year or £37 per hectare per year.

Alongside the tangible damages caused by flooding (for example, damage to property and land), there are other, intangible damaging effects on human health and psychological well-being. The value of avoiding these adverse effects can be estimated using a contingent valuation approach. A contingent valuation approach entails asking individuals what their willingness-to-pay for a reduced risk of flooding is. Respondents may be asked to state how much additional tax they are willing to pay to preserve a particular ecosystem service for example, or to state the amount of compensation they would be willing to accept to give up the ecosystem service. Studies have also attempted to estimate the value of reduced flood risk using a contingent valuation approach, for example (Joseph, Proverbs, and Lamond 2015) finds that the average willingness-to-pay per household to avoid or reduce the intangible impacts of flooding, including psychological impacts, is estimated at £653 per household per year.

Alternatively, the monetary value of reduced flood risk can be considered equal to the costs associated with building an alternative type of flood defence. However, again, site-specific information would be required to determine the type and scale of an alternative flood defence.

While the aforementioned methods can go some way to estimating the value of reduced flood risk, it should also be noted that they only account for market aspects of flood damages and do not account for non-market aspects, such as the inconvenience, stress and health impacts caused by flooding. Avoidance of these additional damaging effects should also be incorporated into any valuation. While it is difficult to place a monetary value on the total benefit of reduced flood risk, this benefit should not be excluded from the overall evaluation of the costs and benefits of a peatland restoration project.

Increased biodiversity

Peatlands support a large proportion of the plant and animal species which are adapted to waterlogged, acidic and nutrient-poor conditions (Bain et al. 2011), including a range of rare, threatened or declining animals and plants. Notably, UK peatlands support an important collection of birds, with an exceptionally high proportion of bird species with legal protection under UK and European conservation law (Bain et al. 2011). Protecting the natural habitat of these plant and animal species is therefore vital to avoid biodiversity loss. The restoration of peatlands offers protection for many rare and endangered species, and the opportunity for these species to increase in number and thrive.

Evaluating biodiversity

While there are various methods for quantifying biodiversity, such as measuring biodiversity in terms of the presence and abundance of specific species in an ecosystem or measuring it in terms of species richness (i.e. the number of different species compared to the total number of species), there is no accepted method of monetary valuation. Placing a monetary value on increased biodiversity is a challenging exercise due to its public good attributes, meaning that individuals can benefit from the enjoyment of increased biodiversity without paying for it, and the enjoyment of one individual does not the reduce the availability of biodiversity (and the associated enjoyment gained from it) for others. Biodiversity delivers non-use benefits, which cannot be estimated as they are typically intangible and are not associated with any market transaction or money transfer. A prime motivation for nature conservation is the value people place on the sheer existence of other species and biodiversity and this is not amenable to monetary estimation.

While proxy values may be used to monetise a partial value of biodiversity to individuals, such as donations to conservation NGOs and charities, these proxy methods are usually too general, and/or may include use values. That is, other individual values may be at play when deciding to donate, for example. Double counting issues may arise, as the proxy value may include values attributed to other benefits such as recreation as well as biodiversity. Stated preference methods can also be used when valuing biodiversity, hence attempting to separate the value of increased biodiversity from recreational use values. However, valuation using a stated preference approach usually requires a survey, which is beyond the scope of this study and, as noted above would not cover intrinsic motivation and values beyond the purely economic. Therefore, due to the aforementioned methodological constraints, in this study the additional benefit to wildlife of habitat restoration is not included in the cost-benefit analysis due to the difficulties with estimating a meaningful monetary value.

While no widely accepted method of monetary valuation exists for biodiversity, the *level* of biodiversity in a particular habitat can be quantified by other means, such as measuring biodiversity in terms of the presence and abundance of specific species in an ecosystem or measuring it in terms of species richness (i.e. the number of different species compared to the total number of species). One approach for fully understanding the value of biodiversity within peatlands is to consider the number of rare and specialised species adapted to the peatland conditions, and trends in key species. The IUCN reports that the modification of peatlands has negatively impacted key wildlife species and that a greater proportion of UK Priority Species of peatlands are declining than are increasing. Furthermore, breeding bird populations on peatlands are under pressure from multiple factors including habitat degradation and climate change (Littlewood et al. 2010).

The improvement in habitat conditions resulting from the restoration of peatlands therefore provides invaluable benefits to the rare and endangered species native to them, and although this benefit cannot be valued in monetary terms, it should be considered qualitatively within this cost benefit analysis.

Preservation of important ecological and archaeological information

Restored peatlands are important for the preservation of important ecological and archaeological information such as pollen records and human artefacts. While an archaeologist working in ‘dry land’ conditions may be fortunate to find 10% of what was once there, an archaeologist working in peatlands may find 90% of the material culture of ancient communities (Gearey et al. 2010). Meanwhile, fossilised plant remains preserved in peatlands provide valuable information about past environments and have played an important role in understanding the impacts of climate change. Restoring peatlands therefore helps to protect this scientific value.

Quantifying ecological and archaeological information

Placing a monetary value on the benefit of increased preservation of ecological and archaeological information is difficult. While in theory it is possible to value via stated preference methods, there is a double counting risk if the survey covers use values also valued under other categories, for example, recreation. Furthermore, it is likely that individuals do not fully understand the importance of peatlands in terms of preserving ecological and archaeological information. A report from the IUCN acknowledges that there is a ‘need to explore current perceptions and knowledge and consider ways to present information from the historic environment record that will help to raise consciousness of the value of peatlands in the broadest sense’ (Gearey et al. 2010).

The preservation of ecological and archaeological information is usually assessed qualitatively, and this is the approach adopted in this analysis. While it is difficult to place a monetary value on the scientific value added by peatland restoration, this additional benefit should not be disregarded, and should be considered alongside all the other environmental, social and economic benefits offered by a restored peatland, as discussed above.

The value of combined benefits

A national level survey in Scotland was carried out with a representative sample of Scotland’s population, to estimate the benefits provided from peatland restoration (Glenk and Martin-Ortega 2018). Participants were provided with a description of three peatland conditions (poor, intermediate and good) and were asked to choose between three alternative scenarios. In two scenarios, for a given cost, there was an improvement in the peatland condition, leading to improvements in the delivery of three ecosystem services: carbon sequestration, water quality and biodiversity. In the final scenario there was no improvement in the condition of peatland, at no cost. Applying statistical methods to analyse the choices made by the survey respondents, the study estimates their willingness to pay for environmental improvements to peatlands. The average monetary value that individuals attached to the benefits associated with peatland restoration (i.e. shifting from intermediate to good condition) in terms of carbon sequestration, improved water quality and biodiversity, ranged from £127 to £414 per hectare per year, depending on the degree of improvement and location of restoration.

2.4 Identified costs of peatland restoration

The costs of peatland restoration depend on the type of habitat (i.e. upland or lowland), the accessibility of the site and the level of degradation of the habitat (i.e. near-natural, drained, eroded) (Committee on Climate Change 2020a). Lowland and upland peatlands require different restoration techniques, which result in different costs of restoration. These costs are low compared to other nature-based solutions (e.g. the restoration of salt marshes and creation of woodlands), however peatlands in their natural state yield no private benefits. For this analysis, the costs associated with restoration of upland peatlands are used in the cost benefit analysis, as these represent the most common type of peatland in UK. The restoration costs can be classified in three main categories: capital costs, operational costs, and opportunity costs.

Capital costs

Capital expenditure refers to the upfront costs required to initiate the restoration programme. These costs include expenses for plantation and re-vegetation, the cost of erecting fences, the cost of the required machinery, the cost of finance incurred by borrowing to pay for the initial investment. Table

2.1 shows the capital costs of restoration for upland and lowland peatlands per hectare of habitat used within the cost benefit analysis.

Table 2.1 Capital costs of peatland restoration (£/ha)

Cost Type	£/ha
Upland peatland restoration costs	1,061
Upland peatland financing costs	412
Total upland peatland cost	**1,473**
Lowland peatland restoration costs	1,968
Lowland peatland financing costs	762
Total lowland peatland cost	**2,731**

Source: (Vivid Economics 2020)

Note: The capital costs are estimated using per hectare costs of restoration activities weighted by the percentages of peatlands in England belonging to the near natural, drained, or eroding categories. The nature of restoration activities varies depending on the types of peatland (upland and lowland) and the conditions of peatlands (near natural, drained, or eroding).

These costs should be interpreted as representative estimations of peatland restorations costs. It is important to highlight that the restoration of upland peatlands in various conditions (i.e. near natural, drained, eroded) may require a different combination of improvement actions (i.e. preventing overgrazing, revegetation, cessation of burning). Therefore, capital costs tend to vary largely depending on the location of the habitat, and on the condition of the land, with degraded sites requiring higher expenditure (Eftec 2015b).

Operational Costs

Operational expenditure refers to the recurring costs of monitoring and managing the restored habitat. These costs include the expense for the maintenance of fences, monitoring of vegetation, wages paid to employees, and the opportunity cost of income forgone (see ‘Opportunity costs’ below). Table 2.2 shows the estimated operational costs of peatland restoration. The operational expenses are estimated to be the same for upland and lowland peatlands. These costs are expressed in present value terms over 100 years, using a 3.5% discount factor.

Table 2.2 Operational costs of peatland restoration (£/ha)

Peatland Type	£/ha
Upland	3,025
Lowland	3,025

Source: (Vivid Economics 2020)

Opportunity costs

The opportunity costs of peatland restoration refer to the price of excluding or limiting previous activities taking place on the habitat (i.e. grazing, farming, shooting), in order to use the land as a nature-based solution (NBS). These costs typically include the price of acquiring the land, the compensatory costs to previous owners or the forgone income for using the land alternatively. The price of acquiring the land usually reflects the opportunity costs of using the land alternatively. However, peatland restoration is assumed to take place without a change in the ownership of the land, hence the land acquisition costs are not included in this cost benefit analysis (Committee on Climate Change 2020a; Vivid Economics 2020). The forgone income from prior use of the land is counted as a recurring cost, paid to the existing landowner, and is included in the operational costs table (see Table 2.2). Prior uses of the land include agricultural production, livestock activities and grouse management.

