

NATURAL CLIMATE SOLUTIONS ENABLING PROJECT: REPORT

Measuring the climate change mitigation potential of the Endangered Landscape Programme

June 2021



NATURAL CLIMATE SOLUTIONS ENABLING REPORT

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1 Introduction

1.1 The Endangered Landscapes Programme

The Endangered Landscapes Programme (ELP) aims to restore natural ecological processes, species populations and habitats, with landscape-scale projects involving many different partners across Europe. The programme is managed by the Cambridge Conservation Initiative (CCI) and supported by the Arcadia Fund.

1.2 Evaluating and Enhancing the Contribution of the ELP to Climate Change Mitigation

Globally, momentum to restore degraded landscapes to achieve climate change mitigation, biodiversity conservation and socio-economic goals is growing. Regional and global initiatives aiming to conserve and restore landscapes and seascapes are providing incentives at the policy level to push restoration up the agenda. Launched in 2011, the Bonn Challenge aimed to restore 150 million hectares of degraded landscapes by 2020 and 350 million hectares by 2030. Since then, 74 pledges have been made globally totalling 210.12 million hectares under restoration (bonnchallenge.org; Casarim *et al.* 2015; United Nations Environment Programme [UNEP], 2021).

Nature-based solutions (NbS) are actions that address societal challenges, including improved human well-being, biodiversity loss and climate change mitigation by actions to protect, sustainably manage, and restore natural or modified ecosystems (IUCN n.d.). It is estimated that NbS could contribute over one third of the total climate change mitigation required by 2030 to achieve the targets of the Paris Agreement and keep global warming to just below 2°C (Griscom *et al.* 2017). NbS are thus an essential part of the global mitigation effort. However, NbS can only combat climate change when accompanied by decarbonisation across all sectors.

Within NbS, the restoration of degraded ecosystems plays a crucial role, alongside effective conservation, reducing emissions from habitat loss and improving management of production lands (IPCC 2018; Bastin *et al.* 2019; Strassburg *et al.* 2020). Ecosystem restoration is the process of halting and reversing degradation, resulting in improved ecosystem services and recovered biodiversity (United Nations Environment Programme [UNEP] 2021). It is increasingly recognised that ecosystem restoration is most effective when conducted over large areas both on land and in the sea. The ELP encompasses projects across Europe which aim to restore landscapes over large areas. At this scale, restoration activities encompass a wide range of practices and ecosystems and may include re-establishing habitats that have previously been converted, improving the condition of degraded ecosystems and preventing further degradation through improved land management practices. Landscape-scale restoration activities and their multiple benefits, including climate change mitigation, are particularly relevant as the UN Decade for Ecosystem Restoration begins in 2021, running until 2030 (UNEP 2021).

As such, NbS are increasingly recognised as vital tools in limiting the devastating impacts of climate change and reaching the mitigation goals of the UNFCCC Paris Agreement. However, despite their importance, the climate change mitigation benefits of improving biodiversity and ecosystem integrity are currently under-represented in high-level discussions. Improving our understanding of the links between restoration and climate change mitigation will elevate the profile of NbS at the policy level.

Project aim

This project aimed to estimate the climate change mitigation potential of ELP projects across Europe. Comparing project outcomes against a baseline 'business-as-usual' scenario demonstrated the emissions reduction and carbon sequestration benefits of achieving biodiversity-focused restoration goals, and how these could be maximised.

1.3 Capacity needs within the ELP

Although Endangered Landscapes Programme projects are often designed to deliver biodiversity conservation socioeconomic benefits, restoration activities taking place can both reduce emissions associated with project sites and sequester and store large volumes of carbon. Therefore, understanding the impact that a project has on a site's GHG balance and its contribution to climate change mitigation highlights the additional value of these projects alongside their biodiversity conservation, ecosystem functioning and socioeconomic outcomes.

However, measuring the potential climate change mitigation of a project requires in-depth knowledge of habitats within the project site, land use and land management changes which have occurred, or will occur, as a result of the project and an understanding of the baseline, or 'business-as-usual' scenario. Furthermore, projects need to understand the range of measurement options available (i.e. methodologies and tools), their data, time and resource constraints, and the intended use of the results (e.g. measuring, reporting and verifying (MRV) for carbon crediting).

Building capacity with the ELP to measure and monitor GHG benefits and contribution to climate change mitigation will elevate our understanding of the multiple benefits of these projects and highlight the importance of landscape restoration to climate change mitigation policy and practice.

1.4 GHG and Carbon Accounting Tools

Methods for measuring and monitoring carbon stock enhancements and greenhouse gas emissions reductions have been growing in recent years, particularly with the establishment of schemes which provide payments for reducing emissions from deforestation and carbon stock enhancement through ecosystem restoration (such as REDD+) and increasing private sector interest in offsetting emissions through the voluntary carbon market. These efforts have largely been focused on forest ecosystems, particularly in tropical and sub-tropical ecological zones. Despite growing interest, there has been little development in methodologies to account for carbon stock and GHG emissions changes from restoration practices relative to "business-as-usual". This is largely due to difficulties and complexities in measuring and monitoring carbon stock enhancements in large areas with dynamic land use changes, and because the benefits of carbon stock enhancements from restoration may be marginal when compared to maintaining carbon stocks through the conservation of intact ecosystems, particularly forests and peatlands. However, restoration activities across degraded ecosystems and landscapes can represent a significant sink of atmospheric carbon. Furthermore, the benefits of landscape restoration go beyond just carbon and other GHGs, with projects providing wider biodiversity and socio-economic benefits within and beyond their site boundaries (Casarim *et al.* 2015).

A range of GHG and carbon accounting tools exist, utilising different methodologies and covering a range of ecosystems. Tools for this Natural Climate Solutions project were assessed on their suitability to landscape restoration activities, their GHG and geographic coverage and the applicability of their results. Two tools were selected, EX-ACT (FAO 2021) and Carbon Benefits Project (Carbon

Benefits Project 2020). Each tool had the potential to cover ecosystems and land use and management changes taking place across ELP projects. Each tool also allows the user to refine calculations through inputting Tier 2 emissions factors. Neither tool is limited to assessing just CO₂ emissions, with both including emissions of non-CO₂ gases in their equations (reporting results in CO₂e). These include methane emissions from livestock production and peatlands as well as nitrous oxides. Both tools also calculate uncertainties in their outputs, follow IPCC (2006) and stock difference methods and can be used for ex-ante and ex-post assessments. Finally, both tools require relatively low inputs for time, data and skills required to use them, with resources and guidance available where needed.

Other available tools

Several tools exist which include options to understand climate change mitigation potential of LULC changes, with varying levels of input and technical skills required. For example, the **InVEST Carbon Storage and Sequestration model** (Natural Capital Project n.d.) estimates the change in carbon stored across landscapes between different scenarios. The tool uses a simple approach, assigning a carbon stock value to each land cover class. The difference in carbon stored between the two scenarios can be calculated using the spatial layers output by the model. It does not currently allow the inclusion of emissions factors for e.g. peatlands and newly established forested areas. Furthermore, it would not be possible to include emissions from inputs and livestock, these would have to be calculated separately. For several landscape restoration projects where peatland restoration or changing livestock densities are included, this approach would limit their ability to understand the changes in their emissions. The approach is also unable to account for direct land-use and land management changes (e.g. through changes to inputs such as fertiliser or disturbances to soils).

The **TESSA Toolkit** (Peh *et al.* 2013) provides information and methodologies for site-based assessments of a variety of ecosystem services including global climate regulation, water-related services, harvested wild goods, cultural services, pollination services and coastal protection services. The tool includes an 'alternative state' which can be compared to the current land use within a site. The tool uses flow charts to demonstrate where a site's ecosystem services are benefiting society. Whilst aimed at assessing ecosystem services at the site scale, the tool methodologies would require the user to collect data from the site and complete calculations outside of the toolkit itself. To fully understand the impacts of a project on carbon stock and sequestration, it is recommended to undertake these assessments. However, doing so can take considerable time and resources.

The [USAID AFOLU Carbon Calculator](#) (Winrock International 2014), available for certain countries and regions (EU countries excluded) is web based and allows the user to input information about their project. This includes activity (e.g. forest protection, afforestation/reforestation, grazing management and forest degradation through wood-harvesting), area, avoided actions (fire, deforestation and illegal logging) and carbon stock. The tool requires the user to answer a series of questions to produce a calculation with carbon estimates over the project's lifetime.

The [Forest Landscape Restoration Carbon Storage Calculator](#) developed by Winrock International provides an online tool with a simplified input to allow forest-based restoration projects globally to estimate the carbon stored as a result of their activities. Here, the user must select their country and region, which refines the available inputs for tree species being planted/restored. The user can only select one tree species and must then enter the hectares planted/restored each year over a 20-year period (not the cumulative amount) for plantations and natural regeneration. The tool then calculates

the estimated carbon stored by forest landscape restoration (FLR) activities per year and total. This tool provides a quick and easy to use estimation for forest-based activities. However, the tool is limited in the species which can be input, and available options may not accurately reflect forested areas on the project site. Furthermore, it is not possible for the user to create forest classes and adjust emissions factors. Therefore, the tool may be limited in its accuracy and its useability for landscape level restoration projects.

A range of tools specific to ecosystems, sectors and regions are also available. For example, in the UK the **Woodland Carbon Calculator** (Woodland Carbon Code 2021) and **Peatland Carbon Code tools** (Peatland Code, n.d.) are available, as well as tools specific to the agriculture sector which include the **Farm Carbon Toolkit** (Farm Carbon Toolkit n.d.), **Cool Farm Tool** (Cool Farm Alliance n.d.) and **Agrecalc** (agrecalc n.d.). FAO's [Global Livestock Environmental Assessment Model \(GLEAMi\)](#) (FAO 2018) offers in-depth assessment of greenhouse gases associated with livestock at every stage of production.

The decision on which tool to use should be context-dependent and factor in data availability, time, cost, and the intended use of the outputs (e.g. reporting or understanding the impacts of different potential management approaches). Ex-ante tools, such as EX-ACT and CBP, are intended for use in understanding the impact of different management practices on the greenhouse gas balance of a project and for planning purposes. However, they can also be used for retrospective assessments to gain an understanding of potential climate change mitigation contribution once a project has been completed. However, measuring, reporting and verification of carbon stocks and sequestration and avoided emissions for carbon credits will require in-depth analysis and on-site sampling.

2 The GHG Accounting Tools

Here we assessed the suitability of two GHG assessment tools for quantifying the climate change mitigation potential of ELP projects. These tools estimate carbon stocks and net GHG fluxes (either sequestration or emissions) from land use systems under different management over a given period.

2.1 EX-ACT

EX-ACT (Ex-ante Carbon balance Tool) is a spreadsheet-based tool developed by the Food and Agriculture Organization to estimate the impacts of forestry, agriculture and fishery on the projects' GHG balances (FAO 2017). The tool is designed to help project developers prioritise activities with the greatest potential for climate change mitigation. EX-ACT assesses project benefits in terms of the difference in GHG emissions between the project and a baseline "business-as-usual" scenario. The tool uses default Tier 1 values based on the location and climate specified by the user (IPCC 2006; IPCC 2014b), accounting for carbon stored and sequestered as well as emissions from inputs and livestock. EX-ACT allows the user to input Tier 2 values and encourages their use where appropriate. EX-ACT covers the entire AFOLU sector, including forestry, agricultural inputs, energy, infrastructure, management of organic soils, coastal wetlands, fisheries and aquaculture (FAO 2019).

The tool is publicly available, though users are required to create a log-in before downloading the tool. It is also regularly updated with improved calculations, Tier 1 values and bug fixes; therefore, it is recommended to check for the latest version before starting any new analysis. Resources, guidance documents, papers and webinars on the tool can also be found on the tool website.

Key links

- Tool download: <http://www.fao.org/in-action/epic/ex-act-tool/suite-of-tools/ex-act/en/>
- Help sheet for EX-ACT: http://www.fao.org/fileadmin/templates/ex_act/pdf/Technical_guidelines/EX-ACT_technicaldescription_EN_v7.pdf (outdated for current tool version)
- Online course for using EX-ACT: <https://olc.worldbank.org/content/estimating-ghg-emissions-and-carbon-sequestration-agriculture-forestry-and-other-land-use-ex>
- Table 4 for checklist <http://www.fao.org/3/a-i8075e.pdf>

2.1.1 Data requirements

All inputs in the tool (table 1) are required for the initial, without project (baseline) and with project scenarios.

Table 1. EX-ACT tool sections and inputs relevant to ELP projects and the Tier 2 inputs which can be included.

