Annex: Abatement measures methodology

Working version 20-10-2025

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Contents

1. Objective

This document summarizes the methodology for selecting and providing estimates of the costs and benefits of abatement measures for biodiversity loss within the scope of the BiROFin project. The abatement measures are actions, interventions or practices that reduce pressures leading to biodiversity loss or enhance the provision of the selected ecosystem services, such as pollination services, and soil quality. Similar to measures to abate or reduce greenhouse gas emissions under climate change mitigation and adaptation efforts (UNFCCC, 2008[1]), these measures are expected to reduce the loss of biodiversity and ecosystem services as part of broader biodiversity and nature recovery efforts. We

[1] UNFCCC resource guide for preparing the national communications of non-annex I parties - Module 4 : Measures to mitigate climate change

provide cost estimates, including capital and operational expenditures, as well as benefits in terms of improvements on biodiversity and ecosystem service recovery. Our approach to the cost and benefit analysis yield cost estimates per hectare per year for implementing a particular measure in a specific country. Benefits are expressed in terms of direct benefits such as cost savings for farmers, and indirect benefits such as improved productivity resulting from improved ecosystem services.

2. Abatement measures

2.1. Definition of abatement measures

We define abatement measures as activities, interventions, or practices that benefit biodiversity and contribute to its recovery by addressing the causes of its decline. These activities focus on preserving natural capital, thereby enhancing the provision of ecosystem services.

2.2. General approach to costs and benefits estimations

This work package estimates costs of abatement measures by considering initial implementation costs, the expected level of implementation within a country, and the area in which the measure can be implemented. It also estimates economic benefits of implementing measures. For the latter, this work package builds on the GDP losses at country level delivered by the macroeconomic modelling of climate and biodiversity loss scenarios (WP3). The underlying logic is that the climate and biodiversity loss scenarios are introduced into the MAGNET model as productivity shocks impacting production volumes and GDP at country and sectoral levels. Implementing abatement measures has a positive effect on the provision of ecosystem services, contributing to the recovery of reduced crop productivity after the shocks. *Figure 2.1.* offers a schematic representation of this logic and the links between scenario modeling, macroeconomic impacts, and reduction of productivity loss.

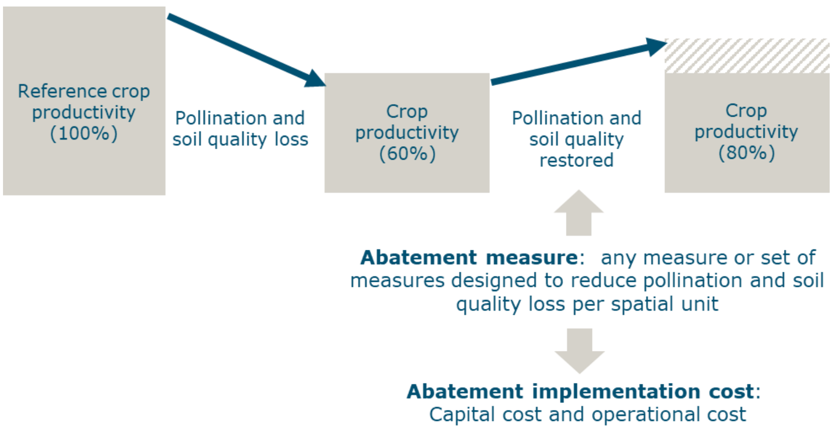

Figure 2.1. Summary of logic from productivity loss to estimation of benefits from abatement measures (percentages are for illustrative purposes).

Figure 2.2. details the different data components (i.e. types of data) used, showing which methods they feed into, and how *methods* connect to the outputs of this Work Package. For context with the main slide deck report, Output 1 is presented in Figure 10, Output 3 is in

Figure 12, and Output 4 is in Figure 11. This methodological document refers to the data components, methods, and outputs as they are numbered and connected in this Figures. It describes the different methodologies and assumptions followed to produce the results presented in the slide deck report. Throughout this document, we will refer to the numbered components, methods, and outputs.

