Ref. Ares(2021)5337860 - 30/08/2021

MIND STEP

MODELLING INDIVIDUAL DECISIONS TO SUPPORT THE EUROPEAN POLICIES RELATED TO AGRICULTURE

Deliverable D1.2: Indicator framework for measuring the impact of policies/global drivers on IDM units in agriculture

AUTHORS	Marta Pérez-Soba (JRC), Silvia Coderoni (UCSC) John Helming (WECR), Marc Muller (WECR) Paolo Sckokai (UCSC), Alessandro Varacca (UCSC)
APPROVED BY WP MANAGER:	Author name (partner abbrev)
DATE OF APPROVAL:	29.08.2021
APPROVED BY PROJECT COORDINATOR:	Hans van Meijl (WR)
DATE OF APPROVAL:	29.08.2021
CALL H2020-RUR-2018-2	Rural Renaissance
WORK PROGRAMME Topic RUR-04-2018	Analytical tools and models to support policies related to agriculture and food - RIA Research and Innovation action
PROJECT WEB SITE:	

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 817566.

This page is left blank deliberately

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 817566.

TABLE OF CONTENTS

LIST OF FIGURES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

LIST OF TABLES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

ACRONYMS

CAP - Common Agricultural Policy

EU - European Union

FADN - Farm Accountancy Data Network

IACS - Integrated Administration and Control System

IDM - Individual Decision Making

LPIS - Land Parcel Identification System

MS – Member States

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

EXECUTIVE SUMMARY

This deliverable presents the indicator framework developed in MIND STEP for estimating the impact of agricultural policy measures and/or global drivers on Individual Decision Making farm units. First, we review relevant indicator datasets, and select indicators meaningful to answer the policy questions described in MIND STEP Deliverable 1.1. We structure this draft list around relevant themes covering both the economic, environmental and social dimensions of sustainability, and the MIND STEP policy questions. We considered a larger number of themes linked to the environmental impacts, following the conclusions of the first stakeholder workshop. This is an important feature of the MIND STEP framework. Second, we validate the draft list with the MIND STEP core group of stakeholders, via a questionnaire and an online (second) stakeholder workshop, where we discuss the list and the results of the questionnaire. Third, we do a systematic literature review, using the Web of Science and Scopus, targeted to identify additional indicators, relevant at the farm level, cited (in research or practice) to assess agricultural policy impacts. Finally, we present the consolidated MIND STEP indicator framework, resulting from the stakeholder feedback and the literature review. The presented indicator framework will be used as input for the data framework in WP2, the modelling work in WP3, WP4 and WP5 and for the policy evaluation in WP6. In this way, the indicator framework will ensure a harmonized and consistent use of indicators across the MIND STEP project. In addition, the second stakeholder workshop has shown that the framework is a stimulating platform for discussions about the potential impacts of the new CAP.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

1. INTRODUCTION

The new EU's 2023–2027 Common Agricultural Policy (the CAP), which accounts for around a third of the EU's budget, has a great potential to foster a sustainable and competitive agricultural sector. In fact, the new CAP will play a key role in reaching the Farm to Fork and Biodiversity Strategies. Indicator frameworks underpinning sustainability governance can help to unlock this potential. Particularly those indicators that help to assess trade-offs and/or unintended consequences that might result from the implementation of some policy measures.

However, a completely integrated set of agricultural indicators that is operable from farm to national and global scales is not yet available (Firbank, 2020). Ideally, farm performance should be assessed using disaggregated data that can be re-aggregated into high-level indicators of performance, allowing flexibility in case the choice of indicators and outcomes evolves (Firbank, 2020).

In this deliverable, we approach this challenging need and present a novel indicator framework to measure the impact that policy questions identified in MIND STEP[1] can have on Individual Decision Making (IDM) units in agriculture. This indicator framework will be used as input for the data framework, the modelling work and for the policy evaluation. In this way, the indicator framework will ensure a harmonized and consistent use of indicators across the MIND STEP project.

The indicator framework will cover the three dimensions of sustainability. Kelly et al (2018) stressed that the contribution of a farm to sustainable agriculture involves the production of goods and services (economic dimension), the management of natural resources (environmental/ecological dimension) and the contribution to rural communities (social dimension). Consequently, assessment of policy impacts on farm's sustainability will inevitably involve these three interconnected dimensions.

Indicator definition. We consider indicator as 'a variable which supplies information on other variables which are difficult to access and which can be used as a benchmark to take a decision' (Gras et al., 1989). These indicators need to be clearly connected to the nine objectives of the new CAP, particularly those linked to environment, climate, landscape and biodiversity, as proposed by the Core stakeholder Group in the first MIND STEP workshop (see Deliverable 1.1)[1].

In addition, the indicators need to provide information at farm level, which is central to MIND STEP. The ecological and economic interactions are most pronounced at farm level (van Wenum et al., 1999). The big challenge is that harmonised, good quality environmental datasets to produce the environmental indicators are often lacking. For example, the Eurostat database contains information from which some of the CMEF indicators are derived to track the integration of environmental concerns in the CAP. However, Eurostat data are not available at farm level. There are only three datasets that are collected consistently at farm level throughout the EU on a yearly basis. They include the Farm Accountancy Data Network (FADN); the IACS (Integrated Administration and Control System)

[1] See Deliverable 1.1 - Report on policies and global drivers affecting Individual Decision Making (IDM) units in EU agriculture

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

database, which manages CAP payments to farmers; and the Land Parcel Identification System (LPIS) spatial database, which is part of IACS and monitors land parcels and land use at farm level.