Tool Section	Relevant restoration activities	Required inputs description	Optional inputs description	Tier 1 inputs description	Tier 2 inputs description
Description	Project description and climate/soil inputs	Project duration, location, climate and soil type	Project description	N/A	N/A
Land Use Change	Deforestation and Afforestation/Reforestation, other land-use changes (e.g. grassland to forest)	Area, initial and final land uses	Use of fire and harvested wood products	Select suitable forest and/or land use types	Vegetation biomass (AGB, BGB, litter and deadwood), Soil carbon stocks, Vegetation biomass growth increment
Croplands	Annual and/or perennial cropping systems (remaining or converted to/from other land uses) Low-density tree planting (e.g. establishment of parkland)	Area, initial and final land uses Management (tillage, inputs, residue)	Yield	Appropriate crop/agroforestry system	Soil carbon stocks, tillage factor, inputs factor, residue/biomass available Perennial: above and below ground biomass growth increments
Grassland	Changes to grassland management or degradation level	Area, grassland management	Yield, fire management	Select suitable grassland management category	Soil carbon stocks

	Livestock changes	Livestock category, number of heads	Livestock productivity, livestock production in tonnes	Select suitable livestock category	Enteric fermentation, emissions from manure management
Forest Management	Change in forest degradation (measured in change in total biomass)	Area, forest degradation level	Fire occurrence, periodicity, and impact	Select suitable forest vegetation	Forest degradation level (% of biomass lost), vegetation biomass carbon (AGB, BGB, litter and deadwood), Soil carbon stock, land use factor
Inland Wetlands	Peatland degradation and/or rewetting (section 6.2.2.) Also LUC on organic soils and forest management on organic soils	Area, water table level	Fire (residues and soil), % ditches	Appropriate land use cover, water table level (e.g. drain -> rewet).	CO ₂ , CH ₄ , N ₂ O etc. and offsite emissions factors (change associated with drainage/rewetting)
Coastal Wetlands	Excavation, drainage and rewetting of coastal vegetation (e.g. seagrass) Aquaculture (see tool for more detail) Coastal fisheries (see tool for more detail)	Area, type of vegetation	N/A	Area, type of vegetation, % excavated, % drained, area rewetted and % nominal biomass restored	Biomass carbon (AGB, BGB, Litter and deadwood), soil carbon (up to 1m depth), CO ₂ and CH ₄ emissions factors
Inputs	Fertiliser and pesticide inputs	Volume (tonnes) applied per year (site wide)	N/A	Type of fertiliser or pesticide	Emissions from field (CO ₂ and N ₂ O) and emissions from production (transport, storage, transfer)

2.1.2 Using the Tool

The tool is a set of linked Microsoft Excel sheets, providing the user with a guided workflow to complete all relevant tool inputs and sections for their project. The tool includes 'Definition' and 'HELP' sheets with descriptions to aid users in selecting relevant inputs throughout the tool. The tool is also based on IPCC (2006), IPCC (2014b) and IPCC (2019) methodologies. These can be consulted for more information on calculations, Tier 1 inputs and emissions factors.

Project Description

Figure 1. Initial project description page of the EX-ACT tool.

The initial project description page asks users to provide information on their projects. Section 1.1. Project description does not alter any of the tool's calculations, this information is intended for the purpose of sharing the tool, and users can input as much or as little information as required.

Section 1.2. Project site and duration must be filled in for each project. These inputs influence the tool's calculations and Tier 1 defaults used. To aid users, the tool has a 'HELP' tab, with maps to help users select the correct inputs for the Climate, Moisture and Soil type inputs. Tool developers recommend that the project duration (in years) totals 20 years (or multiples of), following IPCC (2006) defaults. However, any duration can be input, and the tool will adjust its results according to 20-year timelines for changes to land-use, ecosystem degradation etc.

Source:	Value
CO ₂	1
CH ₄	34
N ₂ O	298

Figure 2. Section 1.3 of the EX-ACT tool, allowing user to select the Global Warming Potential used by the calculations.

The tool also allows the user to change the Global Warming Potential (GWP) used in the calculations. Options are: 100 yr AR5 without CC feedback, 100 yr AR4 and 100 yr SAR. Which GWP values are used depends on what the tools results will be used for. Currently, reporting for Nationally Determined Contributions and National Greenhouse Gas Inventories use GWP values from the IPCC Fourth

Assessment Report, 100 yr AR4 (Forster *et al.* 2007). Therefore, selecting this option may be preferable if there is a need to align results for reporting. Similarly, this option is required if Tier 2 emissions factors have been calculated using these GWP values. However, projects may wish to use the latest GWP values from the IPCC Fifth Assessment Report (IPCC 2014a).

Project activities

2.1 DEFORESTATION						If country-specific data			
Type of vegetation that will be deforested	HWP (tDM/ha)	Fire used? (y/n)	Final land-use after deforestation		Forested area (ha)				
			Land-use type	Agroforestry system	Start	Without	With	With	
Planted Temperate oceanic forest	0	NO	Annual fallow	Please select	750	750	D	707	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
Please select	0	NO	Please select	Please select	0	0	D	0	D
						Total defore:			

Figure 4. Example of EX-ACT tool inputs within section 2 'LUC Deforestation'.

Following the initial description sheet, projects should then move through each relevant section of the tool, selecting appropriate inputs from the drop-down menus. Drop-down options for vegetation and land-use are based on broad, Tier 1 habitat types, project location and climate. These can be further tailored to the project by selecting the 'Tier 2' button included in each sub-section. This brings the user to the emissions factor inputs for that sub-section, where they can be updated with Tier 2 emissions factors which have been calculated or sourced from the literature based on the detailed information about the habitat type.

2.1 DEFORESTATION										Back
Type of vegetation that will be deforested	All units are in tC/ha									
	Above-ground		Below-ground		Litter		Dead wood		Soil carbon	
	Default	Tier 2	Default	Tier 2	Default	Tier 2	Default	Tier 2	Default	Tier 2
Planted Temperate oceanic forest	82.3	46.5	23.2	16.7	2.9	2.6	36.8	0.0	81.0	
Please select	0.0		0.0		0.0		0.0		0.0	
Please select	0.0		0.0		0.0		0.0		0.0	
Please select	0.0		0.0		0.0		0.0		0.0	
Please select	0.0		0.0		0.0		0.0		0.0	
Please select	0.0		0.0		0.0		0.0		0.0	
Please select	0.0		0.0		0.0		0.0		0.0	
Please select	0.0		0.0		0.0		0.0		0.0	
Please select	0.0		0.0		0.0		0.0		0.0	

Use this part only if you want to refine the analysis at Tier 2
 IPCC default values are provided for your information only, EX-ACT will use Tier 2 values automatically wherever specified.

Figure 5. Example of updated emissions factors in the EX-ACT tool for emissions associated with deforestation.

The tool allows the user to select the same broad 'Tier 1' vegetation or land use category multiple times, but each input can be adjusted in different ways using the Tier 2 inputs. Some sections of the tool also include inputs for users notes, to further distinguish different inputs where the same broad input category is used.

4.1.2. Grassland systems remaining grassland systems (total area must remain constant)

User notes	Grassland management ?		
	Start	Without	With
Heathland	High intensity grazing	High intensity grazing	Non-degraded
Grassland	Severely degraded	Severely degraded	High intensity grazing
	Please select	Please select	Please select

Figure 6. Example of grassland inputs in the EX-ACT tool.

The tool requires inputs for the start of the project (the initial state) and expected changes under without the project (Baseline scenario) and with the project (Project scenario) for each habitat/area included. The tool can account for changes between land uses and relevant sections are set up to account for these (e.g. grasslands converted to other land uses).

The tool is set up to allow the user to work through each section and include inputs where relevant. However, several activities relevant to ELP landscape restoration projects may not be straightforward to input. These are described in detail below:

Accounting for reforestation on deforested land

The tool has some limitations where the same area of land will experience more than one land use change. For example, a project may deforest an area of plantation forest and replace it with native forest vegetation. This would be a two-step process, deforestation (or felling) and then reforestation. Tool developers recommend accounting for this by using two EX-ACT tool workbooks, with one accounting for the emissions associated with deforestation on that area of land, and another for the reforestation. In most cases, the remainder of the project will be included with the deforestation calculation, however this may change on a project to project basis. This approach avoids issues of double counting on the same area of land. Results from the two workbooks must then be combined for reporting.

Inputting peatland Tier 2 emissions factors

The tool also has dedicated inputs for any changes taking place on organic soils. These include land-use changes and forest management, but section 6.2.2. 'Other land-use management' includes the draining and rewetting of peatlands, which is relevant to several ELP projects. Here, emissions factors associated with the drainage or rewetting of peatlands can be input to tailor the results to the specific ecosystems. Values should be the absolute emissions associated with each type (or degradation level) of peatland, and the tool will calculate the change in emissions of peatlands between two states. For example, if rewetting drained peatlands, the Tier 2 emissions factor values associated with the drained and rewetted peatland state should be input into the Tier 2 inputs for section 6.2.2. 'Emission factors for drainage associated with other land-use management'. Tool developers recommend only assessing the emissions associated with peatlands which are undergoing management changes. The water level table inputs should then be changed to reflect any management changes which are expected to occur under each scenario.

Water table level		
Start	Without	With
Drained	Drained	Drain. -> Rewet.

Figure 7. Example inputs for water level for peatlands being rewetted by a project. The drained -> Rewetted inputs prompts the tool to calculate the change in emissions associated with those two states under the Project scenario.

Fire occurrence on peatlands

Within the inland wetlands section, it is possible to include fire on peatlands. However, this is in regard to intentional fire setting during management. In some project areas, wildfires may affect peatlands, particularly where they have been drained and are therefore more susceptible. This occurrence of these wildfires will be difficult to predict and therefore it may not be possible to enter them into the tool, particularly for prospective assessments. Although these events likely contribute significantly to a project's GHG balance, they may have to be excluded from these analyses due to uncertainty in understanding their frequency and extent.

Inclusion of low-density woodlands and parklands

The tool has limited ability to input low-density woodlands and parklands, especially in shorter term projects. Through conversations with the EX-ACT team, we have determined the best way to account for these areas. By defining these areas as 'Perennial' we are able to specify the Tier 2 values to better reflect the carbon balance of the project. In the projects we have investigated, the primary change is the planting of low-density trees and shrubs on a grassland to create a low-density woodland or grassland, therefore we utilised Section 2.3 'Other Land Use Changes' detailing the change of the indicated area from 'Grassland' to 'Agroforestry'. In the Tier 2 emissions section, the above-ground biomass of the grassland is set to 0 to account for a non-significant change in grassland biomass between Grassland and Silvopasture systems, particularly in temperate regions (Cardinael *et al.* 2018; Dollinger and Jose 2018). The expected biomass at the end of the project is then input into the First-Year biomass section of the Tier 2 values. Finally, all growth factors in the Perennial section associated with Other Land Use changes are set to 0 and Soil Management Factors set to 1 to avoid associated emissions being calculated where they are not relevant.

Accounting for land use changes on multiple types of grassland

Where land use changes occur on grassland (e.g. afforestation) it is only possible to select grassland in one condition (e.g. non-degraded with no additional inputs). Land-use changes occurring on grasslands may take place on grasslands under different management regimes (e.g. inputs use) and conditions. Therefore, it is recommended to select the grassland condition and management which is the most broadly applicable to all grassland being converted to other land use. This may limit the accuracy of the results where land-use change is expected to impact soil carbon and grassland vegetation.

Introducing restoration activities/ animal or inputs changes part-way through a project's timeline

Some project activities may occur after the implementation of core activities, such as the introduction of livestock towards the end of a project's assessment period. In this case, the introduced emissions

can be accounted for by creating another EX-ACT workbook, inputting data on the new livestock and setting the project period to only account for the duration of time they spend in project over the assessment period (e.g. 5 years). The results of the GHG emissions should then be totalled with the original workbook.

Outputs

The tool includes a results section summarising all inputs across each section. Here, results are summarised by scenario (Baseline and Project) and the balance between the two scenarios is reported. Negative results indicate a net uptake of greenhouse gases (carbon sequestration).

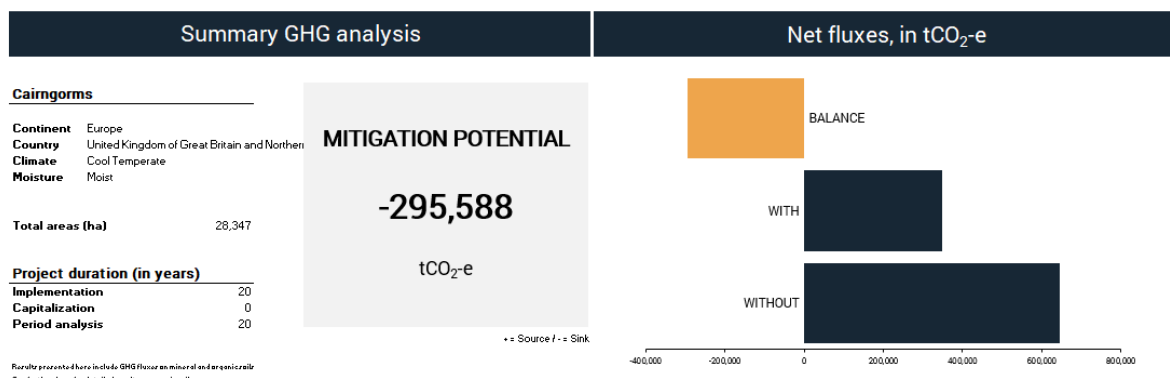


Figure 8. Example headline results reported by the EX-ACT tool.