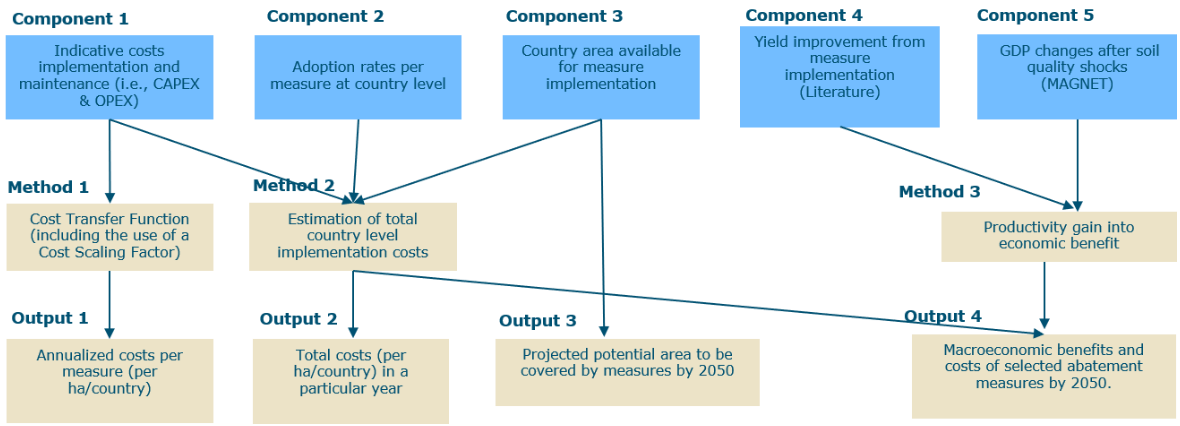

Figure 2.2. Systematic approach for assessing costs and benefits, including data components, methodologies, and results.

2.3. Selection of abatement measures

Based on a review of academic and grey literature, as well as consultation with experts in agriculture, plant science, and related fields, a comprehensive list of measures was compiled. The goal was to identify practices that reduce pressure on drivers of pollination service loss and soil quality degradation. For example, focusing on improving habitat quality for pollinators involves enhancing soil erosion and soil organic carbon content to restore pollination services and improve soil quality, respectively. The list included the following 13 measures: decision support systems, precision pesticide application, sensor-based pesticide application, controlled traffic farming, nematode application for biological control, organic fungicide application, diversified crop rotations, conservation tillage, organic manure application, cover crops, agroforestry, sustainable forest management, flower margins.

Three levels of selection criteria (Table 1) were used to narrow down the long list of measures to a total of 6 abatement measures. After the long list of measures was submitted to the screening criteria levels 1 and 2, the low availability of research describing and quantifying impacts to biodiversity (Criterion 1.2) meant that some measures were excluded from the selection[2]. For instance, precision farming[3] ensures less use of pesticides and thus improves pollinator populations, and practices following ecological principles4 provide resources and habitat for pollinators and wider benefits to biodiversity (Cole et al., 2020; Riemens et al., 2021). However, the exact number of pollinators benefiting from the measures and the increased service in pollination that they can offer is very difficult to

[2] decision support systems, precision pesticide application, sensor-based pesticide application, controlled traffic farming, nematode application for biological control, organic fungicide application,

[3] decision support systems, precision pesticide application, sensor-based pesticide application

[4] Nematode application, organic fungicide.

estimate5. Regarding criteria from level 2, specific links to agricultural yield for measures such as controlled traffic farming are absent. Since this would limit further analysis of cost-benefit estimates, this measure was excluded from of the selection.[6]

Table 1: Levels of criteria for screening and selecting abatement measures.

Level	Criteria	Description	Source
1	Contribution to Biodiversity Restoration	The measure contributes to reversing biodiversity loss, either directly or as part of a broader impact pathway	Peer-reviewed literature and or expert knowledge.
2	Empirical validation of ES impact	The measure's effect on a specific ecosystem service is supported by empirical evidence.	Peer-reviewed studies or reports from reputable organizations
3	Link to Agricultural productivity	The measure has a known or expected effect on agricultural yields,	Expert opinion and literature if available
4	Alignment with policy	The measure supports or is aligned with relevant sustainability and/or biodiversity goals and targets.	United Nations SDG's, EU's biodiversity strategy, EU's CAP.

Six abatement measures were selected for further analysis: conservation tillage, organic manure, cover crops, agroforestry (silvoarable), flower margins, and diversified crop rotations. Table 2 presents a working definition of the measures and their key benefits in relation to the impact pathways in Appendix 1. Box 1 provides more detail on the expected benefits of each measure.

Table 2. Overview of selected abatement measures. This includes the working definitions, the expected general benefits from their implementation, and potential contribution to the ecosystem services of interest.

Abatement measure	Definition	Benefit in relation to impact pathway (Source)
Conservation tillage	a technique of soil cultivation where a significant portion of the previous crop's residues are left on the soil surface after harvest.	Increased soil health by increasing soil microbial biomass, reduction of soil erosion, increases in soil organic carbon (SOC) levels (Wang et al., 2020; Breil et al., 2023; Mondal et al., 2023)
Organic manure	the application of either animal waste, vegetable compost, and agricultural residues to help maintain and	Increased biodiversity via species richness in the soil, increased SOC levels (Riemens et al., 2021; Gross & Glaser, 2021; Breil et al., 2023; IEEP, 2024)

[5] Although some literature is available, for example by reporting effects of precision farming as increased amount of pollinator visits to flowers of a particular crop which correlates with increased pollination services and yields (Pecenka et al., 2021); specific cost data at the level of CAPEX and OPEX were not available and therefore these measures were not included for further analysis.
[6] Potential negative or positive impacts of measures on other ecosystems are not taken into account when selecting the measures.