The following chapters describe the approach to develop the indicator framework. The approach is designed to deliver a structured long list of indicators that is fit for purpose, legitimate and cover a broad range of the key issues identified in the MIND STEP policy scenarios.

First, we review relevant indicator datasets, and select indicators meaningful to answer the policy questions. We structure this draft list around relevant themes covering both the economic, environmental and social dimensions of sustainability, and the MIND STEP policy questions. Second, we validate the draft list with the MIND STEP core group of stakeholders, via a questionnaire and an online stakeholder workshop, where we discuss the list and the results of the questionnaire. Third, we do a systematic literature review, using the Web of Science and Scopus, targeted to identify additional indicators, cited (in research or practice) to assess agricultural policy impacts. Finally, we present the consolidated MIND STEP indicator framework, resulting from merging the draft list with the literature review.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

2. SELECTION AND GROUPING OF RELEVANT INDICATORS

2.1. Review of agricultural policy relevant indicator datasets

In order to develop the indicator framework, the first stage was to review key indicator datasets currently used *to assess the impacts of EU agricultural policy*, either in the CAP or in research, relevant for Individual Decision Making (IDM) units in agriculture:

- The Common Monitoring and Evaluation Framework (CMEF) [2] , which is the set of performance indicators to assess the CAP 2014-2020. We included the Context indicators, because they reflect relevant aspects of the general contextual trends in the economy, environment and society that are likely to have an influence on the IDM. The Result indicators because they measure the direct, immediate effect of the policy measure (e.g. number of rural jobs created. And the Impact indicators because they estimate longer term effects (e.g. decrease in GHG emissions).
- Agri-environmental indicators (AEIs)[3], which track the integration of environmental concerns into the Common Agricultural Policy (CAP) at EU, national and regional levels. AEIs are a set of 28 indicators, developed by the Commission in close collaboration with Member States following the Commission Communication on Agri-environmental indicators of 2006 (COM 2006). This set was included because the stakeholders selected the environmental and climate objectives of the CAP as the most relevant for MIND STEP[4].
- The FLINT project (2017) [5] data-infrastructure developed to assess the sustainability performance of farms on a wide range of relevant topics for the MIND STEP policy scenarios, including market stabilization, income support, environmental sustainability, climate change adaptation and mitigation, innovation, and resource efficiency. See Poppe et al (2016).
- AgMIP [6] - Agricultural Model Intercomparison and Improvement Project – includes a community of experts advancing methods for improving predictions on the future performance of agricultural and food systems. Several partners of MIND STEP are part of AgMIP and therefore we have access to those relevant indicators used in the "Modelling for sustainable farming systems".

---

[2] https://agridata.ec.europa.eu/extensions/DataPortal/cmef_indicators.html

[3] https://ec.europa.eu/eurostat/web/agriculture/agri-environmental-indicators

[4] See Deliverable 1.1 - Report on policies and global drivers affecting Individual Decision Making (IDM) units in EU agriculture

[5] https://www.flint-fp7.eu/

[6] https://agmip.org/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

2.2. Selection and grouping of indicators in themes

We used the criteria specified in Table 1 to select relevant indicators from the datasets reviewed in Section 2.1. *Appendix 1* shows the indicator selection, with 36 Agri-environmental indicators, 73 CAP indicators (24 Context, 27 Result and 22 Impact), a combined list of both (agricultural policy indicators), 16 MIND STEP indicators (from AgMIP), and the combined list of policy and MIND STEP indicators. We identified overlaps between the lists and reduced the full list with 125 indicators to a shorter list with 83. We did not include FLINT indicators, as these are not available for all Member States.

Table 1 Criteria used to select indicators from the datasets reviewed in MIND STEP (see section 2.1)

Indicator selection criteria	Concept
Policy relevance	Indicator addresses the CAP policy objectives (particularly the three environmental objectives) and scenario themes identified in MIND STEP
Data availability	Indicator is feasible in terms of current or planned data availability.
Data measurability	Indicator can currently or potentially be modelled in MIND STEP
Geographical coverage	Indicator has an EU geographical coverage.

Following this selection, we selected 83 indicators and grouped them in 22 themes, covering different aspects of the economic, environmental and social dimensions of sustainability (Table 2). We considered a larger number of themes linked to the environmental impacts, following the conclusions of the first stakeholder workshop[7]. This is an important feature of the MIND STEP framework.

