Report on the natural asset profiling and the potential for regional impact forecasting for farmer cluster and biodiversity sensitive farming using the NAP

Deliverable Number: D7.4

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Deliverable Description & Contributors

- **Due date**: March 30th 2025
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- **Work package leader**: Claudio Petucco (LIST)
- **Deliverable Title**: Report on the natural asset profiling (NAP) and the potential for regional impact forecasting for farmer cluster and biodiversity sensitive farming using the NAP
- **Nature of deliverable**: Report
- **Dissemination level**: Public

- **Deliverable description**: This final report will analyse and synthesise impacts of land-scape intervention on biodiversity from their potential effect on natural asset, including both on-farm and off-farm value chain impacts and dependencies at the farm Cluster case studies (Task 2.3). The insights gained in the Pilot Cluster applications, and consultations with governmental, non-governmental institutions and industry will be generalised to forecast potential regional natural asset impacts where appropriate land use and habitat maps are available (Task 7.3).

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Abbreviations

AES	Agri-Environmental Schemes
AHDB	Agriculture and Horticulture Development Board
BEIS	Business, Energy and Industrial Strategy
CAP	Common Agricultural Policy
CS	Citizen Science
DEFRA	Department for Environment, Food & Rural Affairs
DST	Decision Support Tool
EC	European Commission
EEA	European Economic Area
ES	Ecosystem Services
FADN	Farm Accountancy Data Network
FC	Farmer Cluster
FEAST	Farmland Ecosystem Assessment Support Tool
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HGV	Heavy goods vehicle
ISO	International Organization for Standardization
JRC	Joint Research Centre
MEA	Millennium Ecosystem Assessment
NAP	Natural Asset Profiling
NC	Natural Capital
NPK	Nitrogen, Phosphorus and Potassium
ONS	Office for National Statistics
PCA	Principal Component Analysis
TEEB	The Economics of Ecosystems and Biodiversity
UNEP-WCMN	UN Environment Programme World Conservation Monitoring Centre

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1. Background to the FRAMEwork project

1.1 FRAMEwork Project Executive Summary

Biodiversity is essential for agroecosystem resilience, sustainability, and long-term food security. Traditionally, management for short-term economic returns has taken priority over management for the environment. Current mechanisms for compensating and encouraging farmers to apply biodiversity sensitive management strategies are often inefficient, being applied at individual farm rather than landscape level, and tend to be generic solutions, imposed from the top down at an EU or national level. Monitoring is rarely carried out and there is therefore little scope for evaluating the success of strategies in achieving improvements to farmland biodiversity.

The FRAMEwork project has been designed and develop a novel alternative to this called the **FRAMEwork System for Biodiversity Sensitive Farming** to enable the transition of EU farming systems to a position where they can conserve biodiversity and benefit from the enhancement of ecosystem services, while mitigating agronomic or economic risks. The FRAMEwork System combines the following elements:

- **Advanced Farmer Clusters** – local farmer groups working as a collective to deliver landscape scale management, supported by a Cluster Facilitator with expertise in agriculture and the environment, and linked to a local Cluster Stakeholder Group to inform and promote policy and practice, organised into regional, national, and international networks.
- **Technical Resource** – technical specialists associated with the regional, national, international networks to provide technical information, methods, and tools to support agrobiodiversity monitoring, management and policy including the dedicated DSTs – FRAMEselect and FRAMEtest.
- **Scientific Innovation** – researchers associated with regional, national, international networks to provide knowledge on the ecology, sociology and economics that underpins the functioning of sustainable agricultural systems.
- **Citizen Observatory and Information Hub** – an open access platform to support FRAMEwork networks, sharing activities, information, data and resources between farmers, scientists, policy makers, and citizens.

The FRAMEwork project will design, build, test, and deploy a prototype of the FRAMEwork System for Biodiversity Sensitive Farming and will work with 3 concepts important to the success and delivery of the project: (i) promoting collective landscape management; (ii) applying the approach across a diversity of European farming systems; and (iii) understanding and supporting the social and ecological change associated with a transition to biodiversity sensitive farming. understanding and supporting the social and ecological change associated with a transition to biodiversity sensitive farming.

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1.2 Project Partners

No	Participant organisation name	Type	Country
1*	The James Hutton Institute (HUTTON)	Research Inst	UK
	Game and Wildlife Conservation Trust (GWCT)	Non-profit	UK
3	Groupe de Recherche en Agriculture Biologique (GRAB)	Non-profit	FR
4	Universitaet fuer Bodenkultur Wien (BOKU)	University	AT
5	Eesti Maaulikool (EMU)	University	EE
6	Hoehere Bundeslehr- und Forschungsanstalt fuer Landwirtschaft Raumberg-Gumpenstein (AREC)	Research Inst	AT
7	Fundacion Artemisan (ARTEMISAN)	Non-profit	ES
8	Scuola Superiore di Studi Universitari e di Perfezionamento Sant'anna (SSSA)	University	IT
9	The University of Hertfordshire Higher Education Corporation (UNI OF HERTS)	University	UK
10	Centro de Investigacion Ecologica Yaplicaciones Forestales Consorcio (CREAF)	University	ES
11	Institut National de la Recherche Agronomique (INRA)	Research Inst	FR
12	Internationales Institut fuer Angewandte Systemanalyse (IIASA)	Research Inst	AT
13	Universiteit van Amsterdam (UvA)	University	NL
14	Luxembourg Institute of Science and Technology (LIST)	Research Inst	LU
15	Universitaet Osnabrueck (UOS)	University	DE
16	Taskscape Associates Limited (TAL)	SME	UK
17	Ceska Zemedelska Univerzita v Praze (CULS)	University	CZ
18	Nordisk Fond for Miljo og Udvikling (NORDECO)	SME	DK

*Coordinating institution

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1.3 Purpose of the Deliverable

Using the natural capital asset profiling (NAP) developed in Deliverable D7.3, in this report we analyse dependencies and impacts on natural capital of the Cranborne Chase farmer cluster (UK), under the implementation of biodiversity sensitive farming approaches. This is achieved using a set of environmental indicators, showing the contribution of biodiversity and regenerative farming practices to ecosystem services such as crop pollination and avoided soil erosion to limit any potential disruption in crop production. The report also provides considerations on policy changes that may accommodate the implementation of biodiversity strategies operating at landscape scale.

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Executive Summary

This study implemented a protocol to assess the dependencies and impacts on natural capital of farm systems operating as a farmer cluster, a group of neighboring farmers collaborating to deliver landscape-scale environmental initiatives to halt the decline of biodiversity. The implementation of the protocol will help understand how agricultural systems depend on and affect natural capital ensuring that farming practices do not deplete these resources. In addition, assessing impacts on natural capital can help build resilience against climate change and other environmental challenges, ensuring long-term viability of agricultural systems.

This study suggests how to use the set of environmental indicators proposed following the Natural Asset Profiling approach (NAP), developed in Deliverable D7.3. The NAP was formulated taking inspiration from elements of the Natural Capital Accounting for business (Natural Capital Protocol) and the System of Environmental Accounting–Ecosystem Accounts framework (SEEA-EEA).

Dependencies and impacts of different enterprises (arable, livestock, etc.) on natural capital are assessed at the Cranborne Chase (UK) farmer cluster and compared against a benchmark to understand what aspects of the farming system could be improved to achieve environmental sustainability. We chose the Cranborne Chase farmer cluster as it covers vast areas and two typologies of farming systems, i.e. arable and livestock. In a landscape of thousands of hectares, it is easier to observe the spillovers of ecosystem services generated in a farm to others that exhibit a more limited implementation of biodiversity farming practices. For example, the benefits of pollinator services provided by a farm that invests in landscape features can extend to other farms that require these services (such as arable farms growing field beans) but do not invest significantly in landscape features that support bird and insect biodiversity. The Cranborne Chase farmer cluster is also interesting because it is an example of implementation of agri-ecological measures tackling soil carbon loss (such as low tillage, organic practices, use of grasslands and landscape features). Some of these practices are implemented not only in farms with vocation for organic measures, but also in arable systems (nearly half of our sample) characterized by a very intense use of inputs (mainly nitrogen) to maximize crop production. While the Cranborne Chase farmer cluster shows production and economic figures not aligned to the average UK farm, it is emblematic of the intense farming approach adopted by the arable farming system practiced in the South of England. Therefore, the relationships between landscape features and biodiversity, and the modelling of avoided soil erosion (and consequently carbon loss) can be interpreted as indicative of what we could expect to see for the arable/mixed farming in the region. Finally, some of the results obtained by implementing the NAP at the Cranborne Chase can be extended to the entire nations. Impacts of crop productivity caused by soil carbon loss at the Cranborne through the implementation of the NAP are aligned with estimate made at national scale (on average a loss of £500/ha in case the absence of practices reducing soil erosion).

Indicators used are proxies built on local knowledge of the farming system, accessible and usable by a range of practitioners. We considered indicators commonly suggested by the Common Agricultural Policy (CAP) such as the biodiversity of common species of birds, and extent of semi-natural habitats. Variables referring to the quality of these habitats, abundance of water species, and connectivity

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between landscape patches were not considered as those were also neglected by the standard monitoring approaches suggested by the CAP.

We complemented the analysis of a broad set of indicators with linear correlations and analysis of variance to identify whether farming practices such as organic protocols, and extension of landscape features are associated with and drive positive changes in biodiversity and other aspects of natural capital such as carbon sequestration, soil erosion reduction, and crop pollination.

We found that the **Cranborne Chase farmer cluster has a main dependency on nitrogen and pastureland.** The first is caused by the high intensity production of cereals, the second by the intensive stocking of livestock per hectare. Dependency on energy is not critical. Impacts on soil erosion, greenhouse gas emissions and soil carbon sequestration are within the benchmark proposed. **The implementation on vast areas (from 10% to 30% of the utilized agricultural area in the mixed farms) of agri-environmental schemes (AES) through voluntary actions to subsidize landscape features such as grass strips, field margins, trees and hedgerows, can limit these impacts.**

We found that **the environmental features that influence biodiversity are permanent grasslands and hedgerows.** The first is correlated with the biodiversity of birds, the second with that of pollinators. An expansion of grasslands may contribute to significantly increase bird biodiversity. Reaching the minimum benchmark value for the birds Shannon biodiversity index (assumed at 1.2) would imply expanding the area of grasslands up to 40ha per farm (10% of the cultivated area) causing a reduction in crop production value per hectare that can be compensated by the current public subsidies only in the "marginal" (least) productive areas. Conversely, increasing the area dedicated to hedgerows from the current 0.8% to a more optimal rate of 4.5% seems unfeasible. This relative change can be translated for the Cranborne Chase in an increase of 20 ha of new semi-natural lands subtracted from productive use whose opportunity cost cannot be compensated by the current public subsidies.

Positive aspects of implementing AES are measured through the productivity of avoided soil erosion and crop pollination. By adopting a production function, we found that the avoided soil erosion is estimated at £500/ha for an average reduction in soil erosion of 0.7 t/ha/year. In those farms (three in total) that have shown limited implementation of soil regenerative practices, the marginal productivity of soil on crop production was as high as £2,000/ha, showing the need to invest more in these practices. Benefits from crop pollination on average were estimated at £84/ha, but in some arable lands this estimate could be as high as £200/ha.

In addition, the analysis of the production function showed that natural capital can contribute to 20% of the cereal production (regardless the use of manufactured capital), while pollination may generate up to 55% of the pollinator-dependent crops, confirming estimates provided by other studies based on the embodied energy *(Emergy)* analysis.

The demand for crop pollination did not correspond to an equivalent high supply of pollinators. From the results of the principal component analysis, we may conclude that farms that are mainly adopting AES for increasing biodiversity are in mixed farms, while the greatest demand for pollinators is in arable land (i.e., to contribute to the production of field beans). We may imply an internal transfer of benefits (ecosystem services) within the farmer cluster.

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Our results confirm that **incentivizing and optimizing measures to improve landscape features in farmlands need to be undertaken at landscape scale** although there is still limited appetite to subsidize environmental measures at a scale bigger than the individual farm.

Keywords: biodiversity, natural capital asset profiling (NAP), accounting, farmer cluster

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2. Introduction

The concept of natural capital as a physical stock of resources that yields a flow of benefits to people is widely accepted. These benefits are commonly known as ecosystem services (MEA, 2005). This shift of narrative from the simple analysis of ecosystem services to their interaction with the stock of natural resources, proxied by indicators of extension and condition (quality) is not new. In the recent years several natural capital frameworks have been proposed, some showing an overarching approach to the use of natural assets in decision making (Mace and Bateman, 2020), others more specifically addressing the problem of accounting for nature within national accounting (UN, 2021), tackling the business sectors (Natural Capital Coalition, 2016), or considering the interactions between multiple capitals (e.g., human, social, and physical) (Capitals Coalition, 2021; 2024).

By combining elements of natural capital proposed in the UN SEEA (UN, 20210) with the analysis of natural capital "materiality" for businesses (Capital Coalitions, 2016) and reflecting on the need of an integrated approach (Capitals Coalition, 2021; Capitals Coalitions, 2020a,b), we have developed an approach measuring the benefits for the environment, biodiversity and crop production in those farming systems implementing biodiversity sensitive farming strategies (Martino et al., 2023).

This report describes the implementation of Deliverable D7.3 - A protocol for Natural Assets profiling (NAP) - to assess physical, chemical and biological conditions of natural capital assets in agricultural contexts. The NAP is adopted in a selected farmer cluster covering different enterprises, such as arable and mixed arable livestock farms, to describe impacts and dependencies on natural capital. This is achieved by supplementing primary data collected by a questionnaire survey with secondary data coming from databases and literature.

By implementing the NAP, we offer a simple way to describe the environmental sustainability of the farm that can be replicated over space and time by practitioners to investigate if biodiversity sensitive farming measures are able to generate positive effects for the environment and production. The focus of the H2020 FRAMEwork project is the recognition that biodiversity-sensitive farming represents a critical shift toward more sustainable and resilient agricultural systems. By integrating biodiversity into farming landscapes, these systems can enhance ecosystem services, reduce dependency on external inputs, and improve adaptability to environmental change. While the deliverable D7.2 (Ndlovu et al., 2024) has shaped the social-ecological networks of several farmer clusters to understand the complex relationships between farming practices, biodiversity, and ecosystem services, in this report we focus on a quantitative analyses of key environmental variables suggested by the System of Environmental Accounting –Ecosystem Accounts framework (SEEA-EA) (UN, 2021), and supported by other frameworks (FAO, 2014; Paracchini et al., 2015; Van Cauwenbergh et al., 2007). In this report we consider a range of indicators measuring the dependency and impacts of the farm system on natural capital against a benchmark to answer the following questions:

1. What variables show materiality in terms of dependencies and impacts on natural capital of biodiversity farming approaches?
2. What is the role of landscape features on the biodiversity of birds and pollinators?
3. What aspects of natural capital contribute to the productivity of the farming system?

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4. What is the dependency of farm production on regulating ecosystem services such as avoided soil erosion and crop pollination?

In answering these questions, the report seeks to achieve the following objectives:

- showing how to select, analyse and assess against a benchmark, indicators that can be easily monitored by collecting primary data at farm scale;
- using analysis of variance and simple linear correlations, identify the most important landscape features, their effect on biodiversity index of birds and pollinators, and opportunity cost to production;
- providing through a stochastic frontier approach the impact that regulating ecosystem services may have on production describing margins of improvement by investing in agri-environmental schemes;
- showing at a larger scale the contribution that good soil management may generate for the UK farming (cereal) sector; and,
- summarising results in the light of the EU CAP experience on the use of agri-environmental schemes to suggest a better use of subsidies operating at landscape scale.

The development of the NAP and the promotion of its use has the goal of fostering synergies between agricultural production, biodiversity and the delivery of ecosystem services. Under this perspective, the implementation of the NAP may be useful to advance our understanding of the links between farm management, agrobiodiversity and ecosystem services, proposing a set of indicators that describe not only biodiversity but also other components of the farming system with focus on a range of environmental domains such as atmosphere and land.

We use the NAP to monitor the effectiveness of biodiversity sensitive farming practices by showing their economic and ecological implications and identifying the drivers and limitations of successful outcomes. Working in synergies with the analysis of the sustainability of the farmer cluster, measured by a bundle of indicators referring to social, economic and environmental domains (Task 7.1), this report provides environmental indicators to contribute to the design of a decision-making support tool (FRAMEtest – WP7 task 7.4), designed to test the feasibility and sustainability of different agricultural practices.

The report summarises the methodological approach adopted by the NAP (D7.3), describing the indicators selected and the data collected, and then providing results of the test carried out at the Cranborne Chase (UK) farmer cluster. Biophysical and monetary values of ecosystem services describing the contribution of natural capital to the productivity of the farm cluster are also presented, with expected benefits along the cereal supply chain in the UK under soil conservation scenarios determined by regenerative farming practices. The conclusion presents brief policy recommendations that should be considered in the future CAP to better support regenerative and biodiversity farming strategies.

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3. Methods

3.1 The overarching approach to the implementation of the NAP

This section summarises the approach used to assess the dependencies and impacts of the farmer clusters on natural capital, as detailed in deliverable D7.3 (Martino et al., 2023). The NAP was developed to characterise both qualitative and quantitative aspects of agricultural operations and their links with natural capital (Figure 1). Qualitative valuation can be adopted as a preliminary identification of dependencies and impacts on natural capital focussing on the subjective perception of changes generally investigated by focus groups, or by resorting to farmers' and experts' opinion. Indicators of natural capital examining the extent and quality (condition) of the farm system are implemented. Bio-physical indicators support the quantitative analyses of energy input, emissions of pollution in soil, water and atmosphere (e.g., CO_2, NO_x), and excessive use of materials such as NPK fertilizers that can compromise soil, microbiota, and water quality. In addition, the quantitative analysis considers biophysical indictors of soil management practices and their influence on soil erosion, as well as changes in species biodiversity (some key species of mammals, birds, and insects are indicators of environmental good quality), crops, and diversity of landscape features. It is also part of the quantitative analysis the monetary valuation of the externalities generated by farming and any dependency of farm production on ecosystem services such as avoided soil erosion and crop pollination.

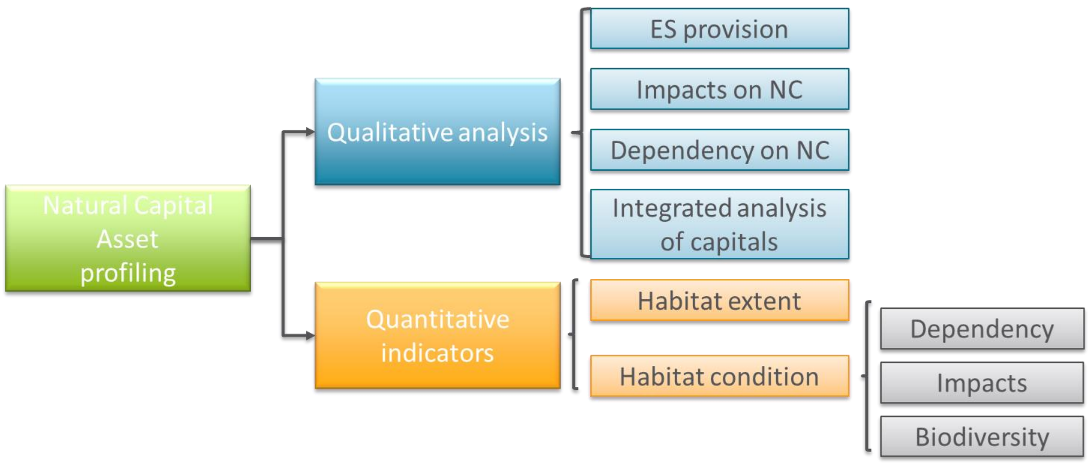

Figure 1. Characteristics of the natural asset profile (NAP) developed in D7.3.

While standard approaches to natural capital valuation ignore the importance of biodiversity, such as the UN SEEA (UN, 2021), and the TEEB Agribusiness (Capitals Coalition, 2020), we think that habitats and species maintenance should be considered as an ecosystem service flow and included into natural capital accounting because of their nature of public good that needs to be monitored and protected. Implications on biodiversity of business operations are now considered by Capitals Coalition (2020a), UNEP-WCMN (2022) and within the natural capital accounting strategies of the European Union (La

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Notte et al., 2021). In the farmland context, biodiversity represented by flagship species such as birds and pollinator insects, but also soil microbiota, plays a crucial role in providing regulating services such as pollination and pest control, that in turn help in lowering operational costs (e.g., expenses for human or manufactured capital like beehives). The quantitative analysis is carried out by combining primary and secondary information (

Figure *2*). Primary data are collected through a questionnaire survey directed to farmers addressing five main areas (for details see the questionnaire survey in Appendix 1[1]):

1. information on production arising from seasonal and perennial crops, and livestock;
2. input used by the farms with focus on the use of different sources of energy (e.g., fuel, electricity, etc.), materials such as seeds, water, fertilisers, pesticides, labour force and capitals goods expressed as machineries and other infrastructure;
3. agrobiodiversity practices such as low to no tillage, use of cover crop, etc.;
4. different biodiversity sensitive farming approaches to sustain birds and insect pollinators;
5. aspects of the farm referring to human, social, and institutional capitals. This set of indicators is not analysed in this report but considered in the Task 7.1.