Abatement measure	Definition	Benefit in relation to impact pathway (Source)
	improve soil structure and organic matter content.	
Cover crops	The use of any plants that are sown specifically to reduce the loss of soil, nutrients and plant protection products during the winter or other periods when the land would otherwise be susceptible to losses.	Increased biodiversity (species richness) , and increased SOC levels (Kremer & Miles, 2012; Joshi et al., 2023)
Agroforestry (silvoarable)	Silvoarable agroforestry refers specifically to combining horticultural crops grown simultaneously with perennial trees.	Improved biodiversity above and below ground, increased SOC stocks (Chatterjee et al., 2018; Cole et al., 2020)
Flower margins	are permanent areas of diverse flowers and grass, planted around or in crop fields.	Increased biodiversity and pollinators populations as well as soil fertility (Cole et al., 2020; Pecenka et al., 2021)
Diversified crop rotations	Implementation of an additional crop to the rotation. The costs of such a measure are very different depending on the basic crop rotation	Increased biodiversity, improved soil fertility and carbon sequestration (Dijkshoorn-Dekker et al., 2024)

Box 1: Selected measures contribute to the recovery of biodiversity and the restoration of pollination services and the improvement of soil quality.
Crop management measures, such as conservation tillage, cover crops, and the use of organic manure, can reduce soil erosion, improve soil organic carbon (SOC) content, and increase in biodiversity in the soil. They reduce soil erosion by improving the structure of the soil, increase SOC by increasing the capacity of soil to sequester carbon and balance nutrients, and promote biodiversity by providing a suitable environment for microbiota in the soil to thrive (Dias Rodrigues et al., 2023; Henry et al., 2022) Agroforestry systems are known to provide stability to the soil, decrease runoff and prevent soil erosion. They also enhance soil life by harnessing various microorganisms, such as fungi and bacteria. With high microbial activity, these microorganisms enable the deposition of organic matter in the soil, thus increasing its carbon content (Fahad et al., 2022; FAO, 2017) and contributing to soil biodiversity.

3. Cost estimation for abatement measures

3.1. Countries selection

The cost and benefits estimates were calculated for Brazil, France, Germany, Italy, the Netherlands, Spain, the United Kingdom, and the United States, where majority of financial sector portfolio rests, according to BiROFin project partners.

3.2. General approach to cost estimates

Three main components are needed to estimate costs of abatement measures. As *Figure 2.2*. indicates these components will be combined and used by different methods to deliver the outputs. More specifically, Component 1(indicative costs of implementation and maintenance (i.e., CAPEX & OPEX) is directly used by Method 1 (the cost transfer function) to extrapolate annualized cost estimates to countries for which data was scarce or not available. Components 1, 2 (Expected adoption of measures at country level), and 3 (country area potentially available for measure implementation) are all input for Method 2 (estimation of total country level implementation costs) and therefore contribute to Output 2 (total costs per ha/country) and Output 4 (macroeconomic benefits and costs of abatement measures) respectively.

3.3. Data collection

To collect data on costs and benefits of the selected abatement measures, we conducted an integrative study of the literature (Snyder, 2019). This approach was chosen over a structured literature review because it allows for greater flexibility in synthesizing insights from diverse scientific domains. Our goal was to build a comprehensive understanding of the topic by integrating findings across disciplines, rather than systematically cataloguing all published studies. This method is particularly suitable for interdisciplinary topics that span multiple fields and methodologies. Furthermore, it aligns with our group's previous work, which has successfully employed this approach to address similar research questions (Dijkshoorn-Dekker et al., 2020).

The literature search was an iterative process, including non-exhaustive literature searches in Google Scholar and Scopus, complemented with insights from experts as well as snowballing. Table 2 summarizes the search terms used in the literature search in Scopus and Google Scholar. Search queries combined terms or synonyms for the measures with concepts for costs and benefits in columns (Table 3) using the Boolean operator “AND”. In contrast, the terms within columns were combined using “OR”. The searches were performed and screened for relevant measures and cost estimations for implementation. For literature on benefits, initial input from experts and relevant literature shared by them helped delineate the search by making a selection of relevant benefits to focus on. For instance, improvements in soil organic carbon are linked to improvements in soil quality; therefore, SOC was used as a proxy for benefits in oil quality derived from the implementation of abatement measures.

To monetize the benefits of abatement measures found in the literature, additional terms were used, column four (Benefits-Part 2) in Table 3, in combination with the benefits identified, column three (Benefits-Part 1).

Literature was reviewed and consultations with experts were performed to dive deeper into specific cost components of abatement measure implementation. The final result of this data collection informed Components 1 and 4 in Figure 2.2.

Table 3. Summary of keywords used for the literature search in Scopus and Google Scholar. The example for measures under precision agriculture is used for the abatement cost column.