Table 2 MIND STEP Indicator framework - themes and respective number of indicators, structured across the three dimensions of sustainability

Dimension	Theme	Number of indicators
Economic		
	Agricultural productivity	9
	Farm income/GDP	4
	Other gainful activities	1

[7] See Deliverable 1.1 - Report on policies and global drivers affecting Individual Decision Making (IDM) units in EU agriculture

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Dimension	Theme	Number of indicators
	Structural change	3
	Land prices	1
	Agricultural trade	2
Environmental		
	Land cover/Land use	10
	Agri-environmental commitments	1
	Feed use	1
	Energy	2
	GHG emissions	7
	Air quality	1
	Nutrient (N,P) balance	6
	Water quality	4
	Water quantity and availability	3
	Soil quality and fertility	4
	Soil erosion	1
	Biodiversity and landscapes	9
	Pesticide use	3
	Animal welfare	1
Social		
	Employment	2
	Training and education	8

In order to assess the data measurability, we asked the seven MIND STEP partners in charge of the modelling (IIASA, INRA, RURALIS, UBO, UCSC, WR, WU) to score if they could model the indicator with their models, and for which policy scenario. Possible scores were “1” or “2”, respectively for indicators actually modelled or potentially modelled. We added the scores and analysed the results using a Heat Map chart (see illustration in Figure 1). The analyses highlighted which indicators were the easiest to be modelled by the consortium and which ones will need additional efforts.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 817566.

Figure 1 Heat Map chart illustrating the current or potential capacity of MIND STEP to model the selected indicators.

Indicator name	Simulate the adoption of carbon taxes on agricultural production	Simulate the adoption of a carbon border tax adjustment toghether with previous instruments	Simulate the adoption of subsidies targeted to climate change mitigation	Impact of different GHG mitigation measures (i.e. constraints on livestock numbers and/or on nutrient disposal).	Create incentives to increase carbon sinks by farmers (and measure the impact of different land use options)	Create incentives for energy transition in agriculture (e.g. renewables)	Simulate the adoption of emission trading systems between farms	Creating markets for ecosystem services (carbon sequestration)	Simulate the impact on the agricultural sector of changes in diets (e.g. reduction of meat consumption)
Agri-environmental commitments	0	0	0	0	0	0	0	0	0
Land use change	3	1	3	4	3	2	0	2	3
Cropping patterns	4	1	4	4	4	2	0	2	3
Soil cover	1	0	1	1	1	1	0	1	1
Farming intensity	4	1	4	5	4	2	0	2	3
Specialisation	3	0	3	4	3	2	0	1	2
Risk of land abandonment	2	0	2	2	2	2	0	1	2
	0	0	0	0	0	0	0	0	0
Energy use in agriculture, forestry and foc	2	0	1	2	1	1	0	1	1
Production of renewable energy from agr	2	0	1	1	1	1.1	0	1	1

Appendix 2 shows the draft indicator framework resulting from the selection process and the revision of overlaps. The indicators are grouped according to the economic, environmental and social impacts and the indicator themes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

3. STAKEHOLDERS CONSULTATION

3.1. Questionnaire

As, unfortunately, we could not have the originally planned 1.5-day workshop due to the COVID19 pandemic, we decided to develop a questionnaire to gather a deeper, individual input from the stakeholders. In addition, the questionnaire results supported a focused discussion during the 1.5 hours online stakeholder workshop (see section 3.2).

The questionnaire is included in *Appendix 3*. The questions had as purpose to collect information about three main issues on the draft indicator framework (section 2.2):

- Completeness of the indicator list;
- Relevance of the indicators for the three scenario groups;
- Number of indicators to analyse the main economic, environmental and social impacts.

The core group of stakeholders consists of 10 stakeholders (*Appendix 3*)[8]. We have summarised below the seven responses received.

I. COMPLETENESS OF THE INDICATOR LIST

QUESTION 1: Is the list of indicators complete?

Scenario groups	YES	NO
Climate change action	3	4
Preserve biodiversity, ecosystem services and environmental care	3	5
Competitiveness in the agricultural sector	3	4

If NO, which indicators are you missing?

Scenario groups	Missing indicators
Climate change action	- More specific indicators of actual outcomes (emissions from different agricultural sectors, levels of (estimated) carbon sequestration etc.) - % farmers using Carbon calculators - Lifecycle Analysis related indicators - Change in commodity price when crossing borders (if not covered by indicator on Carbon price)

[8] See Deliverable 1.1 - Report on policies and global drivers affecting Individual Decision Making (IDM) units in EU agriculture

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Scenario groups	Missing indicators
Preserve biodiversity, ecosystem services and environmental care	- Land use change capturing changes according to management options -Pesticides • environmental impact per unit of active ingredient used in crop protection chemicals • share of UAA under Integrated Pest Management - Livestock • Use of antibiotics in livestock per sector • for scenario 14 - number of farms with different livestock management options • Ammonia emissions from agriculture; manure processing/export-import - Use of precision agriculture technology on-farm - Area/LU of organic farming - Water Exploitation Index (WEI)[9] - Indicators linking practices (fertiliser use, pesticide use, tillage practices) and land use to biodiversity, including semi-natural habitats. Wildlife habitat quality indices types of approach would be good here. Also trends in populations others than birds, trends in habitat area and conservation value, environmental status of fresh waters, etc. - Total amount of subsidies spent per measure - Total amount of fines per measure
Competitiveness in the agricultural sector	- Production by commodity (rather than total productivity) - More on domestic and wider global market share of EU producers in different sectors, more on input prices, more on consolidation trends in agriculture - Farm revenues and farm costs by type of farming -Commodities: number of new commodity certifications, commodity market value -Some indicator showing the decision driving force (willingness) to adapt to the EU measures - Food security - Business risk perception of farmer

[9] The water exploitation index (WEI) is the total fresh water abstraction divided by the long term average available water (LTAA) expressed as a percentage.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

II. RELEVANT INDICATORS

QUESTION 2: Which indicators are relevant per scenario?