2.5 Cost benefit analysis

Introduction

While many types of peatland exist in the UK, for the purposes of simplifying the CBA, it was necessary to identify the costs and benefits specific to a single type of peatland. Upland peatlands were chosen for this CBA, since this type of peatland is more likely to be restored to its natural state than lowland peatlands or fens. The latter type of peatland is primarily used as valuable agricultural land, for which the opportunity cost of using the land as a NBS would be substantially higher than converting upland peatlands to NBS.

CBA findings

Table 2.3 below presents the net present value over a period of 100 years for the identified costs and benefits of peatland restoration, quantified in monetary terms.

Table 2.3 Net present value of costs and benefits (£/ ha)

	Present value
Benefits	
Carbon Sequestration	18,179
Recreation	2,622
Total value of benefits	**20,801**
Costs	
Capital costs	1,473
Operational costs	3,025
Total value of costs	**4,499**

Source: Cambridge Econometrics
Note: Opportunity costs are accounted for within operational costs as ongoing payments to compensate for forgone income associated with the prior use of the land (see section 2.4 for more details).

Comparing the quantified benefits with the associated costs of restoring peatlands to provide a NBS, a benefit-cost ratio (BCR) of 4.62 is derived. This means that for every £1 spent, £4.62 can be expected to be returned in economic and social benefits. Although not all benefits are monetised within this analysis, a positive benefit-cost ratio would suggest a compelling argument in favour of restoration projects. However, it is important to acknowledge that the nature of the costs and benefits are closely dependent on the location and characteristics of the habitat. It follows therefore, that complex and extremely costly restoration programmes could potentially have a negative BCR whereas others will have substantially higher BCRs.

Further benefits to consider

As detailed in earlier sections, there are many additional benefits which are not included in the quantified CBA but should be considered alongside the final benefit-cost ratio to fully understand the positive impact investment in peatland restoration can generate. The economic benefits are summarised in Table 2.4.

Table 2.4 Economic and employment benefits of peatland restoration

	Benefits for 100 hectares of restored habitat	Benefits for 1.6m hectares of restored peatland
Temporary jobs	3	48,000
Job-years	7	112,000
GVA from capital investment (£ '000)	156	2,503,913
GVA from operational investment (£ '000)	321	5,140,902

Source: Cambridge Econometrics

Summary

The CBA carried out in this study estimates a positive benefit-cost ratio. For every £1 of investment made in restoration projects, £4.62 of economic benefits are generated. In addition, restoration projects generate direct employment opportunities in often remote areas, while also further generating indirect and induced employment opportunities and increased gross value added (GVA) throughout the wider economy. There are many additional benefits which are often difficult to quantify, especially in monetary terms, and which cannot therefore be directly included in the final benefit-cost ratio, but are described and acknowledged in Chapter 2. Clearly, the restoration of peatlands to a more improved and natural state generates many further positive impacts beyond avoided carbon emissions and future carbon sequestration possibilities. Together, the positive benefit-cost ratio and further benefits discussed in this report present a compelling argument for increased investment in the restoration of this important and valuable natural habitat.

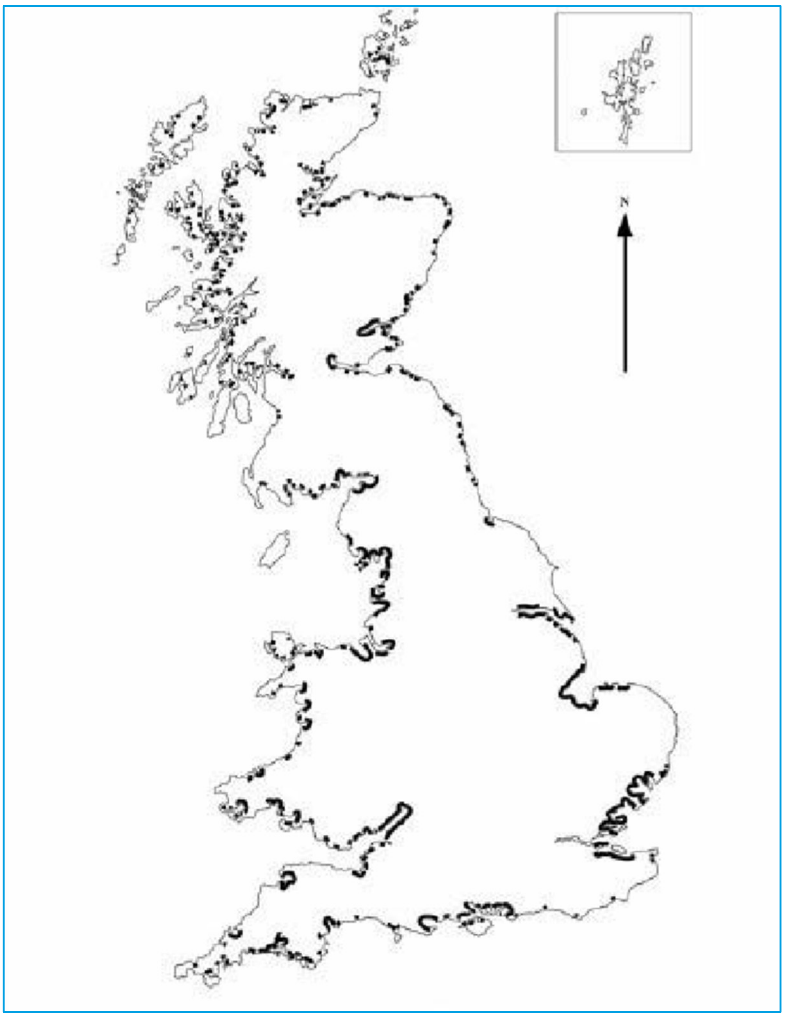
3 Salt marshes

3.1 Salt marshes as a nature-based solution

Salt marshes are wetland habitats, characterized by salt-tolerant species that populate the upper limits of the tidal shorelines. Figure 3.1 below shows the distribution of salt marshes in the UK. Salt marshes are widely distributed across the UK and the most extensive areas are present in the counties of Hampshire, Kent, Essex, Norfolk, Lincolnshire and Lancashire (ONS 2016).

Salt marshes are limited in area, when compared with other natural habitats. Salt marshes account for approximately 48,266 hectares in the UK, while peatlands and semi-natural woodland cover 13m hectares and 350,000 hectares respectively (Adnitt et al. 2007).

Figure 3.1 Distribution of salt marshes in the United Kingdom



Source: (Adnitt et al. 2007)

Vegetation in salt marshes capture large amounts of carbon dioxide through the process of photosynthesis. The sequestered carbon is then incorporated in salt marshes soil and trapped in layers of deposited sediment for long periods of time (Eftec 2015a; ONS 2016). Salt marshes are also a natural flood defence, calming wave energy and reducing flood risk. Therefore, salt marsh restoration represents a nature-based solution, which contributes to enhanced climate change mitigation and adaptation.

How might salt marshes be restored?

Sea level rise and coastal erosion pose a significant threat to salt marshes, as these result in intertidal habitat loss. To prevent erosion of salt marshes, re-creation and restoration of the habitat are required. Restoration of salt marshes typically involves removing or realigning the existing sea wall, to allow tidal water to flood the marsh. An alternative approach requires installing tidal exchange structures within the sea wall to recreate the intertidal habitats. These processes are implemented using management realignment or regulated tidal exchange schemes. Restoration activities also include the introduction of sediment in the marsh to avoid erosion in areas where the sediment supply is limited.

Identified benefits of salt marsh restoration and quantification

As well as providing a NBS, in their natural state, salt marshes offer other environmental, economic, and social benefits.

While some benefits are tangible and therefore relatively straightforward to monetise, such as increased economic output, in many cases the benefits of restoration are intangible. Assessing the monetary value of intangible costs and benefits is often very difficult. Where costs and benefits cannot be easily monetised, qualitative supporting arguments are formed and considered within this cost benefit analysis. In the sections that follow, we separate out the benefits which can be quantified in monetary terms (and are therefore included in the cost-benefit analysis), and those that cannot (and which are therefore considered qualitatively here).

3.2 Benefits which can be quantified in monetary terms

Carbon sequestration

Salt marshes act as a carbon sink, absorbing carbon from the atmosphere and storing it in sediments for long periods of time. However, erosion of the habitat due to sea level rise or land development can jeopardize its potential to capture and store carbon, with adverse effects on the environment and climate. Therefore, salt marsh restoration would reduce emissions of carbon, and in the long term, provide further scope for reducing emissions through increased carbon sequestration.

Quantifying carbon sequestration

Determining the monetary value of carbon sequestration requires an assessment of the net amount of carbon sequestered each year. This can be measured as tonnes of carbon dioxide equivalent removed each year for each hectare of habitat. Carbon sequestration provided by salt marshes varies over time following a restoration project (Burden, Garbutt, and Evans 2019). In the first 20 years following restoration, the average carbon sequestration factor is 3.81 tCO_2/ha/yr while this changes to 2.35 tCO_2/ha/yr in the period 20-50 years following restoration, and to 2.38 tCO_2/ha/yr in the period 50-100 years following restoration[4]. The monetary value of this ecosystem service is usually derived by applying current and projected non-traded prices of carbon to the rate of carbon sequestration (Box 2 Carbon Valuation). The latter are periodically published by the UK government and are based on the abatement costs of meeting targeted emissions reductions (BEIS 2019a). This approach

[4] These carbon sequestration factors are calculated from average C accumulation rates specified in (Burden et al. 2019).

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is adopted in the cost benefit analysis to account for the climate regulating benefit of salt marshes. An average rates of carbon sequestration in salt marshes specified above are taken and multiplied by the projected non-traded prices of carbon published by BEIS for the period 2020-2100.

3.3 Benefits which are difficult to monetise

Employment and economic opportunities of restoration

Salt marsh restoration projects have a positive effect on employment, through the creation of additional jobs. These jobs are typically associated with the engineering work conducted on the habitat and the monitoring of the restored habitat. However, employment impacts depend on the extent of the restoration work and engineering interventions required. Restoration projects are expected to increase output also in the sectors delivering goods and services to carry out the restoration. Accordingly, increased employment (and therefore additional wages into the economy) would have a positive effect on household expenditure, creating further demand and output elsewhere across the economy.