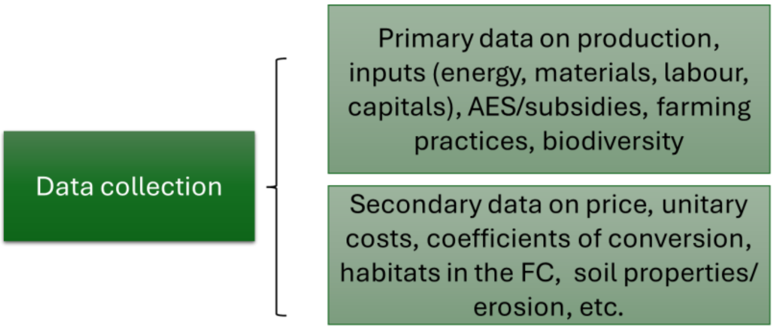

Figure 2. Types of data used for the natural capital assessment.

Secondary data refer to information that could not be readily provided by farmers such as soil properties and the extent and condition of habitats and species. We used recent maps produced within the FRAMEwork project to measure the extent of habitats such as woodlands, hedgerows, grassland, and riparian vegetation protecting river waters from pollution diffusion. In addition, we used information from the literature and databases such as the FADN[2], reporting economic data of EU farms such as price of inputs, cost of labour, etc., and to establish economic benchmark. Other sources available from academic literature and websites[3] were consulted to obtain soil properties, coefficients to convert material inputs (nitrogen, energy, etc.) in indicators suitable to measure the dependencies and impacts of farming on natural capital, and thresholds (or benchmarks) necessary to assess the

[1] This is a further elaborated questionnaire survey building on the version proposed in the Appendix VIII of Deliverable D7.3, benefiting from comments of researchers and practitioners.
[2] FADN database. Standard results about the economic situation of EU farms by different groups https://agridata.ec.europa.eu/extensions/FarmEconomyFocus/FADNDatabase.html
[3] Our World in Data 2022" (https://ourworldindata.org/grapher/carbon-intensity-electricity?time=latest&region=Europe).

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performance of the farm cluster for each natural capital indicator. Details are provided in the Deliverable D7.3.

3.2 The analysis of the natural capital assets in the farmer cluster

Indicators describing the relationships between the farming system and natural capital consider two aspects: habitat extent and condition (quality) (

Figure ***3***). Under the first category of indicators, we measure the proportion of natural and seminatural habitats and assess the extent to which the farming context reaches a level of diversification compared to a pure homogenous arable system. Thus, the calculation of habitat extension is a precursor for the analysis of the diversity of landscape patches, their fragmentation and connectivity. It can be used to collect information over time about changes on natural, seminatural and artificial habitats.

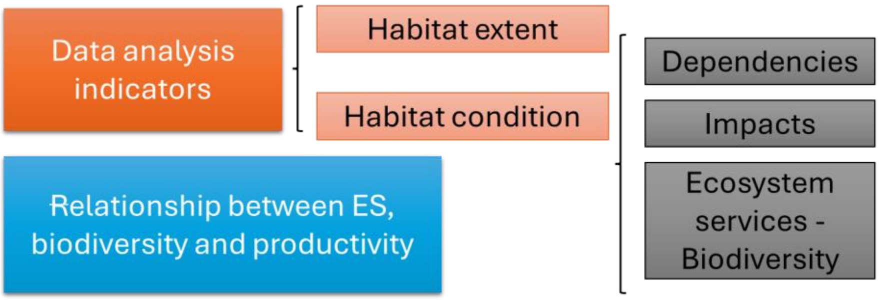

Figure 3. Information used for the analysis of the NAP in the farmer clusters.

A detailed classification of the habitats considered in this report is proposed in Table 11 of Deliverable D7.3. These habitats are aggregated for convenience in five main categories: arable land, woody areas, hedgerows, permanent grassland (herbaceous areas), and semi-natural habitats of the riparian zone. Mapping these habitats over time is useful to measure temporal changes and consider them according to internal or external drivers of impact in the farming system. In this report, we do not provide analysis of the temporal change of the farm habitats. Conversely, a comparison against a benchmark referring to optimal ecological conditions, or the average area occupied by these habitats in the European farming system, is proposed.

The second category of indicators addresses the quality of the farmland habitats and more generally the performance of the farming system. These indicators cover a range of domains (from GHGs emissions to soil erosion; from material and energy use to species and ecosystem diversity). These indicators were selected according to their simplicity of collection and the possibility to be used by farmers and practitioners to assess the "materiality" of natural capital on production (Gualandris et al., 2015). By "materiality", we refer to any consequences on the business operation. Impacts on the financial and legal environment of the business should be considered. Reputational changes in consumers with potential losses in revenue, and increase in taxes, fees, and other costs, expressed as compensations imposed by the legal authority to fix damages to the environment and society, are important too. However, these aspects of materiality are not effectively assessed in this report. We focus on environmental indicators tied to farm operations, paying particular attention to those that underperform against a benchmark.

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Examples of impact drivers and dependencies are reported in Table 1 and Table 2. Impacts on the environment may cause a reduction in the capacity of the business to deliver outputs. In this report, we show examples of good practice in managing soil to reduce erosion, protect habitats for birds and pollinator insects, and contribute to yield. To achieve this, we propose econometric relationships between biodiversity, regulating ecosystem services and crop production. Addressing these connections is vital because degradation of the environment may determine an increase in operational costs. This occurs when ecosystem services, like carbon sequestration, soil fertility, and crop pollination, need to be replaced by human-made services (e.g., manufactured capital) (Capitals Coalitions, 2023).

Table 1. Impact drivers that may positively or negatively affect the farmer cluster (adapted from Table 5 of Deliverable D7.3).

Business – input/output	Driver category
Input	Water use – consumption of water
	Land/habitat use -reduction of natural habitat
	Crop diversity
	Birds and pollinator diversity
Output	Greenhouse gas emissions – from farm operation
	Carbon sequestration – from soil/habitat management
	Soil erosion – soil loss due to harvesting and any other farm operation

Table 2. Natural capital dependency drivers for the farmer cluster (adapted from Table 6 of Deliverable D7.3).

Typology	Dependency category
consumptive	Energy
	Water
	Nutritional elements - fertilizer, seeds, fodder for livestock
	Land use for livestock
Non consumptive	Regulating services – water filtration, flood regulation,
	Resilience of crops – pollination and pest control
	Assimilative capacity – pollutants removed by vegetation and river
	Knowledge – to improve skills and practice approaches that improve ecosystem resilience
	Wellbeing, cultural values – mental and physical health, access to green spaces

3.3 Indicators for the assessment of the natural capital in the farmer cluster

Table 4 proposes indicators of environmental performance following the natural capital asset condition types suggested by the UN SEEA. The table reports if each indicator is a measure of dependency or impact on natural capital, and if it is expression of stock or flow of natural capital. A combination of

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primary and secondary information is used to calculate biophysical and (where possible) monetary values for the indicators proposed.

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Table 4. Selection of the ecosystem condition indicators proposed in Deliverable D7.3.

Asset condition type	Indicator	Dependency/ impact	Stock/ flow	Data required
Chemical	CARBON FOOTPRINT - Total GHG emissions associated with FC production activities (indicator of atmospheric pollution)	Impact	flow	Primary + secondary
Chemical	CARBON EMISSION DURING HARVESTING (Indicator of Land Degradation)	Impact	flow	Secondary
Physical	VOLUME OF WATER REQUIRED FOR THE CROPLAND (Indicator of Water Use & Withdrawal)	Dependency	flow	Primary
Physical	UNIT OF WATER USED PER UNIT OF PRODUCTION (Indicator of Water Use & Withdrawal)	Dependency	flow	Primary
Physical	SHARE OF ALTERNATIVE WATER RESOURCES (rainwater, surface water and shallow ground water) (Indicator of Water Use & Withdrawal)	Dependency	stock	Primary
Structural	PRESENCE OF GRASS STRIPS (Indicator of Water Quality)	Impact	stock	Primary + secondary
Chemical	ORGANIC CARBON STOCK OF THE SOIL (Indicator of Soil Quality)	Dependency	stock	Secondary
Chemical	PHOSPHORUS STOCK OF THE SOIL (Indicator of Soil Quality)	Dependency	stock	Secondary
Chemical	NITROGEN STOCK OF THE SOIL (Indicator of Soil Quality)	Dependency	stock	Secondary
Structural	PERCENTAGE OF VEGETATED SOIL COVER (Indicator of Land Degradation)	Impact	stock	Primary + secondary
Functional	SOIL LOSS BY WATER EROSION (USLE) (Indicator of Land Degradation)	Impact	flow	Primary + secondary
Functional	SOIL CARBON SEQUESTRATION UNDER SENSITIVE FARMING (Indicator of land degradation)	Impact	flow	Primary + secondary
Structural	SOIL TILLAGE INDEX (Indicator of Land Degradation)	Impact	stock	Primary

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Asset condition type	Indicator	Dependency/ impact	Stock/ flow	Data required
Structural	TREE COVER STOCK/AREA OF WOODLAND (Indicator of Ecosystem Diversity)	Impact /dependency	stock	Primary + secondary
Structural	HEDGEROW STOCK (Indicator of Ecosystem Diversity)	Impact	stock	Primary + secondary
Structural	CROP DIVERSITY (Indicator of Ecosystem Diversity)	Impact	stock	Primary
Chemical	N FARM-GATE BALANCE (FERTILIZERS MANAGEMENT) (Indicator of Material Use)	Dependency	flow	Primary + secondary
Chemical	N USE EFFICIENCY (Indicator of Material Use)	Dependency	flow	Primary
Chemical	PESTICIDE USE (Indicator of Material Use	Dependency	flow	Primary
Physical	ENERGY INPUTS REQUIRED FOR CROPLAND (Indicator of Energy Use)	Dependency	flow	Primary
Physical	AMOUNT OF PRODUCTION PER UNIT OF ENERGY (Indicator of Energy Use)	Dependency	stock	Primary
Physical	RENEWABLE ENERGY - SHARE FOR THE TOTAL ENERGY CONSUMPTION IN FARMING (Indicator of Energy Use)	Dependency	flow	Primary
Physical	RENEWABLE ENERGY PRODUCED IN THE FARM (Indicator of Energy Use)	Dependency	flow	Physical

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3.4 The area of work

We have tested the NAP at the Cranborne Chase UK farmer cluster, covering several typologies of farm enterprises. This cluster is located in Wiltshire, England (UK), as an example of arable and mixed farm type. This cluster is currently composed of 19 farms and extends for 20,000ha. Each farm size is approximately 500ha, characterised mainly by arable land (395ha). Main crops cultivated are wheat and barley. Mixed farms complement the arable production with livestock grazing and cattle beef rearing. Some of these mixed farms operate adopting an organic protocol.

3.5 The questionnaire

To analyse the impacts of biodiversity sensitive farming, we have collected both primary and secondary information. Primary data were collected by a questionnaire survey whose ethical implications were reviewed by the Ethics Committee of the James Hutton Institute (see Appendix 1, 2 and 3). The questionnaire is divided in several sections: 1) size and type of farm, 2) agricultural produce, 3) livestock farming, 4) labour and capital costs, 5) farming business resources (seeds, fertilizers, pesticides, fuels, electricity, etc.), 6) subsidies and agri-environmental scheme implemented, 7) other types of diversified income, and 7) quali-quantitative questions referring to farm business policies, protocols, and attitudes to governance, social and economic matters. The last part of the questionnaire is not adopted here but used to evaluate the overall sustainability of the farm in the Task 7.1.

Secondary data are contained in databases and maps produced by EUROSTAT, the European Environmental Agency (EEA), and European Commission (EC)/JRC. We extracted indicators referring to soil carbon stock; soil erosion/soil erodibility; soil and water retention, and soil nutrients (N, P, K).

4. The selected indicators

This section summarises the approach followed for the analysis of the indicators proposed in Table 4, with proposal and justification of a benchmark. Indicators are reported according to their dependency or impact on natural capital and are aggregated by subject. A more extensive description is proposed in Deliverable D7.3.

4.1 Indicators of dependency

4.1.1 Water

This is measured through gauges and is quantified in cubic meters per year (m^3/year). Its consumption is variable and related to the typologies of crops cultivated, soil properties and bioclimatic conditions (Wriedt et al 2009). To monitor the efficiency of the resource used, we suggest measuring water per unit of surface (m^3/ha), per weight of crop production (m^3/t) or per head of livestock. Examples of water requirement in Europe for crops are provided by Wriedt et al (2009), who showed that net water use (soil water deficit) ranges from 42 mm/yr (420 m^3/ha/year) in the UK to 1,120mm/yr (11,200 m^3/ha/year) in Spain. Data from Wriedt et al (2009) is used to establish a benchmark in the arable farm system. For instance, a benchmark for the UK water abstraction can be considered the interval 55 to 98 m^3/ha.

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In addition, water can be abstracted from several sources. Measuring water share coming from alternative sources can be important to judge on the sustainable use of this resource.

4.1.2 Fertilizers and pesticides

The use of fertilizers is reconstructed through the questionnaire survey asking the type of product, the quantity used for each crop, and the area of application. Alternatively, information about the total cost spent for fertilizers can be combined with the unitary cost available in datasets to deduce the total amount of fertilisers used. Average fertiliser cost was €100-150/ha in 2018 (EU Agricultural Economic briefs (europa.eu)), while from 2018 to 2022 it increased by 200% (GB fertiliser prices | AHDB). To get a measure of efficiency, it is opportune to normalise the amount of fertilizer used by the cultivated area. Benchmark adopted for this indicator is the average input of NPK for different farming systems in Europe (European Commission, 2021):

- Field crops: 150kg/ha
- Horticulture: 350kg/ha
- Permanent crops<100kg/ha
- Milk: 100kg/ha
- Granivores: 100kg/ha
- Mixed:100kg/ha

Nitrogen farm gate balance can be reconstructed in the farmer cluster by performing an analysis of the nitrogen metabolism as proposed by Sainju (2017). This balance is determined through:

- recording the value of any major inputs of nitrogen (coming from soil, external fertilization and fixation);
- recording the value of nitrogen embedded in the final outputs;
- calculating the difference between the previous measures.

The three steps proposed above are implemented by collecting primary data on the use of nitrogen in the farm, and secondary data on the outtake of nitrogen for different typologies of crops. Table 36 (page 109) and Table 37 (page 110) of the NAP (Deliverable D7.3) provide details on the average amount of nitrogen fixated by leguminous and the percentage of nitrogen absorbed by several crops. Benchmark proposed for different farming systems is the average nitrogen farm gate balance in European farms (EEA, 2019):

- 68kg N/ha for the crop system;
- 155kg N/ha for dairy farm;
- 135kg N/ha for pig farm

The use of pesticides is recorded following the same approach used for fertilizers. Farmers were invited to directly state the quantity of pesticides used per crop, and the area dedicated to each crop, or to provide information on the expenses sustained to acquire the product and the number of applications (sprays) per crop. The cost of pesticides was deduced by secondary information retrieved from the web (http://www.agchemicalsolutions.com/pesticides). Benchmark is expressed as the average amount of pesticides (kg) used in European farms per unit of area (hectare). In 2022, Eurostat recorded

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a consumption of 322,000 ton of pesticides (Eurostat, 2024) spread over 157 million ha of cropland. From these figures, we can estimate that the average use of pesticides is about 2.05kg/ha.

4.1.3 Energy

We considered the total energy used in the farming process as measured in kWh. Indirectly, energy consumption can be considered a measure of CO_2 emissions from the farming operations. This indicator is measured through primary information collected by the questionnaire survey on the use of fuel, oil, lubricant, and electricity from the grid. Conversion from litres of fuel to kWh is made by using a scaling factor. We assumed that 0.11 litres of fuel produce 1 kWh of electricity (fuel efficiency units conversions).

Efficiency can be measured as the amount of energy per area of land cultivated or per tonne of production. A benchmark for this indicator is derived by Paris et al. (2022), who estimated the annual energy use in agriculture (open field) at 1,431 PJ (Peta Joule=10^{15} Joule). On-farm energy (mainly represented by diesel) accounts for 31% of the total energy inputs, while irrigation, storage, drying, and other activities require 8% of electricity from the grid (Paris et al. 2022). We assumed that 39% of 1,431 PJ is the energy necessary for infield operations. Converting this estimate in kWh (155 billion) (EUROSTAT, 2022) and dividing it by the total European agricultural land (157 million ha), gave a benchmark of 987 kWh/ha.

The share of energy provided by the grid through renewable sources is a good indicator of how sustainable the consumption of energy in the farming system is. This indicator is easily measured by formulating a specific request to the farm owner/manager. The benchmark adopted is the average renewable energy consumed in 2022 in the EU, equivalent to 22.5% of the total energy consumption (EEA, 2024).

The energy produced through wind turbines and photo-voltaic systems is a measure of the amount of renewable energy generated in the farm. This indicator captures the level of production decoupled from CO_2 emissions. However, there is a lack of statistics on the renewable energy produced and used in the European farms, making it challenging to establish a benchmark. Solar panels may produce in the UK ideally 480,000kWh/ha (Biofuelwatch, 2018) To generate for a hectare of land half energy required by farming (equivalent to nearly 400 kWh/ha), it is necessary to install more than 4,150 panels covering a surface of 0.83ha. Thus, if we assume as benchmark the production of 50% of the energy used in the farm, the surface covered by the photovoltaic panels should be equal to 0.17% of the farmland.

4.1.4 Income

Farmers can specify through the questionnaire survey the activities that are directly or indirectly related to farming and indicate the income share of these activities. This indicator is a measure of income diversification and a proxy for the farm's survivability in case of reduced farming subsidies. The benchmark, which we have considered, is the average income obtained from diversified activities as a percentage of the total farm business income. This is approximately 20%.

An important source of income is given by the Pillar I subsidies of the CAP, and voluntary implemented agri-environmental schemes (AES) (Pillar II). The first information is measured as percentage of subsidies with respect to the total revenue. The second is measured assuming the five most important AES by amount received per hectare, and the area involved by each scheme. Because of the lack of information in the literature, we have decided to use figures contained in the EU Farm Accountancy Data Network (FADN) to establish a benchmark. The FADN database showed in 2022 for the EU 27 subsidies amounting to €13,500 for the field crop sector; €14,300 for mixed farming; and €22,000 for dairy farm. In terms of income share, this is equivalent to 9%. This value is used as benchmark in this report. The latter figure is a weighted average split as follow: 16% for livestock, 13% for field crops, 11% for mixed crops, 7% for dairy, 8% for other permanent crops, and 1% for horticulture.

4.2 Indicators of impact

Indicators of impact refer to the increase in carbon emissions due to the use of direct emissions from fuel and energy consumption, the use of fertilizers and pesticides and change in soil properties caused by water erosion, harvesting and tillage practices.

4.2.1 Carbon emissions from material and energy use

4.2.2 Carbon emissions from soil erosion: the importance of farming practices

We have considered the carbon released from soil by erosion and corrected for arable land by agricultural practices (Panagos et al.,2015). The universal soil loss equation (USLE) is used to measure erosional processes of ecosystems compared to bare land (Panagos et al., 2015) in tonnes per hectare per year. This calculation is provided using secondary information on soil erosion mapped by the JRC of the EU Commission (Soil erosion by water (RUSLE2015)). The conversion from soil erosion to carbon loss is then made by adjusting soil erosion by the content of carbon in the areas of interest. This is achieved using mapped information of carbon content such as the Topsoil Soil Organic Carbon (LUCAS) for EU25 produced by the JRC.

Panagos et al. (2020) showed that approximately 25% of the EU land has an erosion rate higher than the recommended sustainable threshold (2 t/ha/year), and more than 6% of agricultural lands suffer from severe erosion (11t/ha/year). Under a sustainable soil erosion threshold of 2t/ha/year, assuming an average content of carbon of 3%, a benchmark of 0.22t/ha/year of carbon lost as CO_2eq is considered.

Agricultural practices may alter the amount of carbon emissions. We consider soil carbon emissions as the difference between the soil erosion measured under standard conditions in conventional arable land, and the erosion achieved by applying conservative agricultural practices. Panagos et al. (2015) describe how to recalibrate the USLE equation under the presence of soil conservative farming approaches such as low or no tillage, use of cover crops and presence of vegetational habitats such as grass and shrubs. Details can also be found in Table 32 of Deliverable D7.3.

It is difficult to propose a benchmark for the avoided soil carbon emissions compared to the loss measured by the USLE equation. We can expect any change ranging from 0 to 100%. The higher this change, the better the performance of the conservative approaches implemented in the arable system.

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4.2.3 Soil carbon sequestration

This indicator is essential to monitor sustainable farming practices and reduce soil degradation. Change in soil carbon can be obtained by introducing natural elements such as grass strips, green cover banks, natural meadows, and hedgerows. We use the carbon sequestration rates proposed by Aertens et al. (2013), who estimate a sequestration of 0.1t C/ha/year for hedgerows, 0.1t C/ha/year for practicing no tillage, 0.16t C/ha/year for using cover crops and 2.75t C/ha/year for implementing agroforestry practices. To set a threshold above which the performance of the farm can be considered optimal under this indicator, we refer to the adoption of organic best practices (including composting and agroforestry).