Reporting includes overall summaries as well as graphs with results broken down by activity/habitat and the contribution of different greenhouse gases to the overall balance.

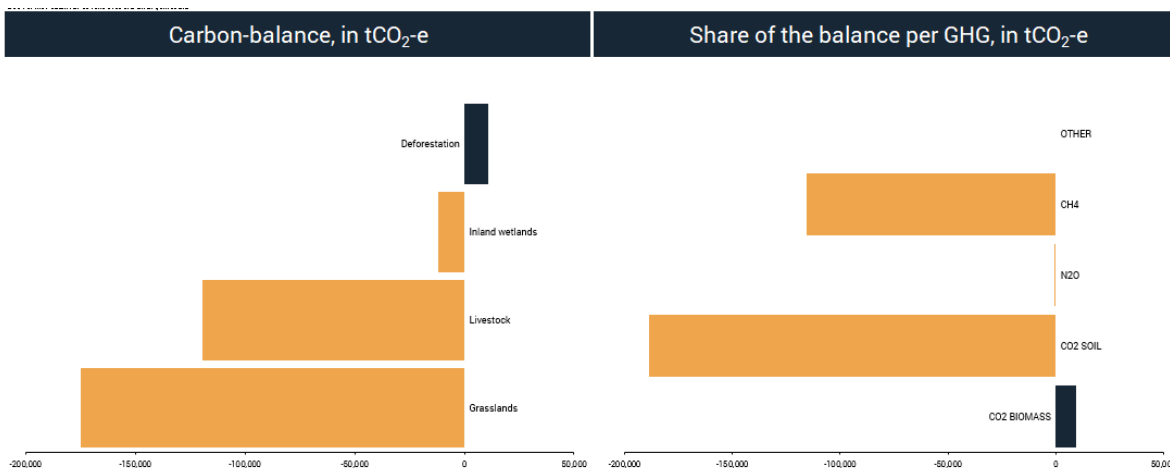


Figure 9. Example carbon balance results from the EX-ACT tool, with change in emissions associated with different land uses and activities as well as the contribution of each greenhouse gas to the overall balance.

Graphs can be used straight from the tool for reporting; however, the results section of the tool also provides a detailed results table. From here, the user can pull results for reporting and generate graphs manually as needed. Results for different activities or habitats can also be combined as appropriate, or further split out by going back to the relevant sheet within the tool workbook.

DETAILED RESULTS

Project nam	Cairngorms	Project duration (in years)	20	Total area (ha)	28,347	Global warming potential	
Continent	Europe			Mineral soil	17,546	CO ₂	1
Country	United Kingdom of Great Britain and Northern Ireland	Implementation		Organic soil	10,801	CH ₄	34
Climate	Cool Temperate	Capitalization	0	Waterbodies	0	N ₂ O	298
Moisture	Moist	Period analysis	20				

GROSS FLUXES				SHARE PER GHG OF THE BALANCE					AVERAGE ANNUAL EMISSIONS		
In tCO ₂ -e over the whole period analysis				In tCO ₂ -e over the whole period analysis					In tCO ₂ -e/yr		
PROJECT COMPONENTS	WITHOUT	WITH	BALANCE	CO ₂ BIOMASS	CO ₂ SOIL	N ₂ O	CH ₄	ALL NON-AFOU EMISSIONS*	WITHOUT	WITH	BALANCE
Land use changes											
Deforestation	0	10,788	10,788	9,633	1,149	5	0	0	0	539	539
Afforestation	0	0	0	0	0	0	0	0	0	0	0
Other land-use	0	0	0	0	0	0	0	0	0	0	0
Annual	0	0	0	0	0	0	0	0	0	0	0
Cropland											
Perennial	0	0	0	0	0	0	0	0	0	0	0
Flooded rice	0	0	0	0	0	0	0	0	0	0	0
Grasslands & Livestock											
Grasslands	0	-175,022	-175,022	0	-175,022	0	0	0	0	-8,751	-8,751
Livestock	249,533	130,308	-119,225				-119,225		12,477	6,515	-5,961
Forest mgmt.	0	0	0	0	0	0	0	0	0	0	0
Inland wetlands	395,687	383,557	-12,130	0	-14,982	-568	3,420	0	19,784	19,178	-606
Coastal wetlands	0	0	0	0	0	0	0	0	0	0	0
Inputs & Invest.	0	0	0	0	0	0	0	0	0	0	0
Total emissions, tCO₂-e	645,220	349,632	-295,588	9,633	-188,854	-562	-115,805	0	32,261	17,482	-14,779
Total emissions, tCO₂-e/ha	22.8	12.3	-10.4	0.3	-6.7	0.0	-4.1	0.0			
Total emissions, tCO₂-e/ha	1.1	0.6	-0.5	0.0	-0.3	0.0	-0.2	0.0			

* = Source / - = Sink

Results presented here include GHG fluxes on mineral and organic soils
See further down for detailed results on organic soils
* Includes fisheries, aquaculture and inputs & investments that are not included in the AFOLU definition.

Uncertainty level	tCO ₂ -e/yr	Percent
Without	32,261	37%
With	17,482	40%
Balance	-14,779	43%

Figure 10. The detailed results summary provided by the EX-ACT tool, including gross fluxes and breakdowns of emissions associated with different carbon pools and gases.

2.1.3 Tool limitations

Although it has been possible to use the EX-ACT tool across all projects in this analysis, it is important to consider some limitations when deciding whether to use this tool for GHG accounting.

- As mentioned above, the tool has limited ability to input low-density wooded areas, such as parklands, or to account for projects where there may be some low-density regeneration of trees. It is possible to adjust inputs within the perennial section to account for these, but results may not accurately reflect expected growth rates and disturbances to the soil.
- The forest equations used are simple when compared to some other tools. They do not allow the user to input detail such as natural annual losses (e.g. from pests, diseases, wind etc.). Inputs for harvested wood products are also limited, with only the option to input where deforestation occurs, rather than where forests remain forests with annual allowable cuts.
- Deforestation rates in project sites may be expected to change as a result of a project being implemented. However, the exact area which is expected to be deforested in the Baseline or Project scenarios may be unknown. Projects may have estimations for annual deforestation rates (e.g. % loss) calculated from historic deforestation data. However, tool inputs do not currently allow deforestation estimates to be input this way. Instead the user would have to use the rates to calculate the total area which might be deforested over the projects lifetime under each scenario.
- In the peatlands section, it is not possible to enter emissions factors so that the emissions associated with peatlands remaining unchanged (e.g. intact peatlands and drained peatlands not being rewetted) can be calculated. This is due to the tool focusing only on activities which affect the GHG flux of a project. As these emissions won't affect the GHG balance of a project, it may not be necessary to calculate the emissions associated with them.

- When grassland is transitioning to other land uses, the tool limits the types of grassland to one. Therefore, if grassland areas under multiple different management practices are being converted to other land uses, the user must choose only one management practice. Here, we recommend choosing the management practice which covers the greatest proportion of grassland being converted. However, this will result in some inaccuracies when accounting for changes in emissions.
- The tool does not have dedicated inputs for shrublands or heath. This is particularly relevant to several ELP projects where habitats such as heather moorlands could not be appropriately classed as forested areas, but where carbon storage may be higher than when compared non-degraded grasslands due to different community complexities and compositions. However, detailed on-site analysis would have to be undertaken to determine whether species diversity influences the volume of carbon stored in associated soils and vegetation. Throughout this project, we treated these ecosystems as grasslands and assumed no difference from a carbon perspective.

2.2 The Carbon Benefits Project

The Carbon Benefits Project (CBP) Tool is an online tool developed by Colorado State University, as part of the wider CBP consortium (Carbon Benefits Project 2020). The tool allows users to assess the GHG emissions in terms of amount of carbon stored and sequestered as well as the impact of livestock and inputs such as fertilisers. The tool offers two carbon assessments, simple and detailed, as well as the option to use a socio-economic model. The simple assessment uses default Tier 1 emissions values from underlying datasets (IPCC 2006) based on spatially explicit project boundary data supplied by the user. The detailed assessment allows the user to input any available pre-existing Tier 2 values to further tailor the outputs to their own projects.

The tool is accessed online, with the user required to set up an account. Within the account, the user can create several different projects and input detailed qualitative information for each. This approach makes the tool less collaborative than EX-ACT, where the users can share the spreadsheet-based tool, however, it is possible for multiple users to be logged into the account simultaneously, though not recommended to work on the same projects at the same time. The tool outputs a PDF summary report, with a description of the project and a map of the project's location. The output details the overall GHG balance of the project, and the emissions associated with both the Baseline and Project scenario. The tool automatically summarises these results into a table format, grouping the results where appropriate, e.g. by biomass or soil carbon, livestock-related emissions etc. Furthermore, the tool allows the user to download a 'Detailed Report' for each of the scenarios. These are Excel workbooks with the inputs and calculations used for all relevant activities, allowing the user to interrogate and better understand the tool's workings.

The tool only covers terrestrial land cover classes and doesn't include a dedicated peatland section. Instead the tool has a simple wetlands section and the emissions factors are determined based on the spatial data input to the tool and the overlap with the Harmonised World Soils Database (Hiederer 2012). Using spatial data, the tool can determine appropriate inputs such as temperature and include multiple soil types within the analysis.

Key links

- Create an account and access the tool: <https://cbp.nrel.colostate.edu/>

- Additional help sheet for CBP: <http://banr.nrel.colostate.edu/CBP/wp-content/uploads/2018/10/CBP-CSU-General-Tutorial.pdf>

2.2.1 Data requirements

Table 2. Relevant CBP tool sections and required and optional inputs.

Tool Section	Relevant ELP activities	Required (Tier 1) inputs description	Optional inputs description	Tier 2 inputs description
Project description, areas and land use	N/A	Project description, spatial data on project boundaries (does not have to be exact), total area for each land-use category	N/A	N/A
Forestland	Deforestation, Afforestation/reforestation	Area, tree type, tree age range	Natural losses and wood removal	Create project specific tree type, Above-ground vegetation biomass, above-ground vegetation biomass growth increment, Root:Shoot

Grassland	Changes to grassland management or degradation level Inclusion of silvopasture habitats	Area, select grassland system, select grassland condition and relevant inputs	Fertiliser, organic inputs, improved grass varieties, irrigation, liming, legume sowing. Burn frequency Silvopasture: tree type, tree age range	Aboveground biomass (if burning occurs) Biomass inputs for trees in silvopasture (if applicable)
Settlements	Trees planted in urban areas	Tree type, tree age range, number of trees/ tree crown cover present	Natural losses and wood removals	Above-ground biomass and growth increments for specific tree species.
Wetlands	Wetland drainage and rewetting	% wetlands drained	N/A	Not recommended to change emissions factors associated with soils.
Annual Crops	Annual cropland systems (remaining or converted to/from other land uses)	Type of cropping system, Area, Improvements (Y/N), Tillage (Full, reduced, none), Fertiliser applied, residue management (retained, burned, grazed, collected).	N/A	Create project specific crop type, above-ground vegetation biomass
Perennial Crops	Perennial cropping systems (remaining or converted to/from other land uses)	Perennial cropping system, Area, Perennial crop age range, residue	Wood biomass natural losses (e.g. pests, fires), wood harvesting, fuelwood gathering,	Create project specific perennial type, above-ground vegetation biomass, above-ground

		management (retained, burned, grazed, collected).	number of trees cleared/planted	vegetation biomass growth increment
Agroforestry	Agroforestry cropping systems (remaining or converted to/from other land uses), not including silvopasture.	Area, type of annual cropping system (see above for inputs), tree age ranges, wood loss and removals	Wood biomass natural losses (e.g. pests, fires), wood harvesting, fuelwood gathering, number of trees cleared/planted	Create project specific crop type, above-ground vegetation biomass, above-ground vegetation biomass growth increment
Livestock	Livestock changes	Livestock category, population, months in the project activity area Percent of manure left in system	N/A	Basic enteric fermentation, manure methane emission factor

2.2.2 Using the Tool

The use of the tool requires an internet connection and tool developers recommend accessing the tool through Chrome, Safari or Mozilla Firefox browsers.