Quantifying economic opportunities of restoration

The effect of salt marsh restoration on employment and gross value added (GVA) is estimated through an Input-Output (IO) analysis, using CAPEX and OPEX costs as inputs to a UK-level IO model developed by Cambridge Econometrics. The IO model determines how the initial investment in restoration trickles down through the economy as greater expenditure (and therefore increased output) in associated supply chain sectors. While GVA is expressed in monetary terms, it is not usually included in a CBA, hence its contribution to the overall benefits associated with salt marsh restoration is acknowledged in this section, alongside the employment benefits.

Employment opportunities of restoration

Projects to restore salt marshes have a positive effect on employment, through the creation of additional jobs both in the restoration phase itself, and in ongoing future operation and maintenance of the habitat. Conversely, job losses in activities originally carried out on the land may arise as a result of salt marshes restoration. The negative effect of job losses however is reflected in the opportunity costs of restoration.

The IO modelling carried out within this analysis estimates the number of temporary jobs generated to carry out the restoration activities, resulting from the upfront capital investment. In a scenario where the costs of restoration are low, around 14 new temporary jobs per 100 hectares of habitat can be created during the restoration stage. Meanwhile, in a scenario characterized by medium costs, around 30 new jobs can be created to carry out restoration activities. Finally, a scenario with high costs of restoration is expected to generate around 74 new jobs in the restoration phase. These estimates include jobs that are created as a direct result of the restoration project, as well as jobs within supporting industries (i.e. jobs within associated supply chains), and further jobs created as a result of increased household incomes and consequent increased household spending.

In the UK, total salt marsh habitat is expected to shrink by 4.5% in the next twenty years due to climate change (Adnitt et al. 2007). If these habitats were to be restored, an additional 308 temporary jobs could be created in a low restoration cost scenario, 660 in a medium restoration cost scenario and 1,628 in a high restoration cost scenario. Although, these estimates refer to temporary jobs in the restoration projects, the value of the increased job opportunities should be considered alongside the benefit-cost ratio described above.

Increased gross value added (GVA) from restoration

Salt marshes restoration increases gross value added (GVA), through the investments in the conversion of the habitat to a NBS. The IO modelling carried out within this analysis estimates that, in a scenario with low restoration costs, the upfront capital investment is expected to generate £8,799 in GVA per hectare of restored habitat during the restoration stage. In a scenario with central costs of restoration, £19,422 is generated in GVA for per hectare of restored habitat. Finally, a scenario with high costs of restoration is expected to generate £48,024 in GVA per hectare of restored habitat. These estimations include both the direct impact on GVA resulting from the restoration project, as well as the indirect impact associated with supporting industries in the supply chain and further value added from increased household incomes and household spending. The restoration of 4.5% of UK salt marshes could generate between £19m and £105m in GVA during the restoration phase, as a result of the required capital investment.

Nursery areas for fish, crustaceans, and insects

Salt marshes provide nursery areas for juvenile fish. During tidal inundations, juvenile fish in the marsh represent a source of nutrition for fish predators. These are typically large sea fish, which are highly valued in the commercial fishing industry (i.e. sea bass). There is evidence to support the beneficial fish nursery service provided by salt marshes. Studies conducted in the United States demonstrate that a loss in coastal wetland habitats resulted in reduced fish production (ONS 2016). In addition, research conducted in England showed that restored intertidal salt marshes were well utilised by juvenile fish, with beneficial effects for sea bass production (Colclough et al. 2005). As a matter of fact, it has been shown that a high proportion of the species fed in salt marshes are economically important on the commercial market (Green et al. 2009). Restoring salt marshes is therefore likely to enhance fish stocks, for recreational and commercial purposes. Seafood processing sectors as well as consumers and fishing recreationalists would benefit from the nursery service offered by restored salt marshes.

Evaluating nursery areas

The monetary valuation of restored salt marshes as nursery areas for juvenile fish is difficult. In theory, a monetary value can be derived using a production function of fish, which would assign the contribution of salt marshes in fish production. However, this approach requires extensive data collection and processing and there is no evidence of attempts to calculate this monetary value. Although it is straightforward to attribute an economic value on fish, it is very challenging to determine a monetary value for the contribution of salt marsh restoration to the improved fish production. However, despite the significant gap in the literature, the value of fish nurseries provided by salt marshes should not be excluded from the overall valuation of salt marsh habitats.

Improved water quality

Restored salt marshes improve water quality by absorbing and removing pollutants from wastewater before they reach coastal waters. The salt marsh acts as a sink for pathogens and pollutants present in watercourses, including herbicides, pesticides and metals and reduces the toxic effect of polluted water on organisms and marine species. This ecosystem service contributes to improving the quality of water, preserving wildlife and biodiversity within the habitat and benefitting water companies, commercial fisheries, consumers, and agents operating in the recreation and tourism sector. Hence, restoring salt marshes contributes to many economic and social benefits.

Studies conducted in France, England and the Netherlands have shown that salt marshes are particularly effective in reducing the concentration of both nitrogen and phosphorous from water (Boorman et al. 1995). The resulting purification of water was found to enhance plankton communities within marshes (Adnitt et al. 2007), therefore boosting the production of valuable commercial fish.

Evaluating improved water quality

Improved water quality in salt marshes, and the more favourable conditions created for the animal species living in the habitat is difficult to measure in monetary terms, as it represents a non-market benefit.

Nevertheless, some studies have attempted to value improved water quality in salt marshes. For example, a study conducted for the UK National Ecosystem Assessment estimated that the water quality benefit provided by coastal wetlands (including salt marshes and intertidal mudflats) is on average £2,676 per hectare of habitat (2010 prices) (Morris and Camino 2011). Similarly, if coastal wetlands increased by 10%, the additional monetary benefit would be approximately £1,793 per hectare (2010 prices) (Morris and Camino 2011). These estimates are informed by case studies of coastal wetlands in Europe and were then applied to the UK context.

Reduced flood risk

Salt marshes form a natural line of coastal defence against wave inundations, by dissipating wave energy and reducing wave heights. This prevents extreme flooding occurring and avoids the costs of building and maintaining man-made defence lines. Improved flood management, which can include the restoration of natural salt marshes, contributes to reduced costs of flooding and insurance premiums, while increasing private property values in high flooding risk areas (Natural England 2014). Flood alleviation also leads to lower physical and psychological distress (e.g. gastroenteritis, mental illness). Medical research suggests that, as a result of flooding, adults tend to suffer long-term mental health effects (Tunstall et al. 2006). Therefore, improved flood management could bring tangible benefits to households and businesses located in high flood risk areas. Hence, the restoration of salt marshes offers a cost-effective solution for flood alleviation, while also providing the additional environmental, economic and social benefits discussed in this chapter.

There is reasonably strong evidence for the contribution of salt marshes to reducing flood risk. For example, the Blackwater Estuary managed re-alignment scheme was implemented in Essex with the aim of improving flood management. The project was found to reduce the maintenance costs of flood defences and to avoid the cost of developing alternative defence structures. The restoration project also contributed to enhanced recreation and biodiversity (Morris and Camino 2011)(Shepherd et al. 2007). Similarly, The Humber Estuary was restored with the aim of strengthening the flood defence. The restoration programme brought benefits to society of £8.7m over 100 years (Turner et al. 2007).[5]

[5] This estimation also accounts for the value of biodiversity, the avoided carbon emissions costs and the maintenance and replacement costs.

Evaluating reduced flood risk

There are various different methods of valuing the flood alleviation service provided by salt marshes.

First, the replacement costs approach is used to calculate the cost of replacing the flood defence service provided by a natural habitat with a man-made flood defence that provides equivalent protection. It has been estimated that salt marshes in the UK are associated with large savings in capital costs from the avoided construction of new sea defence walls. These costs range from £30 to £60 for each squared meter of salt marsh (King and Lestert 1995). Furthermore, a study conducted for the UK National Ecosystem Assessment (Morris and Camino 2011) estimated the economic benefit of flood defence offered by coastal wetland (including salt marshes and intertidal mudflats), using economic values informed by similar valuation studies on salt marshes. The study suggests that the value of flood control provided by coastal wetlands is on average £3,739 per hectare (2010 prices). A similar study, determined the value of improved flood management provided by salt marshes, using the replacement costs approach. The cost of building a man-made flood defence, if the salt marsh did not exist, was estimated to be £2,116 per metre of seawall (2017 prices). In addition, the overall value of the flood alleviation service provided by the habitat is estimated at £5.59bn (2017 prices) (Thornton et al. 2019).

The major limitation to the replacement cost method is that it may overestimate the value of the benefit of reduced flood risk, since it assumes that the replacement would always take place. In addition, building a man-made barrier can be more expensive than the damages associated with flooding, which represents an alternative method for valuing reduced flood risk benefits.

The damage cost approach is used to estimate the costs of flooding, which are subsequently avoided by restoring the habitat. These costs are usually incurred by farmers, private property owners, businesses, and recreationalists. Studies at Medmerry managed realignment programme, undertaken for flood protection reasons, attempted to attribute a monetary value to the benefits generated, using an estimation of replacement costs. The programme was associated with £285m avoided costs for flood defence (over 50-year time frame) (Eftec 2015a)

The stated preference method is also a suitable approach for valuing reduced flood risk benefits, estimating individual’s willingness to pay for flood alleviation.

The studies discussed here provide strong evidence in support of the existence of flood mitigation benefits provided by salt marshes, and this benefit should be considered alongside all the other environmental, economic and social benefits discussed in this report. Furthermore, the approaches described in this section for valuing reduced flood risk do not incorporate the avoided physical and psychological damage associated with flooding experiences. Avoidance of these damages adds to the compelling argument in favour of restoring salt marshes.

Increased biodiversity

Salt marshes are populated by many rare and diverse invertebrates and provide feeding and shelter areas to migrant species. The fauna is typically a mixture of marine, freshwater and terrestrial species (Adnitt et al. 2007; The Wildlife Trusts 2020). Many of these species are rare and are not present in any other natural habitat. Marine species are present in the low part of the marsh, while terrestrial and freshwater species occur in the upper marsh. However, degraded salt marshes could lead to loss of biodiversity and extinction of rare plants and animals. Salt marsh restoration as a nature-based solution therefore has the co-benefit of preserving biodiversity.