It is estimated that organic farming produces in Northern Europe 28% higher soil carbon levels than non-organic farming. This represents a soil carbon sequestration rate of approximately 560kg C/ha/year (2tCO_2/ ha/year) for each hectare of cultivated land converted to organic farming in the UK (Soil association, 2009). We use a benchmark of 1tC/ha/year as upper limit of carbon sequestration achievable in non-organic farming.

4.2.4 Land management and composition of habitats

The composition of the farm in terms of habitat diversification is considered an indicator of good land management. The more homogenised is the farm landscape, the more degraded it can be considered.

Benchmark measuring a good mix of land uses is extracted by the European Environmental Agency and EUROSTAT publications. According to the EU Green Deal, a good diversity can be achieved bringing back high-diversity landscape features on at least 10% of agricultural land by 2030, including woody features (e.g., tree lines or tree groups), and hedges among other small habitats.

Woody landscape features covered 5% of the EU's agricultural land in 2018, ranging from 2.6% in Cyprus to 9.3% in Ireland (EEA, 2024b). Permanent vegetation consists of a broad range of habitats (woodlands, grasslands, permanent crops, agroforestry, etc.) that in the EU covers 34% of the agricultural area and are vital for a wide variety of ecosystem services essential for our society (Schils et al., 2022). Similar information is provided by EUROSTAT that estimates permanent vegetation to cover 37% of farmlands (EUROSTAT, 2023). We consider the latter value the benchmark against which to compare the permanent vegetation reported in the farmer clusters.

Notwithstanding a good presence of total permanent vegetation, the contribution of shrubs, hedgerows and field margins is still negligible. According to Staley et al. (2023), the average hedgerows extent in the UK, in landscapes where hedges are a frequent feature, is approximately 4.2 km/km^2. Fuller et al. (2001) found that species richness (e.g., birds' richness) would benefit from an increase in hedgerows extent in the United Kingdom to around 8–13.8 km/km^2.

The average width for hedgerows is 2.7 m in the UK (Gelling et al., 2007). However, this may range between intensively managed shrubs (2.5m width) and less intensively managed shrubs (7m width) (Kratschmer et al., 2024). If we set the optimal density at 10 km/km^2 (average of the value reported by Fuller et al., 2001), and the width at 4.75 m (average of the values reported in Kratschmer et al., 2024), the area of the farmer cluster that should be dedicated to hedgerows is 4.75%.

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Additional indicators that measure the state of land management and degradation are the area of farm receiving low to no soil tillage, and the field covered by cover crops in winter. The first is measured by asking farmers to report the area of land that is not under conventional tillage. The UK still has very high per cent of normal tillage. Low tillage in the UK is 47.6% of arable land, while only 7% is under no-tillage, compared to some EU countries where it is estimated to be close to 50% (Jaworski et al., 2024). The average figure in Europe for low to no tillage practice is 26% of the agricultural land (Kertész et al., 2013). We use this statistic as a benchmark to measure the performance of low tillage farming. Regarding the second indicator, the literature shows that cover crops were grown on 19% of the European arable land where no winter crop was established. However, there are considerable regional differences, ranging from 0% (North, South and East of Europe) to 92% (Atlantic coast) (Fendrich et al., 2023). We use the figure of 19% as a benchmark to assess the performance of the farmer cluster.

4.2.5 Crop diversity

A wider range of crops can be grown to limit the diffusion of monoculture and improve soil quality. Thus, land management can be improved by increasing the diversity of crops expressed as richness of cultivar per hectare. The number of crops cultivated in the previous 12 months is used to calculate the Shannon index of crop diversity. There is not a benchmark for the Shannon index, but the maximum value it can get is equal to the *natural log* of the number of crops produced. For many farming systems not more than 5 or 6 crops are produced. Therefore, we expect a maximum theoretical value between 1.6 and 1.8. However, real values record in the EU are only between 0.5 to 0.9, with the upper bound of the interval only reachable in organic farming (Schaak et al., 2023).

In the typical European farm, characterised by 10-30ha of arable land, it is recommended to grow at least 2 different crops, while farms operating with more than 30ha of arable land should grow at least 3 different crops. The main crop should not cover more than 75% of the arable land. This means dedicating on average 5 to 10ha of arable land per crop (ClimateXchange, 2016).

4.2.6 Agri-environmental schemes

Another proxy of greener agriculture is given by the area of land covered by agri-environmental schemes (AES). This indicator is measured using primary information from the farmers about whether they are enrolled in a public/private scheme, the income received per hectare, and the typologies of land use management in place. In England, 26% of agricultural land was targeted for AES in 2023 (JNCC, 2023). We use as a benchmark the average amount of European land managed under AES (22.5%).

4.2.7 Species diversity

We have considered diversity of birds and pollinators species to monitor the biodiversity management strategies of the farm. Species diversity is measured by the Shannon index (Konopiński, 2020). This is a measure of the variety of species that considers both the richness and the evenness of the community.

The basic information to quantify this indicator was collected through field surveys, coordinated by the farmer clusters facilitator, in selected areas and transects of the farmer clusters covering several habitats where number of individuals and species were recorded. FRAMEwork has set an internal protocol (unpublished) for farmers and farmer cluster facilitators to collect data on birds and insects

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and proposed a range of indicators and metrics implemented in the DST FEAST (Warner and Tzilivakis, 2022). The protocol shows farmer cluster facilitators how to make the correct use of a spatially stratified sampling design, in which clusters are divided into squares appropriate for the average farm size (typically 0.5-1km^2). A subset of squares is surveyed with an equal number of control squares, under the same farming system, identified outside of the cluster. Deliverable D7.3 (Figure 24 and Table 26) shows an example of data monitoring in the Southern Estonia farmer cluster of the relative abundance of the most common species of butterflies and pollinator insects (*Bombus* species). Value of the Shannon index is expected to be between 1.5 to 3. We assume this range (mainly the lower bound) as a benchmark in this study.

4.2.8 Water quality

Water quality should be measured considering the concentration of pollutants, and in particular nutrients and pesticides. Because of the difficulties in measuring this information, we have used as a proxy the presence and extension of grass buffering the riverbank of the farms. We have identified all areas of water in the cluster, and then selected 10 random 10m x 10m squares that touch one side of the water body. We have calculated the cover of herbaceous area in these squares because of the strong evidence of agrochemical mitigation (Cole et al., 2020). According to these authors, the effectiveness of buffer strips to absorb diffused pollution tends to be positively related to width, increased distance from in-field management practices, and greater area of vegetation that intercepts pollutants. Schmitt (1998) suggested that widths of 7.5m was effective at trapping sediments and sediment-bound pollutants (e.g. insoluble phosphates), whereas controlling of soluble pollutants (e.g. nitrates and dissolved phosphorus) required a vegetation buffer of 15m. This is confirmed by other authors such as Lin et al (2002) who found that increasing buffer strip width from 4m to 8m would not reduce loadings of soluble herbicides. Similarly, a meta-analysis by Valkama et al. (2019) indicated no impact of width on nitrogen removal efficiency, contrary to the model predictions made by Zhang et al. (2010).

These results make it difficult to derive a generic optimum grass width at the riparian bank, however, for gentle slopes (less than 10% gradient), widths of 8–15m may be considerate adequate (Dorioz et al., 2006). We assume as a benchmark the presence of a buffer strip of 10m characterised by 100% herbaceous habitat. We assume that each hectare of buffer strip can remove up to 70kg of the nitrogen farm gate balance (upper bound) (Lyu et al., 2021; Dlamini et al., 2022).

5. Analysis of data

The indicators proposed in the previous sections were measured for each farm and averaged to get the mean value for the farmer cluster. To calculate the dispersion of the data, standard deviation was used. The average value for each environmental indicator is simply compared with the benchmark to suggest what aspects of the farmer cluster are more critical for farming and the protection of natural capital.

These indicators can be used to assess the impact of regenerative practices and biodiversity sensitive farming strategies on avoided soil erosion, soil carbon sequestration, landscape change composition, use of low tillage, and diversity of birds and pollinators.

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The impact of natural capital condition on crop production is estimated using a production function approach. This approach is commonly used to address the impacts that natural capital may have on marketable outputs. Here, the environment is treated as an "input" to the economic activity, as a measure of the impact it may generate on the production of a marketed output (Barbier, 1994; 2000). A Cobb-Douglas like production function (Biddle, 2011; Felipe and Adams, 2005) is used to regress crop production versus a proxy representing physical and manufactured capital, and a second covariate representing natural capital. While the Cobb-Douglas function requires specification of the classical inputs of production such as energy and fertilizers, fixed assets, agricultural area and labours (Bernini and Grilli, 2024), because of our limited dataset, we have considered only two variables, one as a proxy for natural capital, the others as a proxy for fixed and manufactured capital. The goal is to test the effect that agri-environmental schemes, proxied by the area of the habitats dedicated to pollinators and regenerative practices have on the productivity of the arable system.

6. Ecosystem services in the farmer cluster

Some of the indicators outlined in the previous sections can also be described as ecosystem services. These are "contributions of ecosystems to the benefits that are used in economic and other human activities" (UN, 2021, page 121). These benefits represent the utility arising from the farming system through the production of a range of final goods or services. While ecosystem services contribute to the generation of environmental and social benefits, they can also be considered input in the production process along with other factors such as produced assets and labour. This is particularly evident in agriculture, where the human and manufactured inputs are essential to generate yield. The ecosystem services evaluated in this report are listed in Table 5 and classified according to the MEA (2005) in provisioning, regulating and cultural.

Table 5. Ecosystem services in agricultural environment and benefits generated assessed in this report (source: modified by the SEEA (2021)).

Ecosystem Services	Description	Ecosystem	Ecological factors determining the supply	Metrics	Benefits
Crops provisioning services	Provisioning services - contribution to the growth of cultivated plants	Arable land	Water retention carbon and nutrient stock promoted by nutrient cycling	Tonnes of production per crop and per ha	Crop products
Grazed biomass provisioning services	Provisioning services - contribution to the growth of grazed biomass that is an input to the growth of cultivated livestock	Pastures	Soil fertility, water supply, genetics	Tonnes of grazed biomass	Livestock and livestock product

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Ecosystem Services	Description	Ecosystem	Ecological factors determining the supply	Metrics	Benefits
Perennial crops	Provisioning services - contribution to the growth of cultivated plants	Fruit trees, olive groves, vineyard	Soil fertility, water supply, genetics	Tonnes of production per typology and hectare	Fruits, olives grapes and derived products (oil and wines)
Water supply	Provisioning services – contribution of water flow regulation, water purification, and other ecosystem services to the supply of water	Freshwater, ground water	Quantity and quality of water stocks	Cubic metres of water, by type of quality	Consumptive use by the economy and society
Climate regulation	Regulating services – contribution to reducing concentrations of GHG in the atmosphere through the removal (sequestration) of carbon	Forest, woodland and shrubland ecosystems, also grasslands and cropland ecosystems	Ecosystem type and condition, especially structural State (tree cover density)	Tonnes of carbon and other greenhouse gases sequestered in biomass and soil	Reduced concentrations of GHG in the atmosphere leading to less climate change and fewer adverse effects
Soil erosion control	Regulating services – contribution to the stabilising effects of vegetation, that reduce the loss of soil (and sediment) and support use of the environment (e.g., agricultural activity, water supply)	Forest, woodlands, arable land with cover crops	Geology, soil type, vegetation, cover crops, rainfall patterns	Tonnes of soil Retained, higher fertility, reduced need of fertilizers	Soil stability: reduced runoff, and retained fertility
Water purification	Regulating services – contribution to breakdown or removal of nutrients and other pollutants by ecosystem components	Mainly freshwater and associated vegetation	Ecosystem condition and chemical state affect	Tonnes of pollutants remediated by type of pollutant	Reduced concentrations of water pollutants providing improved health outcomes

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Ecosystem Services	Description	Ecosystem	Ecological factors determining the supply	Metrics	Benefits
Pollination services	Regulating services - contribution by wild pollinators to the fertilization of crops that maintains or increases the abundance and/or diversity of other species that economic units use or enjoy	Many ecosystem types (shrublands, woodlands), mainly near cropland areas	Abundance and location of wild pollinators	Area of crops pollinated; number of pollinators visits	Higher crop production dependent on pollinators; reduced need for alternative forms of pollination, including paid pollinator services

6.1 Economic valuation of ecosystem services

Building on the list of the ES proposed in Table 5, we have selected some of those services that can be valued in monetary terms such as crop and livestock production, carbon emissions, soil carbon sequestration, water purification, crop pollination and soil retention (avoided erosion).

6.1.1 Crop and livestock production

The most common approach for the valuation of crop is the resource rent. This approach consists in removing from the gross value of the produce the cost of inputs and employment to obtain the gross operating surplus; then by subtracting from this last value the depreciation of fixed capital and the return on produced assets, it is possible to obtain the resource rent. The latter is considered the monetary contribution of natural capital to the production of biomass. The survey proposed in Appendix 1 contains a series of questions to facilitate the estimation of the gross revenue and any cost that must be removed to get the resource rent (Equation 1):

$$RR = TR - C - (rK + \delta) \qquad Eq. 1$$

RR is the resource rent; TR is the total revenue from sales; C is wages and other input costs; r is the return to produced capital; K the produced capital used in the production process; δ is the depreciation value of the produced capital. Details on how to use Eq.1 are proposed in Deliverable D7.3.

6.1.2 Carbon emissions avoidance

Emissions avoidance under low to no tillage practices is used to measure the economic value of the avoided carbon loss by multiplying this indicator by the non-traded value of the carbon price, as proposed by the UK Government (2021). In 2020, the central value of a tonne of non-traded CO_2 was estimated at £241. In a similar way, it is estimated the value of carbon sequestration considering the capacity of soil carbon retention provided by landscape features such as agroforestry, hedgerows and grass strips.

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6.1.3 Avoided soil erosion

The value of avoided soil erosion is assessed by measuring the marginal impact on crop production of regenerative practices reducing erosion by using a production function approach (see results section for more details). This marginal impact is multiplied by the value of the crop production to estimate the marginal change in value of avoided soil erosion.

6.1.4 Crop pollination

The value of crop pollination is assessed similarly to that proposed for avoided soil erosion. A regression analysis is used to quantify the marginal change in the production of pollinator-dependent crops (e.g., field beans) for a variation in the area dedicated to agri-environmental schemes, considered a proxy for biodiversity measures (see results section of the regression analysis for more details).

6.1.5 Water purification

To measure the value of water purification, we have extracted the area of grassland within 10 meters from the riverbank for all the farmers in the farmer cluster. We assumed that each hectare of riparian grassland can remove up to 70kg N/ha/year (Lyu et al., 2021; Dlamini et al., 2022). We used the nitrogen farm gate balance as a reference point for the total amount of nitrogen that the riparian system can remove. We have used the prudent value of £14/ kg of nitrogen removed, as assessed for the EU territory by JRC, using the cost of a constructed wetland as a proxy of the monetary benefits generated by the removal of nitrogen. For details, see Deliverable D7.3, section 9.3.2.

7. Results

7.1 The characteristics of the Cranborne Chase farmer cluster (UK)

We have collected primary data on the structure, economy and production of 12 farms sampled at the Cranborne Chase, Wiltshire, (UK), during the farming season 2022/2023. Five of these farms operate in the arable system, while the remaining are mixed farms combining crop production and livestock grazing. The size of each farm (500ha) exceeds the average size reported in the UK statistics (85ha), and the area dedicated to crop cultivation occupies 79% (395ha) of the whole farm surface.

The average number of crops cultivated per farm was 4.58 and the average land utilised per crop is 70ha. The main crops produced were wheat and barley generating an average cumulative output per farm of 1,400t, while secondary productions were given by oats (280t), seed rapes (226t) and field beans (200t). Wheat was the crop with the highest production (9.5t/ha), while the average total output was 6.2t/ha.

The average livestock enterprise was characterised by the presence of 172 units of livestock, with a range that goes from 4 to more than 300. The most common types of livestock were beef cows, heifers for breeding and steers. The livestock unit per hectare was 2.15. Land dedicated to fodder production was 83ha with a production of nearly 13t of fodder per ha. This is equivalent to a production of 27t of fodder per unit of livestock. These figures show that the mixed farms were self-sufficient in livestock feed and were capable of being net exporter of fodder. The characteristics of the farm cluster are summarised in Table 6.

Table 6. Average characteristics of the Cranborne Chase farms (based on a sample of 12 farms).

Descriptor of the farm	Average	Standard deviation
total size of the farm (ha)	500.67	483.65
arable land (ha)	395.25	429.17
rented land (ha)	77.41	95.64
crop production (t)	2,935.04	3,183.48
total crop production per hectare (t/ha)	6.25	2.88
wheat production per hectare (t/ha)	9.56	2.19
crop diversity N. of crops	4.58	2.47
crop diversity - hectare of land per unit of crop	69.73	51.33
crop diversity - Shannon Index	0.44	0.21
livestock (N)	172.33	175.65
land for livestock grazing (ha)	83.57	114.28
livestock unit per hectare	2.12	1.25
hay silage/fodder crop (t)	572.33	993.18
land for fodder crop (ha)	71.75	133.37
fodder crop per hectare (t/ha)	12.86	12.18
fodder crop per unit of livestock	27.70	59.00

7.2 The economy of the farmer cluster

The total revenue ranged from £64,000 to £2,500,000 per farm, with an average value of £994,000. Nearly three quarters of this value (73%) was generated by agricultural activities, while the remainder was from diversified income such as agri-tourism (9%) and public subsidies (18%). The latter were made of support to income and voluntary agri-environmental measures. Revenues from environmental subsidies generated by the implementation of agri-environmental schemes (AES) were 9% of the total income.

Costs for the acquisition of manpower, energy (electricity and fuels) and materials (e.g., seeds, fertilisers, pesticides, etc.) and the depreciation of capital assets such as machineries and buildings were estimated in the range £24,000 to £1,800,000, with an average estimate of £485,000 per farm. Table 7 reports the share of costs among several categories. More than 80% of the total costs was covered by material, energy and depreciation of capital assets.

Table 7. Average costs per farm within the farmer cluster.

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Category	Average cost (£)	Cost in per cent (%)
Feed	5,108.33	1
Fertilisers and pesticides	199,713.82	41
Fuel, electricity	87,830.40	18
Labour	69,514.61	14
Depreciation of machineries and buildings	122,999.19	25
Total	**485,166.35**	**100**

The farm income business, or profit, as a difference between revenue and total cost, was estimated in the range £40,000 - £1,300,000, with an average of £509,000. This is equivalent to a profit per unit of area (hectare) of £1,588/ha, with diversification between the arable and mixed farming system. The arable farm had a profit of approximately £1,200/ha, while the mixed farm of nearly £1,900/ha. The contribution of agricultural activities (crop production and livestock rearing) in these two farm systems was 42% and 25% of the farm business income, respectively. The mixed farms seemed more dependent than arable farms on other activities to support their profitability as proposed in Figure 4.

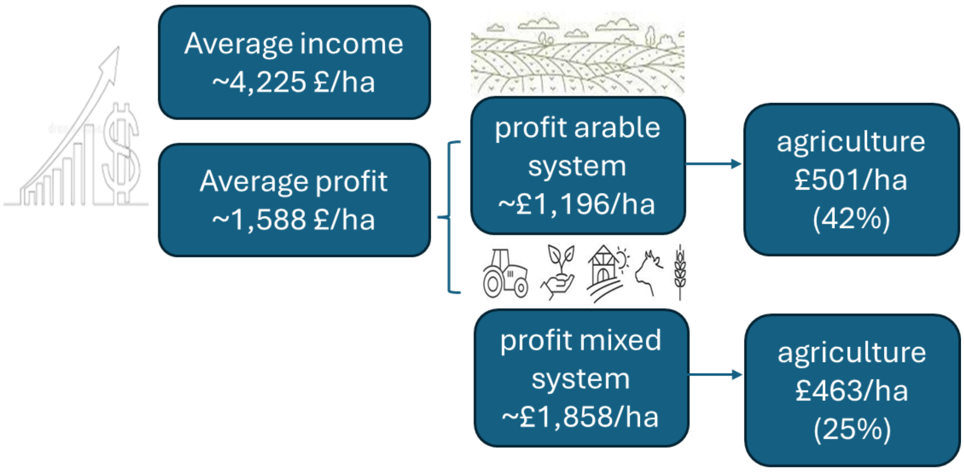

Figure 4. Infographics summarising the impact of agricultural production on the profitability of the farm.

Profits generated only by the agricultural activities, although positive for the farmer cluster (£247,500 per farm), were negative in three cases, one arable and two mixed farms, ranging from £-145,000 to £-2,700. For these farms the diversification of income seems a necessity.

The profit of the agricultural activities alone can be assimilated to the *resource rent*. This is the economic benefit generated by the natural capital when costs of all human, physical and financial assets are removed. In only three cases, the resource rent is negative representing a net loss ranging from 2% to 42% of the total profit. Overall, the average resource rent in the farmer cluster is positive

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showing that natural capital contributes to 48% of the whole profit (Figure 5. Estimate of the resource rent as a measure of the impact of natural capital in the production of crop and livestock). This estimate is exaggerated, because it does not consider the return in capitals. However, it is congruent with figures proposed by La Notte et al. (2021), who found average values of resource rent in the EU farm system between 20% and 40%.