Abatement measure	Costs	Benefits- Part 1		Benefits- Part 2
Agroforestry		Soil quality	Carbon sequestration	Yield improvements
Cover crop*	Investment*		Soil organic carbon levels	(increased) Productivity
Flower margin* OR hedgerow*	Expenditure*		Soil organic matter	
Conservation tillage OR no tillage				
Organic manure OR green manure	Outlay		Soil fertility	
Intervention	Amount	Biodiversity	Biodiversity improvements	
Action	Cost*		Mean species abundance	
measure	Operational (abstract)	Pollination services	Pollinator population improvements	

To collect specific CAPEX and OPEX data for specific measures, a questionnaire was prepared, and 15 experts from the field of agriculture and agricultural economics were contacted.[7] An introductory meeting was held to explain the assignment's objectives and the questionnaire. Experts filled in the questionnaire and meetings to clarify the content of the questionnaire were held when necessary.

3.4. Component 1: Cost estimates composition: CAPEX & OPEX

Annualized costs for different measures at the country level (Output 1) are presented in Table 4. Table 5 below shows detail on what was considered under CAPEX, OPEX and the period used to annualize cost estimates.

Table 4. Estimates cost of abatement measures, they should be interpreted as approximations (per hectare per year 2023 USD).

	Cover crop	Conservation tillage	Organic manure	Flower Margins	Diversified crop rotation	Agroforestry silvoarable
Netherlands	214	216	340	96	744	147
Germany	183	185	291	82	637	126
Spain	219	171	270	76	590	117
Italy	148	150	236	66	515	102

[7] In total 15 expers were contacted. These experts were from Germany, Italy, U.K, the Netherlands, France, and Portugal.

France	116	205	322	91	705	140
United Kingdom	205	207	326	92	713	141
Brazil	81	82	128	36	281	56
United States	220	222	349	98	764	151

Note: Values in bold are original cost estimates extracted from the literature or expert knowledge. Sources for these values are listed here[8]. All other values are derived using the Cost Transfer Function (CTF); details on the CSF calculation can be found under Method 1 section below and Appendix 1.

Table 5. Description of measure, how CAPEX and OPEX were constructed and the time frame assumptions used to annualize costs per hectare per country (Output 1).

Measure	Description	CAPEX	OPEX
Cover crops	Sowing non-harvested crops (e.g., legumes, clover, grasses) during fallow or between cash crops to reduce nitrogen runoff, improve soil structure, and enhance soil carbon	Costs included are inputs for initial investment.	
Conservation tillage	Avoiding or minimizing ploughing to preserve soil structure and reduce emissions	Purchase of a no-till drill or retrofit (~$1,203/ha), annualized over 10 years (typical machinery life)	OPEX: 2 hour per ha per year for machine operator at 30 EUR per hour. (excludes crop input costs; includes labour and machinery only)
Diversified crop rotation	Implementing 3–5-year rotation cycles with diverse crops (e.g., legumes, cereals, cover crops)	Includes machinery adjustments and potential storage or handling investments, amortized over 10 years	Higher labour and management costs, plus variability in input needs and yields across crops.
Organic manure	Applying composted manure or slurry to replace synthetic fertilizers.	Purchase of manure spreader or upgrade to manure storage (~$220/ha), amortized over 10 years	Higher recurring labour costs and equipment operation for transport and application.
Flower margins	Establishing strips of wildflowers or pollinator plants at field edges.	Planting and seed cost estimated at ~$155/ha, amortized over 5 years (reflecting margin lifespan)	Moving or maintenance a few times per year; moderate labour input. We assumed that the

8 Cover crop Netherlands, Spain, France(Smit et al., 2019); Conservation tillage Germany (Seibert, n.d.); Organic manure Netherlands (KWIN-AGV, 2018); Flower margins Spain (Ortega-Marcos et al., 2022); Diversified crop rotation France (Moret-Bailly & Muro, 2024); Agroforestry silvoarable United Kingdom (Burgess et al., 2003).

Measure	Description	CAPEX	OPEX
			land for flower marging was not used for production
Agroforestry silvoarable	Planting widely spaced trees (e.g., 156 trees/ha) in arable fields in combination with annual crops. Costs are taken from DEFRA (2003), adjusted for 2023 prices using a UK inflation factor of 1.68, and converted using an exchange rate of £1 = $1.244.	Includes: £212/ha for establishment (planting, site prep), £9/ha for beating-up (replacing failed trees), £910/ha for developmental pruning over years 2–9.Total CAPEX = £1,131/ha. Adjusted for inflation: £1,131 × 1.68 = £1,899.84. In USD: £1,899.84 × 1.244 = $2,362.04/ha. Annualized over 30 years: $2,362.04 ÷ 30 = 78.79/ha/year.	Includes: £21/ha/year for routine maintenance (e.g., pruning, weed control), £9/ha/year for insurance. Annual OPEX = £30/ha/year. Adjusted for inflation: £30 × 1.68 = £50.4. In USD: £50.4 × 1.244 = $62.56/ha/year

3.5. Component 2: Adoption rates

Adoption rates refer to the percentage of a measure which is implemented on the land potentially available for that practice. These rates are used in two ways:

- Combined with the land area available to implement a measure in a country (Component 3) to produce output 3
- Combined with the initial implementation costs (Component 1) one can estimate output 2.