Biodiversity provides both tangible ecosystem services and intangible benefits. In particular, salt marsh biodiversity provides healthy habitats for species reproduction, enhanced fish cultivation for commercial purposes, contributes to maintaining water quality, and offers recreational opportunities. Hence, the restoration of salt marshes can potentially improve nature conservation, while also providing economic benefits.

Evaluating biodiversity

Traditionally, the value of biodiversity has been attributed to the presence of important vegetation types and their variation across different salt marsh types (ONS 2016; Thornton et al. 2019a). Although the quantification of species populating salt marshes is feasible, attributing a monetary value can be difficult. This is mainly because biodiversity delivers intangible benefits, like existence values, that are not always possible to monetise (Eftec 2015b).

Partial estimates of the economic value of some components of biodiversity can be derived using the stated preference method, where individuals are required to express their preferences towards nature conservation, however it may be difficult to separate the value of increased biodiversity from recreational use values. Despite this, some studies have applied the stated preference method to attempt to place a valuation on salt marsh biodiversity.

The economic value of salt marshes is expected to increase when biodiversity is preserved and enhanced (Morris and Camino 2011). For example, the UK National Ecosystem Assessment estimates the biodiversity value of coastal wetlands (including salt marshes and intertidal mudflat), by using the individuals' willingness to pay (to preserve nature) method. The annual value of biodiversity in coastal wetlands was estimated at £2,786 per hectare (2010 prices) (Morris and Camino 2011). Similarly, (Christie et al. 2011) gathered information on individual's willingness to pay for enhancement to 'charismatic and non-charismatic species', and 'sense of place', as a result of implementation of UK Biodiversity Action Plans. The value for coastal floodplain habitats was estimated at £75 per hectare (2010 prices) (Christie et al. 2011). These values provides some indication of the value of increased salt marsh biodiversity, that can be considered alongside the monetised cost benefit analysis. We stress though that these are partial estimates and many human values associated with biodiversity are ethical, not economic, in nature.

Recreation

Restored salt marshes offer some recreational opportunities, providing an area for walking and enjoying wildlife.

Evaluating recreation

While restored salt marshes can offer recreational activities, the extent of recreational visits and the value of the recreation is more difficult to quantify and monetise than the recreational benefits associated with restoration of other natural habitats (e.g. peatlands and woodland). This is mainly because the quantification and monetisation of recreational benefits usually uses approaches such as revealed preferences (approach adopted in the cost benefit analysis in this study), but data which can be used in a revealed preferences approach is difficult to obtain for salt marshes. While survey data on number of visits and expenditure exists for many natural habitats in the UK, visits to salt marshes is included in a broader category of visits to coastal habitats. A large proportion of visits to coastal habitats will be to beaches, with salt marshes likely to only represent a small share of visits. Therefore, it is very challenging to determine the marginal increase in recreational visits to salt marshes resulting from restoration. The lack of data available to be able to carry out a robust revealed preferences approach means that the cost benefit analysis in this study considers the recreational benefit of restored salt marshes qualitatively.

3.4 Identified costs of salt marsh restoration

The costs of salt marsh restoration are dependent on the scale and the location of the work, and the extent of the engineering interventions required. For this analysis, data on costs of salt marsh restoration were provided by the ABP mer review of salt marshes restoration projects implemented in the UK between 1991 and 2015 (ABP mer 2015). These costs are highly variable, ranging from £856 to £1,007,452 per hectare of restored habitat. To account for the high variability of costs in the analysis, low, central and high cost estimates were derived and incorporated in the cost benefit analysis. The low, central and high costs represent respectively the 25th, 50th and 75th percentiles from the range of costs provided by ABP mer (ABP mer 2015). These costs are presented in Table 3.1 below.

Table 3.1 Capital costs of salt marshes restoration (£/ha)

	Low	Central	High
Capital costs	10,726	23,676	58,543

Source: (ABP mer 2015) and Cambridge Econometrics quantification

Due to data availability, operational costs are not accounted for in this analysis. These are expected to be very small for salt marshes, as nature itself can contribute to maintaining the habitat. However, land acquisition expenses are included in the costs of salt marshes restoration reported by ABP mer (ABP mer 2015). The upfront expense for land acquisition is used as a proxy for the opportunity costs of converting the land from its former use.

3.5 Cost benefit analysis

Introduction

Although it was not feasible to monetise all the benefits associated with salt marshes restoration, this cost benefit analysis provides a lower-bound estimation of potential economic benefits.

CBA findings

Table 3.2 below presents the net present value over a period of 100 years for the identified costs and benefits of salt marsh restoration, quantified in monetary terms. As explained in detail in Section 3.4, low, central and high estimates of costs are included in the cost benefit analysis of salt marshes, to account for the high variability in the costs of salt marsh restoration.

Table 3.2 Net present value of costs and benefits (£/ ha)

	Present value
Benefits	
Carbon Sequestration	14,048
Total value of benefits	**14,048**

Costs	Low	Central	High
Capital costs	10,726	23,676	58,543
Operational costs	-	-	-
Total value of costs	**10,726**	**23,676**	**58,543**

Source: Cambridge Econometrics
Notes: Due to data availability, operational costs are not reported in this table. Land acquisition costs are accounted for within capital costs as an upfront payment for the conversion of land from its former use.

Comparing the quantified benefits with the associated low-cost scenario, a benefit-cost ratio of 1.31 is derived. Similarly, comparing the benefits of salt marshes restoration with the central and high cost scenarios, the derived benefit-cost ratios (BCRs) are 0.59 and 0.24 respectively . This means that depending on the nature of the costs needed, for every £1 invested in restoration, £1.31can be expected to be returned in a low cost scenario, £0.59 in a medium cost scenario, £0.24 in a high cost scenario. The positive BCR in the low cost scenario is an argument in favour of salt marsh restoration projects. However, this benefit-cost ratio has some limitations, as it does not incorporate all benefits of salt marshes, and it does not account for the operational costs of restoration (although these costs are acknowledged to be limited).

Further benefits to consider

As acknowledged in earlier sections, there are many additional benefits which are not included in the quantified CBA, but should be considered alongside the final benefit-cost ratio to fully understand the positive impact investment in this particular nature-based solution can generate, alongside its climate mitigation potential. The economic benefits are summarised in Table 3.3, for scenarios with low, central and high cost estimates.

Table 3.3 Economic and employment benefits of salt marsh restoration

	Low	Central	High
Temporary jobs per 100 hectares of restored habitat	14	30	74
Temporary jobs per approx. 2k hectares of restored habitat	308	660	1,628
GVA from capital investments per 100 hectares of restored habitat (£ '000)	880	1,942	4,802
GVA from capital investments approx. 2k hectares of restored habitat (£ '000)	19,357	42,728	105,654

Source: Cambridge Econometrics

Summary

Restoring salt marshes is expected to generate economic, social, and environmental benefits. However, the data provided by ABP mer illustrates that restoration programmes can be particularly costly and complex for salt marshes. These costs are dependent on the location and scale of the works, and the extent of the engineering intervention required (ABP mer 2015) . The large upfront costs required may discourage the implementation of restoration projects. However, restoring salt marshes is shown to provide additional benefits in terms of biodiversity, water quality, fish production, flood alleviation, as well as new job opportunities and increased gross value added (GVA). Although it was not possible to monetise the overall benefits, it is important to recognise their value to inform policy decisions.

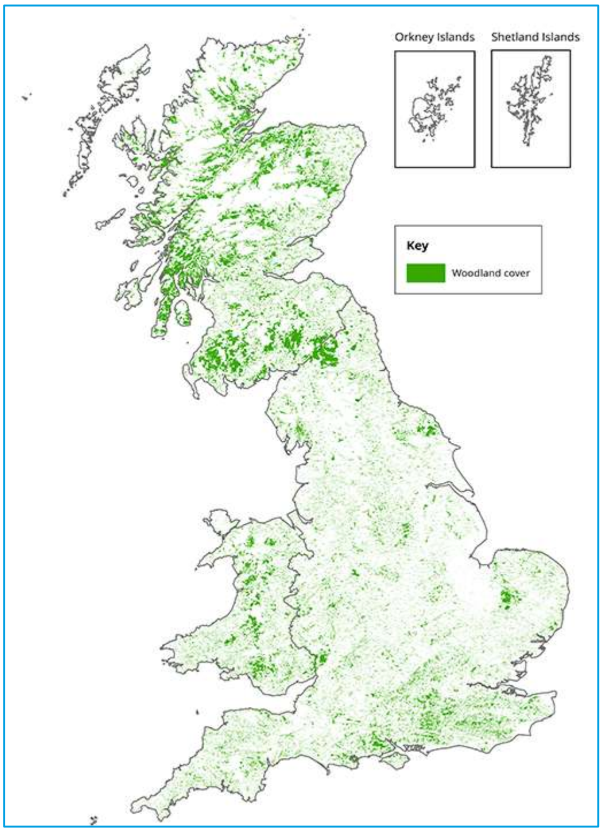
4 Woodland

4.1 Woodlands as a nature-based solution

Woodlands are defined as tree-covered areas, which include plantation forests, native forests and lower density or smaller stands of trees. Woodlands are usually classified into two main categories: coniferous and broadleaved.

Woodlands represent 13% of total land use in the UK, of which approximately 51% of these woodlands are coniferous. Figure 4.1 below shows the extent of woodland areas of Great Britain. 46% of UK's woodlands are located in Scotland, 41% in England, 10% in Wales and 4% in Northern Ireland. Overall, in the last decade, woodland area has increased steadily by 4.4% from 3.05m hectares in 2009 to 3.19m hectares in 2019 (ONS 2020).

Figure 4.1 Extent of Great Britain woodland



Source: Forestry Commission 2018

Woodlands are a natural carbon sink, absorbing carbon from the atmosphere and locking it up for several decades. Moreover, woodlands absorb large quantities of water on the ground, hence alleviating flood risk. In addition, trees' foliage can remove floating particles and improve air quality in polluted environments. Foliage also contributes to reducing air temperature during warm seasons and mitigating the effects of seasonal heat waves. These ecosystem services delivered by woodlands provide valuable natural solutions for climate change mitigation and adaptation.