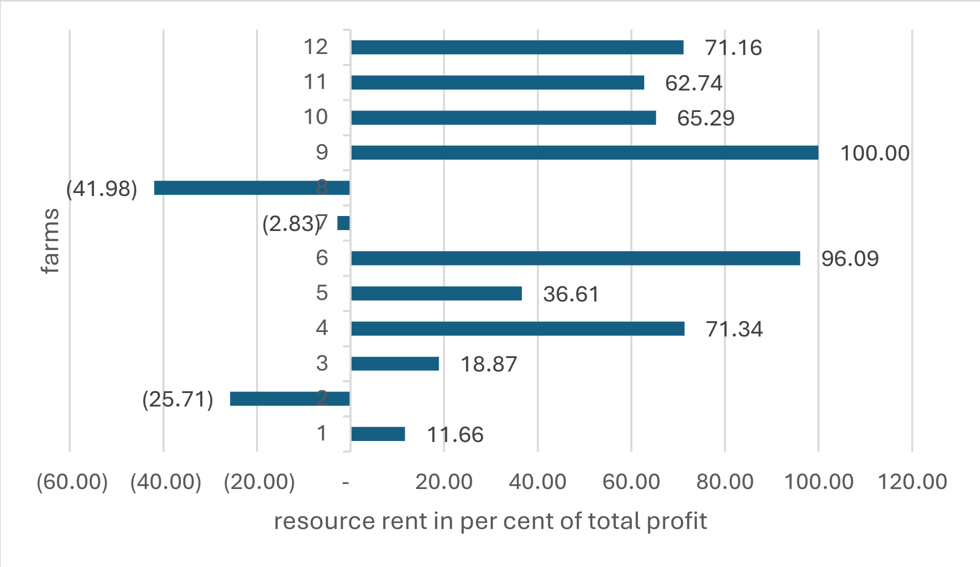

Figure 5. Estimate of the resource rent as a measure of the impact of natural capital in the production of crop and livestock.

7.2.1 Agribusiness activities

The figures proposed in the previous section show the importance of complementing farm income with additional earnings from a variety of activities. These activities range from property rental to self-catering. Some farms have their own farm shop and generate income through the production of solar energy. Renting properties can be quite remunerative representing in some cases 20% to 60% of the total income. Energy production and the organization of events can generate additional income from 3% to 5%. The revenues arising from the diversification of the economy is equivalent to 11% of the profit.

7.2.2 Agri-environmental schemes

While direct payments are essential for the financial sustainability of the farm, representing a big proportion of the farm income, in our survey we have focussed on the total income generated by agri-environmental schemes (AES). These represent 7% of the total subsidies, generating an average income of £338/ha, equivalent to 21% of the profit. The average area of the farm covered by AES is 242ha, representing 38% of the total area of the farm. Figure 6 summarises the main schemes implemented at the Cranborne Chase.

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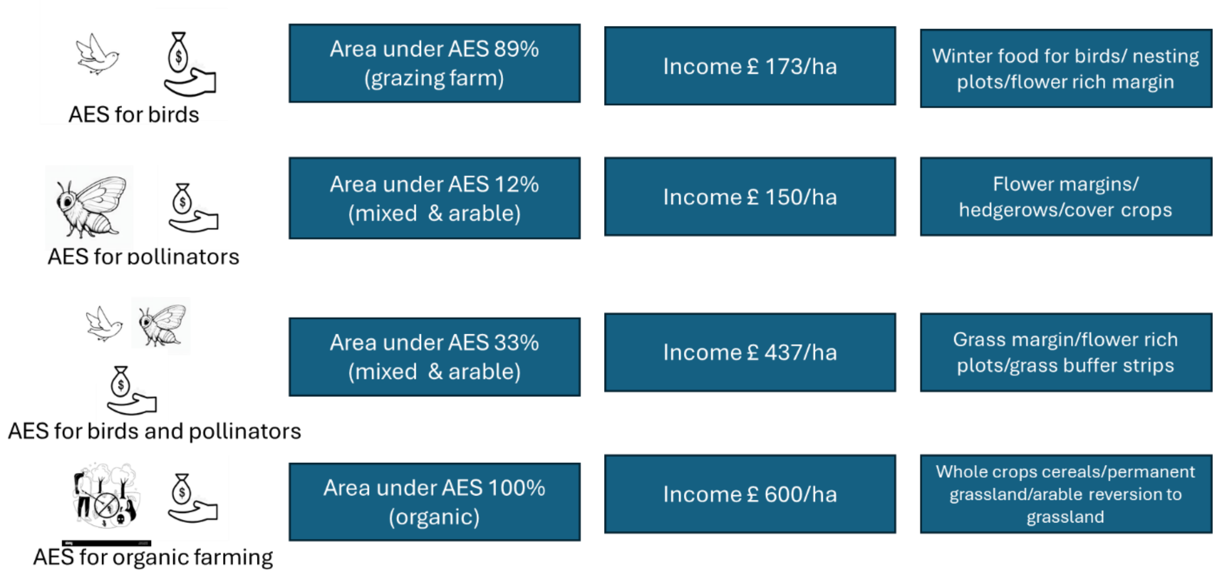

Figure 6. Info-graphic reporting the main AES used at the Cranborne Chase and their economic contribution to the income of different typologies of farms.

As shown in Figure 6, the highest support to farm income is generated by those agri-environmental measures facilitating a transition to organic production and reversing arable land to grassland. Measures supporting birds and pollinators are characterised by the implementation of grass margins, flower rich plots and grass buffer strips. In arable and mixed enterprises, these measures cover on average 33% of the farm size. There is a grazing farm in our sample that has nearly 90% of the area under AES designed to protect birds, while other mixed and arable farms implement measures for pollinators only such as flower margins and hedgerows extension in 12% of the farm.

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8. Materiality of natural capital on the farm business

This section presents some of the indicators of dependency and impact listed in Table 4 that are considered critical in the performance of the farmer cluster.

8.1 Material dependency of the farm business

Table 8 proposes metrics of dependency on external input and natural capital. Others relating to the role of ES on farm business (i.e., production) are proposed in the section "*Dependency of crop production on natural capital*".

Table 8. Dependency of farming at Cranborne Chase on Natural Capital.

Dependency of crop system	average	std dev	benchmark	benchmark reference
water - m3/ha/year	12.88	26.34	50-90	Wriedt, G., Van der Velde, M., Aloe, A., Bouraoui, F. (2009). Estimating irrigation water requirements on Europe. Journal of Hydrology 373(3-4), 527-544.
N farm gate balance - kg N/ha	0.08	89.98	68	EEA. 2024. Agricultural land: nitrogen balance.
NPK use - kg/ha	197	101	150	EEA. 2024. Agricultural land: nitrogen balance.
Dependency of livestock system	**average**	**std dev**	**benchmark**	**benchmark reference**
livestock - unit/hectare	2.15	1.25	0.7-0.8	Eurostat. 2023. Agri-environmental indicator
fodder crop per unit of livestock -t/year/LSU	27.7	59	3.5	Rana, P., Tewari, S.K., Kumar, V. and Kumar, A., 2016. Floristic structure, composition and functional characteristics of home gardens in Garhwal Region, Uttarakhand, India. International Journal of Agriculture, Environment and Biotechnology, 9(6), pp.1045-1059.
Dependency of farming from energy system	**average**	**std dev**	**benchmark**	**benchmark reference**
energy inputs per hectare - KWh/ha	938.27	566.19	987	The annual energy use in EU open-field agriculture is at least 1431 PJ. Taking only the energy from diesel (31%) and electricity (8%) as benchmark, this is equivalent to 155 billion kWh, or 987 kWh per ha in the EU, assuming the total agricultural land is 157 million ha in Europe (Paris et al., 2022).
share of energy consumption from renewable - %	10.83	27.52	22.5	In 2022, 22,5% of the energy consumed in the EU was generated from renewable sources, according to our early estimates.

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Table 8 shows a very limited consumption of water. However, this is not a sign of lack of dependency on this natural asset, but rather the difficulty to report the right amount of water utilised because of the lack of a system metering the water used by the cropping and livestock enterprises. Literature on arable system shows that for the UK a minimum of 50 m^3/ha/year of water is required (Wriedt et al., 2009), a value three times higher than the estimate made in this report.

The farmer cluster shows a higher use of fertilizer than reported by the European average farm. Nevertheless, many farms can remove nearly the totality of the fertilisers through uptake into the grains and stems of the cultivars. Data collected reveals that only three farms are critical (an arable, a mixed and a horticulture system), having a nitrogen farm gate balance higher than the benchmark (68kg N/ha/year, the average nitrogen balance for the arable system in Europe). In Table 8, additional input such as pesticides is not reported because its consumption was not considered critical (less than 2kg/ha).

The livestock system is highly dependent on natural capital. In fact, the livestock enterprise is totally independent from external sources of fodder and characterised as a net exporter of animal feed. The density of livestock per hectare (2.15 units) is two to three times higher than the European average (0.7-0.8), despite being a typical figure for improved grazing systems. This makes the livestock enterprise highly dependent on permanent grasslands with risk of increasing soil compaction and erosion because of the high-density of animal stock.

In terms of energy, the Cranborne Chase farmer cluster uses less energy than the EU average farming system. The amount of energy taken from the grid electricity and fuels is calculated as 938 kWh/ha compared to a benchmark of 987 kWh/ha.

A non-satisfactory figure is provided for the use of renewable energy. Renewable energy consumption is half the average European use. However, the benchmark proposed refers to the demand of renewables from the whole society and not just the farming sector.

8.2 Impacts of the farm business

The farming system can generate a series of impacts on natural capital. Table 9 summarises the negative effects on the natural capital measured by indicators referring to pollution of atmosphere, degradation of soil, and impacts on biodiversity. From Table 9, it emerges that the Cranborne Chase farmer cluster generates impacts on two environmental domains, land degradation and biodiversity.

Soil management practices such as reduced soil tillage, adoption of cover crops, expansion of grasslands and shrublands, are delivering carbon sequestration below the adopted benchmark. A better performance is shown by organic farms.

All the farms report at least five different types of crops. This is considered a good standard for the EU farming system, where on average 10 to 15ha are dedicated to each crop. Considering the scale of the Cranborne Chase (10 times bigger than the average EU farm), the amount of land dedicated to each crop is much bigger (70ha) than in the European farming system. The diversity of crop production measured by the Shannon Index is 0.44 versus an optimal value of 0.8 - 0.9 (Schaak et al., 2023). These

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figures support the need to implement features such as semi-natural habitats that may contribute to break the landscape homogeneity of the arable system.

Landscape features that have received limited interest include hedgerows. Although dedicated schemes to extend hedgerows area are available, only 0.80% of the farmland is occupied by this landscape feature. This figure is much lower than the selected benchmark of 4.5%, considered as minimum requirement for generating ecosystem services such as crop pollination.

The increase in biodiversity is considered a critical aspect, with special attention to pollinators. Biodiversity index for pollinators (0.7) was only half the lower bound of the benchmark (1.5) because of the limited variability of semi-natural habitats in arable land. Conversely, the extensive use of grasslands providing suitable habitats for birds increased the Shannon index so that it was only 16% lower (1.2) than the lower bound of the benchmark (1.5).

Some of the negative indicators proposed in Table 9 are compensated by positive impacts, as suggested in Table 10. Within the Cranborne Chase, we recorded relatively low amount of CO_2 emissions per ton of crop production which is nearly half the benchmark proposed by the UK Agriculture and Horticulture Development Board (AHDB) in 2022.

The adoption of low tillage and cover crops is also well established; and the higher diversification of the farming landscape by permanent grasslands, hedgerows and woody features (such as trees lines) compared to the European agricultural system, generates CO_2 sequestration in the order of 0.55t/ha/year.

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Table 9. Key indicators measuring negative impacts of farming at Cranborne Chase on Natural Capital.

Impacts of crop system and land management on CO_2 sequestration	average	std dev	benchmark	Benchmark reference
soil carbon sequestration - t CO2e/ha/year	0.55	0.46	0.5-1	The conversion of a farm from standard to organic practices (including composting and agroforestry) can sequester 1tC/ha/year. Organic farming practices produce 28% higher soil carbon levels than non-organic farming in Northern Europe. This represents a soil carbon sequestration rate of approximately 560kg C/year (2 tCO2/yr) for each hectare of cultivated land converted to organic farming in the UK - Soil association (2009).
Impacts of crop production on land management	**average**	**std dev**	**benchmark**	**Benchmark reference**
crop diversity - Shannon Index	0.44	0.21	0-1	Typical values are generally between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4. Applied to crop diversification, this indicator ranges from 0.8 to 0.9, where the highest value is achieved in case of organic farming (Schaak et al., 2023).
biodiversity of birds - Shannon Index	1.25	0.22	1.5-3.5	Typical values are generally between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4. The Shannon index increases as both the richness and the evenness of the community increase. A summary of indices for estimating diversity and dominance are proposed by the University of Idaho.
biodiversity of pollinators (bumblebees) - Shannon Index	0.71	0.12	1.5-3.5	As above.
Impact of crop production on land use	**average**	**std dev**	**benchmark**	**Benchmark reference**
scrubland and hedgerow stock- %	0.80	0.40	4.5	Several taxa would benefit from an increase in hedgerow extent in the United Kingdom to a density of 8–13.8 km/km^2 (Staley et al., 2023). To set the benchmark, we assume here a density of 10 km/km^2 and an average width of 4.5 m.

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Table 10. Key indicators measuring positive impacts of farming at Cranborne Chase on Natural Capital.

Impacts of the crop system on atmospheric emissions	average	std dev	benchmark	benchmark reference
GHGs emissions from farming – t CO_2e/t produce/year	0.21	0.08	0.2-0.3	A benchmark for the CO2e emissions per ton of cereal is 300-400kg per ton of product. This figure includes the CO2 emitted by fertilisers manufacturing AHDB and CHA (2022). Benchmark for only field operation 0.2-0.3.
GHGs emissions from soil erosion - conventional tillage - CO_2e t/ha/year	0.15	0.00	0.22	Panagos et al. (2020) showed that ca. 25% of the EU land has erosion rates higher than the recommended sustainable threshold (2 t/ha/yr) and more than 6% of agricultural lands suffer from severe erosion (11 t/ha/yr). Under a sustainable threshold of 2 ton/ha/year, assuming an average content of carbon of 3%, the benchmark is 0.22tC/ha/year.
Impacts of the crop system on farm management	**average**	**std dev**	**benchmark**	**benchmark reference**
area receiving low to no tillage - %	64.20	38.12	26	Conservation agriculture is practiced on 22.7 Mha, representing 25.8% of arable land in Europe (Kertesz and Modarasz, 2014)
crop diversity – number of crops	4.58	2.46	3	It is suggested to have at least 3 crops for 30ha and more of farmed land. Farmers with 10 to 30ha of arable land are recommended to grow at least 2 different crops; those with more than 30ha arable land must grow at least 3 different crops, with the main crop covering no more than 75% of the arable land (ClimateXChange, 2016).
area of land dedicated to cover crop - %	58.73	36.87	19	In 2016, cover crops were grown on 19% of the European arable land where no winter crop was established, with considerable regional differences, ranging from 0% (North, South and East of Europe) to 92% (Atlantic coast) (Fendrich et al., 2023).
impact of crop production on land use	**average**	**std dev**	**benchmark**	**benchmark reference**
tree cover stock/woodland - %	12	11	10	The EU Green Deal aims to bring back high-diversity landscape features on at least 10% of agricultural land by 2030, including woody features like tree lines, tree groups and hedges among other small habitats.
grassland/permanent vegetation - %	38.90	30.60	34	Permanent grasslands cover 34% of the European Union's agricultural area and are vital for a wide variety of ecosystem services essential for our society (Schils et al., 2022).

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9. Effect of natural capital and AES on birds and pollinator biodiversity

We have assessed the diversity of birds and pollinators using the Shannon Index, a measure of how diverse species in a community are. This index is affected by the number of species and their abundance. In the following sections, the Shannon index for birds and pollinators is presented showing their relations with natural capital and the area dedicated to different agri-environmental schemes (AES).

9.1 Bird biodiversity

Figure 7 shows the boxplot of the birds Shannon Index in three different farming systems and between farms adopting different AES. Pasture is the system that shows the highest average value and the least dispersion. The farms implementing AES tailoring bird biodiversity show on average the highest value of the index. Some farms implementing a mix of AES for birds and pollinators show values going beyond the benchmark. However, the same category of AES addressing both birds and pollinators schemes may achieve very poor performance. We can deduce that the environmental characteristics of the farms and farming practices may have an important effect in causing this result.

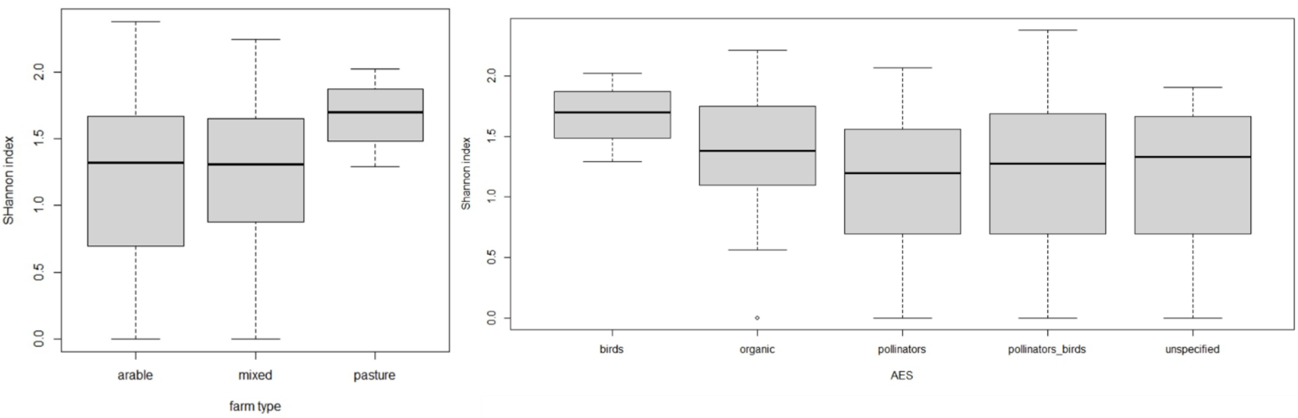

Figure 7*.* Boxplot of the birds' Shannon index in different farming systems (left) and measured under different agri-environmental schemes (AES).

The impact on bird biodiversity of different AES is confirmed by a mixed linear regression. Sampling plots are as random variable, while typologies of farming, AES and time of sampling are fixed effects. The variables AES and time of sampling explain the difference in the Shannon Index (

Table ***11***). This information, combined with Figure 7 suggests that AES for birds and organic farming practices have a better performance over other AES.

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Table 11. Analysis of variance – linear mixed model of bird biodiversity under farm types and AES.

Variable	Sum of squares	Mean of squares	Num Df (degree of freedom)	Den Df (degree of freedom)	F value	Pr(>F)
Farm type	0.05329	0.02665	2	325.32	0.1393	0.87001
AES	1.62379	0.54126	3	261.96	2.8298	0.03894*
Survey (time)	1.27840	1.2784	1	250.11	6.6837	0.01030*
Farm type:AES	0.30730	0.30730	1	291.36	1.6066	0.50598
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1						

The linear mixed model proposed in

Table ***11*** is used to make a prediction of the Shannon Index as shown in Figure 8. Organic mixed farms are expected to have the highest average Shannon Index and the least mean error. Excluding organic farming, arable farm systems outperform mixed farms. The expected average birds' Shannon Index is similar between the pasture and organic farm systems, although in pasturelands the estimate is uncertain.

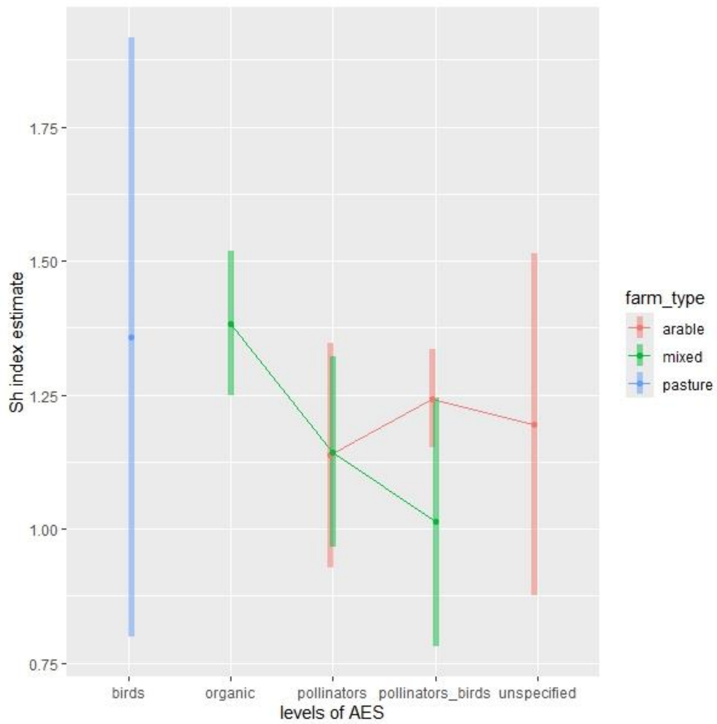

Figure 8. Prediction of the Shannon index for different farm systems under different AES. Dots represent the average value, while the bar the 95% confidence interval.