The initial adoption rates for the year 2025, presented in Table 6 are based on literature and expert knowledge.

Table 6. Estimated adoption rates in 2025 for all country-measure combinations[9]. When data was unavailable in the literature or from experts, these adoption rates were left blank. Therefore, it is not possible to show these country-measure combinations in Output 4 (Figure 11 in slide deck report), numbers should be interpreted as approximations.

Adoption rates in %	Conservation tillage	Organic manure	Cover crops	Flower Margins	Diversified Crop rotation	Agroforestry silvoarable

[9] References: Conservation tillage: USA (Blanco-Canqui & Ruis, 2018); France, Germany, Italy, Netherlands, Spain, UK (González-Sánchez et al., n.d.) .Organic manure: USA (Lim et al., 2023); France, Germany, Italy, Netherlands, Spain, UK using the percentage of organic agriculture from (FAOSTAT, 2025). Cover crops: USA (Vilsack & Hamer, 2022); France, Germany, Netherlands, Spain, UK (Smit et al., 2019). Flower margins: Netherlands is expert opinion. Diversified crop rotation: USA (T. Wang et al., 2021); France, Germany, Italy, Netherlands, Spain (Nuscheler et al., 2025). Agroforestry silvoarable: France, Germany, Italy, Spain (Rubio-Delgado et al., 2023).

Brazil	70	-	6	-	-	-
France	2	10	84	-	71	1
Germany	1	7	20	-	71	5
Italy	5	18	-	-	71	2
Netherlands	1	20	98	10	71	-
Spain	8	8	12	-	71	17
UK	3	3	66	-	-	-
USA	24	8	4	-	30	-

We model the evolution of adoption rates from 2025 to 2050 under three scenarios (middle, optimistic, and pessimistic) to estimate the country level costs and benefits of abatement measures over time. While the output files provide results for all three, this section outlines the core assumptions behind the simulation of adoption dynamics, and shows the increases in adoption rates expected under the middle scenario.

Adoption is modeled using an S-curve, a standard diffusion pattern consisting of slow uptake initially, rapid growth in the middle, and a plateau as saturation is reached. [10]The shape of the curve depends on the initial adoption level in 2025. If initial adoption levels are already high, growth remains modest. If initial adoption levels are low, however, adoption grows more steeply over time. This allows for country- and measure-specific variation. To reflect real-world constraints, we apply a general adoption rate cap of 90%, accounting for institutional and behavioural limitations. In all three scenarios, the projected adoption rate in 2050 depends on the initial level in 2025. However, the size of the assumed increase varies across scenarios. Table 7 shows the assumptions applied in the middle scenario, expressed in percentage points. For example, an adoption rate of 10% in 2025 with a 25-point increase leads to a projected rate of 35% in 2050. Table 8 presents the expected adoption rates by 2050, by country and measure under the middle scenario.

Table 7. Assumed Change in Adoption Rate (2025–2050) – Middle Scenario (*All changes are in percentage points*)

2025 Adoption Rate	Increase by 2050 (percentage points)
0–10%	+25 points
10–30%	+20 points
30–50%	+10 points
50–70%	+5 points
>70%	0 points

[10] Please note that in our modelling exercise, we did not formally model the relationship of the adoption rates with profits and yield improvement. As far as we know such a study linking those is not available to the research and it is outside the scope of our study.

Table 8. Assumed adoption rates in 2050 for all country-measure combinations, numbers should be interpreted as approximations.

%	Conservation tillage	Organic manure	Cover crops	Flower Margins	Diversified Crop rotations	Agroforestry silvoarable
Brazil	75	-	31	-	-	-
France	27	35	84	-	71	26
Germany	26	32	40	-	71	30
Italy	30	38	-	-	71	27
Netherlands	26	40	98	35	71	-
Spain	33	33	32	-	71	37
UK	28	28	71	-	-	-
USA	20	33	29	-	50	-

Please note that in our modelling exercise we did not formally model the relationship of the adoption rates with profits and yield improvement. As far as we know such a study linking those is not available to the research and it is outside the scope of our study.

3.6. Component 3: Area

Land area considered for measure implementation is arable land. Arable land for all countries in the selection are presented in Table 9. For all measures except flower margins and silvoarable, the total of this land area is taken into account and combined with indicative costs (Component 1), and adoption rates (Component 3) to result in Output 2 and 4. For flower margins and silvoarable systems, approximately 10% of arable land is considered suitable for implementation. This is based on expert interviews and insights from the SAFE project (European Commission, 2024), respectively.