Project description

Before adding data to the project, the tool requires basic information about the project to be entered. Aside from the project duration, this information is used in the generation of the report and does not affect the results of the tool. These include, name, status, country, activities, summary of project goal and information on funding. It is not necessary to fill these in unless you would like to share the report generated by the tool.

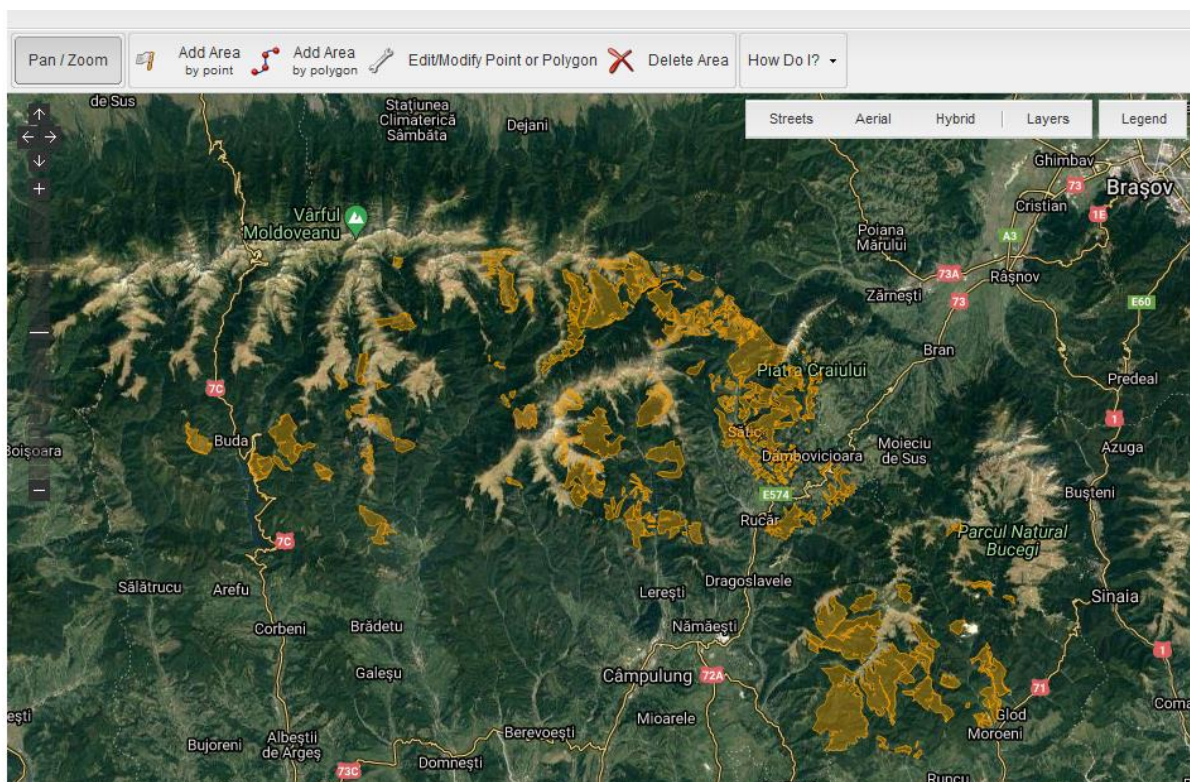


Figure 11. Example of uploaded spatial data to the CBP tool to define the project area and boundaries.

The tool also requires spatial data on project boundaries, this can be uploaded to the tool (e.g. as a shapefile) or drawn directly onto a map. This data refines the climate and soil inputs to the tools calculations and does not need to be exact. If there are multiple contained areas across the project (as in figure 11) it is possible to treat these separately or as a whole in the analysis.

Once uploaded, the tool requires the user to input the total area of each land use category under each scenario. These do not need to equal the area of the boundaries uploaded or drawn, but each scenario must have the total area. A map of land use and project activities does not need to be uploaded, only the project boundary data.

Land Use Category	Initial Land Use (ha)	Baseline Scenario (ha)	Project Scenario (ha)
Forestland	14726	14726	14726
Grassland	2002	2002	2002
Settlements	0	0	0
Wetlands	0	0	0
Annual Cropland	0	0	0
Perennial Cropland	0	0	0
Agroforestry	0	0	0
Livestock	9745	9745	8379
Total Area (ha)*	16728	16728	16728

* The total area includes all of the area in all of the first seven land use categories, but does not include the number of livestock.

Figure 12. Example of area and livestock inputs for each scenario in the CBP tool.

Project activities

The tool then allows the user to select either a 'Simple' or 'Detailed' assessment for the GHG accounting. The simple assessment limits the user to Tier 1 inputs. If these are thought to be suitable, or there is not enough data to use Tier 2 inputs, it is recommended to use the simple assessment. Otherwise, the detailed assessment should be used. This allows the user to create habitat types and modify the emissions factors for existing ones in the tool.

Within the assessment there are three main sections, 'Initial Land Use', 'Baseline Scenario' and 'Project Scenario'. Each of these sections must be completed individually before the tool can be run, when this is possible the red 'X' beside them will change to a green ✓.

Within each section there are subsections for each land use and for livestock inputs. Any sections which were not included in the area inputs detailed above, will be greyed out and not possible to click on.

Within the forestland, grassland (silvipasture), perennial crops and agroforestry sections, there is the option to include detail on forest management and losses. For example, the percent (%) of each forest class lost due to natural causes (fires, wind, pest/disease and other) annually can be entered (figure 13).

Forest Type	Tree Age Range*	Area (ha)*	Fires (%/yr)	Wind (%/yr)	Pest/Disease (%/yr)	Other Losses (%/yr)
Temperate oceanic forest natural vegetation	> 20 years	500	10	0	0	5
Temperate oceanic forest plantation	> 20 years	350	0	0	0	0
Temperate oceanic forest natural vegetation	<= 20 years	500	0	0	0	0

Figure 13. Above-ground biomass affected by natural losses each year (%) as entered into the CBP tool.

Similarly, the volume of wood removed by timber harvest, fuel wood gathering, pruning or other manmade processes can be entered for each forest class within these sections (figure 14). Unlike the EX-ACT tool, these can be entered without the tool assuming the forest is being deforested in the process. The tools model is sensitive to these biomass losses (both natural and wood harvesting) and values should only be entered where the user is confident in them. We recommend taking a conservative approach where unsure. Furthermore, if biomass is allowed to recover (through natural regeneration or active planting) tool developers recommend not including them in the model inputs.

Forest Type	Tree Age Range*	Area (ha)*	Timber Harvest (m ³ /yr)	Fuelwood Gathering (m ³ /yr)
Temperate oceanic forest natural vegetation	> 20 years	500	8	0
Temperate oceanic forest plantation	> 20 years	350	0	0
Temperate oceanic forest natural vegetation	<= 20 years	500	0	0

Figure 14. CBP inputs for forests undergoing timber harvesting and fuelwood gathering. Figures are losses per year.

Finally, the tool allows the user to input the total forest area being cleared (with and without burning) and the total area being reforested/afforested within each forest class (figure 15). For areas being reforested/afforested, the tool includes a section to input when this activity occurred (which quarters of the project period). It is not currently possible to input this for areas of forest being deforested or specify whether reforestation occurs on these areas (e.g. plantation being deforested to be reforested with natural forest vegetation).

Forest Type	Tree Age Range*	Area (ha)	Total Area Cleared without Burning (ha)	Total Area Cleared with Burning (ha)	Total Reforestation / Afforestation Area (ha)
Temperate oceanic forest natural vegetation	> 20 years	500	0.00	0.00	0.00
Temperate oceanic forest plantation	> 20 years	350	175.00	0.00	0.00
Temperate oceanic forest natural vegetation	<= 20 years	500	0.00	0.00	500.00

Temperate oceanic forest natural vegetation, <= 20 years

In which quarters of the project period was area afforested/reforested?

1st 5 years 2nd 5 years 3rd 5 years 4th 5 years

Figure 15. Inputs for afforestation and reforestation, with the option to adjust the timeline for areas being reforested.

Each section within the tool includes 'Emissions factors'. Clicking this will take the user to the emissions factor inputs, where they can be adjusted as needed. The tool allows the user to alter all emissions factors (i.e. input Tier 2 factors), however, those highlighted in red are not recommended to be changed. When inputting emissions factors for forestlands, we recommend creating your own forest class rather than adjusting the emissions factors of existing classes, as the Tier 1 factors for forests would become overwritten making it difficult to identify where they have been adjusted. Outside of forests it is not possible to create your own classes (e.g. for a livestock species not included in the tool), therefore we recommend using the notes section to log changes.

Within the livestock section, there is no option to add your own category of animal (e.g. Deer). Therefore, it is recommended that another animal not relevant to the project is selected, and the emissions factors are adjusted to reflect the animal present in the project.

Outputs

Once enough information has been entered into the tool for it to run, it will notify the user and give the option to produce a report. On the report page, the user can download a project report (pdf) or generate

more detailed outputs for each scenario. These are Excel workbooks which include all the calculations and inputs used by the tool. These are particularly helpful for understanding the outputs provided in the overall pdf summary report.

2.2.3 Tool limitations

Main limitations:

- The online nature of the tool has meant that technical bugs prevented some of our analysis from being completed. Therefore, the detailed outputs were used to create an offline version, using inputs and equations from the online tool. We have liaised with tool developers who are continuing to update the online tool.
- The tool has a very limited wetlands section. Several projects include peatland restoration activities and the tool was not able to account for these in detail (e.g. through the incorporation of relevant emissions factors and inputs).
- It is not possible to change some of the underlying data within the tool, or update with more specific data if this is available. Therefore, some data on e.g. soil type, may not be representative of the project. This could be particularly noticeable in projects with a small overall area, where slight inaccuracies in soil classification could have a large impact on the projects results.
- Biomass carbon pools within forested areas are limited to above and below-ground biomass, it is not currently possible to include deadwood or litter biomass carbon within the tools. Therefore, the tool may underestimate emissions or sequestration from forests where these carbon pools are considered relevant.
- Outside of afforestation, the tool assumes that immediate changes occur when altering land use management and to livestock populations. This approach may not be appropriate for many ELP projects, where landscape changes occur gradually because of natural regeneration or slow uptake of different management practices. Therefore, the tool may overestimate contributions of e.g. grassland condition improvements to the overall greenhouse gas balance.
- The tool bases its calculations on the total area of different land uses at different points in time, but the user is unable to specify more precise transitions between land uses. E.g. when the area of both forest and wetland increase, and the area of both pasture and cropland decrease, it is not clear how many hectares of pasture have been afforested. This may therefore result in underestimations of emissions where the land use transitions themselves are expected to result in emissions (e.g. through management changes or disturbances to vegetation biomass and soils).

2.3 Tool Comparison

Table 3. Main differences between the tools which influence the results for landscape restoration projects.

Difference	EX-ACT Approach	CBP Approach	Recommendation
Global Warming Potential (GWP) value	The tool allows the user to change the Global Warming Potential (GWP) used in the calculations. Options are: 100 yr AR5 with CC feedback, 100 yr AR5 without CC feedback, 100 yr AR4 and 100 yr SAR. The default option is '100 yr AR5 with CC feedback' from the IPCC Fifth Assessment, AR5 (IPCC, 2014). However, there is also the option to use the IPCC Fourth Assessment report, AR4, which may be more suitable depending on how results are being used.	Currently the tool uses values from the IPCC Fourth Assessment (Forster <i>et al.</i> , 2007). These values are used for reporting around Nationally Determined Contributions and national greenhouse gas inventories. There is currently no option to use values from AR5.	Either tool can be used, however, EX-ACT allows the user to select the most appropriate values for the project. The values used by CBP do align with Nationally Determined Contribution and national greenhouse gas inventory reporting.