The stakeholders were asked to choose the 10 indicators (from *Appendix 2* or proposed by them) that they considered more meaningful to describe the impacts in each of the three scenarios groups.

We have listed in the Table below the more chosen indicators, with the number of selected times between brackets. The indicator names are marked in colours according to the impact dimension (orange is economic, green is environmental and blue is social) to show the distribution among the three dimensions per Scenario group.

Scenario groups	Relevant
Climate change action	- Greenhouse gas emissions from agriculture (7) - Land use change (5) - Carbon price (5) - Share of agricultural land under commitments to improve climate adaptation (4) - Carbon demand (4) - Energy used in agriculture, forestry and food industry (3) - Production of renewable energy from agriculture and forestry (3) - Share of agricultural land under commitments to reducing emissions, maintaining and/or enhancing carbon storage (permanent grassland, agricultural land in peatland, forest, etc.) (3) - Share of farms benefitting from CAP investment support contributing to climate change, mitigation and adaptation, and to renewable energy or biomaterials production (3) - Soil organic carbon in agricultural land (3)
Preserve biodiversity, ecosystem services and environmental care	- Gross nutrient balance – nitrogen (3) - Share of livestock units under supported commitments to improve environmental sustainability (3) - Nitrogen from fertilisers (3) - High Nature Value farmland (3) - Farmland birds index (3) - Percentage of species and habitats of Community interest related to agriculture with stable or increasing trends (3) - Land cover (2) - Agri-environmental commitments (2) - Farming intensity (2) - Share of agricultural land under management commitments for water quality (2) - Nitrates in ground water (2)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

	- Share of agricultural land under management commitments beneficial for soil management (2) - Agricultural land covered with landscape features (2) - Area supported for afforestation and creation of woodland, including agroforestry (2)
Competitiveness in the agricultural sector	- Total factor productivity in agriculture (6) - Farm income by type of farming (5) - Farm income by region (5) - Crop yield (3) - Age structure of farm managers (3) - Share of farmers receiving investment support to restructure and modernise, including to improve resource efficiency (3) - Labour productivity in agriculture (3) - Real export price (3)

III. NUMBER OF INDICATORS PER SCENARIO

How many indicators are needed to tell the story?

Number of indicators	Number of votes[10]
Less than 9	0
Between 9 and 15	6
More than 15	2

The indicators most voted were:

- Total factor productivity in agriculture
- Cropping patterns
- Yield per hectare per crop type
- Farm income by type of farming
- Farming intensity
- Land use change
- Labour productivity in agriculture and food industry
- Yield per hectare per crop type
- Farm costs per type of farming
- Nr of agricultural holdings
- Risk of land abandonment

[10] One stakeholder chose two options

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

- Environmental impact per unit of active ingredient used (Pesticides)
- Pesticide use (Pesticides)
- Impacts on ecosystem services, including several indicators (air quality, soil quality, water quality, etc.)
- Biodiversity (bird species and habitats)
- GHG emissions

3.2. Conclusions from the questionnaires

Completeness

The current list with 83 indicators was found rather complete, but four stakeholders added new indicators to the list. The added list includes interesting additions that will be considered by the consortium and decide if it is feasible to use them in the models available.

Relevance

The environmental dimension was the most selected sustainability dimension. It was the only dimension selected for Climate change and Biodiversity scenarios. While the economic dimension was the most selected among the other two for the Competitiveness scenario.

We also observed a strong coincidence in the indicator themes relevant for each scenario group:
The largest agreement was in the Climate change scenario. All were environmental indicators. From the most relevant 10 indicators, 6 indicators belong to the theme GHG emissions, 2 to energy, 1 to land use/land cover and 1 to soil quality and fertility (soil organic carbon in agricultural land).
In the Biodiversity scenario, all were also environmental indicators. From the most relevant 14 indicators, 5 indicators belong to biodiversity and landscapes, 3 indicators to air and water quality (mainly linked to Nitrogen emissions from livestock and fertilisers), and 3 to agri-environmental commitments, and land cover/land use.
In the Competitiveness scenario, most were economic indicators. From 8 indicators, 3 belonged to agricultural productivity and 2 to farm income. This was the only scenario group with a social indicator (Share of farmers receiving investment support to restructure and modernise, including to improve resource efficiency).

There were some indicators relevant across the three scenarios: Farming intensity and Land use change.

Number of indicators

The minimum number of indicators to describe the policy impacts in each scenario depends on the level of ambition, but **9-15 may be enough to analyse the key impacts**.

Overall remarks

- The stakeholders did not choose as relevant the social impacts for the Climate change and Biodiversity scenario groups. However, several mentioned the **importance of Training and education**, particularly the uptake of relevant advice.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

- There is a need for **indicators that measure changes**:

(1) Actual changes in conventional farming practices and products, such as tillage practices, share of agricultural land under management commitments beneficial for soil management

(2) Changes in alternative farming systems – organic, agroecology (once defined), agroforestry. For example:
- *Share of agricultural land under Integrated Pest Management*
- *Share of organic systems*
- *Share of agricultural land concerned by supported specific actions which lead to a sustainable use of pesticides in order to reduce risks and impacts of pesticides*
- *Share of Utilised Agricultural Area supported by the CAP for organic farming maintenance or conversion*

(3) Changes in labour use
(4) Related structural changes in the most affected sectors, such as crop production moving inside (or outside), geographical relocation etc.
(5) Market share and changing level of imports/exports in key sectors
(6) Changes in investment patterns on most affected farm types/ business risk perception of farmer
(7) Changes in deployment of new technology/ Share of farms with CAP risk management tools/Share of farmers receiving investment support to restructure and modernise, including to improve resource efficiency
(8) Impacts on crop prices and margins over time/ Food prices/input and output prices.