Table 9. Potential land area for measure implementation. Source: Arable land (FAOSTAT, 2025).

Country	Arable land (1000 ha)
Brazil	55,642
France	18,653
Germany	11,657
Italy	7,084
Netherlands	1,004
Spain	11,691
UK	5,997

USA	151,592

3.7. Method 1: Cost transfer function

To estimate the cost of implementing sustainable environmental practices across different countries, we utilize a cost transfer function. Our analysis begins with the cost database compiled by Verhoeven et al., (2024), which includes 114 unique cost estimates for land restoration practices such as afforestation, silvo-pastoralism, area closure, and forest conservation. These estimates cover 75 countries across all continents except Australia, making the database highly relevant for our purpose.

The land restoration database is suitable for two key reasons. First, it provides country-specific cost estimates for sustainable environmental practices. Second, it includes measures like agroforestry, which is directly relevant to our selected abatement measures. Furthermore, due to the limited availability of detailed implementation cost data for the specific abatement measures, this broader database offers valuable insights. Understanding how the cost of similar sustainable practices varies across countries enables us to identify cost patterns and estimate the relationship between these costs and country-specific characteristics. We use this relationship to predict costs for other measures where direct estimates are not available.

The development of the cost transfer function using the land restoration country-level database begins by identifying key variables that explain the variation in the country-specific cost of implementing different restoration efforts. The predictor variables are drawn from the World Development Indicators (WDI) database, maintained by the World Bank.

To ensure data quality and robustness, we selected predictors with minimal missing values and strong explanatory power for country-level cost variation. Building on (Verhoeven et al., 2024), who found GDP to be a key driver of restoration cost differences—and also considered lending rate, road density, and agricultural output—we extended their approach by incorporating additional country-level variables from the World Development Indicators (WDI), such as population density, agricultural land area, access to credit, government efficiency, and political stability. The primary criterion for including a variable in the cost model was its contribution to explaining variation in implementation costs across countries, which is explained by R^2.

Given the high correlation among many WDI indicators (e.g., GDP per capita, government efficiency, and political stability), we applied ridge regression to address multicollinearity. This regularization technique reduces the risk of overfitting by shrinking regression coefficients (Friedman et al., 2010).

To improve the predictive performance of the cost model and increase the proportion of explained variation, additional predictors were incorporated, including population density, agricultural land area, access to credit, and government efficiency[11].

The final cost model explains approximately 55% of the variation in country-specific implementation costs.[12] Using the estimated predictor values and their associated coefficients (see Appendix 1), we derived the Cost Transfer Function (CTF). Overall, the results indicate that costs tend to be higher in countries with substantial human capital, productive agriculture, and robust institutions — likely reflecting the influence of skilled labour, strict compliance demands, and the higher cost of modifying advanced farming systems.

The general formula for estimating the cost of implementation in Country X based on the cost observed in Country Y is:

$$\boldsymbol{CostX} = \text{Cost}_{\boldsymbol{Y}} \cdot \frac{\boldsymbol{CSF_X}}{\text{CSF}_{\boldsymbol{Y}}}$$

Since log-transformed predictor variables are incorporated in the cost model to address non-normality and potential non-linearity in the cost-predictor relationship, the final equation used is:

$$\boldsymbol{CostX} = \text{Cost}_{\boldsymbol{Y}} \times \boldsymbol{e}^{(\boldsymbol{CSF_X} - \boldsymbol{CSF_y})}$$

This approach offers a data-driven framework to estimate costs across countries while focusing on the most impactful predictors.

3.8. Method 2: Estimation of total country level implementation costs

Estimating country-specific costs involves combining literature sources, expert input, and the use of a cost transfer model. For 2025, initial cost estimates are drawn from available data where possible; for country–measure combinations lacking direct estimates, the cost transfer function is used to fill the gaps.

[11] Independent variables used in the regression (all log-transformed) include: agricultural value added (yr2020AgriVA_log); gross capital formation (yr2020CapForm_log); cereal yield (yr2020CerealY_log); credit to the private sector (yr2020CredPS_log); greenhouse gas emissions (yr2020GHGEmi_log); government effectiveness (yr2020GovEff_log); Human Capital Index (yr2020HCI_log); inflation (yr2020Inflat_log); mobile subscriptions per 100 people (yr2020MobSub_log); political stability (yr2020PolStab_log); population density (yr2020PopDens_log); share of protected areas (yr2020ProtArea_log); and rule of law (yr2020RuleLaw_log). All data are from the World Development Indicators (2020).