<p>Rate of change</p>	<p>The tool allows the user to specify an implementation and account period for the project. Furthermore, most inputs allow the user to specify whether the rate of change is immediate, linear (default) or exponential and will adjust results accordingly.</p>	<p>The tool allows the user to specify which quarters of the project afforestation and deforestation activities occur over (e.g. in the first 5 years of a 20-year project). However, outside of forest habitats, an immediate rate of change is assumed.</p>	<p>EX-ACT's inputs are preferred for accounting for rate of change, which can have a large impact on results for landscape restoration projects, as activities are likely to occur slowly over long time periods (e.g. regeneration). Furthermore, some forestry activities may occur over shorter time periods than a quarter of the project length (e.g. felling of non-native plantations).</p>
<p>Accounting for Land-Use Changes</p>	<p>EX-ACT tool inputs require the user to specify changes in land use, e.g. area of grassland becoming forested, as well as e.g. grassland remaining grassland.</p>	<p>It is not currently possible to specify direct land-use change within the tool (e.g. transition from arable land to silvopasture).</p>	<p>EX-ACT is preferred as land-use change can result in emissions that are dependent on the specific transitions taking place and the tool calculations can take this into account. Furthermore, it allows the user to include management changes on specific habitat areas which do not change to another land-use.</p>

<p>Forestry calculations</p>	<p>The tool currently has limited inputs for forestry calculations and does not include options for natural losses (e.g. wildfires, pests and disease). Furthermore, the tool does not allow harvested wood products to be input without assuming deforestation is occurring.</p>	<p>The tool allows the user to include a range of inputs for forest losses. These include natural losses (represented as % annually) and harvested wood products. Furthermore, the tool allows the inclusion of area afforested and deforested within the same input (avoiding double counting experienced with EX-ACT).</p>	<p>Where forestry activities (afforestation and deforestation) are the main features of a project we recommend using CBP. However, there must be confidence in the values input for losses (e.g. wildfires, pests, diseases) and harvested wood products as the tool is very sensitive to these. The tool is also limited to above-ground and below-ground carbon pools. Where other carbon pools are considered important sinks/sources of emissions, the EX-ACT tool should be used.</p>
<p>Estimation of soil organic carbon stock</p>	<p>Outside of wetlands, the tool requires the user to input the dominant soil type across the project. Within the tool, the user can specify soil organic carbon stock where appropriate (e.g. across different classes of grassland degradation). For large projects covering multiple soil types, this may be a limitation.</p>	<p>The tool uses spatially explicit data from the Harmonised World Soils Database (FAO). It is not currently possible for the user to upload soil data or state the soil type by habitat.</p>	<p>For projects spanning larger areas, selecting just one dominant soil type may not be appropriate with the EX-ACT tool. It may be possible to split the project calculations across multiple tools, each with the most relevant soil type selected.</p> <p>The data used by CBP may be too coarse, and it is not possible to state which soil types correspond with which habitats, an even proportion is assumed by the tool. Therefore, the user should look at the detailed results to make sure they are appropriate.</p>

			Tool selection is therefore on a project by project basis.
Livestock management	<p>The tool includes the option to input data on mitigation options (such as feeding practices, specific agents and breeding practices) as well as data on production.</p> <p>User can select appropriate rate of change.</p>	The tool is limited to inputting the number of heads and the time spent in the project area per year (months). Immediate rate of change applied to changing populations.	Either tool can be used. Where extra detail can be included, EX-ACT is recommended for livestock calculations.
Emissions from inland wetlands	The tool has a dedicated section for inland wetlands (peatland etc.) and the option to include whether these are forested or not.	The tool has a simplified wetlands section which allows the user to specify the area of wetland and the % drained. It is not possible to specify whether these areas are peatland or otherwise.	It is currently recommended to use the EX-ACT tool for any projects where wetland degradation and restoration are a core component of it.
Emissions from coastal ecosystem management and vegetation.	The tool has a dedicated section for coastal wetlands (including seagrass) as well as fisheries and aquaculture management.	It is not currently possible to include these habitats in the tool calculations.	It is recommended to use EX-ACT if coastal ecosystems are a component of a project.

Inputs management	Dedicated inputs section including fertiliser and pesticide use.	Option to include inputs in grassland and cropland sections. Simplified approach with Yes/No tick boxes for several inputs.	EX-ACT recommended due to range of input options, including pesticide.
Detail in calculations	EX-ACT does not currently allow the user to see the calculations which feed into the final emissions values shown in the tool output. These are hidden in separate sheets and it's not possible to access them.	The CBP tool includes the option to download detailed outputs in an Excel format for each scenario. These allow the user to view the formulas and inputs used by the tool.	The CBP detailed reports are useful in understanding and validating how the tool has arrived at certain outputs.

2.4 Tool selection

Each tool has benefits and limitations when applied to landscape restoration activities, and for several projects, either tool would be applicable. However, the inclusion of certain restoration activities and habitats can influence tool selection (Table 4).

Both tools are constantly evolving and being updated. Therefore, the suitability of each tool or different landscape restoration projects may change in the near future. Furthermore, it is important to note the usability of each tool. Each tool has a different interface, with EX-ACT being Excel based and CBP being hosted online. Being able to work offline and share Excel workbooks may be beneficial for some, whereas the detailed calculation outputs provided by CBP may be more suitable for others.

The accuracy of each tool also depends on the methods and emissions factor values used. Tier 1 methods provide the lowest degree of accuracy, whereas the use of Tier 2 or Tier 3 methods and emissions factors increase the accuracy of the tools. Where possible, it is always recommended to use Tier 2 or Tier 3 emissions factors.

Table 4. Recommended decisions for specific habitats within projects or restoration activities.

Landscape restoration activity/habitat inclusion	Tool recommendation	Explanation
Peatland drainage/rewetting and other inland wetlands	EX-ACT	Tool includes a dedicated inland wetlands section, which includes the management of organic soils (drainage and rewetting).
Coastal wetlands drainage/rewetting	EX-ACT	Tool includes a dedicated coastal wetlands section, which includes the management of vegetation including seagrass. Furthermore, the tool includes inputs for coastal fisheries and aquaculture management.
Forest management (including harvested wood products and natural losses)	Both, but CBP if this is the focus of the project and detailed inputs are available.	Both tools include sections for forest management, afforestation, and deforestation. However, the CBP tool allows more detailed input (including natural losses and harvested wood products). Therefore, if forest management activities are the core focus of the project, we recommend using the CBP tool.

<p>Establishment of low-density woodland and parkland.</p>	<p>Both, but CBP if this is the focus of the project.</p>	<p>It is possible to include these habitats in the EX-ACT tool, however, CBP inputs allow them to be included within the grassland section and for Tier 2 biomass and growth increment values to be included. The tool does not assume land-use change and therefore, doesn't calculate emissions which may not be appropriate.</p>
<p>Natural regeneration of degraded habitats and gradual decrease in grazing intensity and inputs.</p>	<p>EX-ACT</p>	<p>The EX-ACT tool does not assume an immediate change in livestock populations or the use of inputs. The tool allows the user to adjust the project implementation period and select the most appropriate rate of change.</p>

3 Climate Change Mitigation Assessment Methodology

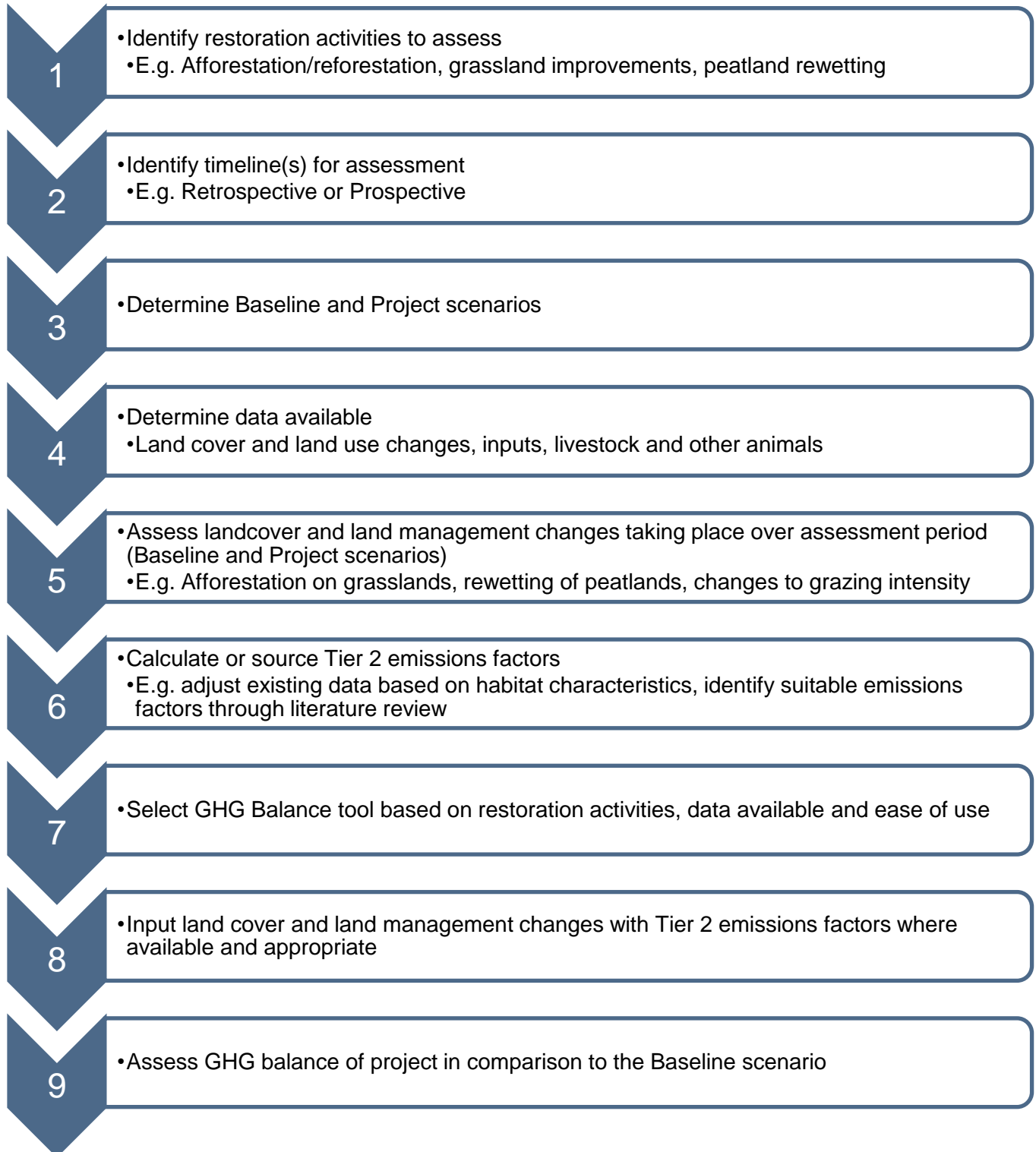


Figure 16. General workflow for assessing the climate change mitigation potential of projects with the GHG balance tools.

3.1 Initial tools review

Both CBP and EX-ACT tools were reviewed for their suitability in the project, the activities they could assess, and the data inputs and requirements were logged and compared between the two tools. A spreadsheet was put together which could be shared with ELP projects for them to fill in the data inputs with their data along with a questionnaire form to understand the restoration activities being undertaken and the data requirements of projects. ELP Project engagement

At the beginning of the project, ELP projects (both in the planning and implementation stages) were contacted to determine whether they would be interested in participating in the Natural Climate Solutions project. Of those contacted, there was a high level of interest.

Calls were scheduled (taking place over Zoom and Microsoft Teams) with interested projects to learn more about their work, determine their interest and their data availability.

For each project, we determined appropriate assessment timeframes through discussions. For example, whether a retrospective, prospective assessment, or mixture of the two would be appropriate. These discussions were also used to improve understanding of the habitats within project sites and the restoration activities taking place.

Based on initial discussions with projects, relevant inputs within each tool were identified. These were used to determine the information and data which would be required from projects. The availability of data was used to determine which inputs could be sourced through literature review or bespoke calculations. Data was then collected from projects via a data input excel sheet and questionnaire form.

3.2 Scenarios

There will always be a degree of uncertainty with scenarios, however making them as evidence based and accurate as possible increases the reliability of results produced by these tools. Where there were unknowns, the most conservative estimates were taken in this analysis. The analysis highlighted that many projects did not have a large amount of evidence to develop detailed baseline scenarios, with the exception a few projects, including Carpathia. In these cases, it was assumed that the Baseline scenario would be a continuation of the initial state of the project area, with management practices remaining unchanged.

3.2.1 Developing the Baseline scenario

Where possible, Baseline scenarios should be evidence-based and conservative. Where there were data limitations, it was assumed that the Baseline scenario would represent a continuation of the initial land-use and land management in the project site. In some cases, there was data on historical trends or evidence for land use and management changes which would have likely occurred had the project not taken place (figure 17).