- There is a need for some specific indicators on:
    - **Biodiversity**, indicators that assess the impacts on populations of indicator species including pollinators + *Birds and species diversity;*
    - **Agricultural productivity**, some indicators on the impact on crop yields (selecting key crops) and yield variability and prices.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

3.3. Second stakeholder workshop

The second Stakeholder workshop focused on the relevance of the MIND STEP indicator framework to estimate the impacts of the selected policy scenarios and the ability of the MINDSTEP toolbox to model the scenarios.

The objectives

- to get feedback on the completeness and relevance of the indicator framework to estimate the impacts of the policy scenarios;
- to illustrate the use of the MINDSTEP toolbox for selected policy scenarios.

The workshop

In the 2.5 hour online workshop, seven members of the core group of stakeholders provided their feedback in a lively conversation with the policy team and modelling experts. The Agenda of the workshop is included in *Appendix 5*.

In the first session, Silvia Coderoni presented how the outcomes of the first stakeholder workshop (June 2020) were processed. The policy team grouped the 24 policy scenarios looking at the 9 post-2020 CAP objectives suggested by the stakeholders into three topics: 1) climate change action, 2) preserve biodiversity, ecosystem services and environmental care, and 3) increase competitiveness. She also presented the results of the analysis of the policy scenarios by the modelling team regarding their potential to be modelled at different spatial scales. All scenarios in Group 1 can be modelled, most of the scenarios in Group 2 can be modelled, and more than half of the scenarios in Group 3 can be modelled.

Afterwards, Marta Pérez-Soba presented the current version of the MIND STEP indicator framework. She introduced the methodology developed to define the framework and the outcomes of the questionnaire.

The presentations were followed by the discussion of emerging questions: 1) what is the ideal number of indicators to assess the impact of a policy? and 2) Can the new indicators proposed by the stakeholders be modelled?

In the second half of the workshop John Helming presented the MIND STEP model toolbox in details, and Hugo Storm from UBO illustrated the use of the toolbox for a selected scenario "Mandatory reduction of input use" using FarmDyn and Agripolis. The presentations were followed by a discussion where stakeholders presented their views on the appropriateness of the toolbox, and how the models and tools should be developed and tested to created trust in them.

Emerging questions

- Number of indicators – large number is experienced as cumbersome/simplification needed
- Is it feasible to model in MIND STEP the new indicators proposed in the questionnaire?
    - Environmental impacts per unit of production (ton/ha), or per unit of input (e.g. pesticide active ingredients)
    - Impact on crop prices and margins, and on food prices
    - Impacts on investment patterns of most affected farm types
    - Changes in deployment of new technologies/ share of farms with CAP risk management tools (% farmers using Carbon calculators)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

- Use reliable indicators, e.g. Livestock numbers.
- Environmental indicators: specify if it is a proxy or a real effect.
- Quality of the indicators should be assessed as well.
- Consider is indicators can measure changes over time
- Use of carbon calculators on farm
- Assess interdependencies among indicators
- Need to inform on the spatial and temporal resolution
- Regarding pesticides: not only the type of active ingredient is important, but also the quantity of each ingredient.

Conclusions

It was very encouraging to see the enthusiastic reactions of the stakeholders. We heard the need to review the list of indicators focusing on their reliability and capacity to inform about the links between policy measures, their adoption and their (interlinked) impacts on climate, environment and structural changes. Also to dare to fail exploring new indicators.

There is a large potential of uptake of MIND STEP outcomes. Our results can help researchers, NGOs, and citizens to participate in the CAP reform debate so that public spending provides public goods.

Simplification of indicators is needed, but assessing specific impacts requires many indicators; environment and biodiversity have many domains. We need to find a balance between broadness and completeness.