The better performance of pasture and organic systems in providing higher bird biodiversity, seem to be related to lower crop yield, reduced use of fertilisers, and a higher presence of grasslands, as shown at Figure 9 and by the pairwise correlations at Table 12. As expected, increase in fertilisers and crop yield are associated with a reduction in the Shannon Index, while permanent vegetation and soil carbon sequestration are positively correlated with the index. In contrast to expectation, higher crop diversity is not associated with higher bird biodiversity (Table 12).

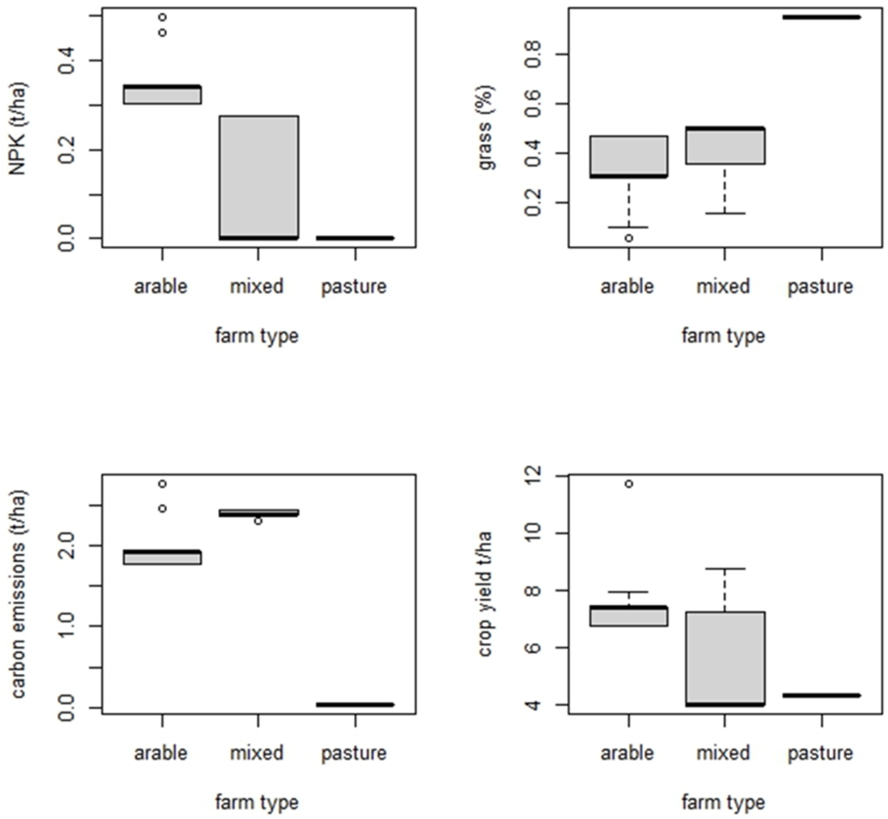

Figure 9. Performance of farm types under different environmental indicators.

Table 12. Pairwise correlation between birds Shannon Index and natural capital indicators.

Natural capital indicator	Pairwise correlations All significant at p level<0.05
NPK per ha	-0.7463*
CO_2e farm emissions per ha	-0.8445*
Soil carbon sequestration per ha	0.7795*
Crop yield per ha	-0.8246*
Permanent vegetation (grassland)	0.9117*
Crop diversity	-0.839*

The backward stepwise linear model proposed in Table 13 shows that the only variable (amongst landscape features and soil regenerative practices) that affects the birds' Shannon Index is the presence of permanent vegetation, that at the Cranborne Chase is mainly represented by grassland.

Table 13. Stepwise regression model explaining impact of permanent vegetation on the birds Shannon Index and natural capital indicators.

Variable	Estimate	Std error	t-value	Pr(>t)
Intercept	0.99103	0.05639	17.575	2.18e-06 ***
Permanent vegetation (%)	0.67766	0.12465	5.437	0.00161 **
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Residual standard error: 0.09535 on 6 degrees of freedom (4 observations deleted due to missingness)				
Multiple R-squared: 0.8313, Adjusted R-squared: 0.8031 F-statistic: 29.56 on 1 and 6 DF, p-value:0.001607				

Prediction of linear model in Table 13 is shown in Figure 10, where it is evident how the pasture system outperforms the others because of the nearly exclusive presence of permanent grassland that facilitates the presence of suitable habitats for birds.

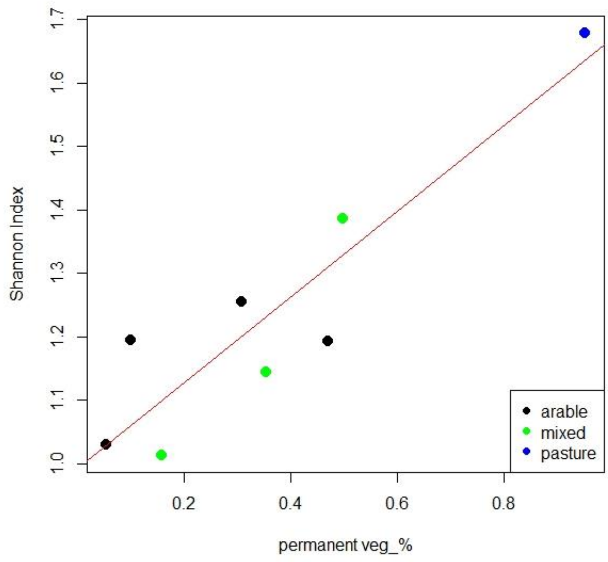

Figure 10. Plotted observations (dots) and expected values (regression line) of the birds Shannon index versus percentage area of permanent vegetation in the farm.

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9.2 Impacts of grassland extension on crop production and income

The model proposed in Table 13 is a linear-log relationship showing that a 1% increase in permanent vegetation would increase the Shannon index of 0.0067 units. If we assumed a scenario characterised by 10% increase in grasslands, the expected average Shannon index in the farmer cluster would be expected to change from 1.24 to 1.31. We can expect this scenario to generate an opportunity cost because of the loss of 10% of the arable land in each farm. On average, this loss would affect an area of 40ha per farm. If the additional land chosen for expanding grassland was "marginally productive", with a limited productivity of 4t/ha (lower quartile), we might expect a loss in net profit of £12,800-£16,000 per farm, equivalent to £320 to £400/ha. The current average AES income is £340/ha, sufficient to generate an economic incentive to extend grass over marginally productive areas.

9.3 Pollinator biodiversity

Pollinator biodiversity (bumblebees' species) is summarised by the Shannon Index in the boxplot proposed in Figure 11. It is not possible to visually depict the differences in the average value of the Shannon index between the three farming systems, but only in its variability (standard deviation) (Figure 11, left boxplot). A clearer picture is provided in Figure 11 (right boxplot), which shows differences in the Shannon index between different AES. Organic, birds and pollinators AES appear to offer values closer to the average (0.77), but the differences between these farms do not appear to be statistically significant. Conversely, difference in biodiversity value between farms non-implementing AES is more evident (Figure 11, right boxplot).

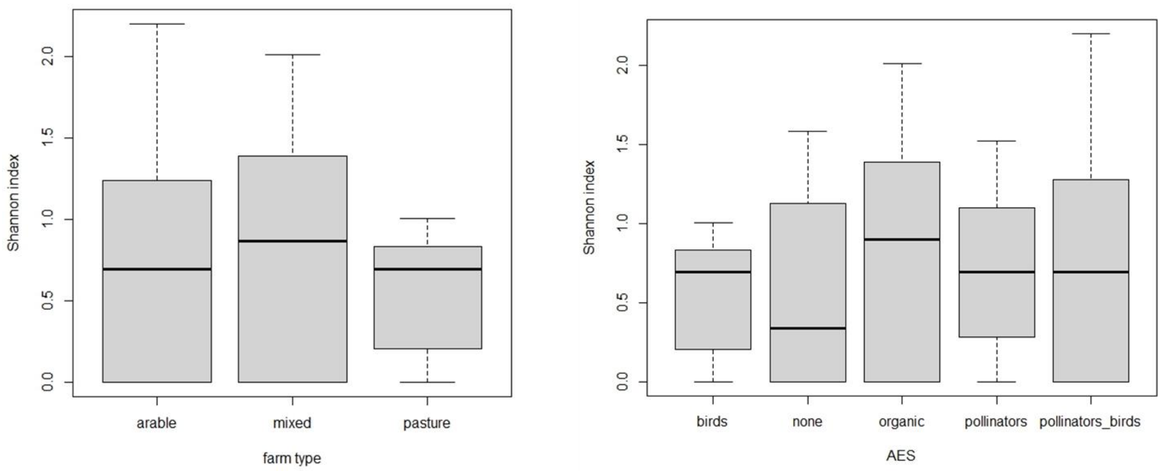

Figure 11. Boxplot of the pollinators Shannon index in different farm systems (left) and under different agri-environmental schemes (AES).

Figure 11 suggests lack of evidence between farm types, AES and biodiversity Shannon index, as also proposed by the analysis of variance in Table 14, where we have modelled sampling transects and time of survey (survey round) as random effect, while farm types and AES as fixed effect.

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Table 14. Analysis of variance – linear mixed model of pollinator biodiversity under farm types and AES.

Random effect Groups Name	Variance Std.Dev.
Transect (Intercept)	0.20420 0.4519
Survey Round (Intercept)	0.05728 0.2393
Residual	0.18170 0.4263
Number of obs	148, groups: Transect, 85; Round, 2

Variable	Sum of squares	Mean of squares	Num Df	Den Df	F value	Pr(>F)
Farm type	0.182408	0.091204	2	91.01	0.5020	0.6070
AES	0.07080571	0.023524	3	104.74	0.1295	0.9020

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

While the difference in pollinator biodiversity is not significantly affected by different farm types and AES (Table 14), the variability of the Shannon index proposed in Figure 11 (left) in arable and mixed farms seems to be related to some key landscape features proposed in Figure 12 such as the reduced presence of grass and the greater availability of trees, hedgerows and shrubs.

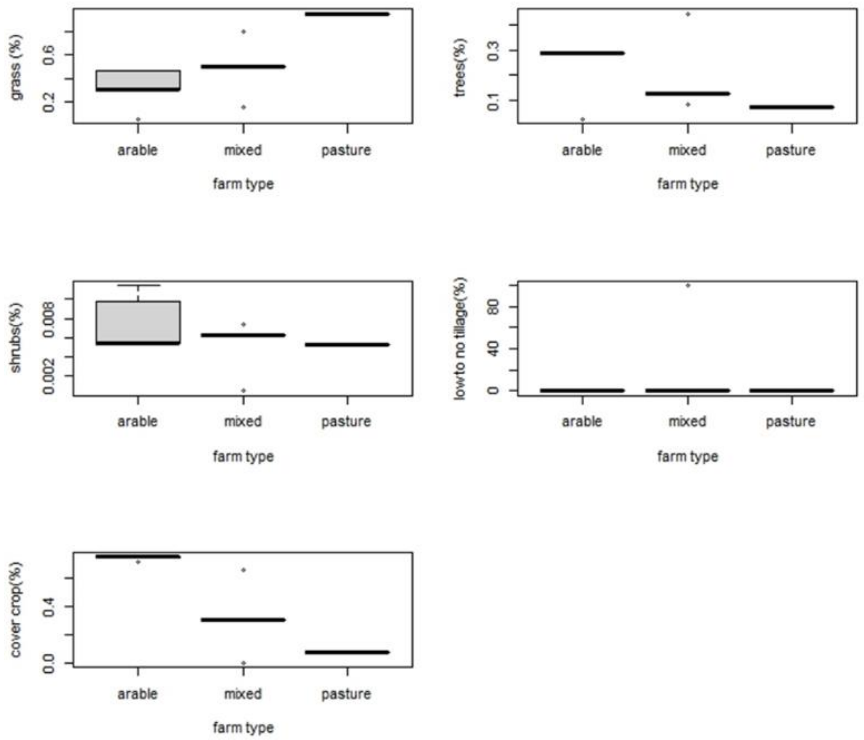

Figure 12. Boxplot showing environmental features of the Cranborne Chase farmer cluster under different farm types. Farms implementing AES for pollinators are characterised by reduced cover grass

and relevant presence of shrubs, hedgerows and cover crops. These features seem to influence biodiversity positively, compared to farming systems characterised by mainly the presence of grassland (e.g., pasture) (Figure 13).

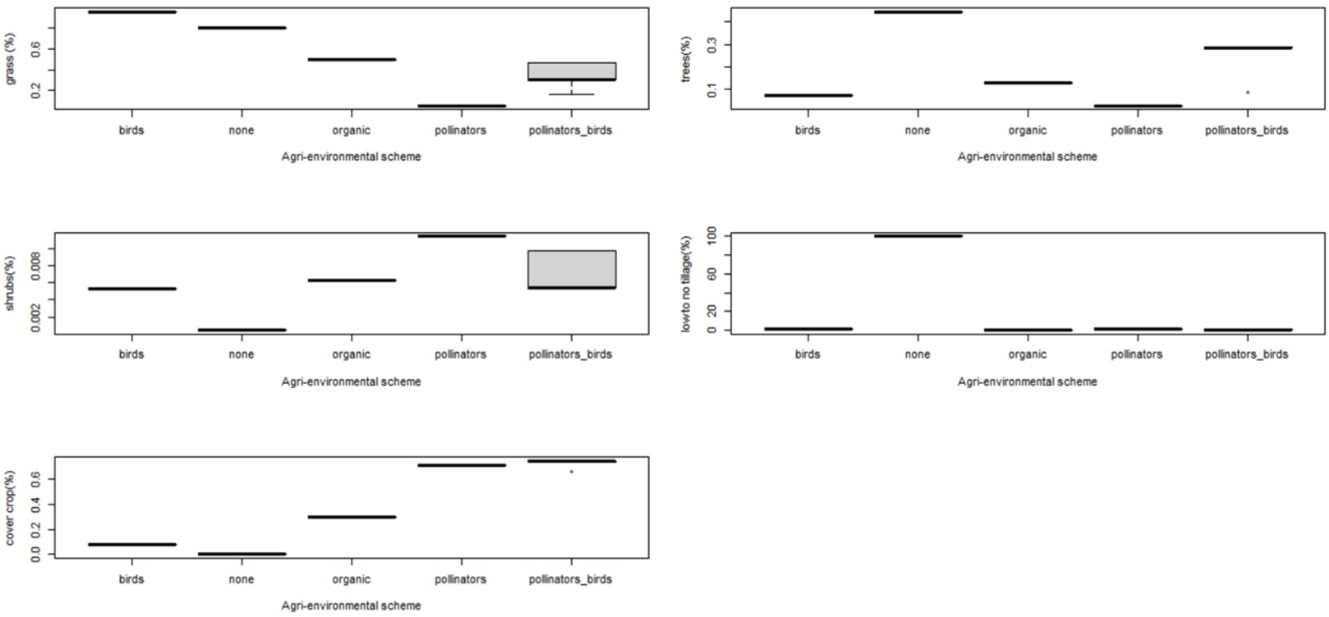

Figure 13. Boxplot of the environmental characteristics of the farmer cluster classified according to different AES.

We used a backward stepwise linear regression model to show the importance of hedgerows (over other landscape features) in increasing pollinator biodiversity (Table 15). The Shannon Index for pollinators is a function of the natural log of the hedgerows area (Table 15 and Figure 14).

The log-log regression model proposed in Table 15 indicates that an increase of 1% in hedgerows generates a 7% increase in the Shannon index. To increase the pollinators index from 0.7 to 1, it is necessary to extend the area dedicated to hedgerows by 200%. This would imply that at least 2% of the average area of each farm (nearly 10 ha, compared to the current 4 ha) should be dedicated to the cultivation and management of hedgerows.

Table 15. Stepwise regression model explaining the impact of hedgerows on the pollinators Shannon Index.

Variable	Estimate	Std error	t-value	Pr(>t)
Intercept	0.43787	0.04400	9.952	0.000175
Log(area hedgerow+1)	0.0730	0.0265	2.755	0.040066
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				
Multiple R-squared: 0.6029, Adjusted R-squared: 0.5235 F-statistic: 7.591 on 1 and 5 DF, p-value: 0.04007 Residual standard error: 0.06083 on 5 degrees of freedom				

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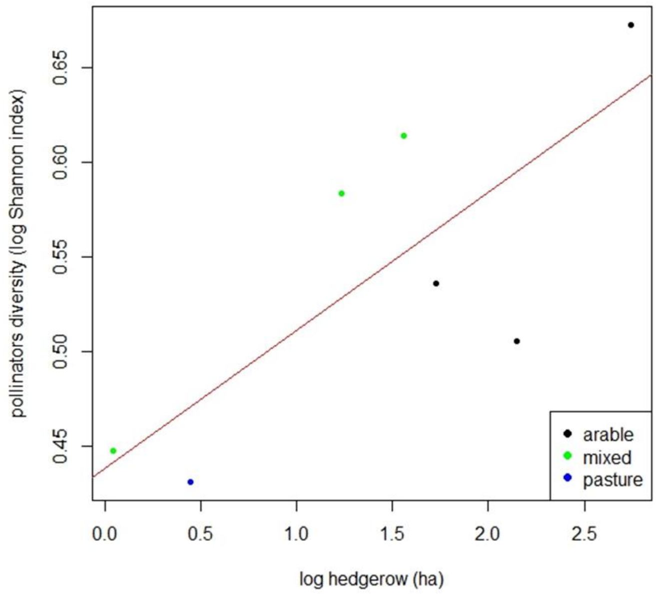

Figure 14. Observations (dots) and expected values (red line) of the relationship between pollinator biodiversity and area dedicated to hedgerows.

Figure 14 visualises the relationships between the area of hedgerows and pollinator biodiversity. This relationship was made using 7 data points. Of these, only one represents pasture farming (the blue dot). This agricultural system offers the largest area dedicated to grassland, but the least availability of semi-natural features preferred by pollinators. Conversely, mixed and arable systems are those characterised by a greater extension of hedgerows and trees.

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10.Dependency of crop production on natural capital

We expect that crop production may have strong dependency on some ecosystem services. In this section, we explore this hypothesis complementing the information provided in Table 8 that has summarised dependencies of the farm cluster only on external inputs (e.g., energy and materials).

To show the role of ecosystem services on crop production, we have implemented a Cobb-Douglas production function (Cobb & Douglas, 1928), originally designed to estimate the impact of labour and capital on a country's economy. We have used this approach to assess the benefits of soil retention and crop pollination on cereal and field beans production, respectively.

We impose that the agricultural production is characterised by constant economy of scale (Kariel and Savagar, 2022). Under this assumption, crop production increases by a scalar *k* if all factors of production are scaled by the same factor *k*. To simulate constant return to scale, we apply to the regression model a restriction imposing that the sum of the coefficients of the regressors is equal to one. Because of the limited data available, running the production function with the full set of variables explaining labour, land and capital is not possible. Therefore, we run two models, each characterised by two regressors, one representing natural capital, the second physical capital. In the first model, crop production is regressed against the total energy (electricity, fuels and fertilisers) used in the farming system and the avoided soil erosion. In the second model, field beans production is regressed versus pesticides and the area extension of agri-environmental scheme for birds and pollinators, as a proxy for the supply of crop pollination.

10.1 Impact of soil avoided erosion on crop production

Table 16 shows the results of the impact of soil retention on crop production. To get the coefficient for the variable avoided soil erosion, we used the following transformed variables:

- (Dependent variable): [ln(crop production+1) -ln(total energy per ha+1)]
- (Independent variable): [ln(avoided erosion+1)- ln(total energy per ha+1)]

Table 16. Production function showing the impact of soil retention (avoided soil erosion) and total use of energy on the average crop production.

variable	estimate	Std error	t value	Pr(>t)
Intercept	-3.9813	1.6516	-2.411	0.0367*
ln(Avoided Erosion +1) t/ha/year	0.3624	0.1971	1.839	0.0958 .
Multiple R-squared: 0.2527, Adjusted R-squared: 0.1779				
F-statistic: 3.381 on 1 and 10 DF, p-value: 0.0958. Residual standard error: 0.3977 on 10 degrees of freedom				
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				

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With a p level <0.1, it is possible to say that avoided erosion has a marginal impact on crop production. To measure the coefficient for the second regressor (the total energy used in the farming system), we used the following regression:

- (Dependent variable): [ln(crop production+1) -ln(avoided erosion+1)]
- (Independent variable): [ln(total energy per ha+1)- ln(avoided erosion+1)]

The estimate for the total energy variable is equal to 0.6376 (the complementary to one of the avoided soil erosion regression coefficient), and the standard error 0.1971; It is highly significant with t value 3.236, and p(>t)=0.0089**.