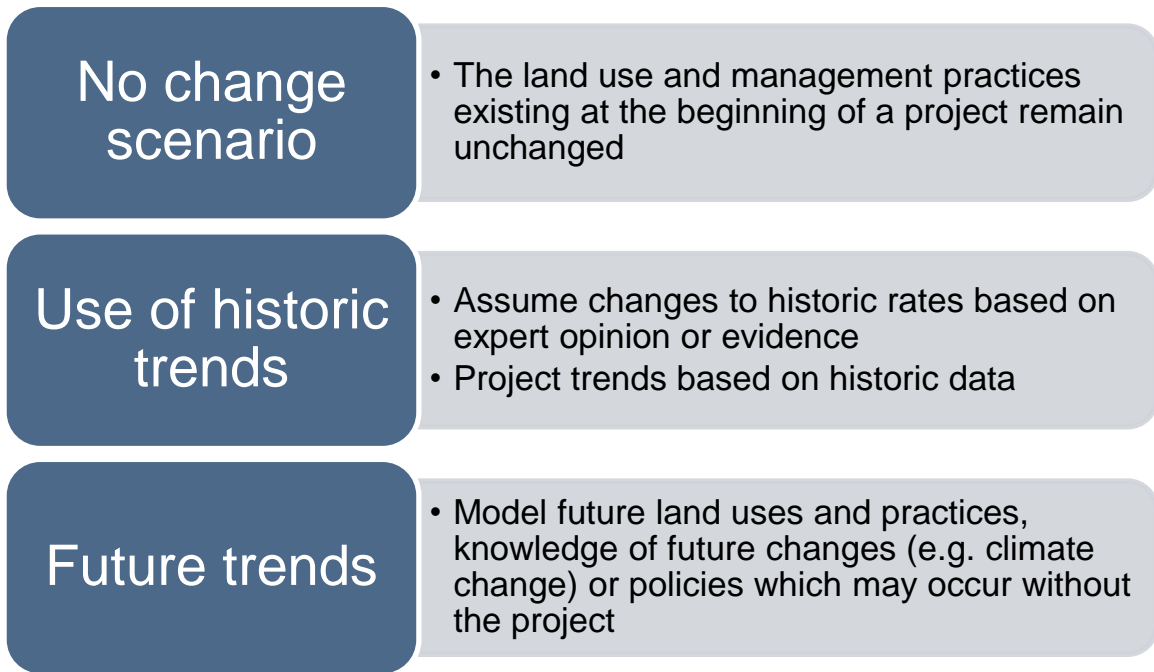


Figure 17. Potential approaches for developing the Baseline scenario.

3.2.2 Developing the Project scenario

Project scenarios were based on restorative actions which had taken place (for retrospective assessments) or based on expected restoration activities and management plans for projects being planned and implemented (prospective assessments).

3.3 Land cover changes

Where possible, land cover changes were estimated using data provided by projects. This data was largely habitat mapping which the projects had access too, and in some cases projects new the size of different habitats within their project boundaries without the need to share GIS data. However, spatial data from projects with the level of detail required was often limited. Therefore, publicly available global, national, and sub-national datasets were scoped for suitability in the assessment and the most appropriate one was chosen in consultation with the project.

Furthermore, maps were often not available for both the start and end of the project assessment period. Therefore, consultations with projects were used to estimate changes which had taken place or were expected to take place relative to the available data. This information formed the basis of the assessment.

3.4 Restoration activities

Table 5. Overview of projects assessed as part of the Natural Climate Solutions project, appropriate tools for each project and the limitations of their use. * Project was not assessed, but tools were reviewed for suitability.

Country	Project Name	Assessment Period	Size of Project (ha)	Restoration activities	Type of assessment	Tier 2 values used	Which tool(s) can be used	Tool limitations
Belarus and Ukraine	Polesia	2019-2039	272,427	Conservation of existing habitats Rewetting 6000 ha of peatlands	Prospective	Peatland emissions	EX-ACT	Main benefit is conservation, and the tools are aimed at land management change, or avoided loss. Main restoration activity is peatland rewetting, which the CBP tool is not able to account for.
United Kingdom - England	Haweswater	2011-2020 and 2020-2040	2,254	Introduction of natural grazers Tree planting Peatland Rewetting	Both	Vegetation biomass, peatland emissions and animal emissions	EX-ACT	Project includes peatlands rewetting, which could not be accounted for with the CBP tool.
	Lowther	2019-2029	216	Introduction of natural grazers Tree planting to create parkland and low-density woodland	Prospective	Vegetation biomass, animal emissions	Both	Both tools had limited ability to incorporate low-density woodland and parkland.

Country	Project Name	Assessment Period	Size of Project (ha)	Restoration activities	Type of assessment	Tier 2 values used	Which tool(s) can be used	Tool limitations
Georgia	Iori River	2020-2040	42,069	Introduction of rotational grazing scheme to improve grassland degradation Restoration of degraded gallery forest	Prospective	Vegetation biomass, animal emissions	Both	Rate of change applied by CBP tool to livestock and grassland condition was immediate, which may not accurately reflect the project.
Portugal	Coa Valley – Faia Brava Reserve	2000-2020	881	Introducing natural grazers Planting and improving forest habitats Reducing timber harvesting	Retrospective	Vegetation biomass, animal emissions	Both	Rate of change applied by the CBP may not have been appropriate. EX-ACT has limited ability to incorporate low-density forested areas.
	Montado Mosaic	2020-2040	269,759	Improving grassland and preventing further degradation through the reduction in grazing intensity.	Prospective	Vegetation biomass, animal emissions	Both	Rate of change applied by the CBP may not have been appropriate. The EX-ACT tool was limited in its ability to incorporate increased tree density in

Country	Project Name	Assessment Period	Size of Project (ha)	Restoration activities	Type of assessment	Tier 2 values used	Which tool(s) can be used	Tool limitations
				<p>Increasing tree density on pseudo-steppe habitats.</p> <p>Establishing low-density montado and mixed shrubland communities.</p>				pseudo-steppe environments.
Romania	Carpathia - FCC Wildland	2012-2020 and 2020-2040	16,728	<p>Protect existing native forest and reforest felled areas</p> <p>Reduction of grazing intensity on 423ha of grassland to improve vegetation condition</p>	Both	Vegetation biomass, animal emissions	Both	Forestry equations within the CBP tool are more complex and better suited to including harvested wood products.
United Kingdom - Scotland	Cairngorms Connect - Wildland Limited	2000-2020	31,220	<p>Reduce deer grazing intensity</p> <p>Afforestation of native woodland</p> <p>Rewetting of peatlands</p>	Retrospective	Vegetation biomass, peatland emissions and animal emissions	EX-ACT	Project includes peatlands rewetting, which could not be accounted for with the CBP tool.

Country	Project Name	Assessment Period	Size of Project (ha)	Restoration activities	Type of assessment	Tier 2 values used	Which tool(s) can be used	Tool limitations
Turkey	Gokova Bay *	Not Assessed	NA	Restoring seagrass meadows	Prospective	Vegetation biomass	EX-ACT	CBP tool is not able to account for coastal ecosystems
United Kingdom - Wales	Caemardin Farm, Wales	1980-2020 and 2020-2040	283	Replace intensive sheep grazing with natural grazers Rowan tree planting Grassland improvements	Both	Vegetation biomass, peatland emissions and animal emissions	EX-ACT	Project includes peatlands rewetting, which could not be accounted for with the CBP tool.

3.5 Emissions and Removal Factors

Both tools use “Tier 1” values as defaults, these are globally agreed mean emissions factors for broad habitat-region combinations primarily derived from IPCC (2006), with some sections using updated values (IPCC 2014b; Cardinael *et al.* 2018). Whilst useful in the absence of more specific values, Tier 1 values are mean figures associated with broad habitat types and/or a general region, and as such often contain a high degree of uncertainty. Tier 1 estimates are frequently assembled from multiple data sources and study sites. More refined, country-specific emissions factors for narrower habitat types are termed “Tier 2” values. Where available, such values are preferable as they are likely to be more appropriate and provide more accurate estimates of GHG fluxes. Tier 3 site-based values are the most demanding in terms of methodological complexity and data requirements (IPCC 2006).

Many GHG balance tools utilise Tier 1 values for the basis of their calculations. Where appropriate, Tier 2 GHG values have been used to tailor the calculations to the ELP project, reducing uncertainty and better reflecting the emissions associated with a site.

To identify Tier 2 values, using detailed information on the habitats in the projects and the area of interest, the peer-reviewed and grey literature can be reviewed to determine appropriate values to use within the tools. These should be refined by geographic location, habitat, and species composition and age where possible.

3.5.1 Other Data sources and tools

Several publicly available data sources were used to prepare inputs for the tools. These included:

- Copernicus land cover (Buchhorn *et al.* 2020) and national land cover datasets.
- Hansen *et al.* (2013) data on annual forest loss to calculate deforestation rates within project sites.
- ESA CCI Fire dataset (Chuvieco *et al.* 2018) to analyse the impact of fire on forests within project sites.
- National greenhouse gas inventory reports for livestock emissions factors and forest biomass estimates.
- Gridded Livestock of the World (Gilbert *et al.* 2018) dataset to estimate livestock numbers where these were unknown.
- Milne and Brown (1997) for conversion factors for vegetation biomass units.
- Levy *et al.* (2004) for root:shoot ratios.

The Woodland Carbon Calculator

For UK-based projects, the Woodland Carbon Calculator (Woodland Carbon Calculator 2021) was used to estimate biomass within forest classes. The tool allows the user to input information on species composition, age, density and yield to produce estimates of above-ground biomass per hectare.

However, this tool does have some limitations. The Woodland Carbon Calculator is a useful tool for estimating the carbon stock and sequestration potential of woodlands being planted in the UK. However, the tool relies on the “Sycamore, Ash, Birch” (SAB) class for many species. This uses a generic model which is limited in the differences between sycamore and birch. Furthermore, ash is now rarely planted in the UK as a result of ash dieback disease. Therefore, there are likely higher

uncertainties associated with values calculated using this class than other species with more specific classes.

Within the Woodland Carbon Calculator, there is limited information used to create the yield models. The model calculates yield based on one of seventeen reference species, with most broadleaf species being assigned to the SAB group. Therefore, whilst more specific than some models, it still provides a generalisation in some areas. Furthermore, yield classes for each tree type were often higher in the Woodland Carbon Calculator than would be planted in the project site. Therefore, we selected the lowest possible yield class, though biomass carbon estimations may still be overestimated.

These tools are constantly evolving, and a new version of the Woodland Carbon Code is expected soon. During 2021, the data used with the WCC is being reviewed and revised to include new growth and yield models and estimates of the contributions made by root and branch biomass are being refined (Woodland Carbon Code n.d.).

Although useful for UK based projects, the WCC tool was not used in estimates for projects based outside of the UK. Input values within the tool may not have been appropriate and no equivalent tool was found for other parts of Europe. Therefore, biomass values were sourced from the literature for non-UK based projects.

3.6 Feedback to developers

Over the course of the project, tool developers were consulted to develop guidance on the best ways to use the tools for landscape restoration focussed activities as well as feedback on any potential limitations of the tools.

Several technical bugs within both tools were identified over the course of the project and tool developers have been addressed. In particular, a new version of EX-ACT, Version 9.0.1 and EX-ACT version 9.0.2 were released (after version 9.0) which addressed these. Version 9.0.1 was used for this analysis with a workaround in place to address the final bugs, with version 9.0.2 being released after project analysis had been completed. Furthermore, another version of the tool is due to be released summer 2021. This will also be accompanied by updated tool guidance documents.

Bugs in both tools are still being addressed, though workarounds have been implemented to address these for analysis during the project.

3.7 Input Data Gaps and Limitations identified

Project mapping data

Detailed mapping of projects before activities began and projected future land use (both with and without the project) were often not available. Similarly, knowledge of changes which had taken place since the beginning of the project were sometimes limited due to long project timeframes.

Project habitat data

Some literature searches for appropriate Tier 2 values were limited by lack of information on key habitat characteristics, e.g. tree species and/or densities. Therefore, some more generalised assumptions had to be made to find appropriate Tier 2 values for emissions factors.

Scenarios

Baseline scenarios are important for understanding the climate change mitigation benefits of a project and increasing the reliability of the results requires a detailed understanding of how the landscapes would have been managed had the project not occurred. Several projects were able to provide clear ideas or evidence for these scenarios. However, it was often assumed that the initial land use and management would remain unchanged under the baseline scenario.

Emissions factors

Some projects had detailed information on habitat characteristics, but suitable Tier 2 values which matched these were limited. Therefore, Tier 2 emissions factors may have been limited in their representation of GHG fluxes within a given project. However, despite limitations these values were likely more accurate than using Tier 1 default values provided by the tools.

Although peatland emissions factors were available for projects within the UK (Evans *et al.* 2017). The lack of appropriate emissions factors is particularly relevant for peatland habitats, which can be both sources and sinks of atmospheric carbon. Improved estimates are therefore required to refine these results. However, doing so can be a costly process. Applying chamber measurements or eddy covariance towers over long periods of time to collect data from sites and account for interannual variations and large areas to account for spatial heterogeneity can cost 10,000 Euro per ha per year. Furthermore, GHG fluxes on certain types of peatlands are difficult to measure, such as those covered by forest, heathland or bushland vegetation, as seen in Polesia. Here, CO₂ released by the soils can be (partly) neutralised by associated vegetation. Furthermore, there is a lack of knowledge on emissions fluxes concerning rewetting of peatlands without vegetation cover (Ekardt *et al.* 2020).