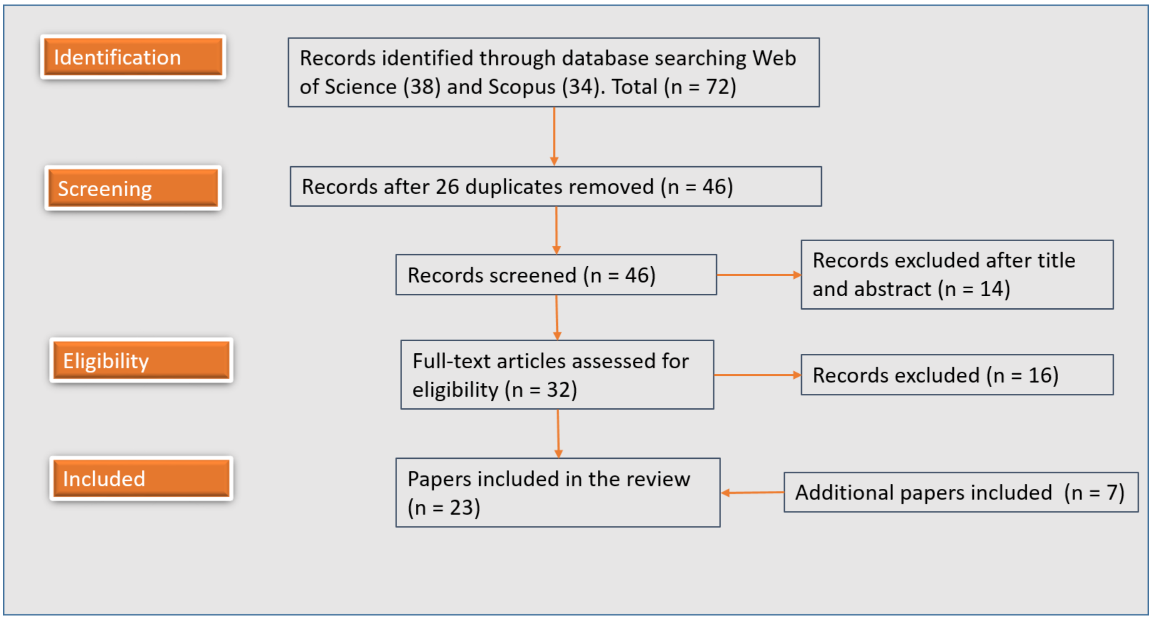
This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 817566.

4. SYSTEMATIC LITERATURE REVIEW

4.1. Search strategy

Keywords	**Web of Science** TOPIC: ("agric* polic*") AND TOPIC: (indicator*) AND TOPIC ("farm scale" OR "farm level") **Scopus** TITLE-ABS-KEY (("agric* polic*") AND (indicator*) AND ("farm scale" OR "farm level"))
Search dates	No time restrictions
Databases	Web of Science and Scopus, run on 23 June 2021
Selection criteria	Five main criteria led to the exclusion of a paper: (1) it does not deal with agricultural indicators at farm level; (2) it does not deal with impacts of policies/policy scenarios; (3) it does not deal with EU; (4) the indicators have not been implemented (thus, they are "theoretical"); (5) it is not written in English. Studies that passed the criteria were subject to critical appraisal carried out on paper-by-paper basis. The search returned 38 papers (Web of Science) and 34 (Scopus) papers potentially relevant, from which 46 papers remained after excluding replicates. From these, 14 papers were excluded after reading the title and abstract, and 16 after reading the full text according to the above-mentioned criteria. References in the selected papers delivered 7 additional relevant papers. Finally, 23 papers were selected (see Figure 2 with the PRISMA flow diagram).

Figure 2. PRISMA flow diagram showing the flow of information through the different phases of the Systematic Review. It maps out the number of records identified, included and excluded, and the reasons for exclusions.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

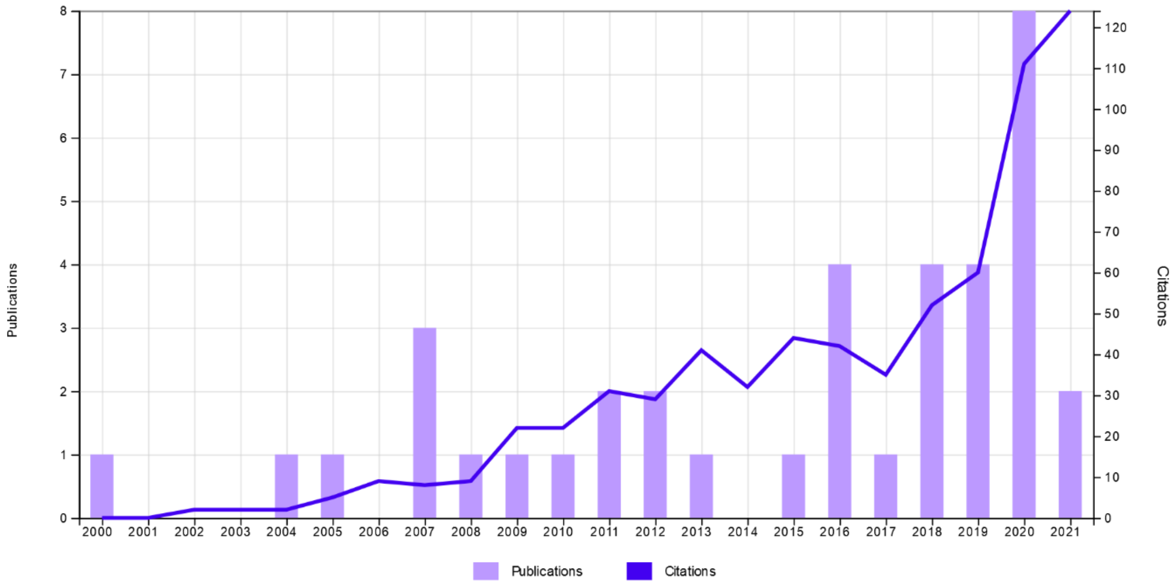
The Web of Science provides some analysis of the results of the literature search (Figures 3 and 4).