How might woodlands be restored?

To deliver climate benefits, woodlands need to be restored, protected and maintained. Thus, woodland conservation requires a combined approach of preserving native woodland, protecting woodlands previously degraded by grazing and by the invasion of non-native species and planting new and diverse trees.

Identified benefits of afforestation and quantification

Woodlands provide a large range of environmental, social, and economic benefits. While some benefits are tangible and therefore relatively straightforward to monetise, in many cases the benefits of woodlands are intangible. Assessing the monetary value of intangible costs and benefits is often very difficult. Where costs and benefits cannot be easily monetised, qualitative supporting arguments are formed and considered within this cost benefit analysis.

In the sections that follow, we separate out the benefits which can be quantified in monetary terms (and are therefore included in the cost-benefit analysis in Section 4.5), and those that cannot (and which are therefore considered qualitatively here).

4.2 Benefits which can be quantified in monetary terms

Carbon sequestration

Trees absorb atmospheric carbon in tree biomass (trunks, foliage, and roots) and soil. The amount of carbon stored by UK woodlands increased by 7.3% between 1998 and 2011 but fell in 2012 and has not yet recovered (ONS 2020). In order to meet the UK government's target to reach Net Zero emissions by 2050, tree cover should increase from 13% to 17% at least, which requires planting approximately 30,000 hectares of woodland each year (Committee on Climate Change 2020a). Woodland creation, together with improved woodland management, would deliver annual savings in emissions of 15 $MtCO_{2e}$ (Committee on Climate Change 2020a; Woodland Trust 2016b). Moreover, the economic value of carbon sequestration by UK woodlands is gradually increasing, as the non-traded price of carbon is expected to escalate until 2080 (ONS 2020).

Quantifying carbon sequestration

Monetising the contribution of woodlands to emissions reductions first requires an assessment of the net amount of carbon sequestered each year. This is measured as tonnes of carbon dioxide equivalent removed each year for every hectare of habitat. The UK National Atmospheric Emissions Inventory (NAEI) releases data on the current and future projections of carbon removal for the forestry sector. Similarly, the Forestry Commission developed a carbon accounting model, CARBINE, which estimates the stock of carbon stored in trees. Woodlands remove approximately 5.7 tCO_2 per year per hectare of habitat (ONS 2020), and this value is used within the cost benefit calculations presented in this report. The amount of carbon sequestered per hectare of woodlands is assumed to remain constant in the projected period. The annual monetary value of carbon sequestration is then obtained by multiplying the UK carbon sequestered by woodlands each year by the projected non-traded price of carbon in each year up to 2100 (Box 2 Carbon Valuation). Current and projected non-traded prices of carbon are periodically published by the UK government and are based on the abatement costs of meeting target emissions reductions (BEIS 2019a). This approach is adopted in the cost benefit analysis to estimate the monetary value of carbon sequestration.

Recreation

Woodlands provide a favourable habitat for outdoor recreational activities, including walking, cycling and bird watching. The number of visits to UK woodlands has gradually increased between 2009 and 2017 and the time spent in woodland has also increased by 165m hours between 2015 and 2017

(Natural England 2020; ONS 2020). This is partly explained by the fact that woodlands have become more accessible to the population for recreational purposes, with 1.4m hectares accessible in UK in 2016 (ONS 2020; Woodland Trust 2017). Recreational activities in woodlands are also associated with improved long-term health outcomes, which is reflected in lower risks of premature deaths (Committee on Climate Change 2020a).

Quantifying recreation

The value of woodland recreation is typically estimated using the travel cost method, which is a revealed preferences approach. This approach uses the cost of travelling to a woodland site as a proxy for the economic value of recreational visits. The costs of travelling to a woodland include the expenses for fuel, public transport, parking fees, and entrance tickets etc. Studies showed that individuals attribute a value to recreational visits ranging between £1 and £3.5 (Defra 2020b). A major limitation of the travel cost method is that the approach can possibly underestimate the value of recreational activities, since expenditure or price does not necessarily reflect individuals value of the visit.

Alternatively, the value of recreation in woodlands can be derived using stated preference methods. Using survey data, this technique infers the willingness to pay by individuals for visiting woodlands. The stated preference technique was implemented to estimate the value of recreational visits to woodlands in Great Britain. The estimated economic value ranges between £2.23 and £3.69 per visit (2014 prices) (Binner et al. 2017; Willis et al. 2003).

In this cost benefit analysis, the monetary value of recreation is estimated using the travel cost method. The number of visits to UK woodlands was obtained from the ONS Woodland Natural Capital Account (Broadmeadow et al. 2018) and is based on the Monitor of Engagement with the Natural Environment (MENE) survey, which covers recreational visits by respondents in England (Natural England 2020). The Outdoor Recreation Valuation Tool (ORVal) provided information on the recreational value of visits to woodlands in England (Exter University 2018). This estimate was used to derive expenditure per hectare of accessible woodlands. It is important to acknowledge that the benefits of recreation vary significantly depending on the location of woodlands (Beaumont et al. 2010; Binner et al. 2017). As a matter of fact, the value of recreation is expected to be higher for urban forests and woodland in proximity to densely populated residential and commercial areas. Due to methodological constraints, the value of recreation estimated within this analysis does not incorporate site-specific factors, hence it should be treated as a representative value.

Air pollution removal

Trees act like natural air filters, as their foliage tends to remove airborne particles and improve air quality in polluted areas. The main polluting particles spread in the atmosphere are particulate matter (PM_{10} and PM_5), ammonia (NH_3), ozone (O_3), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). These emitted particles typically lead to increased cardiovascular and respiratory diseases. The World Health Organization estimated that air pollution was associated with 7.6% of all deaths in 2016 worldwide (WHO 2018). The ability of woodlands to remove these harmful pollutants means planting trees as a nature-based solution also generates the additional benefits of increased air quality and improved health.

Quantifying air pollution removal

The value of air pollution removal can be derived using an estimate of the avoided damage costs associated with exposure to pollution. These costs are regarded as health benefits for avoided respiratory and cardiovascular diseases, premature deaths, and loss of life years. The damage costs are reported by the Department for Environment, Food and Rural Affairs (Defra 2020a). In addition, data on air pollution removal by UK vegetation were modelled by the Centre for Ecology and Hydrology (Jones et al. 2017). Hence the monetary value is derived by multiplying the quantity of pollutants removed per hectare of woodland by the avoided damage costs.

Alternatively, the hedonic price method can be used to infer the price premium of private properties located in pollutant-free areas. In addition, the stated preference method can be used to estimate the willingness to pay to avoid harmful pollutants.

Due to data availability, the use of hedonic price and the stated preference methods is not feasible for this study, therefore in this cost benefit analysis, the monetary value of air pollution removal is estimated using the avoided damage cost method. The quantity of pollutants removed was provided by the UK Centre for Ecology and Hydrology (UK CEH) study on air pollution removal (Jones et al. 2017). This study reports estimates on the removals of particulate matter (PM_{10}), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ammonia (NH_3) and ozone (O_3). The damage costs were obtained from Defra (Defra 2020a) and can be interpreted as the health benefits associated with the reduction in pollutant concentration to which people are exposed. These damage costs were uplifted by 2% cumulatively each year, as suggested in the Defra guidance on air quality appraisal (Defra 2020a). The uplift factor reflects the assumption that the willingness to pay for health outcomes would rise in line with real per capita GDP growth. Both damage costs and pollution removal are assumed to remain constant in the projected period. It is important to acknowledge that the value of this ecosystem service may vary depending on the location of woodlands. Woodlands in proximity to densely populated urban areas and industrial agglomerations tend to deliver health benefits more effectively. Therefore, site-specific benefits of air pollution removal should be considered when carrying out afforestation projects. Due to methodological constraints, the value of air pollution removal estimated within this analysis does not account for site-specific factors, hence it should be treated as a representative value.

Provision of timber and biofuel

Woodlands are extensively used for timber production and bioenergy sources. In the UK, timber production increased by 51% between 2000 and 2018. Accordingly, the proportion of timber used for wood fuel increased from 3% in 2000 to 21% in 2018 (Forest Research 2019; ONS 2020). Furthermore, in 2018 the electricity generated from bioenergy (including wood fuel) accounted for 31.6% of renewable electricity (BEIS 2019b). The Government Policy Statement on Forestry and Woodlands notes that the forestry and timber processing sector contributed £1.7bn in Gross Value Added (GVA) and employed around 14,000 people directly in 2010 (Defra 2013). Therefore, the creation of woodland areas would deliver tangible economic benefits for a wide range of economic agents.

Quantifying provision of timber and biofuel

The monetary valuation of woodland provisioning services is a reasonably straightforward estimation. Specifically, the quantity of timber removed from woodlands is multiplied by the price per standing tree (stumpage price), for which data is readily available. The Forestry Commission provides detailed data on tree felling, while Forest Research regularly publishes estimates of the stumpage price. However, it should be acknowledged that the production of timber and wood fuel conflicts with the provision of other ecosystem services (i.e. recreation, carbon sequestration, biodiversity). This is because the former requires large scale felling, which reduce a woodlands' potential to store carbon, endanger biodiversity and exclude recreational activities on the habitat. Although timber production represents a tangible private benefit, this cost benefit analysis does not include the monetary value associated with the production of timber and wood fuel. Its inclusion in the CBA would conflict with the aim of the analysis to provide estimates of costs and benefits associated with the use of woodlands as nature-based solutions.

4.3 Benefits which are difficult to monetise

Employment and economic opportunities of afforestation

Woodland restoration is expected to generate positive economic impact through the creation of additional jobs and economic output. A tree-planting project increases output in sectors delivering the goods and services to carry out the woodland creation, and increased employment has a positive effect on household expenditure, creating further demand and output elsewhere in the economy.

Quantifying economic opportunities of afforestation

The effect of afforestation on employment and gross value added (GVA) is estimated through an input-output (IO) analysis, using CAPEX and OPEX costs as inputs to a UK-level IO model developed by Cambridge Econometrics. This approach allows the determination of the indirect and direct effects on economic output. The tool is based on the assumption that an initial investment or expenditure creates output in specific sectors. The IO tool is used to quantify the increase in purchases of goods and services required to deliver that output, and consequently additional impacts further up the supply chain. While GVA is expressed in monetary terms, it is not usually included in a CBA, hence its contribution to the overall benefits associated with afforestation is acknowledged in this section, alongside the employment benefits.