Uncertainty

Both tools provide uncertainty estimates in their outputs, however each is reported differently. EX-ACT applies a Tier 1 uncertainty approach (IPCC 2006) to calculate a rough level of uncertainty for each project component (rounded to the nearest 10 percent) (Toudert *et al.* 2018). This is reported as an overall annual uncertainty percentage for each scenario. It is not possible to see how this breaks down across the different activities and land covers. CBP provides annual uncertainty estimates for each activity, calculated using the IPCC (2006) error propagation method. Overall values for each scenario and the GHG balance are also reported by the tool. However, it was not possible to calculate these for this case due to this analysis being done offline.

4 ELP Climate Change Mitigation Potential

Projects across the ELP were contacted for participation in the Natural Climate Solutions enabling project. However, participation in the project was voluntary, several projects had time and data constraints which limited their ability to participate.

Participating projects are outlined in table 5 with information on project size, activities and tool suitability. The Gokova Bay (Turkey) project was not assessed due to data delays resulting from the Covid-19 pandemic. However, tool suitability for the project and input data requirements were scoped for this project.

Over the course of the project a total area of 635,837 ha was assessed (including areas which remained unchanged within project sites). Habitats included ranged from forests and woodlands to grasslands, peatlands, pseudo-steppe and shrublands. Alongside direct restoration activities, assessments included emissions reductions from avoided deforestation and degradation as well as livestock emissions and inputs use. Including these gave a fuller picture of a project’s climate change mitigation potential and wide range of activities taking place in landscape restoration projects.

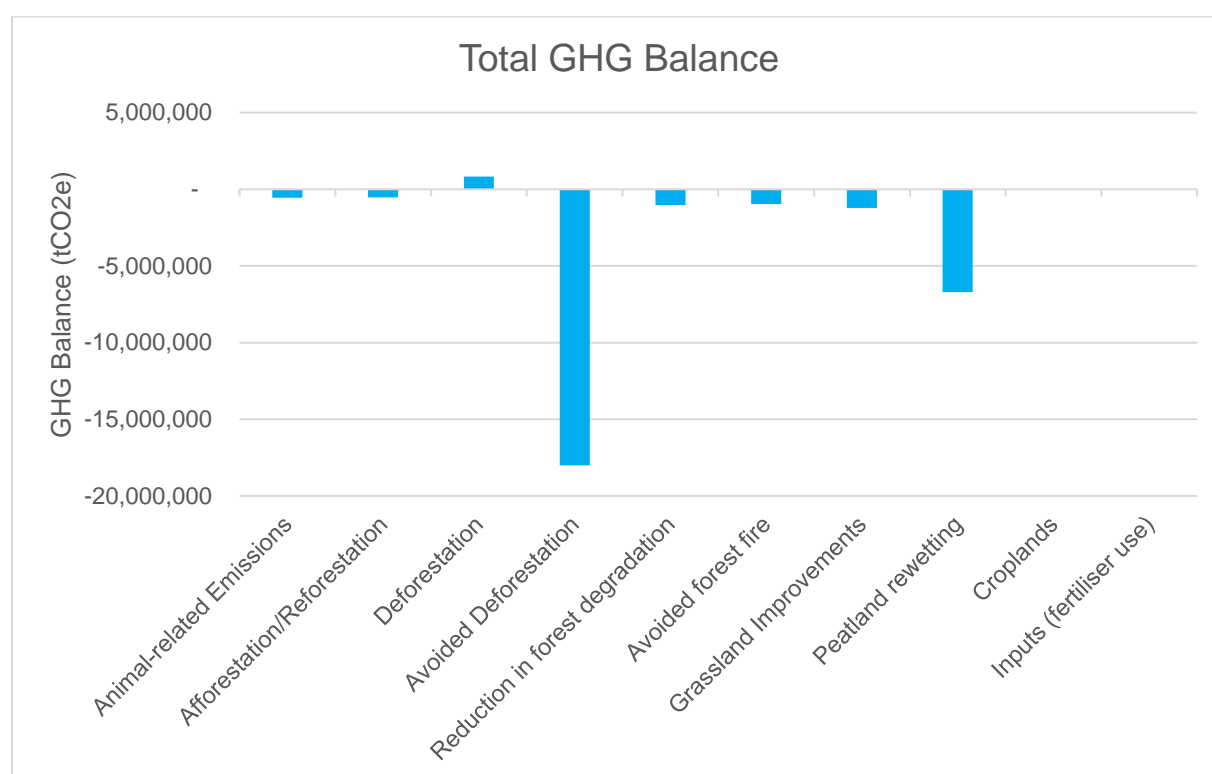


Figure 18. Total GHG balance across all assessments, by project activity.

The total GHG balance of all projects assessed was estimated to be -28,194,658 tCO₂e, i.e. a. emissions reduction/sequestration of about 28 million tCO₂e across the time period assessed. However, the projects’ results may not be comparable due to different timelines and assessment tools used. On average, projects were estimated to sequester -38,481 tCO₂e per year (table 8). Furthermore,

this GHG balance for projects only represents a snapshot of their expected climate change mitigation potentials. Most assessments occurred over a period of 20 years as per IPCC (2006) default guidance. However, project activities are likely to go far beyond this and their GHG benefits will likely improve over time. It is also important to note that avoided emissions from deforestation was based on estimated deforestation rates which could occur during the projects lifetime, and there may be a large amount of uncertainty associated with them and what the final land-use of the deforested areas would be.

When excluding avoided emissions from deforestation and forest fire (conservation actions), the total GHG balance across project assessments is estimated to be -9,233,895 tCO₂e (table 7). Across projects, the rewetting of peatlands represented the greatest reduction in emissions and carbon sink, totalling -6,715,689 tCO₂e. This was largely due to the contributions made by the rewetting of 6,000 ha in Polesia, which was estimated to represent a net negative balance of -6,696,608 tCO₂e relative to the Baseline scenario. Afforestation/reforestation activities also made large contributions to the GHG balance, however per hectare values varied across projects due to differing tree densities and species compositions across established woodlands.

*Table 7. The total GHG balance across all projects assessed and broken down by restoration activity. Emissions reductions from reduced deforestation and fire impact on forests are not included due to uncertainties in results. Negative numbers represent a reduction in GHG emissions or carbon sink and positive numbers represent a source of GHG emissions. * Total areas represent areas within each project undergoing restoration, not total area of each project site.*

Activity	Total area covered across projects (ha)	Total GHG balance across projects (tCO ₂ e)	Total GHG balance per hectare (tCO ₂ e/ha)
Afforestation/reforestation	10,630	-533,127	-50.15
Grassland improvements	82,350	-1,222,459	-14.84
Reduced forest degradation	144,581	-1,027,557	-7.11
Emissions from deforestation as a restoration action	1,970	835,632	424.17
Peatland rewetting	6,807	-6,715,689	-986.59
Changes to animal populations	NA	-556,985	NA
Changes to cropland areas and management	3,488	-2,240	-0.64
Changes to inputs use (e.g. fertilisers)	NA	-11,469	NA
Total *	249,827	-9,233,895	-635.16

4.1 Project level results

Table 8. Estimated carbon sequestered, emissions avoided, overall balance for each project (results from most appropriate tool). For detailed breakdowns of emissions, see individual project reports.* **Avoided emissions from deforestation and reduced forest fire impact not included in the Carpathia and Polesia outcomes due to uncertainty in results these GHG balance contributions not directly resulting from restoration.**

Country	Project Name	Duration of assessment (years)	Size of Project (ha)	Activity with greatest contribution to GHG balance	Tool used	Baseline total emissions (tCO ₂ e)	Project scenario total emissions (tCO ₂ e)	GHG Balance (tCO ₂ e)	Per hectare GHG Balance (tCO ₂ e/ha)	Annual GHG Balance (tCO ₂ e/year)
Belarus and Ukraine	Polesia *	20	272,427	Peatland rewetting	EX-ACT	8,828,545	2,132,691	-6,695,853	-24.58	-334,793
United Kingdom - England	Haweswater – Assessment 1	9	2,254	Afforestation	EX-ACT	10,998	6,705	-4,294	-4.7	-477
	Haweswater – Assessment 1	20	2,254	Grassland improvements	EX-ACT	21,511	-35,928	-57,449	-25.49	-2,872
	Lowther	8	216	Reduction in livestock-related emissions	CBP	4,101	3,180	-921	-4.26	-92.1
Georgia	Iori River	20	42,069	Grassland improvements	EX-ACT	20,051	346,030	-366,081	-8.70	-17,302

Portugal	Coa Valley – Faia Brava Reserve	20	881	Reduction in livestock-related emissions	EX-ACT	3,663	-964	-4,627	-5.04	-231
	Montado Mosaic	20	269,759	Increased tree density in pseudo-steppe habitat	EX-ACT	-6,467,369	-8,185,778	-1,718,409	-6.37	-85,921
Romania	Carpathian Mountains – Assessment 1*	8	16,728	Grassland improvements	CBP	9,128	-6,648	-15,776	-0.94	-1,972
	Carpathian Mountains – Assessment 2	20		Reforestation		19,626	-32,187	-51,814	-3.10	-2,591
United Kingdom - Scotland	Cairngorms Connect – Wildlands Limited	20	31,220	Grassland improvements	EX-ACT	463,045	161,269	-301,776	-9.67	-15,089
United Kingdom - Wales	Caemardin Farm, Wales: Assessment 1 (40-year period)	40	283	Reduction in livestock-related emissions	EX-ACT	13,341	-2,907	-16,248	-60.18	-406

	Caemardin Farm, Wales: Assessment 2 (20-year period)	20		Peatland rewetting		1,176	698	-497	-1.77	-25
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4.2 Project results summaries

Reports for each project assessed can be found separately as well as 2-page summary report which can be found.

Polesia

According to the GHG assessment tool EX-ACT, the project is expected to significantly reduce emissions as well as sequester carbon over 20-year period. Expected project activities were estimated to result in a net negative GHG balance of -21,850,741 tCO₂e (including conservation actions).

The rewetting of drained peatlands was estimated to reduce emissions and sequester carbon compared to the drained state totalling -6,695,853 tCO₂e over the assessment period. This included increased methane emissions because of rewetting, however, this was heavily outweighed by carbon sequestration and reductions in emissions associated with ditches.

The assessment also incorporated historical deforestation rates across each forest class (between 2015-2019) in the project site and neighbouring established protected areas. Deforestation rates falling to the latter were calculated to reduce associated emissions by -14,193,030 tCO₂e in comparison to the Baseline scenario.

Similarly, reducing forest fire impact to rates seen in neighbouring protected areas was estimated to reduce associated emissions by -961,858 tCO₂e.

Cumbrian Lakes and Dales: Haweswater

According to the GHG assessment tool EX-ACT, the project reduced emissions and sequestered carbon over the two assessment periods. Restoration activities resulted in net negative GHG balances of -4,294 tCO₂e and -57,449 tCO₂e over first and second assessments. The significant reduction in the sheep population and introduction of native grazers reduced overall direct emissions by -1,165 tCO₂e and -1,682 tCO₂e over the two assessment periods.

Furthermore, the reduction in grazing intensity was expected to result in improved grassland and heathland condition. This was estimated to sequester a further -653 tCO₂e in the first assessment period and -24,113 tCO₂e in the second.

The establishment of scrub/woodland and woodland pasture was estimated to sequester -2,475 tCO₂e and -18,665 tCO₂e into vegetation biomass and soil over the first and second assessment periods.

The rewetting of eroded peatland reduced emissions by -12,989 tCO₂e. This includes both reduced CO₂ emissions, carbon sequestration and increased CH₄ emissions. Over time, CH₄ emissions are outweighed by carbon sequestered.

Cumbrian Lakes and Dales: Lowther Estate

According to CBP, the project could reduce and sequester emissions by -921 tCO₂e between 2019 and 2029 if project aims are achieved.

The creation of low-density woodland and parkland habitats is expected to sequester -900 tCO₂e during the assessment period.

The replacement of sheep with native cattle grazing at low density is expected to reduce direct emissions by -1,480 tCO₂e. As a result of changing management practices, the grassland condition is expected to change from 'improved' to non-degraded. Although this is an ecological improvement, in a carbon sense, this represents a decrease in productivity and carbon storage as inputs are no longer applied. Therefore, this is expected to result in emissions of 2,291 tCO₂e.

Converting arable land and ceasing the use of fertiliser is expected to decrease associated emissions by -512 tCO₂e.

Reducing cropland area and fertiliser use decreased their associated emissions by -1,917 tCO₂e and -10,945 tCO₂e respectively.

Iori River

According to EX-ACT, the project could reduce and sequester emissions over the 20-year period by a net reduction of -378,488 tCO₂e.