[12] This suggests that predictions are typically within a factor of about 2 of observed costs. Such transfer errors are consistent with findings in the value transfer literature, e.g. Londoño & Johnston (2012), who report mean absolute percentage errors around 100% (≈ factor of 2) in a meta-analysis of valuation studies

To calculate total cost estimates at the country level, we combine three components for each country–measure pair:

1. Cost per hectare (Component 1 in Figure 2.2)
2. Adoption rate (Component 2 in Figure 2.2)
3. Suitable land area (Component 3 in Figure 2.2)

These components are multiplied for each year to estimate the total annual cost of implementing a given measure in each country (Output 2 in Figure 2.2).

For future years (2026–2050), we apply the same formula. However, we introduce varying assumptions about how costs and adoption rates[13] evolve over time, to assess the sensitivity of total cost estimates. We define three assumption cases:

- A middle case, where implementation costs decrease gradually over time, with a total reduction of around 20% by 2050 compared to 2025. This reflects incremental technological progress and aligns broadly with the kind of change described in SSP2 (Riahi et al., 2017).
- An optimistic case, where both cost reductions and adoption expansion occur more rapidly.
- A pessimistic case, where implementation costs rise over time due to limited technological progress or increasing input costs.

4. Benefits estimation for abatement measures

We estimate the benefits of implementing abatement measures based on MAGNET models' results on GDP changes related to agricultural productivity loss from pollination and soil quality induced by biodiversity loss. We present these benefits as the avoided GDP loss due to recovering part of that productivity decline. The estimation involves two steps:

4.1. Step 1: estimating yield improvements

Based on the expected yield changes due to implementation of measures as found in the literature (Table 10), yield improvements through 2050 are modelled as a gradual, non-compounding increases relative to baseline yields under conventional practices. A nonlinear build-up function is assumed to reflect how benefits typically materialize over time, consistent with how ecosystems develop in dynamic and non-linear ways (Lehmann et al., 2025):

- slow uptake in the early years,
- faster improvement around the midpoint of the establishment period,
- stabilization once the full benefit is reached.

Each measure has a specific time-to-full-benefit period based on available empirical evidence. Once the maximum expected yield improvement is achieved, it is assumed to stabilize and remain constant thereafter. For instance, (H. Wang et al., 2020) reported a

[13] Assumptions for adoption rates changes are in the previous section.

6.1% yield increase under no-tillage compared to conventional tillage, observed over an 11-year period. In the benefit calculation, we assume a gradual increase starting in 2026, full 6.1% improvement by 2037. After that, it remains stable.

Importantly, yield improvements at any point in time apply only to land that has been under the measure for the relevant number of years. The model tracks adoption by annual cohorts, with each cohort following its benefit build-up curve. Total annual benefits are calculated by summing contributions from all cohorts, weighted by their years since adoption and their position on the benefit curve. This approach ensures that yield benefits realistically reflect both the gradual establishment dynamics of each measure and the progressive expansion of adoption over time.

Table 10. Abatement measures impact yield. References are indicated in the last column, numbers should be interpreted as approximations.

Abatement measure	Average increase in yield per hectare (% compared to baseline over the full time frame)	Timeframe of observed yield increase (years)	Reference
Conservation tillage	6.1	11	(H. Wang et al., 2020)
Organic manure	27	10	(Du et al., 2020)
Cover crops	2.6	1	(Joshi et al., 2023)
Agroforestry (Silvoarable)	20	20	(Graves et al., 2007)
Flower margins	21	10	(Morandin et al., 2016)

4.2. Step 2: Translating productivity gains into economic benefit

This step focuses on using MAGNET results to model changes in global GDP caused by 1% increase in productivity due to improvements in pollination and soil quality as found in the literature. These changes are modelled through 2050, following the previous step.

In Table 11, we present the assumed declines in yields under soil quality loss scenarios with extreme climate events. These are the losses that abatement measures are designed to mitigate or recover, based on the productivity gains resulting from the adoption of practices and their positive yield effects, as shown in Table 10.

Table 11.MAGNET results for the benefit calculation for Soil quality loss with extreme climate events scenario

Year	*Baseline Global GDP (trillion USD)*	*Global GDP (trillion USD)*	*GDP loss per ha. In USD*	*Land productivity loss per ha (in %)**	*The marginal GDP effect of a 1% change in land use productivity per ha*
2025	98.80	98.80	0.0	0.0	-
2030	112.71	112.69	5.1	5.9	0.9
2035	126.84	126.76	32.2	11.4	2.8
2040	140.79	140.51	109.0	16.5	6.6

2045	155.24	154.54	270.2	21.4	12.6
2050	170.18	168.69	568.3	26.0	21.9

Source: MAGNET scenario results

Using the data from Table 11, we calculated the change in global GDP resulting from a 1% change in land productivity loss per hectare over time, using the following equation:

$$\text{GDP loss per hectare} = \frac{\boldsymbol{\Delta GDP}_{\text{global}}/\boldsymbol{\Delta\,\%\ Land\ productivity\ loss}}{\text{Relevant total cropland}}$$

where: $\boldsymbol{\Delta GDP}_{\text{global}}/\boldsymbol{\Delta\,\%\ productivity\ loss}$ represents the change in global GDP per 1% loss in productivity (derived from the MAGNET scenario analysis). Total cropland refers to the total number of hectares of cropland impacted by the productivity loss shock. This relationship is then plotted in the following figure.