Employment opportunities of afforestation

Woodland creation and restoration projects have a positive effect on employment, through the creation of additional jobs both in the restoration phase itself, and in ongoing future operation and maintenance of the habitat. It should be noted that job losses may arise as a result of afforestation. These jobs are typically associated with economic activities originally carried out on the habitat. Although the job losses are not directly counted in this analysis, the negative effect of displaced activities is reflected in the opportunity costs of restoring woodlands.

The IO modelling carried out within this analysis estimates that the upfront capital investment for afforestation can generate around 25 temporary jobs for 100 hectares of habitat, to carry out plantation activities. In addition to these, once the habitat is restored, around 6 job-years for 100 hectares of habitat are expected to be created during a period of 100 years for ongoing monitoring and management activities[6]. These estimates include job-years that are created as a direct result of afforestation and ongoing operation and maintenance of the woodland, as well as jobs within supporting industries (i.e. jobs within associated supply chains), and further jobs that result as a result of increased household incomes and consequent increased household spending.

If the advice of Committee on Climate Change were to be pursued (Committee on Climate Change 2020a), the creation of 30,000 hectares of woodland in UK would create approximately 7,500 temporary jobs to carry out restoration activities and additional 1,800 job-years for ongoing maintenance operations needed during a period of 100 years. The value of these increased job opportunities should be considered alongside the benefit-cost ratio described above.

Increased gross value added (GVA) from afforestation

Woodland restoration increases gross value added (GVA) through the investments carried out to convert the habitat to a nature-based solution. The IO modelling carried out within this analysis estimates that the upfront capital investment is expected to generate a total impact of £12,219 of GVA for every hectare or restored habitat during the restoration phase. In addition, the operation and maintenance of the restored habitat is estimated to generate a total impact of £3,139 of GVA for every hectare of restored habitat, during a period of the lifetime of 100 years. These estimations include both the direct impact on GVA resulting from the restoration project and ongoing maintenance operations, as well as the indirect impact associated with supporting industries in the supply chain and further value added from increased household incomes and household spending.

If the advice on planting 30,000 hectares of woodlands were to be pursued (Committee on Climate Change 2020a), £366m can be generated in GVA during the tree-planting stage, as a result of the capital investment. Similarly, the investment in the maintenance of a new woodland habitat is expected to generate £94m in GVA, over a period of 100 years.

Improved water quality

Pollution entering water bodies can be caused by fertilisers used in agriculture, food waste, emissions from transport, animal faeces and leakage from industrial production. There is evidence to suggest that well-located woodland planting can lead to improvements in the quality of surface water and groundwater (Binner et al. 2017). In particular, trees alongside watercourses are capable of reducing water pollution, through the uptake of nitrates and phosphate and the reduction of pesticides and sediments concentration. Typically, broadleaved woodlands perform better in reducing water pollution, while coniferous woodlands may affect water quality negatively, due to acidification of soil (Nisbet et al. 2011). Adverse effects on water quality are also associated with intensive tree felling in upland woodlands. Woodlands situated in proximity to cultivated fields were shown to be associated with 76-98% reduction in nitrate in groundwater. Moreover, woodlands, together with grasslands, uptake more sediment in watercourses then other land uses (Binner et al. 2017). Improved water quality provided by woodlands leads to lower treatment costs incurred by water companies

[6] Job-years represent the cumulative years of full-time employment (FTE) jobs over a period of time, i.e. the total number of jobs for one person for one year. An FTE job represents one person's work for one year at regulated norms (e.g. 40 hours a week for 52 weeks a year, excluding holidays). Using this accounting, two separate, six-month jobs would therefore be counted as one FTE job.

(Nisbet et al. 2011), which are generally reflected into lower prices for purchasing drinking water, with tangible benefits for final consumers. Therefore, planting trees is expected to deliver both economic and environmental benefits, hence benefitting water companies, water bill payers, farmers, fisheries, energy producers and recreationalists.

Evaluating improved water quality

Determining the value of water quality improvements remains difficult. In theory, this value can be estimated using a cost-based approach, hence deriving the equivalent cost of developing alternative purification techniques. A case study undertaken in Denmark showed that afforestation brings cost savings in treating drinking water, while also successfully reducing nitrate accumulation. These costs were estimated at £445/€485 per hectare (Nisbet et al. 2011). Similarly, the conversion of arable land to woodlands in Lincolnshire in UK resulted in reduced nitrate concentration in groundwater (Nisbet et al. 2011). The related treatment costs to reduce nitrate concentration were estimated to be nearly four times lower than land use conversion. This rough comparison fails to consider the future benefits associated with improved water quality, as well as the value of additional services provided by woodlands. The adoption of the cost-based method would require detailed data on marginal costs of water treatment, which are usually not publicly available or scarcely reported in the literature. Although water companies could easily identify the costs needed for water treatment, the monetisation of this benefit remains difficult. This is because it is very challenging to model the specific contribution of restoration programmes to the improved quality of water.

Alternatively, the value of improved water quality can be inferred by collecting information on the willingness to pay by individuals for marginal improvements in water quality. The National Water Environment Benefits Survey suggests that the average annual benefits of improving water quality in England and Wales's watercourses would be between £650 and £1.2bn (Europe Economics 2017). This estimation is based on the willingness to pay approach, but it does not indicate the economic value associated with woodland. However, this approach would involve an extensive process of data collection, which goes beyond the scope of this study.

Although the evidence on the value of water quality is limited, this assessment presents valuable reasoning to consider this ecosystem service as an important possible source of economic and social benefits.

Reduced flood risk

Through the 'sponge effect', woodlands intercept rainfall and absorb surface water flow. Leaves and branches intercept rainfall, allowing the ground to gradually absorb water. Similarly, roots enable the water to better infiltrate the soil, while also capturing part of the water. This is because woodland's grounds are characterised by natural pores, which favour water infiltration in the soil. Hence, woodlands can reduce flood flows in flood risk catchment areas. When compared to asphalt, woodlands are able to reduce water runoff by up to 62% (Armson et al. 2013). However, the benefit of water absorption depends on the scale, location, type and management of woodlands. Absorption is typically larger in the summer than in the winter, and it is highly beneficial in upland areas, floodplains and alongside rivers (Woodland Trust 2014a). The degree of water absorption decreases with rainfall intensity and is expected to be higher for coniferous then for broadleaved woodlands (Binner et al. 2017). The UK Centre for Ecology and Hydrology (UKCEH) performed an extensive review of the literature on woodland flood alleviation, concluding that a larger woodland area is associated with lower flood peaks (Stratford et al. 2017). Further evidence showed that woodland plantation in flood-risk regions can lead to reductions in local peak flood flows of up to 40% (Woodland Trust 2014b). Moreover, the Pont Bren woodland planting project demonstrated that woodlands are highly efficient in absorbing water and reducing runoff. In particular, water infiltration is expected to be 60 times higher within tree shelterbelts then in farmlands. The benefit of water absorption was surprisingly found to occur just two years after plantation (Woodland Trust 2013).The outcome of this project has been particularly useful for local farmers, who started planting trees in order to avoid future flood damages. A similar project, designed for the town of Pickering, targeted woodland planting on floodplains. The project showed that woodland creation reduced the risk of flooding from 25% to less than 4% (Forest Research 2020b).

Forest Research identified 83% of the land area in Great Britain to be at risk of flooding (Broadmeadow et al. 2018), demonstrating the scale of the potential benefit increased woodland could provide some areas. Extreme flood events inflict high costs for farmers, private property owners and businesses. Therefore, woodland can provide a cost-effective and low maintenance solution to reduce the risk of flooding, while improving resilience to climate change.

Evaluating reduced flood risk

The literature on woodland ecosystem services valuation points towards the adoption of cost-based methods to estimate the avoided flood damage costs to properties, transport, and local businesses. Avoided damage costs are typically used as a proxy for the economic value of flood alleviation. An example of valuation adopting a cost-based approach is provided by a Forest Research analysis, which estimates the value of flood alleviation for woodland in Great Britain, examining the cost of setting up flood water storage in the absence of woodlands. The benefits of flood management were estimated to be £218m per year for coniferous and rural broadleaved woodlands (Broadmeadow et al. 2018). However, the cost-based approach does not consider the full cost of flooding, which can also be associated with social and psychological distress. In addition, data on damage costs are usually not available publicly, as these vary depending on the specific location affected by flooding. Estimates of the full benefit associated with flood alleviation can also be derived by adopting the revealed preference approach, which aims to determine the price premiums for properties with reduced flood risk. Alternatively, the stated preference method is used to derive households’ and businesses’ willingness to pay to avoid flood damages.

Both revealed preference and stated preference methods are beyond the scope of this study, and hence, we consider the evidence above to demonstrate the potential benefits an afforestation project could generate in terms of reduced flood risk.

Increased biodiversity

The creation and conservation of woodlands are expected to enhance biodiversity. Biodiversity in woodlands is determined by the amount of light beneath the canopy, the richness of the species, the age of trees and the number of microhabitats available (Humphrey et al. 2003). However, it should be noted, in order to enhance biodiversity, the plantation of trees should take place in appropriate locations. If afforestation takes place in open ground habitat (i.e. heathlands and grasslands) biodiversity will be endangered. The report on UK biodiversity published by Defra (Defra 2019b), indicates that the number of species (including birds, butterflies, and bats) in UK woodlands has been decreasing over time. The decline is associated with changes in woodland management and loss of woodland habitats, which resulted in a lack of habitat diversity and food resources. Woodland biodiversity delivers a range of services, which benefit various agents. Namely, farmers benefit from improved soil fertility and pollination services, recreationalists benefit from the enjoyment of visits, health enhancement and cultural appreciation. In addition, biodiversity in woodland also contributes to maintaining a healthy and functioning ecosystem, which is crucial for water and food provisioning and human well-being. Therefore, woodland restoration delivers tangible benefits, which need to be considered alongside the cost benefit analysis, to inform policy decisions.