Figure 3 shows the research categories (Figure 3). It is interesting to see that the larger number of papers are linked to environmental topics (environmental sciences, environmental studies, green sustainable science technology, ecology, biodiversity conservation), while few are on agricultural economics and none on social sciences. This analysis reflects quite well the large interest of agricultural research on environmental impacts.

Figure 3. Research categories resulting from the literature search in the Web of Science. The areas on the chart are not strictly proportional to the values of each entry (source: Web of science)

Figure 4 depicts the times cited and number of publications over time, showing a growing trend in both publication parameters.

Figure 4. Times cited and number of publications from 2000 -2021 (source: Web of science)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

4.2. Results from the systematic literature review

The main outcomes of the systematic review of the 23 selected papers, including the literature references, list of indicators, databases and the scale, are summarised in *Appendix 6*. We classified the new indicators - not in the draft list - from the papers using the same three types of Impacts and Indicator themes as in the draft indicator list. When needed, we added new indicator themes. The final list of indicators resulting from merging the draft list with the literature review list is in *Appendix 7*.

We summarised below the main results of the systematic literature review:

(1) The papers range from those addressing the use of a composite indicator as a measure of a specific aspect of agricultural sustainability (e.g. Bartolini et al., 2021 on Extensification, or Grzelak et al., 2019 on Environmental Sustainable Value). Others propose various concepts and frameworks for the classification of indicators (e.g. Gomez-Limon and Riesgo, 2009 use the OECD framework (OECD, 2001), and define sets of indicators to quantify how different policy measures may affect the different dimensions of agricultural sustainability.

(2) Nearly 90% of the papers deal with the environmental aspects – either individually (9 papers), or in combination with the economic and social dimension (6 papers), or only with the economic (4 papers) or the social dimension (1 paper).

(3) We found 81 NEW indicators in the papers, from which 30 are economic, 36 environmental and 15 social.

(4) The new economic indicators add information on:
- Farm income, particularly on the input expenses (that reduce the profit rate);
- Structural change, including farm succession, conversion to organic farming and proportion of area tenanted.

In addition, two new indicator themes emerge – (1) Farm economic performance, with 5 indicators, and (2) Indicators for adoption rates of risk management instruments, with 6 indicators. Interestingly, these new themes come from 6 different papers.

(5) The new **environmental indicators** add information on:
- <u>Land cover/Land use</u>, including Land use diversity (Shannon index), and indicators specifying classes of the Utilised Agricultural Area relevant to assess environmental impacts, such as Set aside and Fallow, Non-food crops and Permanent grassland.
- <u>Energy</u>, including energy balance and specific costs of electricity and machinery, heating and vehicle fuels and oil per ha UAA.
- <u>Air quality</u> includes ammonia emissions.
- <u>Nutrient balance</u>, including livestock indicators (livestock units per forage area and total numbers), gross nutrient balance of potash, Nitrogen Use Efficiency, and specifying the use of organic and mineral fertilisers.
- <u>Soil quality and fertility</u>, includes diversity of crop production (which was already included under biodiversity).
- <u>Biodiversity and landscapes</u>, with 7 new indicators that provide new ways to deal with the complexity of the impacts. An interesting proxy is the parcel size.
- <u>Pesticide use</u> is deemed important, with 6 new indicators including area treated with pesticides, crop protection costs, use and risks.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

- Animal welfare, which changes the name to Animal wellbeing (health and welfare). This theme is particularly relevant in paper 4 (Brennan et al, 2020) that provides 5 new indicators to assess it.

(6) The new **social indicators** add information on:

Employment, including seasonal labour employment, workforce stability, risk of abandoning agricultural activity and economic dependence on agricultural activity.

In addition, two new indicator themes emerge – (1) Quality of life, including education level and other 5 indicators, and (2) Community wellbeing, including multifunctionality (contribution to rural economy) and availability of services.

(7) The most frequently selected indicators in the literature review studies are 16 - 4 economic, 11 environmental and 1 social - (Table 3). Nitrogen nutrient balance is by far the most selected indicator (12 papers), followed by Farm labour force/Employment (9 papers) and Crop diversity/Biodiversity (8 papers).

Table 3. List of indicators most frequently selected in the reviewed papers. The indicators marked in blue are the new ones emerging from the systematic literature review.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME	PAPER ID
Economic				
	Farm income/GDP	11	Farm income by type of farming	11, 15, 21, 22, 23
		12	Farm income by region	11, 15, 16, 21, 22, 23
		24	Profit rate (income in relation to operation income)	16, 18, 19, 22
		26	Public/EU subsidies (investment, etc.)	2, 16, 18, 23
Environmental				
	Land cover/Land use	60	Utilised Agricultural Area/ Utilised Agricultural Area minus woodland area	2, 7, 22, 23
	Energy	71	Energy use in agriculture, forestry and food industry/ Fuel quantities/	7, 9, 21, 23
	GHG emissions	75	Greenhouse gas emissions from agriculture/farms	3, 9, 21, 23
	Nutrient (N,P, K) balance	90	Gross nutrient balance – nitrogen (farm gate)/ N surplus and N output in agricultural products	3, 6, 9, 15, 16, 17, 18, 19, 20, 21, 22, 23
		91	Gross nutrient balance – phosphorus	16, 17, 19, 21, 22, 23
		92	Gross nutrient balance – potash	16, 17, 19, 21
		95	Organic fertilisers use/urea quantities/manure proportion	9, 14, 17, 21
	Water quantity and availability	101	Water use in agriculture/ Volume of water applied to soils for irrigation purposes/Water consumption per kg of product	3, 14, 18, 20, 23
	Soil quality and fertility	105	Soil organic carbon in agricultural land	16, 19, 21, 23
	Biodiversity and landscapes	111	Genetic diversity /Number of crops/ Index of crop diversity (Shannon Index)/ Number of crops with a share of > 5% in arable farm area/Proportion of legumes in crop structure/proportion of cereals and maize/% spring crops	1, 5, 12, 14, 16, 18, 19, 20
	Pesticide use	128	Consumption of pesticides	3, 19, 21, 23
Social				
	Employment	143	Farm labour force	2, 3, 7, 15, 18, 20, 21, 22, 23