These regression coefficients are lower than one, thus respecting the decreasing marginal utility of the production factors, and their sum adds up to one, respecting the constant return to scale. Using the coefficients reported in Table 16, it is possible to write the production function as:

$$Y = \{A(X+1)^b(Z+1)^c\} - 1 = \{0.01866(X+1)^{0.3624}(Z+1)^{0.6376}\} - 1 \qquad \text{Eq.2}$$

where *Y*=crop production*; X*=avoided erosion per hectare; *Z*=total energy per hectare; b=0.3624; c=0.6376; A=0.01866=exp(-3.9813) are coefficients of the linear regression. The coefficient for avoided erosion is equal to 0.3624+/- 0.04648; while the coefficient for the total energy use is equal to 0.6376; +/- 0.04648.

These coefficients are elasticity of substitution that explain the change in production for a per cent change in the factor of production. Thus, 1% increase in avoided soil erosion generates an increase in crop production of 0.36%. Similarly, 1% increase in energy consumption, causes a change in production of 0.64%.

At the average value of the avoided soil erosion of 0.68t/ha/year, the regression models predicts that 1% change decrease in soil erosion generates an increase in crop production of 0.022t/ha/year. This is equivalent to a marginal change in production of 3.28t of crops/ha/year for a reduction in soil erosion of 1t/ha/year. Considering the net production value of £100/t, the marginal value of 1 tonne of soil erosion avoided is £328/ha/year.

At the average soil erosion reduction of 0.68t/ha/year, the marginal productivity of this factor is £455/ha. As shown in Figure 15, many farms can reduce soil erosion beyond the average value of 0.68t soil/ha/year, generating a marginal value in crop production lower than £455/ha/year. Only three farms show a higher soil erosion rate. These farms have the potential to invest in practices reducing soil erosion, as proposed by their higher marginal value, estimated between £500 and £2,000/ha/year.

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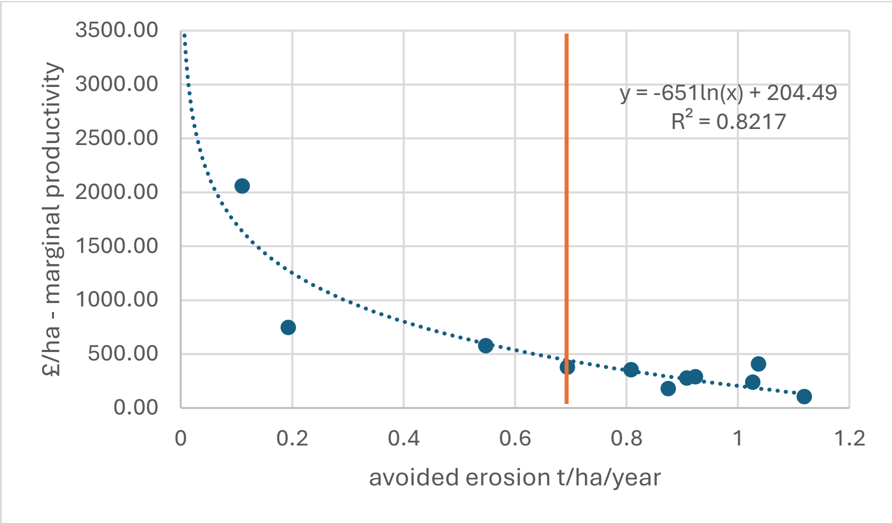

Figure 15. Marginal change in crop production as a function of avoided soil erosion. The red bar is the average avoided soil erosion of the farmer cluster (0.68t soil/ha/year). At this value the marginal crop productivity is £455/ha/year.

10.2 Contribution of avoided soil erosion to crop production and energy saving

We can use Eq. 2 to calculate the contribution of natural capital to the total production assuming no net contribution from human and manufactured capitals. This is 1.16t/ha/year, equivalent to 20% of the total production. This figure can be read as the contribution of natural capital to supporting the total production net of the influence of other forms of capital. This result aligns to estimates made by La Notte et al (2021), who using the *Emergy* analysis, found an average contribution of natural capital to the EU crop production between 20% and 30%.

The model proposed by Eq.2 assumes that the factors of production are perfect substitutes. Therefore, if we increase the avoided soil erosion, we can generate a saving in energy consumption, while keeping crop production constant.

We can use this model to simulate some scenarios. Figure 16 shows two different levels of production (red and green isoquants). Along each isoquant the production does not change, and it is guaranteed by an infinite trade-off between the production factors (avoided soil erosion and energy). We could increase crop production from 6 to 9t/ha/year (50%) (a shift from the red to the green isoquant), keeping constant the energy use at 8,479kWh/ha/year, but increasing the avoided soil erosion from 0.7t/ha/year to 3.6t/ha/year (simulation 1, blue point in Figure 16). This scenario cannot be easily achieved, as shown by Figure 15, where the capacity to retain soil in the farmer cluster shows a certain saturation just after the value of 1t/ha/year. The target of a maximum avoided soil erosion rate of 1.2t/ha/year seems more achievable. The latter figure is chosen as the best performance achieved in the farmer cluster. Under this scenario, it is possible to keep the production of crop at 6t/ha/year by reducing the energy consumption from 8,479kWh/yea/ha/year to 7,274kWh/ha/year (simulation 2, grey point in Figure 16). Thus, improving soil retention up to 2t/ha/year through conservative measures would have the positive impact of reducing the use of energy by about 1,205kWh/ha,

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equivalent to 33kg of nitrogen per hectare. This would generate a reduction in expenses for fertilisers estimated at £26.4/ha (using 2022 prices).

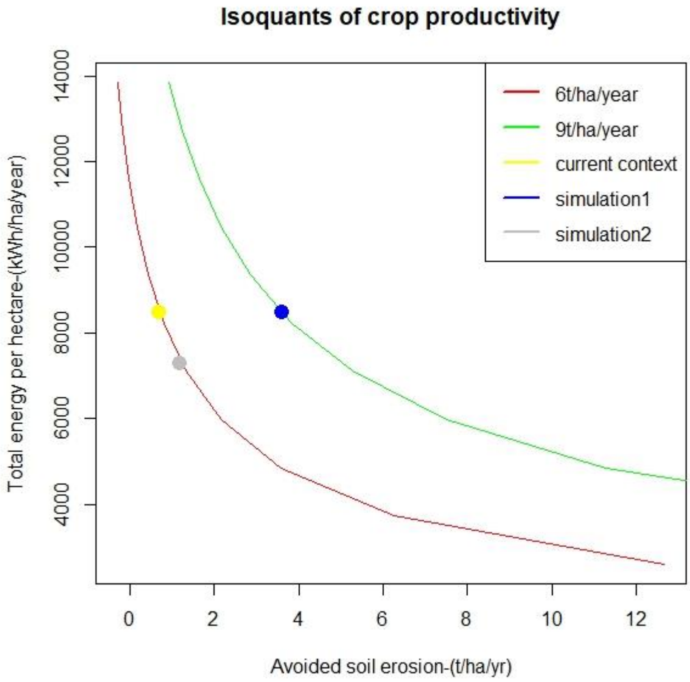

Figure 16. Isoquants showing how to maintain or increase crop productivity by combining level of energy use and avoided soil erosion.

10.3 Benefits of crop pollination on field beans production

We describe the impact on pollinators dependent crops (e.g., field beans) under the current use of AES. Table 17 reports the coefficients of a production function regressing the production of field beans versus area of the farm affected by AES and the use of pesticide. As per regression analysis proposed in Table 16, we simulate a farm system with constant return to scale.

Table 17: Production function showing the impact of AES and use of pesticides on the production of beans (a pollinator dependent crop).

variable	estimate	Std error	t value	Pr(>t)
Intercept	3.30897	0.13748	24.07	1.771 10-5
Log(Pesticide+1) - kg/ha	0.71528	0.03495	20.47	3.36 10-5
Log(Area under AES +1) t/ha/year	0.28472	0.03495	8.14	5.99 10-6
Multiple R-squared: 0.9905, Adjusted R-squared: 0.9882				
F-statistic: 418.9 on 1 and 4 DF, p-value: 03.365 10-5 Residual standard error: 0.195 on 4 degrees of freedom				
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				

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The production function approach can be written as:

$$Y = \{A(X+1)^{b}(Z+1)^{c}\} - 1 = \{27.66(X+1)^{0.284t}(Z+1)^{0.7153}\} - 1 \qquad \text{Eq. 3}$$

where *Y* is the production of field beans in t/ha; *X* is the area on hectare of AES; and *Z* is the use of pesticide in kg/ha.

Table 17 shows that the elasticity of AES is 0.2847. From this result, we can say that 1% increase in the average area dedicated to AES (equivalent to 2.42ha) causes a change in field beans production of 0.58t. Thus, the marginal change in crop production is 0.24t per each hectare of land where AES are implemented. There are five farms in our sample that produce field beans, three in the arable and two in the mixed farming system. In these farms, the value of pollination goes from a minimum of £15/ha to a maximum of £295/ha, assuming a gross value of beans of £250/t in 2022. The average gross marginal productivity in value of pollination for the farmer cluster is estimated at £84/ha.

Table 17 also shows that the marginal effect of pesticides is important, generating a change in field beans production of 7.15% for an increase in pesticides of 10%. However, we might also expect that an increase in pesticides could reduce biodiversity of pollinators, which in turn could have a negative effect on beans production. This indirect effect is not captured in Eq.3. A model including the effect of pollinators on field beans given the effect of pesticide was inconclusive with our dataset.

10.4 Contribution of AES to field beans productivity

Using the average consumption of pesticides (1.26kg/ha), and the average area dedicated to AES, equal to 242ha, Eq.3 estimates an average field beans production of 237t. The contribution provided by AES is 131.6t, equivalent to 55% of the whole production. If we assume AES as a proxy for crop pollination, we can say that this ecosystem service provides more than half of the value of the production of field beans.

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11.Monetary benefits of other regulating ecosystem services

Changing farming practices in the farmer cluster contributes to the generation of other environmental benefits. Two of these are the value of avoided carbon emissions and pollution removal.

Low tillage contributes to the reduction of carbon emissions. The value of carbon emission is estimated by assessing the avoided carbon loss at the non-traded carbon price of £241/tCO_2, as proposed by the Department for Business, Energy and Industrial Strategy (UK) (BEIS, 2021). This price is the marginal abatement cost of carbon using the best available practices. Considering the limited reduction in carbon emissions caused by low to no tillage, this benefit ranges from £0/ha to £29/ha, with an average value of £18/ha. To this benefit, it is necessary to add the value of sequestered carbon by landscape features, equivalent to £132.5/tCO_2 (at the average carbon sequestration of 0.55t CO_2/ha).

Additional monetary benefits emerge from the capacity of the riparian zone to filter the excess of fertilisers used in the arable system. We assume that each hectare of semi natural riparian habitat can remove up to 70kg of nitrogen per year (Lyu et al., 2021; Dlamini et al., 2022). Each farm, on average is characterised by 5.20ha of buffer zone that can remove up to 364kg per year of nitrogen. This estimate can be considered an upper bound value. Using more reliable figures of the nitrogen farm gate balance (just a few farms are over the benchmark of 68kg N/ha/year), the average removed nitrogen per farm by the riparian vegetation is 45kg, equivalent to 9kg of N/ha/year. At the average value of £14/kg of nitrogen (as proposed in the report D7.3), we may conclude that the average economic social benefit of nitrogen removal is £126/ha/year of riparian vegetation.

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12. Relationships between natural capital proxies

We provide further considerations emerging from the implementation of principal component analysis (PCA) to a set of variables explaining the characteristics of the Cranborne Chase farmer cluster for each of the 12 farmers sampled. These variables refer to the production and use of inputs (e.g., fertilisers, energy), the profit generated, the presence of landscape features (trees, hedgerows, grasslands), biodiversity, conservation measures (low tillage) as well as a set of ecosystem services such as avoided erosion, pollination, and removal of nitrogen.

Figure 17 reports the variables plotted in the PCA circle to show their importance (contribution to the explanation to the overall variance) and their correlation. These variables are plotted against the first 2 dimensions explaining 56% of the total variability. Vectors closer to the circumference are more relevant than those closer to the centre and those grouped in small clusters are highly positively correlated. We observe three main groups characterised by higher internal correlation. The top right quadrant incorporates variables explaining the use of inputs (mainly fertilisers), crop production, landscape features like hedgerows and ecosystem services like pollination. The opposite quadrant (top left) groups permanent vegetation, bird biodiversity, landscape features and agricultural profit. Finally, the third one on the bottom right encompasses variables such as pollinator biodiversity, soil retention and the area subject to agri-environmental schemes.

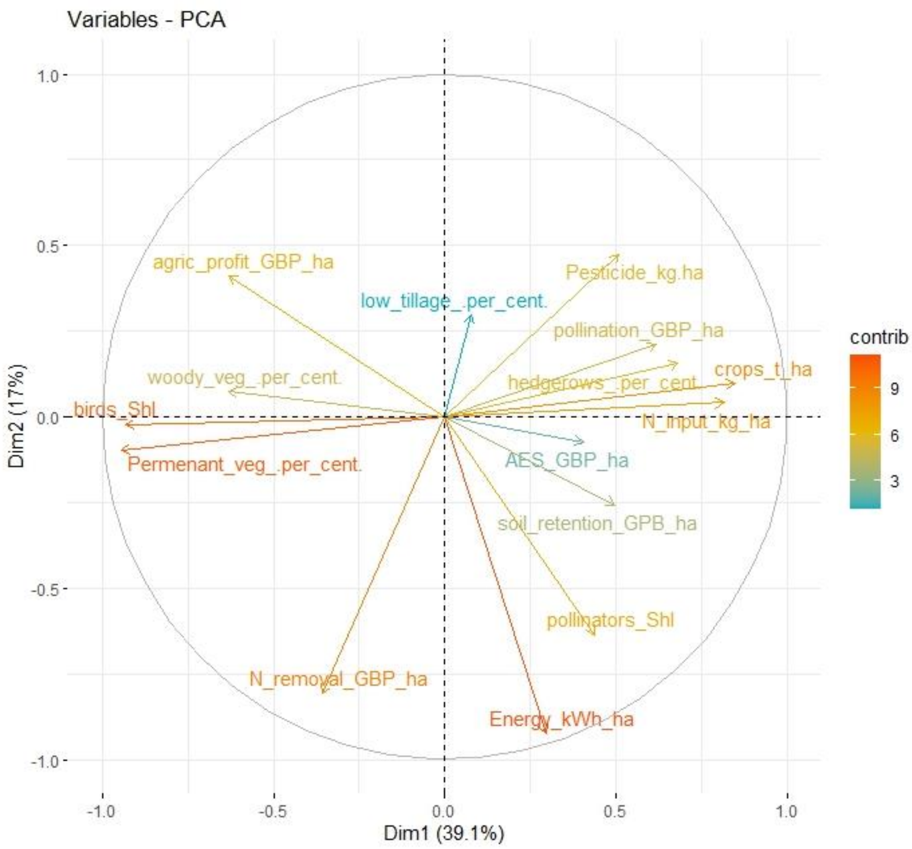

Figure 17. Representation of the variables used in the PCA circumference plotted against the first and second dimensions or principal component explaining 56% of the total variance. Legend: variables in the graph and the unit of measure: *soil_retention_GPB_ha; pollination_GBP_ha; N_removal_GBP_ha; birds_ShI; pollinators_ShI; low_tillage_(per_cent); Permenant_veg_(per_cent); woody_veg_(per_cent); hedgerows_(per_cent);crops_t_ha; N_input_kg_ha; agric_profit_GBP_ha; AES_GBP_ha; Energy_kWh_ha; Pesticide_kg/ha.*

If we look at the PCA biplot of Figure 18 reporting both variables and observations (grouped by types of the farming system), we can observe that the farms correlating with the highest income are those that operate as pasture enterprises. These farms need reduced inputs and then can generate higher profit per hectare. The others (mixed and arable farms) that use higher levels of inputs (pesticides and fertilisers) are characterised by a greater crop production, and by a good adoption of agri-environmental schemes facilitating pollinator biodiversity. Pasture and arable lands are described by the first principal component (PC1), while both principal components PC1 and PC2 are necessary to explain the mixed farms. Some of these mixed farms are better explained by practices that reduce soil erosion and facilitate pollinator biodiversity. These are also characterised by higher use of energy (electricity and fuels) than the farms operating in the arable system because of the additional energy request necessary for managing livestock.

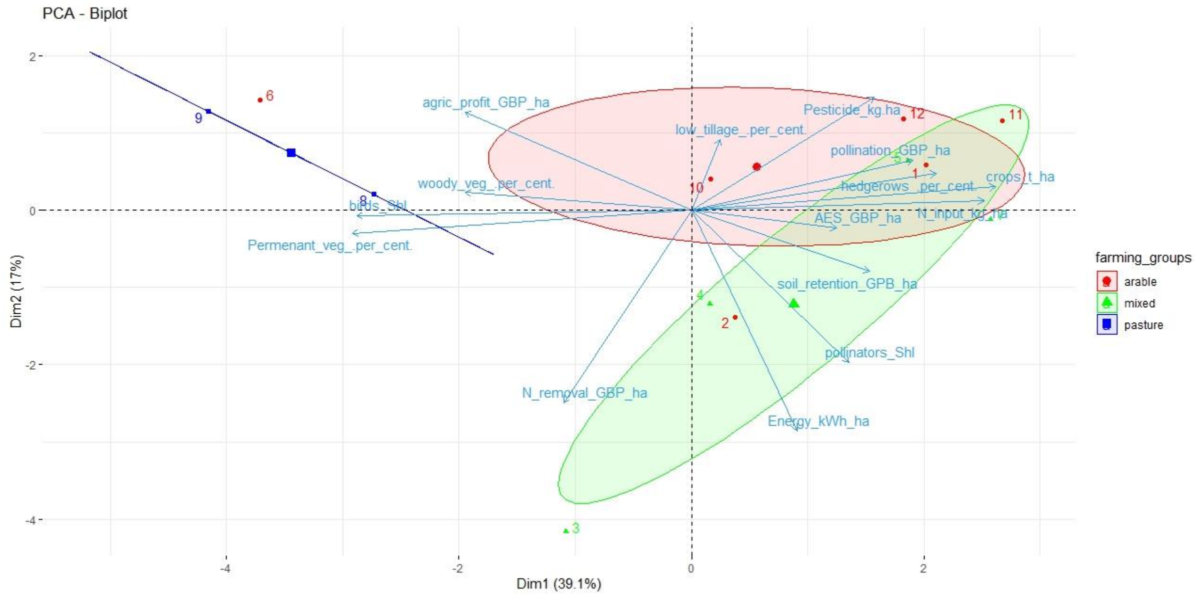

Figure 18. Representation of the variables used in the PCA, and typologies of farms plotted against the first (PC1, Dim1) and second dimensions (PC2, Dim2) or principal component explaining 56% of the total variance.

A different visualization of the natural capital variables is proposed in Figure 19, where farms are classified by nitrogen use (low, medium and high use of nitrogen measured by first quartile, median, and third quartile, respectively). In Figure 19, all variables are standardised (e.g., mean zero and standard deviation one). As also shown by the PCA, it is possible to note in Figure 19 the limited use of fertilisers for farms associated with higher bird biodiversity, as well as high extension of permanent vegetation and profit. These are the pasture farms signalled by the blue (spiderweb) radar plot. The characteristics of the medium intensity farms are reported in the green radar plot. These farms, associated with mixed farms (including also organic farming), are characterised by an extended use of AES, higher values of the pollinators' Shannon index and removal of nitrogen by grass strips. The farms reported by the red radar plot are associated with the highest use of inputs (fertilisers and pesticides) and the greatest level of crop production. These farms invest in landscape features like hedgerows and are characterised by a high demand of pollination services.

Farms operating with high levels of nitrogen input are characterised by a lower level of pollinator biodiversity and higher marginal productivity of crop pollination as measured by the variable "pollination value", compared to mixed farms that use a reduced level of nitrogen. This result suggests that intensive arable farms should invest in biodiversity measures to increase their level of pollinator biodiversity, but also that productivity of pollinator dependent crops is influenced by the supply of pollination services provided by those farms in the cluster characterised by a greater use of organic measures and presence of semi-natural landscape features.