Evaluating biodiversity

Attributing a monetary value on woodland biodiversity is a challenging exercise and is likely to be an underestimate given the non-economic values people hold for nature. Hence, biodiversity has the characteristics of a public good, whose benefits arise globally and are enjoyed across generations. Biodiversity also delivers non-use benefits, which cannot be estimated as they are typically intangible and are not associated with any market transaction or money transfer (i.e. non-use values include the cultural attachment to trees and its preservation).

A number of studies have investigated indicators of biodiversity in woodland, such as the number of species, the distribution of species and the DNA genetic difference-based measures of ecological diversity (The Dasgupta Review 2020). These indicators are useful to derive and approximate the value of biodiversity. In the UK, over 40% of species within the UK Biodiversity Action Plan are associated with woodland habitats (Forestry Commission 2005). However, their population has decreased because of scarce woodland management. The woodland butterflies' indicator in the UK has decreased by 40% since 1990, reaching a historical low in 2012. Similarly, the UK woodland bird indicator in 2017 was 27% lower than in 1970 (Defra 2019a). The UK National Ecosystem Assessment (Beaumont et al. 2010) is the most recent assessment of the impact of woodland planting on biodiversity. In this analysis, biodiversity was assessed through indices of various bird species. The analysis concludes that an increase in woodlands is associated with a higher number of woodland bird species. Accordingly, the UK NEA 'follow-on' assessment finds that afforestation favours the reproduction and preservation of woodland species (Church et al. 2014). The Forestry Commission Biodiversity Assessment also illustrates that new woodlands could provide a suitable habitat for a wide range of species (Humphrey et al. 2003). In addition, Woodland Trust conducted a case study on the restoration of an ancient woodland area and observed the behaviours of rare species populating the habitat. As a result of the restoration, these rare species, that initially were confined to broadleaved areas, also spread into former coniferous areas (Woodland Trust 2016b). Therefore, restoring and planting trees is expected to enrich woodland diversity. However, ancient woodlands would remain richer in species than the recent plantations. This is mainly because there is significant time lag between habitat creation and improvements in biodiversity (Woodland Trust 2020c).

Other biodiversity studies have adopted a cost-based approach to estimate the value of the ecosystem, by collecting information on the costs required to maintain, restore, and recreate woodlands. For instance, restoration costs for Caledonian pine forest were estimated at £776 per hectare per year and used as a proxy value for biodiversity (Hanley et al. 2002). However, this approach does not reveal any information about public preferences on biodiversity.

Alternatively, several studies have attempted to measure biodiversity value through the stated preference method, which aims to gather information on the public's willingness to pay (WTP) for a marginal increase in biodiversity. Using UK surveys data on the WTP for biodiversity, (Willis et al. 2003) estimated that the economic value of woodland biodiversity amounts to £380m per year, the equivalent of £11bn capitalized at 3.5%. According to the study, the monetary value of biodiversity also appears to be higher than the value of recreational activities and the market value of timber products, as shown in Table 4.1. However, the evidence in the literature suggests that the value of woodland biodiversity varies on the type of woodland. (Willis et al. 2003) shows that the restoration of broadleaved woodlands is deemed more important than restoration of coniferous woodlands. This is because the former is perceived as fundamental for nature conservation, while coniferous plantations are generally associated with timber production.

Table 4.1 Social and environmental benefits of woodlands in UK

Social and environmental benefits of forests in Britain	Annual value £m
Recreation	393
Landscape	150
Biodiversity	386
Carbon sequestration	94
Total	**1,023**

Source: (Willis et al. 2003)

Noise mitigation

Woodlands can potentially reduce noise pollution, hence acting as a buffer between residential areas and sources of noise (Forest Research 2020a). For woodlands to be effective in mitigating noise, the targeted area needs to be densely planted with diverse tree species, foliage shapes and sizes (Woodland Trust 2020b). Indeed, foliage is the most efficient part of the tree for scattering noise. On the one hand, broadleaved woodlands tend to perform better then coniferous woodlands in reducing noise. On the other hand, coniferous woodlands are typically associated with a higher year-round level of noise reduction, as they do not lose foliage in the winter (Martin Dobson and Jo Ryan 2000) . Therefore, a noise barrier made of broadleaved trees would need to be wider than coniferous trees, in order to compensate for the leaf-drop season (Woodland Trust 2020b). Noise mitigation from woodlands is highly beneficial for health conditions and psychological wellbeing, as it contributes to reduced annoyance, sleep disturbance and anxiety, while increasing productivity in the workplace. In the UK, the total number of buildings that would benefit from noise reduction is 167,000 (Jones et al. 2018; ONS 2020). Therefore, woodland plantation and restoration contribute to reduced noise pollution, improved health outcomes, and increased labour productivity, while enhancing the aesthetic quality of the area. These benefits can be valued greatly by individuals living in proximity of roadways, aircrafts, and industrial areas.

Evaluating noise mitigation

The valuation of noise mitigation is also difficult due to the intangible nature of the public good. In theory the value of this benefit can be estimated by assessing the health benefit associated with noise reduction in urban areas. However, while the physical amount of noise reduction can be measured and quantified, the effect of noise reduction on recipients is very difficult to monetise. This is because the value of noise reduction is perceived differently by various beneficiaries.

The economic value of noise mitigation can also potentially be estimated using the price premium of private properties located in noise-free areas.

Similarly, the revealed preference method can be used to estimate the cost of alternative noise reduction technologies (i.e. glazing, fencing, roadside noise barriers) as a proxy for woodland noise mitigation value.

Alternatively, stated preference method can be used to infer the individuals' willingness to pay for noise reduction.

A recent study commissioned by Defra (Jones et al. 2018) calculated the monetary value of noise mitigation attributed to woodland in the UK. The estimation is based on economic welfare values, which describe the effect of noise reduction on people's social welfare. These values are estimated by combining a Defra noise modelling tool (Defra 2014) with survey data revealing the willingness to pay for noise reduction. The annual value of noise reduction was estimated to be £41m (2017 prices). However, this value should be considered as a lower-bound estimation, as it only accounts for urban woodlands and it is likely to underestimate the full economic value of noise mitigation.

Temperature regulation and cooling effect

Woodlands provide large, shaded areas, which are beneficial in reducing air temperature during heat waves and warm seasons, both in urban and rural areas. In particular, vegetated areas can reduce air temperature through leaf evaporations, air circulation, shade and reflection of solar radiation away from the ground (Monteiro et al. 2019). Typically, coniferous woodlands provide temperature regulation for a longer period, as they do not lose foliage in the winter. This aspect, however, can prevent other plants from growing, leading to adverse effects on biodiversity. Native broadleaved woodlands are characterised by lighter foliage and usually provide spotted areas of shade. Thus, a combination of both coniferous and broadleaved trees could reduce temperature in the warm seasons, while preserving biodiversity (Woodland Trust 2016a) .

Within cities, woodlands contribute to reducing the urban heat island effect, whereby the temperatures are higher than in rural areas due to urbanisation. The cooling effect of woodlands will be highly valued in future years, as average summer temperatures in the UK are expected to increase (Perry and Prior 2009). The current greenspaces in Greater London have been estimated to decrease temperatures by more than 0.5°C. Similarly, tree coverage in Glasgow and the Clyde Valley region was projected to decrease future temperatures in the summer by 0.3°C (Monteiro et al. 2019).

Temperature mitigation provided by woodlands can benefit the economy, by avoiding labour productivity losses, reducing the use of artificial cooling (i.e. air conditioning) and reducing negative health effects caused with heat waves (e.g. cardiovascular, respiratory and renal diseases). Lower temperatures during the summer can also reduce the number of deaths associated with the intake of particulate matter (PM_{10}), which are typically higher during warm seasons (HM Government 2017; Public Health England 2015).

Furthermore, woodlands in proximity of freshwater contribute to reduced water temperature, hence providing a healthy habitat for species of plants, invertebrates, and fish. In the UK freshwater trout and salmon populations are particularly vulnerable to increases in temperature. The Hampshire Avon project, promoted by Woodland Trust, targeted woodland plantation along the River Avon. The project boosted salmon production in the River Avon area, hence enhancing profits for local fish producers, while preserving biodiversity (Woodland Trust 2016a).

In summary, the creation and restoration of woodlands is expected to enhance temperature regulation services, thus providing a more stable climate. This can benefit residential property owners, energy bill payers, local businesses, and households.

Evaluating temperature regulation

The evidence on the economic value of the cooling effect of woodlands is scarce. This is because it is very difficult to estimate the decrease in temperature provided with woodlands, as this varies greatly depending on geographical location. Ideally, the monetary value of this ecosystem service would include the avoided productivity loss (i.e. measured as changes in gross value added (GVA)), the savings in energy costs from reduced use of air conditioning and the benefits associated with improved health conditions. However, these estimations require data which is not publicly available and can only be derived though complex modelling exercises. A study conducted by Eftec for Defra (Eftec 2018) determined the monetary value associated with the cooling effect of woodlands in eleven city regions in Great Britain using cost savings from air conditioning and the benefit from improved labour productivity. The value of urban cooling services in UK was estimated to be £244m in 2017 (2017 prices). A large share of this value is related to labour productivity benefits. In particular, a one percentage point increase in woodland area could lead to avoided productivity loss of at least £12.8m (Moss et al. 2019). A similar study calculated the value of temperature mitigation services in UK urban areas using energy savings associated with lower use of air conditioning (Binner et al. 2017). Annual savings from energy use were estimated at £22m in inner London alone, which is the equivalent of £0.05 per hour per tree.

These estimations are useful to derive an approximate value of the service provided by woodlands but are not exempt from limitations. First, the monetary values here reported do not account for the benefits accruing in non-urban areas. Second, these evaluations do not incorporate potential health impacts that the cooling effect can deliver. Due to methodological constraints and lack of data available the monetisation of this benefit is not feasible withing this analysis. However, it is important to consider these benefits of afforestation alongside the cost benefit analysis.

4.4 Identified costs of afforestation

The costs of afforestation depend on various factors, notably whether the site requires clearing, draining, weeding, and fertilising. Usually, tree-planting programmes are characterised by large up-front costs, as the cost of acquiring the land can be elevated. For this analysis, the costs of afforestation can be classified into three main categories: capital costs, operational costs, and opportunity costs.