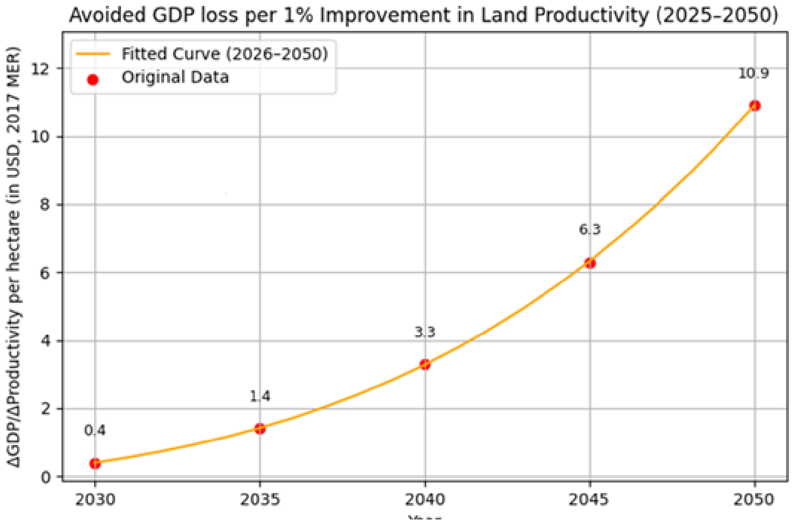

Figure 4.2. Impact of Soil quality loss on Global GDP over time

This relationship can be considered a “benefit function”, in which the avoided damage follows an increasing trend. The results suggest that productivity loss has a cumulative economic impact over time, underscoring the importance of early intervention. A 1% improvement in productivity due to soil quality restoration could increase GDP by up to ~$11per hectare (2017 USD, MER)[14].

We report the global macroeconomic benefits of measures implemented at the country level. Our estimations are based on the global GDP loss avoided for measures implemented in a specific country, estimated relative to the baseline scenario. Specifically, the benefits estimation uses the avoided GDP loss under an extreme climate change scenario with soil quality decline, compared to the baseline scenarios. While abatement measures are conceptually intended to prevent this loss by tackling soil degradation, we did not explicitly use scenarios where we introduce the practices to each

[14] In 2023 USD, this value becomes $17.44. Conversion is based on the World Bank’s global GDP deflator: 3.0 in 2017 and 4.8 in 2023. Source: World Bank.

countrues and produce GDP outcomes with and without abatement measures using MAGNET.

To estimate the country-level economic benefits of adopting measures, the following three components are multiplied:.

1. GDP per hectare recovered with the adoption of measures
2. Adoption rate (Component 2 in Figure 2.2)
3. Suitable land area (Component 3 in Figure 2.2)

The adoption rates for the measures are from section 3.5, land area available at each country to implement those measures are from Section 3.6. For future years (2026–2050), we apply the same formula. However, we introduce varying assumptions about how costs and adoption rates[15] evolve over time as explained in Section 3.5.

We can only estimate the country-level benefits of flower margins for the Netherlands due to a lack of information on the adoption rates of this measure in other countries. Similarly, we are unable to estimate the country-level benefits of agroforestry for Brazil, the UK, and the US, as well as those of diversified crop rotation for Brazil and the UK, for the same reasons.

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[15] Assumptions for adoption rates changes are in the previous section.

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6. Appendix

Appendix 1. Results of ridge regression to produce Cost Transfer Function.

```
Ridge regression                       Number of observations     =         39
                                       R-squared                  =     0.5528
                                       alpha                      =     0.0000
                                       lambda                     =     0.5207
                                       Cross-validation MSE       =     0.7034
                                       Number of folds            =         10
                                       Number of lambda tested    =        100
------------------------------------------------------------------------------
   nsumcost_19_log | Coefficient
-------------------+----------------------------------------------------------
  yr2020AgriVA_log |  -.1628735
 yr2020CapForm_log |   .0716248
 yr2020CerealY_log |   .2059688
  yr2020CredPS_log |   .3034883
  yr2020GHGEmi_log |  -.0846503
  yr2020GovEff_log |   .0271469
     yr2020HCI_log |   2.561873
  yr2020Inflat_log |  -.2611299
  yr2020MobSub_log |  -.5952087
 yr2020PolStab_log |  -.1982944
 yr2020PopDens_log |   .0538555
yr2020ProtArea_log |   .0751789
 yr2020RuleLaw_log |   .0420441
             _cons |   6.402027
------------------------------------------------------------------------------
```