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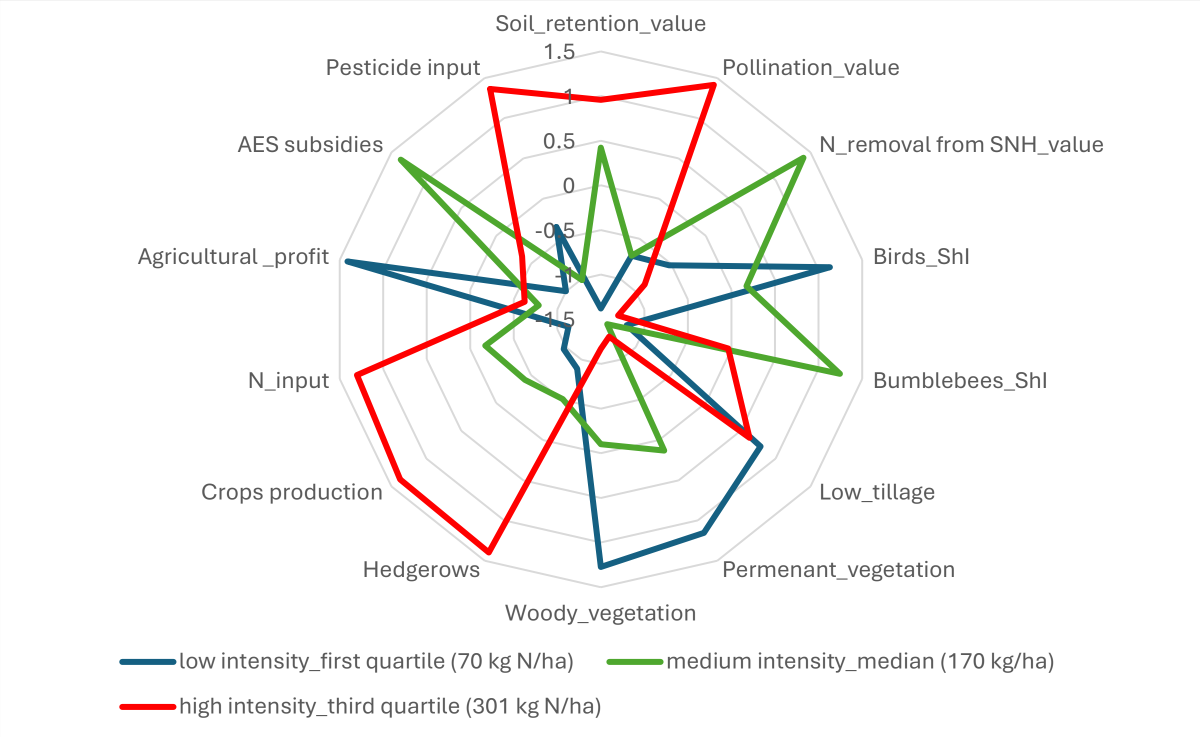

Figure 19. Performance of the Cranborne Chase farms classified according to the intensity use of nitrogen.

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13.Variation in crop production caused by the extension of natural features

We do not have a baseline of natural capital values measured outside the farmer cluster to test the impact of different agri-environmental schemes (AES) on production. Therefore, we use the internal production variability within the farmer cluster to measure production under different typologies of AES (organic farming versus non-organic farming, and birds and pollinators AES versus other types of AES).

Our sample presents three farms operating under an organic protocol, producing 2.78t/ha of crops, compared to conventional farms that show a productivity 2.65 times higher (7.39t/ha). This difference is significant according to a two-sample t-test (Table 18).

Table 18. t-test of the difference in crop production between organic and non-organic farms at the Cranborne Chase.

Group	Obs	Mean	Std err	Std dev	CI 95%
0- AES (non organic)	9	7.399	.7439	2.2318	5.6839 9.1149
1-AES (organic)	3	2.783	1.3953	2.4167	-3.2202 8.7869
difference		4.6161	1.5133		
difference = mean(0) - mean(1)	t = 3.0503	Ho: diff = 0	degrees of freedom =10		
Ha: diff < 0	Ha: diff != 0	Ha: diff > 0			
Pr(T < t) = 0.9939	Pr(|T| > |t|) = 0.0122	Pr(T > t) = 0.0061			

This difference in crop production is less evident when assessed against AES addressing measures for protecting biodiversity. We found that the farms that have the highest crop production (7.52t/ha), operating in the conventional arable system, made greater use of AES supporting bird and pollinator biodiversity (Table 19), compared to mixed farms that requested subsidies for organic farming. This result suggests that reducing productive areas to make space to landscape features is not a limiting factor for arable production, at least where the area dedicated to landscape features like hedgerows occupies only a limited portion of the farm (less than 1%). We may conclude that it is the production practice (e.g., organic) more than the area dedicated to landscape features that contribute to the reduction in crop production.

Table 19. t-test of the difference in crop production at the Cranborne Chase amongst farms that show different use of AES.

Group	Obs	Mean	Std err	Std dev	CI 95%
0- No AES for birds & pollinators	5	4.456	1.4196	3.1743	.5149 8.3979

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1-AES for birds & pollinators	7	7.523	.86924	2.2998	5.3963 9.6502
difference		-3.0668	1.6646		
difference = mean(0) - mean(1)	t = -1.8424	Ho: diff = 0	Satterthwaite's degrees of freedom = 6.91371		
Ha: diff < 0	Ha: diff != 0	Ha: diff > 0			
Pr(T < t) = 0.0542	Pr(|T| > |t|) = 0.1085	Pr(T > t) = 0.9458			

While the current extent of landscape features has a limited impact on crop production, it is not considered adequate to increase the level of pollinators. Staley et al. (2023) suggested that benefits for pollinator biodiversity can occur if hedgerows covered an area of at least 4%. On an average farm of 500ha, this would imply an extension of hedgerows to 20ha, a value five times greater than the area currently occupied by this landscape feature (4 ha). The Shannon biodiversity index could be improved by 43% (from 0.7 to 1) by expanding landscape features (hedgerows) by 150% (from 4ha to 10ha) in a farm of 500ha. However, the estimated forgone income, equivalent to £3,600 (6t crops/ha at the net benefit of £100/t for 6 hectares), can be compensated only by providing public incentives at £600/ha. The current benefit of the subsidies provided at the Cranborne Chase is half this value. Doubling this incentive to offset the lost production under a scenario where landscape features covered 10% of arable land would involve highly expensive public measures equivalent to £570,000 for the Cranborne Chase farmer cluster.

Finally, impacts on production can be also generated by an expansion of permanent vegetation as shown int Table 20. For each percentage of grassland covering the field, 0.078t/ha of production are lost. Changes in bird biodiversity as a function of grassland and the opportunity cost for production are estimated in the section 9.2 describing the impacts of grassland extension on crop production and income.

Table 20: Linear regression showing the marginal change of permanent vegetation on crop production

variable	estimate	Std error	t value	Pr(>t)
Intercept	9.13528	.927898	9.85	0.000***
Permanent vegetation_%	-.0779194	.019753	-3.94	0.003*
R-squared = 0.6088; Adj R-squared = 0.5696;				
F(1, 10) = 15.56; Prob > F = 0.0028				
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				

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14. Potential regional impact of changes in natural capital on the cereal system and the UK supply chain

While natural capital is essential for supporting the economy of producers, its degradation may have important effect, impairing production processes along the supply chain (Dasgupta, 2021). For example, a decline in wild pollinators can reduce yields of crops that rely on insect pollination, as shown in the previous sections. This would increase the cost of farming, as farmers would need to invest in alternative pollination methods to compensate for the reduced pollination services; and could lead to economic losses and greater reliance on imports to meet domestic demand. Ultimately, the higher pressure on external markets may contribute to the disruption of international trade (La Notte, 2024).

In this section, we propose some consequences of the potential impacts of farming on natural capital and how the cereal value chain in the UK may be affected. Though the analysis of these impacts requires the adoption of approaches that go beyond the scope of this report, (such as goal oriented programming (Motevalli-Taher, et al., 2020), general or partial equilibrium models (Athukorala et al., 2018; Dixon and Rimmer, 2019; DEFRA, 2021), and error correction models (Mrabet and Page, 2023) to assess how prices and quantities of commodities may change under the pressure of local and international drivers), we provide some considerations on the current risk for the supply chain of cereals in the UK, building on recent agricultural and economic statistics (DEFRA, 2023a; 2023b; DEFRA, 2024).

14.1 Domestic production and import of cereals in the UK

The majority of the UK's cropped land is used for grain production (3 million ha). Of this area, 1.6-1.8 million hectares are used every year to produce 13 to 15 million tonnes of wheat (DEFRA, 2023a). Cereal grains are mainly used for animal feed (60%), while 38% are for milling, brewing and distilling; and the remaining 2% for seeding. In the short term, these figures are expected to remain stable, with some variations caused by extreme weather conditions, while over the medium long term there is more uncertainty. If a higher demand of cereals may be expected because of the increase in population, GDP growth and demand for meat (DEFRA, 2024), policies related to Net Zero (GovUK, 2021) and the National Food Strategy (DEFRA, 2020) may be an important driver to reduce the role of livestock (and indirectly the demand of silage and haylage). Under this scenario, and without new policies that reduce the demand of meat in the UK, we may expect an internal reduction in supply of livestock, a consequent reduction in the production of cereals, and a likely increase in livestock import.

Changes caused by environmental or international drivers have altered price of primary inputs (energy, fertilisers), with negative effects on the farm gate prices. Nonetheless, domestic production of cereals has remained quite stable with some fluctuations. A significant reduction in supply, registered in 2020 because of unusual weather patterns (DEFRA, 2023a), was followed by a new recovery of the production, estimated in nearly 15 million tonnes. A new reduction in 2024 harvest occurred particularly for wheat (20% less than 2023 with a production of 11 million tonnes), due to wet weather and flooding, with less severe impacts in Scotland (DEFRA, 2024). These fluctuations, although

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important in generating shocks in the domestic markets, do not have any impacts internationally because the UK cereal production accounts only for the 0.7% of the global supply.

Shocks in international markets can be reduced by the fact that the UK is almost self-sufficient in the supply of cereals. The production to supply ratio, a measure of national self-sufficiency, shows a stable trend. In 2022, total supply of food in the UK was at 60%, while at 73% for indigenous foods (DEFRA, 2024; Ching-Pong Poo et al., 2024). This ratio increases to 92% for cereals and 87% for cattle (DEFRA, 2024). Thus, the UK is largely self-sufficient in barley and oats production (DEFRA 2023a). The source of milling wheat is mainly domestic (85%), with a remaining 15% imported from Germany and Canada, and minor quantities from Russia and Ukraine (UK Flour Millers, 2022). This residual quota of 15% is largely made up of hard wheat types not suited to the UK's climate and soils (DEFRA 2023a). Protecting natural capital is important to maintain the self-sufficiency of cereals production as proposed below.

14.2 The role of natural capital in the domestic supply of cereal crops

Climate change is widely recognized as an impact factor of production, potentially leading to an inconsistent cereal supply due to variations in temperature and precipitation (Falloon et al., 2022; Davie et al., 2023; Hasnain, 2024). In 2022 the drop in production of Canadian wheat was the greatest since 1988. This had a significant impact for the UK market, reflected in a very high price of £360/t, an increase of £100/t with respect to the quotation of the previous year (UK Flour Millers, 2022).

Climate change, production intensification, reduced biodiversity in conventional grain fields, and damage to soil through ploughing and use of fertilisers and pesticides, may have over the long-term negative effects on production. Conversely, the reduction in soil erosion determined by regenerative practices may induce benefits to crop productivity. We found in this research that the marginal benefit of regenerative agriculture in the UK farmer cluster is able to reduce soil erosion by 0.68t/ha/year, generating a marginal value in crop production of nearly £500/ha/year. If this figure applied to the whole land dedicated to cereal production (1.8 million hectares), this would generate a positive return of £900m. This estimate is aligned to estimates made by DEFRA (2023a), that found how soil degradation is responsible in England and Wales of a loss of £1.2 billion per year over an area of 2 million ha affected by soil erosion.

Using the case of the Cranborne Chase farmer cluster, we can say that if regenerative practices were not implemented, they would be able to generate a loss equivalent to the production of 5,000,000 tonnes of wheat at the current price of £190/t (October 2024). This is equivalent to 33% of the total benefit generated by cereal production every year. This loss could be ideally compensated by increasing nitrogen fertilisers by about 125,000t (it is assumed a national average yield of 8t/ha), causing an increase in operating costs of £49/ha. While this additional cost may be considered small, equivalent to nearly 10% of the profit generated by a hectare of arable land (around £500), this reduced profit can be compensated only by increasing the price of cereals by 3% (equivalent to £6/t) with inflationary consequence in the price of many products that depend on cereals.

A similar dynamic occurred for the increase in the energy costs. The increased price in energy and energy-related goods has been passed on to food processors, distributors and retailers in the last few years, making pressure on the viability of many businesses (DEFRA, 2024). Since January 2021, food manufacturers have been exposed to input price pressure as certified by the Office for National Statistics that in 2023 recorded an increase by 19.8% (ONS, 2023). These increased costs were both absorbed internally (causing a reduction in profit) and passed onto customers. ONS (2023) has estimated the half of food and drink wholesalers (49.6%), and nearly two-thirds of retailers (63.7%) increased their prices during January 2023 compared with December 2022, as reflected by the Consumer Price Index inflation of the food and non-alcoholic drink sector (16.8% in January 2023).

UK fertiliser prices have mirrored trends in international prices, contributing to higher farm gate prices across the supply chain. A possibility to limit impacts on the supply chain is by stabilising the domestic price of cereals by protecting soil from erosion. This consideration acquires more value after observing the effects of recent climatic events on the price of cereals in some foreign markets. We have registered higher costs in internal markets compared to the international ones. For instance, AHDB (2024) reported that the UK had the fourth highest ex-farm price for winter wheat since 2020, following Spain (£305.01/t), Germany (£253.25/t) and Canada (£248.84/t). The high prices in Spain's cereal markets were attributed to drought conditions.

Changing farming practices, such as the use of cover crops and rotational cropping may help reduce the use of chemical fertilisers and mitigate price fluctuation in the short term. However, beyond the role played by regenerative agriculture (Schattman et al., 2023), additional adaptation measures are necessary to avoid negative impacts of summer heat stress on winter wheat such as earlier maturing and earlier autumn sowing (Davie et al., 2023). Finally, more cost-effective measures over a longer period can be proposed such as advancing the formulation of new strains of cereals that grow in water-limited environments (DEFRA, 2024).

14.3 Limits of this research

This research has implemented the NAP in a farmer cluster, mainly operating in the arable system. More evidence from other farming systems is necessary to test its feasibility. Its application is based on a combination of primary and secondary data, and it relies on statistics collected at individual farm scale. The quantity of information needed to reconstruct indicators measuring dependencies and impacts on natural capital is relevant, and the collection of data time consuming. We found difficulty in engaging with a sufficiently large range of farmers to get a comprehensive picture of the natural capital condition for many EU farmer clusters participating to the H2020 FRAMEwork project.

Using the NAP, we can provide for each environmental indicator a single data point per farm measuring the dependencies or impacts of the farm on a specific aspect of natural capital. To provide strong conclusions on the changes in natural capital within the farmer cluster, data from several farms must be collected. Owing to the limited number of farms that make part of the farmer clusters it is difficult to generate through inferential statistics robust results that may be transferred to a wider context. Confirmation of some of the results emerged at the Cranborne Chase in other EU farmer clusters could be made in the future through a benefit transfer approach by using spatial econometrics analysis if a broad range of data on production and information on cultivated area, capital investment and labour could be retrieved and mapped, possibly, at the same resolution of the information available for natural capital (usually 1km^2).

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We have proposed in this report how different farming systems and typologies of AES relate to natural capital indicators and crops production. The number of indicators used represents a simple implementation. While reflecting some of the current monitoring indicators suggested by the CAP, this set of indicators cannot provide a general picture on the quality of the farming system because of the lack of proxies describing the connectivity of landscape patches, and other measures addressing the role of biodiversity in soil and water systems.

The PCA (Table 18) has shown that indicators describing landscape features, biodiversity and regulating ecosystem services, such as avoided soil erosion and crop pollination, are associated with the implementation of several types of AES. Results proposed in this study can be rationally considered a cumulative effect of practices that have been operated for a long period of time. We have not investigated how long the AES have been implemented. Moreover, we do not expect that in the short term, a new farm entering the farmer cluster and adopting similar AES never adopted in the past might reach comparable results, especially regarding relevant changes in the properties of soil.

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15. Conclusions and policy recommendations

We have implemented a natural capital protocol that merges ideas of ecosystem accounting proposed by the UN (UN, 2021) with the approach proposed by Natural Capital Protocol, a tool developed by the Capital Coalitions (2016) to measure the materiality of natural capital on farm business.

To implement the natural capital protocol at the Cranborne Chase (UK) farmer cluster, we have considered some of the indicators suggested by the UN (2021) and other proxies proposed by initiatives such as the Sustainability Assessment of Farming and the Environment (SAFE) framework (Van Cauwenbergh et al. 2007) and the Sustainability Assessment of Food and Agriculture (SAFA) project (FAO 2014). We focused on a set of variables that can be measured using primary data collected at farm scale (see Table 3 and Table 4), in combination with geo-localised environmental proxies. Key indicators selected refer to the chemical state (e.g. soil organic carbon), compositional state (e.g., species diversity), structural state (e.g., organic farming, crop diversity), and landscape diversity of the farming system. We have not considered functional state such as soil respiration rate or primary production that require in field experiments.

We have found (as expected) that the UK farmer cluster is highly dependent on fertilisers; conversely, it does not present critical issues regarding the use of energy and pesticides compared to the average European farms. We were not able to make a clear judgement on the use of water.

Some key negative impacts emerged but these were also mitigated by adopting agri-environmental schemes. While the biodiversity of birds and pollinators was lower than the one measured in a natural environment, the role in the farmer cluster of vast areas of grasslands for pasture and the adoption of organic protocols in mixed farms contributed to increase bird biodiversity. We recorded lower biodiversity for pollinators. We found that the utilised farm area dedicated to hedgerows contributes to increase the level of pollinator biodiversity. However, reaching a critical threshold seems difficult. The current hedgerows extension in the farmer cluster is 0.8%, much lower than the optimal estimated area (4.5%). Surprisingly, we found that the farms that were mostly adopting AES (in terms of area) to increase the level of landscape features for biodiversity were those operating in traditional arable systems. However, the level of birds and pollinator biodiversity was measured higher in livestock grazing and mixed farms because of a higher presence of permanent vegetation, in particular grassland, and that operated through organic protocols. Therefore, the latter farms were those that contributed mostly to supply pollination services to the arable system that produced the majority of pollinator dependent crops such as oilseed rape and field beans (Figure 19).

Positive environmental aspects also emerged. The implementation of regenerative practices contributed to reduce soil erosion and therefore facilitated soil carbon sequestration. On average the farmer cluster was estimated to sequester 0.55t CO_2/ha/year. In addition, we found the dependency of the crop production on avoided soil erosion. Regenerative farming practices showed to be associated with an average productivity of £500/ha. This figure is congruent with values provided by Defra (2023a) that estimated a loss of benefits equivalent to £1 billion over 2 million hectares of land affected by soil erosion. We consider that increasing awareness of the role that natural capital has in contributing to crop production, may help understand the impacts of climate change (e.g., drought)

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on cereal production, that in the UK have caused the fourth highest ex-farm price for winter wheat since 2020 in Europe (AHDB, 2024).

While this report has addressed the direct economic impacts of pollinators on production, biodiversity sensitive farming can also contribute to ecological processes, not explored in our research, such as control of pests and diseases, and health of soil microorganisms and above ground vegetation (Brilha et al., 2018; Singh et al., 2019). To generate all these benefits, biodiversity protection should be integrated into land-use planning, a strategy not well valorised by the common agricultural policy (CAP) that does not fully invest in coordinated landscape scale initiatives (Cuadros-Casanova et al., 2022). The application of the NAP in the UK farmer cluster has shown that some farms (e.g., the arable farms) investing in AES to improve landscape features such as hedgerows are not supplying higher biodiversity, although their demand of pollination is high. We may deduce that part of their productivity depends on pollination services supplied through biodiversity friendly management approaches implemented in the organic and mixed farms within the farmer cluster (Figure 19). These considerations strongly show that incentivising measures to improve the environmental quality of farming needs to be undertaken at landscape scale and that only schemes that involve a coordinated approach between farms can be an optimal solution to achieve a more effective use of agri-environmental subsidies. In addition, planning biodiversity at landscape scale might be a flexible strategy for generating pollination benefits, reducing bureaucratic burden and delivering solutions at the least opportunity cost.

The H2020 FRAMEwork project has supported the voluntary implementation of coordinated initiatives at landscape scale to facilitate the collaborations between farmers and improve the level of biodiversity. These initiatives, while having the aim to expand the number of farmers taking coordinated and coherent strategies, have not been economically incentivised yet (i.e., CAP subsidies still operate on individual basis). **The results at the Cranborne Chase in terms of reduced impacts on natural capital and dependency on the ecosystem services generated by the farming system advocate for a stronger collaboration between farmers at landscape scale.** Policies that encourage collaboration between farmers and other players and facilitate engagement by involving local communities in planning and the implementation of biodiversity-sensitive farming initiatives should find more space in the future CAP (Moersberger et al., 2024). Extensive voluntary collaboration should be accompanied by educational programs for farmers and the general public to increase understanding and acceptance of biodiversity-sensitive farming practices more widely, as long as research showcases the viability of these practices in delivering win-win solutions for biodiversity and crop production (Pe’er et al., 2022).

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Appendix 1- Questionnaire survey

FRAMEwork: Farm business sustainability questionnaire

We are interested in the sustainability of your farm (all owned and rented land that makes up your farm business) in terms of its productivity, resource use, environmental activities, and policies. The information we collect will be used to calculate how sustainable the Farmer Clusters are, as well as calculating the Natural Capital Assets of the Farmer Clusters.

More information is provided in the Information sheet. Moreover, before starting the questionnaire, carefully read the Consent Form and sign it.