Capital costs

Capital expenditure typically refers to the one-off upfront cost to convert land from its former use. This includes the cost of finance incurred by borrowing to pay for initial investments, the costs of planting trees and building fences and the price of acquiring machinery.

Capital costs are reported for both broadleaved and coniferous woodlands in Table 4.2. Plating broadleaved forests is usually more costly then coniferous woodland, as the former require additional investment in fencing and woodland protection (Vivid Economics 2020).

Table 4.2 Capital costs of afforestation (£/ha)

Cost Type	£/ha
Coniferous planting and establishment costs	4,637
Coniferous financing costs	6,749
Total coniferous capital costs	**11,386**
Broadleaved planting and establishment costs	6,182
Broadleaved financing costs	7,347
Total broadleaved capital costs	**13,529**

Source: (Vivid Economics 2020)

Operational costs

Operational expenditure refers to the recurring costs associated with tree-planting. This includes maintenance costs for fence repairs, pest control, fire protection, payment of wages, contracts fees and expenses for project monitoring. Table 4.3 reports the operational costs for broadleaved and coniferous woodlands. These costs are expressed in present value terms over the period 2019-2120, using a 3.5% discount factor.

Table 4.3 Operational costs of woodland restoration (£/ha)

Cost Type	£/ha
Coniferous maintenance costs	2,576
Coniferous production costs	82
Total coniferous operational costs	**2,658**
Broadleaved maintenance costs	2,576
Broadleaved production costs	10
Total broadleaved operational costs	**2,586**
Broadleaved management maintenance costs	4,688
Broadleaved management production costs	742

Total broadleaved management costs	**5,430**

Source: (Vivid Economics 2020)
Note: These costs do not include the recurring costs of thinning and felling.

Opportunity costs

There is also an opportunity cost associated with afforestation, as land is converted from a previous use (such as converting arable land to woodland). The opportunity cost of afforestation is usually measured as forgone agricultural income, loss in open ground habitats and related reduction in recreational activities, cost of land acquisition and compensation payments for forgone income.

In this cost benefit analysis, the opportunity costs are measured as the price of purchasing the land. Table 4.4 reports the upfront costs of land acquisition for coniferous and broadleaved woodlands.

Table 4.4 Land use acquisition costs

Woodland Type	£/ha
Coniferous	12,715
Broadleaved	12,715

Source: (Vivid Economics 2020)

4.5 Cost benefit analysis

Introduction

The benefits associated with each type of woodland vary to some extent, with coniferous woodland offering greater private benefits in terms of timber production while broadleaved woodland creates greater public benefits in terms of greater biodiversity, and a more recreational opportunities (i.e. more picturesque, more bird-spotting opportunities). Similarly, the costs of tree-planting and ongoing operational costs differ slightly, with broadleaved woodland costing slightly more to plant and to maintain. However, within this cost benefit analysis it was not always possible to find separate data for coniferous vs broadleaved woodland associated with all identified costs and benefits. Therefore, when data presented both values for coniferous and broadleaved woodland, an average of the two values was taken.

CBA findings

Table 4.5 below presents the net present value of the identified costs and benefits of afforestation over a period of 100 years, quantified in monetary terms.

Table 4.5 Net present value of costs and benefits (£/ ha)

	Present value
Benefits	
Carbon Sequestration	29,279
Recreation	32,936
Air pollution removal	13,442
Total value of benefits	**75,656**
Costs	
Capital costs	11,505

Operational costs	2,877
Opportunity costs	12,715
Total value of costs	**27,096**

Source: Cambridge Econometrics
Notes: The costs here presented are obtained as a weighted average based upon the quantity of timber removed from coniferous and broadleaved woodlands. Opportunity costs are expressed as the upfront payment required to acquire the land and convert it from its former use.

Comparing the quantified benefits with the associated costs of restoring woodlands to provide a nature-based solution, a benefit-cost ratio (BCR) of 2.79 is derived. This means that for every £1 spent, £2.79 can be expected to be returned in economic and social benefits. The positive BCR presents a compelling argument in favour of afforestation projects. It is important to highlight that some of the benefits delivered by woodland (i.e. recreation and air pollution removal) vary widely on the site of the habitat, as well as the costs of afforestation. The benefit-cost ratio presented here, therefore, is an indicative estimate, and in fact, the ratio may vary somewhat depending on site- and project-specific characteristics.

Further benefits to consider

As detailed in earlier sections, there are many additional benefits which are not included in the quantified CBA but should be considered alongside the final benefit-cost ratio to fully understand the positive impact investment in afforestation can generate. The economic benefits are summarised in Table 4.6.

Table 4.6 Economic and employment benefits of afforestation

	Benefits for 100 hectares of habitat created	Benefits for 30,000 hectares of habitat created
Temporary jobs	25	7,500
Job-years	6	1,800
GVA from capital investment (‘000)	1,222	366,568
GVA from operational investment (‘000)	314	94,168

Source: Cambridge Econometrics

Summary

The CBA of analysis for woodlands reveals that the benefit-cost ratio is 2.79. This means that for every £1 invested in afforestation, £2.79 can be expected to be returned in economic and social benefits. This result should be interpreted as a representative estimation, as it does not incorporate the overall benefits, not it accounts for site specific factors. Afforestation and woodland restoration were found to enhance biodiversity, reduce flood risk, alleviate heat waves, and noise pollution, and improve water quality, create new employment opportunities and increase gross value added (GVA). However, some of these benefits are site specific, hence they tend to benefit restricted areas rather than the whole of society. Although it is not always possible to monetise all the benefits, all benefits need to be acknowledged and incorporated in a cost benefit analysis and in policy-making decisions.

5 Conclusions

This report provides a substantive overview of the economic and social costs and benefits of nature-based solutions in three habitats of interest: peatlands, salt marshes and woodlands. These natural habitats are known for their capacity to capture carbon from the atmosphere and store it for long periods of time. Restoration and improved management of these habitats could provide a significant natural solution to aid the fight against climate change. A cost benefit analysis approach was used to estimate the value of costs and benefits of restoring peatlands, salt marshes and woodlands in the UK. However, due to the difficulty in quantifying and monetising many impacts, these estimates are essentially partial in nature. Qualitative approaches were used to discuss wider effects on society and on the environment. It is likely that many of the non-monetisable benefits could be substantial in size. It should also be noted that there are substantial variations in the costs and benefits associated with specific sites (above and beyond the inherent uncertainty in estimating and monetising costs and benefits); so the calculated estimates are at best weighted averages, and should not be considered as representative of every site where nature-based solutions might be deployed. Undertaking the right project in the right place could yield substantially higher environmental, economic and social benefits.

This analysis estimates a positive benefit-cost ratio (BCR) for the three habitats considered. Comparing the values of benefits and costs of peatlands restoration, a benefit-cost ratio of 4.62 was derived, meaning that for every £1 invested in restoration, £4.62 can be expected to be returned in economic and social benefits. The upfront capital investment in restoration is expected to create approximately 3 temporary jobs for every 100 hectares of restored peatlands and generate £156k in gross value added (GVA) for every 100 hectares of habitat, during the restoration phase. In addition, the investment in ongoing operation and maintenance of the habitat is estimated to create 7 job-years for every 100 hectares of restored peatlands and generate £3,213 in GVA for every hectare of habitat, during a period of 100 years. The Committee on Climate Change recommends restoring at least 55% of peatland by 2050. The restoration of 55% of peatlands is expected to generate around 48,000 temporary jobs during the restoration phase and 112,000 job-years for the operation and maintenance of the restored habitats. Similarly, approximately £2.5bn and £5.1bn would be generated in GVA as a result of the capital investment and the operational investment respectively.

For the analysis of salt marshes, a range of benefit-cost ratios was derived, estimating that for every £1 invested, between £0.24 to £1.31 can be expected to be returned in economic and social benefits, depending on the scale of costs required for the restoration programme. The cost benefit analysis showed that the costs of salt marshes restoration are highly variable depending on the scale of the work required and the location of the habitat. The restoration techniques required to restore salt marshes can be costly and complex, when compared to peatlands and woodlands. However, the capital investment in restoration projects is expected to affect employment positively, generating approximately 14 to 74 temporary jobs per 100 hectares of restored habitat during the restoration stage. In addition, the capital investment in salt marshes restoration is estimated to generate £880k to £4.8m in GVA for every 100 hectares of habitat, during the restoration stage. The restoration of approximately 4.5% of UK salt marshes could therefore be expected to create up to 1,628 temporary jobs and generate up to £105m in GVA, during the restoration phase.

A benefit-cost ratio of 2.79 was estimated for afforestation project, meaning that for every £1 spent, an average of £2.79 can be expected to be returned in economic and social benefits. Furthermore, the upfront capital investment for afforestation is expected to generate around 25 temporary jobs for every 100 hectares of trees planted and generate £1.2m in GVA during the restoration stage. In addition, the ongoing investments for operation and maintenance of the habitat are estimated to create additional 6 job-years for every 100 hectares of trees planted and generate £314k in GVA annually for every hectare of habitat, during a period of 100 years. The Committee on Climate Change advices on planting at least 30,000 hectares of woodlands in UK. If this recommendation were to be met, around 7,500 temporary jobs would be created in the planting stage and 1,800 job-years would be created for the operation and maintenance of woodlands created. Similarly, £367m and £94m would be generated in GVA as a result of the capital investment and the operational investment respectively.

The cost benefit analysis here presented tends to underestimate the overall benefits associated with nature-based solutions, as a number of the benefits of restoration were assessed qualitatively. Nature-based solutions are expected deliver vital ecosystem services such as enhanced biodiversity, reduced flood risk management, improved water quality. The value of these services must be considered alongside the cost benefit analysis and incorporated in policy debates and decision making.

Although the upfront costs of restoration projects can be large, and highly variable across sites, the overall benefits are in many cases expected to outweigh the initial investment. Therefore, investing in nature-based solutions can help meet Net Zero objectives, while also delivering considerable economic, social and environmental benefits. Increased investment in nature-based solutions could therefore also form part of a green recovery strategy in the short term as Government seeks ways of boosting economic growth following the impacts of COVID-19.

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