The reduction in grazing intensity and subsequent improvement of grassland condition was estimated to sequester -252,968 tCO₂e – a significant contribution. The improvement of grasslands could sequester an estimated -12.2 tCO₂e/ha where condition is transitioning from severely degraded to non-degraded and -6.1 tCO₂e/ha where moderately degraded grassland becomes non-degraded.

Furthermore, the reduced degradation of gallery forest (and increase in vegetation biomass) contributed was estimated to sequester approximately -113,113 tCO₂e. This restoration represents a greater per area effort than grasslands with approximately -43.71tCO₂e/ha being sequestered into forest biomass and soils.

Livestock (sheep and cattle) densities are not expected to change under the Project scenario, and their emissions therefore don't contribute to the GHG balance.

Coa Valley – Faia Brava Reserve

Using EX-ACT, the project was estimated to have reduced and sequestered emissions over the 20-year period by -4,627 tCO₂e. The significant reduction in the sheep population and replacement with native grazers reduced their direct emissions by -2,474 tCO₂e.

Furthermore, the reduction in grazing intensity had further indirect results. The improvement in grassland condition was estimated to sequester a further -456 tCO₂e.

The improved management of holm and cork oak forests, including reduced wood extraction, contributed a reduction in emissions of -1,533 tCO₂e. Furthermore, increasing the area covered by montado and improving its management sequestered -317 tCO₂e.

Reduction in crop residues and fertiliser use also reduced emissions by -13 tCO₂e over the project period.

Finally, some land-use change resulted in emissions (disturbances to the soil and vegetation). However, these were minimal, at just 168 tCO₂e.

Montado Mosaic

According to EX-ACT, the project could reduce and sequester emissions by -1,718,409 tCO₂e between 2020 and 2040 if project aims are achieved.

Increasing tree density in the pseudo-steppe habitat is expected to sequester -912,594 tCO₂e during the assessment period. Furthermore, the afforestation/reforestation of montado and mixed shrubland communities could sequester -440,745 tCO₂e.

The reduction in grazing intensity and subsequent improvement of grassland condition was estimated to sequester -726,392 tCO₂e.

The reduction in livestock reduced their direct emissions by -450,660 tCO₂e.

Reducing cropland area and fertiliser use decreased their associated emissions by -1,917 tCO₂e and -10,945 tCO₂e respectively.

The project introduced emissions from the deforestation of some pine and eucalyptus plantations, totalling 824,844 tCO₂e over the assessment period. However, this was heavily outweighed by subsequent replanting of montado and mixed shrub communities.

Carpathian Mountains

According to the assessment tool CBP, the project could reduce and sequester emissions over the first assessment period (2012-2020) by -15,776 tCO₂e and by -51,814 tCO₂e between 2020 and 2040 if project aims are achieved this increases significantly when conservation actions to avoid deforestation and degradation in existing forests is included.

Reforestation on clear-cut forests contribute -6,956 tCO₂e during the first assessment and could contribute -51,814 tCO₂e during the second assessment. Furthermore, under the first assessment, preventing legal timber harvesting or illegal deforestation could prevent emissions of between 3,101,260 tCO₂e and 2,805,875 tCO₂e.

The reduction in grazing intensity and subsequent improvement of grassland condition was estimated to sequester -7,543 tCO₂e.

The livestock population were reduced slightly during the first assessment due to restricted grazing being put in place. This reduced their direct emissions by -1,278 tCO₂e between 2012-2020.

Cairngorms Connect – Wildlands Limited

Using EX-ACT, the project was estimated to have substantially reduced emissions over the 20-year period by net emissions of -301,776 tCO₂e. The significant reduction in the deer population reduced their direct emissions by -87,665 tCO₂e.

Furthermore, the reduction in deer populations had further indirect results. The improvement in grassland condition was estimated to sequester a further -208,791 tCO₂e. Reforestation of native woodlands sequestered -11,488 tCO₂e.

The rewetting of eroded peatland reduced emissions by -4,620 tCO₂e. However, this includes both reduced CO₂ emissions and increased CH₄. Over time, these are outweighed by the volume of carbon sequestered and methane remains in the atmosphere for a shorter period.

Similarly, the deforestation of plantations resulted in 10,788 tCO₂e emissions. However, these will be heavily outweighed in the long-term with the regeneration of native pine wood continuing to sequester carbon over long periods of time.

Caemardin Farm - Wales

According to EX-ACT, the project could have reduced and sequestered emissions over the first assessment period (1980-2020) by -16,248 tCO₂e between and could reduce and sequester emissions -479 tCO₂e between 2020 and 2040 if project aims are achieved.

The creation of low-density woodland habitats is estimated to have sequestered -73 tCO₂e during the first assessment period and could sequester a further -12 tCO₂e between 2020-2040.

The replacement of sheep with native ponies during the first assessment period reduced their direct emissions by -10,878 tCO₂e. Furthermore, the improved condition of grassland and heaths sequestered a further -3,835 tCO₂e into the soils. During the second assessment, the introduction of 10 cattle alongside the ponies is expected to increase direct emissions by 297 tCO₂e. However, their grazing will likely bring about further ecological improvements to grassland communities.

The gradual improvements to peatlands in the first assessment reduced their emissions by -1,463 tCO₂e and a further reduction of -479 tCO₂e is estimated between 2020-2040.

5 Conclusions

The results of this project highlight the contribution biodiversity conservation-focused landscape-scale restoration projects can make to climate change mitigation goals. There is a need to scale these up in Europe and beyond to contribute towards Nature-based Solutions to climate change alongside emissions reductions and rapid decarbonisation across all sectors.

Outputs from the tools demonstrate that they can successfully measure the GHG impacts of restoration projects, and that these activities can contribute significantly to climate change mitigation. However, there are some key limitations to consider and address. The tools simplify often complex ecological processes and results may therefore not be fully representative of the 'real-world'. This may be particularly evident at a landscape level where some habitats are regenerating naturally, and progress fluctuates year on year with climate and other influences (e.g. grazers and wildfires). Furthermore, there are significant knowledge gaps in our understanding of GHG fluxes resulting from land-use and land management changes and models and emissions factors are constantly being updated as new information is produced. This is particularly evident in peatlands, where emissions factor values are often lacking (Ekardt *et al.*, 2020). There is greater literature available on the GHG impact of active planting of single species stands and simple mixes (such as pine plantations) which are often even aged. However, knowledge gaps on the impact of natural regeneration and complex habitat successions on GHG fluxes and their climate change mitigation persist. Improving our understanding of these will increase the reliability of these assessments. The tools ability to generate accurate results is also limited by the input data used. This includes land cover and land management data, emissions factors and Baseline scenario assumptions. There are varying degrees of uncertainty associated with emissions and removals factors, and the most accurate and up-to-date estimates should be used where possible. Finally, the tools have little ability to account for heterogeneity within habitats and interannual variations in management and inputs use. For smaller projects this may not be an issue, as on a per hectare basis there may not be a large variation in carbon stocks and emissions. However, over larger landscapes this may limit the accuracy of the analysis. It may be useful to run the tool(s) with a range of assumptions to better quantify these uncertainties.

There is a clear need to continue improving our understanding of the impacts land-use and land management changes have on GHG fluxes and their potential contributions to climate change mitigation. Improved data on carbon storage across ecosystems and their associated GHG fluxes with management changes are required to strengthen the outputs of these assessments. Furthermore, enhancing capacity to map landcover changes and assess baseline assessments will further improve the reliability of these assessments.

It should also be noted that assessment of these landscape restoration projects should not be limited to their GHG and carbon benefits. Each project makes significant contributions to improving habits and connectivity for wildlife, which is vital for reverse the trend of biodiversity loss and meeting global targets, such as the Post-2020 Biodiversity Targets (Convention on Biological Diversity [CBD] 2020). Further co-benefits include improved ecosystem service functioning (such as reduced soil erosion and water quality), climate change adaptation (Salvaterra and Pohnke 2021), and socio-economic benefits for local communities (e.g. development of sustainable economies and economic benefits from nature-based tourism).

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Annex 1 – Data gathering

Below is an example data collection questionnaire, which we developed for initial discussions with projects. This approach highlights which inputs are most relevant to projects, which tools are likely to be appropriate and the data availability within the project. Using this information as a basis, more detailed information can be collected. (N.B. this sheet focuses on terrestrial habitats, but it is also possible to include coastal habitats and fisheries in the EX-ACT tool)

Basic requirements

- **Start year** (Can be in the past/now/future)
- **Length of time** (recommend 20 years or multiples thereof)
- **Implementation phase** (time taken to implement changes, e.g. grazing reduction, woodland creation)
- **Description of the Start, Baseline and Project scenarios**
 - o The **Start** is the initial land use and management of the project area
 - o **The Baseline scenario** is what happens without the project and can be simply the same as the start (i.e. no change) or based on knowledge of historic trends, future land-use planning alternatives etc.
 - o **The Project scenario** is what you have done with the land, or plan to do with it.
- **Breakdown of land classes and the areas associated with them**
 - o Can be as simple as 'Woodland', 'Grassland', 'Agriculture', 'Degraded Peatland', 'Near-natural Peatland' etc.
 - o Or more detailed if this data is available, e.g. 'Pasture', 'Moorland', 'Deciduous woodland comprising a mix of oak and birch'.

Table 1a. Example table of land cover inputs. The total land area should be equal in each scenario

Land cover	Start (ha)	Baseline (ha)	Project (ha)
Semi-natural woodland (>20 years)			
Semi-natural woodland (<20 years)			
Plantation forests			
Grassland			
Annual Cropland			
Perennial Cropland			
Peatland			

If land use change occurs e.g. afforestation on grassland, or conversion of cropland to grassland etc. we would need to know the area of each land class being converted.

Table 1b. Example table of livestock inputs, which is the number of individuals for each type of livestock

Livestock	Start (# of individuals)	Baseline (# of individuals)	Project (# of individuals)
Sheep			
Cattle			
Deer			
Horses			
Pigs			

Extra requirements

Woodland

Under each scenario:

- **Area being deforested (ha) and the resulting land use**
 - o Whether any deforested areas are cleared with burning
- **Area being afforested (ha) and the previous land use**
- **Area of forest remaining forest (ha)**

Grassland

- The changes to carbon storage in grassland are measured by changes in status. These tools use a series of broad categories:
 - o **Severe degradation:** major long-term loss of productivity and vegetation cover, due to severe mechanical damage to the vegetation and/or severe soil erosion.
 - o **Moderate degradation:** overgrazed or moderately degraded grassland, with somewhat reduced productivity (relative to the native or nominally managed grassland) and receiving no management inputs.
 - o **non-degraded:** sustainably managed grassland, but without significant management improvements.
 - o **Improved grassland:** higher productivity than nominal/native grassland as a result of management activities such as irrigation, fertilization, legume planting, improved grass varieties, liming, and/or manure/compost applications.
 - o **The IPCC recommends that changes to the grassland condition do not change more than 1 category in a 20-year period.**
- **Area (ha) of each grassland category at the start, and the expected category under the Baseline and Project scenarios**
 - o E.g. the introduction of a rotational grazing scheme may be expected to improve grassland from moderately degraded to non-degraded over the project time period with the stocking density remaining the same. In a Baseline scenario, the grassland may be expected to remain moderately degraded or become severely degraded
- Is any of the grassland managed with fire?

Annual cropland

For each scenario:

- **Area (ha) of each Main season crop**
- Yield (t/ha/yr if known)
- **Yes/No**
 - o Improved agronomic practices
 - o Nutrient management
 - o No till and residue management
 - o Water management
 - o Manure application

Perennial cropland/Agroforestry (inc. silvopasture and parklands)

For each scenario:

- Area (ha) of each Agroforestry type and whether biomass burning occurs
- Yield (t/ha/yr if known)

Peatlands (if applicable)

- Under each scenario:
 - o Area of peatlands being drained
 - o Area of active peat-extraction
 - o Area of peatlands being rewetted
 - o Area of peatland being burnt (wildfire or prescribed)

Agricultural Inputs

- If information is available, could you please specify the amounts (tonnes per year) used across the site under each scenario for:
 - o Lime
 - o Fertiliser
 - o Pesticides/herbicides

Livestock

- **Number of each species in each scenario**
- Production (meat/milk in tonnes/year if known)
- Manure management (e.g. % left in pasture)
- If information is available, we can also input technical mitigation options (%) applied for each species
 - o Feeding practices (%)
 - e.g. more concentrates, adding certain oils or oilseeds to the diet, improving pasture quality....
 - o Specific Agents (%)
 - specific agents and dietary additives to reduces CH₄ emissions (Ionophores, vaccines, bST...)
 - o Breeding (%)
 - increasing productivity through breeding and better management practices (reduction in the number of replacement heifers)