If you have signed the attached Consent form, please tick the box below to have access to the questionnaire:

☐

Please complete as many sections of this questionnaire as you can, reporting information from a **previous 12-month period**, filling in any relevant **white boxes**. Please provide an accurate figure where possible. If you need to alter the reporting units (e.g., swapping km for miles, ha for acres), then please do so, specifying the unit used. Additionally, you can provide an estimate based on a recent figure from a similar 12-month timeframe (e.g., if you are reporting April 2022 to April 2023, but you have an accurate figure from Jan 2022 to Jan 2023), indicating that it is an estimate.

Name of farm/business:		
Country (region):		
Total size of farm:		ha
Amount of rented land:		ha
Type of farm:		e.g., arable / dairy
Any certification?		e.g., organic
12-month reporting period (e.g., tax year)		

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start date		dd/mm/yy
end date		dd/mm/yy

Glossary of units	
ha	hectares
t	tonnes
kg	kilograms
m2	square metre
m3	cubic metre
m	metre
P	Phosphorous
K	Potash/Potassium
N	Nitrogen
l	litre
KWh HGV	Kilo Watt Hour Heavy goods vehicle

Tell us about your agricultural produce

<u>Please complete this section if you produce any **crops**.</u>

1. During the 12-month reporting period, how many different crops did you produce?

2. Please provide details of your **top 5 produce per category (e.g., Agricultural crops, vegetables, fruits)** in terms of <u>income</u> (turnover). Please also indicate any other crops you produce (*), but you do not need to provide details for them.

			Distribution of produce by road (if not your own vehicle)		% bracket of income (turnover) from each of top 5 produce (0-20%; 21-40%; 41-60%; 61-80%; 81-100%)
Agricultural crops	Yield (t)	Area required (ha)	Specify mode of transport to merchant/distribution centre/place of sale e.g., vans (up to 3.5 tonnes) / HGV / refrigerated HGV	Distance (miles)	
Wheat					
Barley					
Oats					

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Oil Seed Rape					
Linseed					
Field Beans & Dry Peas					
Lupins					
Soya					
Maize					
Fodder crops – maize					
Fodder crops – leafy					
Fodder crops – root					
Sugar Beet					
Rye, Triticale					
Hay					
Silage					
Horticultural crops – vegetables					
Potatoes					
Vegetables (general)					
Beans and peas					
Olives					
Custom Vegetables					
Horticultural crops – fruit					
Apples					
Pears					
Nuts					
Cherries					
Plums					
Raspberries					
Strawberries					
Blackberries					
Gooseberries					
Redcurrants					
Blackcurrants					
Cranberries					
Kiwiberries					
Blueberries					
Grapes (vineyard)					
Tree crops					
Firewood					

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Christmas trees					
Timber					
Other (anything not listed above)					

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Please complete this section if you farm any **livestock**.

3. For the 12-month reporting period, please provide details of your top 3 livestock in terms of income (turnover). If you farm more than 3 types of livestock, please could you indicate which you farm (*), but only provide details for the top 3.

Animal	Average number on farm over year	Area of land required (ha)	Cows replaced every year	Value when bought (£ per cow)	Total milk distributed per week (l)	Distance to processing plant/dairy? (miles)	Cull value (£ per cow)	Avg. no. years of productivity	Main feed purchased for animals (t/year)	% bracket of income (turnover) from each of top 3 livestock produce (0-20%; 21-40%; 41-60%; 61-80%; 81-100%)
Dairy cows										
Dairy heifers										

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Animal	Avg. no. on farm over year	Area of land required (ha)	No. animals replaced	Avg. no. years of productivity before culling	Avg. value when bought per animal (£)	Average market lwt or dwt value per animal when sold (£)	Avg. weight per animal (kg)	No. culled / sold	Distance to place of sale / butcher / outlet if meat not sold in your own farmshop (miles)	Main feed purchased for animals (t/year)	% bracket of income (turnover) from each of top 5 livestock (0-20%; 21-40%; 41-60%; 61-80%; 81-100%)
Beef Cows											
Bulls for breeding											
Heifers for breeding											
Steers											
Breeding pigs											
Other pigs											
Ewes											

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Rams											
Lambs											
Goats (Does)											
Goats (Bucks)											
Goats (Kids)											
Deer (all)											
Chickens – layers											
Chickens – broilers											
Ducks											
Turkeys											
Geese											
Any/all bird eggs											
Other animals											

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Tell us about your farm business income and capitals

4. Please tell us about the **farm business personnel**. During the 12-month reporting period, how many people worked at the farm, and how many person-hours did they do across the year? Please include family members/shareholders as well as employees and contractors that do any work for the farm business directly.

Personnel	Role	No. of people	Avg. person-hours per week	Avg. no. weeks per year
Internal/family members				
External/hired personnel				

5. Please tell us about the main **farm machinery** (maximum of 5) you use for your farm business (e.g., tractor, harvester), their age, and rough value if they were brand new?

Farm machinery	No. of units	Age (years)	Approximate value if brand new (£)

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6. Please tell us about the main **farm buildings** (maximum of 5) you use for your farm business (e.g., storage barn, animal shed), their age if known, and rough value if they were built brand new?

Building	No. of units	Age (years)	Approximate value if brand new (£)

7. Please tell us about any **subsidies** you receive. Please give us an estimate of your overall income (turnover) from subsidies as percentages:

Percentage of overall income from all subsidies	%
Percentage of overall income from the basic payment	%
Percentage of overall income from agri-environment scheme payments	%

8. If you receive any **subsidies for agri-environment schemes** (public or private), please could you provide us with details about the schemes and area of land involved (if known). Details only needed for schemes covering the largest areas of land (maximum of 5).

Public or private	**Overall scheme name** (e.g., CS Mid-tier)	**Specify the environmental option/activity** (e.g., wildflower margin)	**Total area under option/activity (ha)**	**Amount money received per ha (£)**

9. Do you undertake any **other business ventures** on your land that provide a percentage of your overall income (turnover), but that aren't directly linked to farming activities (e.g., B&B, studio space, agro-tourism, production of renewable energy, game shoot)? If so, please provide the details below.

Business venture	% of income created

Tell us about your farm business resource usage.

Please tell us about the farm's resource usage during the 12-month reporting period. Please supply an **exact figure** wherever possible. If you cannot find the details to provide the exact figure, then please provide an **estimate** based on your prior knowledge.

Fuel

10. Please provide **fuel usage for your farm machinery**. How much diesel purchased?

Fuel usage (12 months)		
Diesel		litres/gallons

11. How much fuel used for your main road vehicle(s) used to get around the farm?

Fuel usage (12 months)		
Diesel		litres/gallons or miles/km
Petrol		litres/gallons or miles/km

12. Did you purchase any additional fuel for equipment on the farm (e.g., generators, leaf blowers)?

Fuel usage (12 months)

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Diesel		litres/gallons
Petrol		litres/gallons
Lubricating oil		litres/gallons

Electricity

13. Please provide details of your **electricity usage** (and production) for the farm business during your 12-month reporting period. If you are unsure on usage but know how much it cost for the 12-months, please report that instead.

Electricity usage		
Total usage (12 months)		KWh or £
% from renewable source if known		%
Amount produced (provide source e.g., solar, wind)		kWh
Total cost of electricity from mains if known		£

Water

14. Please provide us with the **amount of water** from the mains supply used for the farm business. Please also estimate <u>the percentage of water used from different sources</u> for the farm business. If you know the amount of water used for each of your primary produce (reported earlier), please provide that, or an estimate.

Water use for whole farm business			
Mains (pipeline) water			m3
Total cost of water from mains if known			£
Percentages of water use:	Mains (pipeline)		%
	River		%
	Rainfall		%
	Well or borehole		%

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	Other (please specify)		%
Water usage for top produce (maximum of 5)			
Produce	Total amount of water used for each		
			m3
			m3
			m3
			m3
			m3

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Fertiliser and Pesticides

15. Please tell us about your fertiliser and pesticide use. Did you apply fertilisers (synthetic/natural) or pesticides to your crops during the 12-month reporting period? Please provide details for the **top 5 crops** covering the <u>largest area of land</u>.

Crop	Fertiliser (maximum of 3)	Area covered (ha)	Did you use a glyphosate-based product to help establish the crop, i.e., to clean weeds out of stubbles, destroy a cover crop, etc? Yes/no	Did you use a glyphosate-based product to help harvest the crop, i.e., as a drying agent? (Yes/no)	Did you apply an insecticide between months April - August? (yes/no)	On average across all fields of each crop, how many overall spray rounds did you do (this can be a single product or mixed tanks of different products, including molluscicides and granular applications)?

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16. How much did your fertilisers and pesticides cost for agronomic use on the farm for the 12-month reporting period

Total fertiliser costs (£)	
Total pesticide costs (£)	

Tell us about your farming practices

During the 12-month reporting period, tell us about any **regenerative farming practices** that occurred on your land.

17. If you have any land under cultivation, please tell us about your **tillage activity** below.

Soil tillage		
Total area of your land under cultivation		ha
Area that receives conventional (inversion) tillage		ha
Area that receives conservation* tillage		ha
Area that receives zero tillage		ha

*conservation tillage = minimum/non-inversion tillage that results in 30% residue cover on the soil after drilling

18. Did you grow any cover crops between cash-crops/over winter during the 12-month reporting period? How much of the cover crop was then cut/ploughed before drilling?

Cover crops grown	**No. of ha**	**% removed**

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Tell us about your business policies

19. Please tell us about your farming business **policies**, **protocols**, and **attitudes** to governance, social, and economic matters by responding to each question on a **scale of 1-4**:
    1 = Not in place because not considered relevant.
    2 = Considered but not implemented yet (due to economic or technical constraints).
    3 = In the process of implementation.
    4 = Achieved/implemented.
    These policies do not have to be written documents, they can be unwritten or verbal agreements.

Corporate ethics:	**Score**
Are risk assessments in place for how farming activity might have external impacts to stakeholders and the local environment?	
Are risk assessments in place for the safety and good working conditions of all employees and yourself?	
Do you have a policy to ensure all employee training is up to date regarding health and safety standards (e.g., machinery, handling chemicals)?	
Sustainability protocols:	

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Do you implement any of the environmental ISO 14000 standards in your business (e.g., for irrigation, fertiliser, water treatment, waste removal, product labelling, GHG emissions)?	
Stakeholder engagement:	
Do you encourage communication between yourself and stakeholders in your supply chains?	
Do you facilitate regular meetings between staff and stakeholders on matters of mutual concern?	
Local economy:	
Do you have a policy to procure through local suppliers wherever possible?	
Do you have a policy to hire regional people wherever possible?	
Quality of work and personal life:	
Do you have a system in place to discuss periodically the physical burden and mental health of yourself or your employees?	
Do you have a policy to ensure employees have a sustainable work-life balance (e.g., offering flexible working, 4 day working week, weekends off)?	
Do you have a system in place to ensure employee professional growth is tracked and/or encouraged?	
Gender equality	

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Do you have a policy to hire women in positions of responsibility?	
Do you offer a minimum of 14 weeks paid maternity leave?	

Tell us your thoughts

Is there anything you do as a farmer that you feel is particularly sustainable that we might not have considered in this questionnaire? Or anything that we have covered but you would like to provide more detail on? Please add any thoughts or comments below.

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Appendix 2- Information sheet

Research project

FRAMEwork Farmer Cluster Sustainability Assessment

Timescale: **1st January 2024 – 1st Sept 2025**

Funding body: European Union (Horizon 2020 programme)

About the project

You are invited to take part in a **questionnaire** as part of a collaborative European project called FRAMEwork. FRAMEwork will enrich and innovate existing Farmer Clusters by liaising with local and (inter)national stakeholder groups, and set up new, multi-actor, Farmer Clusters in different cropping systems in Europe, based on existing collaborations to develop and implement place and system-specific biodiversity-sensitive farming practices and evaluate the economic and environmental performance.

Research aims

The project aims to identify sustainability indicators within European farming systems that can be linked with improved biodiversity at the Farmer Cluster level. The questionnaire aims to collect data on your farm's productivity, resource use, environmental activities, and policies so as calculate an array of sustainability indicators that are relevant to agriculture within Farmer Clusters. These can then be analysed for each Farmer Cluster, identifying strengths and weaknesses in the Cluster's sustainability, or against control farms or national averages, to determine if farms within Farmer Clusters are more sustainable than those outside of Farmer Clusters.

What is involved in the questionnaire?

The questionnaire collects **business information** about your farm and should take about **1-2 hours** to complete. We are asking for information on your produce, resource use, farming practices, and business policies.

The information you provide will be used to calculate 'sustainability indicators', which will then be analysed collectively as a Cluster to look for strengths and weaknesses in the Cluster and farming systems. The questionnaire will also provide information needed to assess the Natural Capital of the Farmer Clusters.

Who is responsible for the data collected?

This research is conducted by the Game and Wildlife Conservation Trust (GWCT), James Hutton Institute (UK) and the Luxemburg Institute of science and Technology (LIST). The research team includes several ecological/environmental scientists and economists, that have created the questionnaire and will use the data for analysis.

This research was approved by the Research Ethics Committee of The James Hutton Institute in Dec 2023.

What are your rights as a participant?

Completion of the questionnaire is **voluntary**. You may choose not to take part, or to subsequently withdraw at any time, without providing any reason, and without your legal rights being affected. Your contribution will be kept **confidential**. You can leave answers blank you do not wish to answer, and you can provide your own comment or suggestions at the end of the questionnaire. You are also able to remove any information up until the point of publication of research findings.

Anonymity and confidentiality

The only identifiable information will be the name of the farm and its location (country). The name of the farm will be anonymised when stored electronically to be further analysed. The survey data will only be available once anonymised to FRAMEwork project partner researchers.

Only aggregated findings will be shared with the funder and other parties, ensuring that you are not identifiable in the research outputs. These outputs may be presented at scientific or professional meetings or published as project reports as well as in scientific or professional journals.

Any hard copy completed original questionnaires will be kept in a secured location within GWCT (hard copies) or electronic versions on GWCT secured servers.

What are the benefits and risks of taking part?

The questionnaire can provide **insight into all areas of sustainability** assessments, allowing you as a participant an opportunity to ask questions or consider changes you might make in future where possible. The results will be presented to each Cluster, allowing you to see where you are doing well and where changes could be made.

You will receive **no compensation** for your participation. The data will not be used by any member of the project team for commercial purposes. Therefore, you should not expect any royalties or payments from the research project in the future. There are **no risks** for you and your farm from participating. Your decision whether to participate or not will not affect your participation in other events and activities of the FRAMEwork project.

How do you confirm your interest?

If you agree to complete the questionnaire, please **sign the consent form** and return it alongside the questionnaire. If you have any **questions** before signing the consent form, please ask your Facilitator, and we will respond to any questions via your Facilitator. If you have any further questions at a later date, please feel free to contact Rachel Nichols at rnichols@gwct.org.uk

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Appendix 3 - Consent form

RESEARCH CONSENT FORM FOR QUESTIONNAIRE SURVEY FARMERS

Title of Project:	FRAMEwork - Farmer Cluster for Realising Agrobiodiversity Management across Ecosystems
Principal Investigator:	Simone Martino (Hutton) CoI - Rachel Nichols (GWCT), CoI – Claudio Petucco (LIST)
Study Number:	This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under **grant agreement No 862731**

Please Initial Box

1. I confirm that I have read, or someone else read me, and understand, the information sheet and the instruction for stakeholders for the above study. I have had the opportunity to ask questions, and these have been answered fully and explicitly.	
2. I understand that my participation is voluntary, and that I am free to withdraw at any time, without providing any reason and without my legal rights being affected. I understand that anonymised data (i.e., data that do not identify me personally) cannot be withdrawn once they have been included in the study.	
3. I understand that the study is being conducted by researchers of the James Hutton Institute (“Hutton”, Scotland), The Game and Conservation Wildlife Trust (“GCWT”, England), and the Luxembourg Institute of Science and technology (“LIST” Luxembourg), and that the research is funded by the European Union´s Horizon 2020 Programme; also, the three research institutes mentioned above are supported by the local farm cluster facilitators to interact with farmers and relevant stakeholders for the purposes of this study.	
4. I understand that the farmer cluster facilitators have supported GWCT, LIST and HUTTON by translating the content of the questionnaire in the local language and will support any discussion with farmers relevant for the research into English afterwards (if the main language used in the collection of the data is not English).	
5. I understand that confidentiality will be maintained at all times, and it will not be possible to connect any choices, statements or opinions to me and my farm in any publications/outputs unless I have given my permission for this.	
6. I understand that any idea provided by me will be anonymised and used for analysing the sustainability of the farm and profiling the natural capital approach in the farm cluster.	
7. I agree to take part in the questionnaire survey. I understand that I will be asked to fill a form in word and/or an excel spreadsheet to provide information on several	

indicators/proxies of the farming activity necessary to characterise the sustainability of the farm operations and to investigate dependencies and impacts of farming activities on natural capital.	
8. I agree for any eventual further discussions occurring during the collection of the data at point 7 to be audio recorded, to create media content for the communication activities of the FRAMEwork project.	
9. I understand that notes will be taken during the discussion without connecting ideas, opinion and facts to any stakeholders; also, that if the main language is not English, the local facilitator will access the recording of the discussion to complement the notes taken during the discussion and translate them in English	
10. I understand that any information disclosed within the discussion with the farmer cluster facilitator must remain confidential between the farmer and the farer cluster facilitator and I will not share this information unless I have the relevant person's expressed permission from the farmer cluster facilitator.	
11. I understand that I will receive no compensation for my participation. The information acquired during the questionnaire survey will not be used by any member of the project team for commercial purposes. Therefore, I cannot expect any royalties or payments from the research project in the future.	
12. Please choose one of the options below regarding photographs/screenshots/video: □ I give permission for photos/videos taken during the questionnaire survey where I may be identifiable to be used for publicity and dissemination purposes of this project. □ I do not give permission for photos taken during the questionnaire survey where I may be identifiable to be used for publicity and dissemination purposes of this project. I understand that if I do not give permission, the photographs/screenshots will be edited (e.g., blurred faces) so that I will not be identifiable.	
13. I acknowledge that I have read and understood the privacy notice (see below) and I understand how my personal data will be used in this study.	
14. I understand that the outputs of this research will be circulated in the form of reports, scientific papers, briefings, podcast, blog posts and other content for the FRAMEwork website.	
15. I give permission for the data that I provide in the questionnaire survey to be deposited in anonymised form in a publicly accessible data archive or repository so it can be used for future research and learning.	

___________________________ ______________________________ __________

Name of Participant (please print) Signature Date

___________________________ ______________________________ __________

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PI/Researcher Name (please print)	Signature	Date

Privacy Notice

The James Hutton Institute (Hutton), the Game and Conservation Wildlife Trust (GWCT) and the Luxemburg Institute of Science and Technology (LIST) will use your personal data for the purposes of the research undertaken in the project FRAMEwork – Farmer Cluster for Realising Agrobiodiversity Management across Ecosystems. Our legal basis for processing your data is that it is necessary for our research tasks which we carry out in the public interest. Where we are relying on your consent for processing your personal data, you can ask us to delete or stop processing your data by contacting r.nichols@gwct.org.uk or simone.martino@hutton.ac.uk. In this event, we will stop the processing as soon as we can, and to the extent this is within our control. However, this will not affect the lawfulness of any processing carried out before your withdrawal of consent.

The data collected during the questionnaire survey (consent forms, discussions' notes, paper containing the questions and/or the excel spreadsheet) will be stored securely in GWCT password protected files. Personal data shall be processed only for administrative, operational, accounting, research and monitoring purposes that are necessary for the safe and reliable implementation of the FRAMEwork project, without prejudice to your individual rights under the relevant laws.

Anonymised information collected through the questionnaire survey will be shared between the Game and Wildlife Conservation Trust (GWCT), the James Hutton Institute (Hutton) and the Luxembourg Institute of Science and Technology (LIST) for further elaboration and your farm cluster facilitator when this is necessary for the purposes of the project. In addition, any audio/video recordings may be accessed and used by the project partner Taskscape Co Ltd for the purpose of producing communication material for the project.

GWCT is the Data Controller of your personal data collected in this study. Your personal data shall be retained only for as long as it is necessary for the purposes of the project and shall be anonymised and stored afterwards, without any possibility to link your choices, statements or opinions to your name. Only the anonymous datasets shall be used for statistical elaboration, and shared with LIST and Hutton, to produce results to be communicated and disseminated.

GWCT will only share your personal data with the relevant project partners as outlined above, if required by law, or for the purposes of the project for which you have provided your consent. Anonymised information collected through the questionnaire survey carried out in the UK may be transferred outside of the UK when we need to share data with our EU-based project partners. Data collected by the questionnaire survey carried out in the EU will be processed in the EU and UK.

You have rights in relation to your personal data. Please see our Privacy Notice at www.hutton.ac.uk/terms for further information or contact our Data Protection Officer on dpo@hutton.ac.uk, or by telephone at 01382 346814. If you need a translated version of the Hutton Privacy Notice, please ask us. If you need to contact the Data Protection Officer using a language different from English, we will arrange for the communication to be translated for you.

Simone Martino, The James Hutton Institute, Aberdeen, AB15 8QH, Scotland, UK

Email: simone.martino@hutton.ac.uk