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Interestingly the number (16 indicators) and the type of indicators shown in Table 3 (16) are very similar to those identified by the stakeholders (see Section 3.2).

(8) All the indicators from the literature review are farm level indicators that have been implemented using as data sources FADN, IACS, national datasets and/or farm surveys.

(9) The area covered in the papers ranges from

- EU scale (25 EU member countries, excluding Cyprus, Malta and Croatia; 8 EU Member States; Central and Eastern European Countries, 1240 farms in Atlantic, Continental and Mediterranean Europe; Case study regions in Denmark, France, Germany, Hungary, Italy, Poland and Slovakia)
- to national scale (France, Finland, Germany, Greece, Hungary, Ireland, Italy, Poland, UK)
- to regional scale (the Veneto region in North-eastern Italy; Spanish Northern Plateau; Spanish Duero basin; Southern Spain; UK Upland farms).

(10) The indicators used for the assessment can differ depending on the farm types, rather than being the same for all. For example, Westbury et al (2011) created two different Assessment Criteria Matrices for the arable and livestock farm types.

5. MIND STEP INDICATOR FRAMEWORK

5.1. The consolidated list of indicators and themes

The consolidated indicator list is presented in *Appendix 7.* It results from merging the draft indicator list (*Appendix 2*) and the indicators from the systematic literature review (*Appendix 6*) and therefore it includes indicators currently used in agricultural policy, but also new indicators available from the models, and proposed by the stakeholders or emerging from the systematic literature review.

The 166 indicators are grouped by the three types of sustainability IMPACTS (economic, environmental and social), and by 26 THEMES (8 economic, 14 environmental and 4 social). The list of environmental indicators remains the longest. The environmental indicators cover important themes such as nitrogen balances, use of pesticides, biodiversity and landscapes, water consumption, greenhouse gas emissions, animal welfare, farm practices with respect to carbon sequestration, soil erosion and nitrate leaching. There are fewer economic indicators despite the substantial increase after the literature review. They cover topics such as risk management, farm economic performance, subsidies, farm succession and the use of contracts. The social indicators involve issues such as education and training (use of advisory services or participation in supported Producer Groups, Producer Organisations, local markets, short supply chain circuits and quality schemes), Community wellbeing (e.g. availability of services), and quality of life.

As regards the framework boundaries, the indicator framework mainly focuses on the primary production stage of the supply chain, to support evaluation of farm-level policies that affect farmers'

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

behaviour, according to MIND STEP objectives. It does not include other activities of the chain such as transport, food transformation and packaging, or manufacturing of crop protection products.

The large number of indicators provides high flexibility to the users to select those needed, depending on the question and specific social and biophysical context, the data availability and the accuracy of the analysis. Furthermore, it enables assessment across the heterogeneity of European conditions and farm types. The usefulness of indicators must be decided within the specific context for which they are assessed (Kelly et al. 2018). For example, the restriction imposed under the EU Nitrates directive sets a limit for nitrogen application at 170 kg/ha. However, the Directive has derogations for some Member States, such as Dutch grassland farms that meet certain conditions and may use more animal manure than the 170 kg. If the objective is to assess farm behaviours at EU level, then the MIND STEP modellers will need to select carefully those indicators that represent common standardised assessments.

In addition, we provide a short list of 16 “key” indicators (Table 3), the most frequently selected indicators in the literature review studies. Interestingly, this list is very similar to that identified by the stakeholders (see Section 3.2), which provides a kind of validation of their relevance.

5.2. Way forward

We have developed a comprehensive indicator framework that meets the needs of policy makers, agricultural modellers and stakeholders, and is endorsed by a systematic literature review. The objective of the framework is to evaluate the effectiveness and efficiency of the policy measures of the three groups of MIND STEP scenarios, through a better understanding of farmers’ behaviour and the choices that they make in trade-offs between economic, environmental and social objectives of the new CAP.

The framework enables MIND STEP modellers to make a choice upon the degree of integration of metrics, ranging from a single, integrated measure of performance (Areal et al., 2018) to the use of separate indicators. Both have pros and cons, as discussed previously in section 3. For example, multiple, single indicators can miss the interactions between them, especially if some of the indicators are correlated, and the question is to identify aggregations of performance across multiple variables.

This MIND STEP indicator framework will be used as input for the data framework in WP2, the modelling work in WP3, WP4 and WP5 and for the policy evaluation in WP6. In this way, the indicator framework can ensure a harmonized and consistent use of indicators across the MIND STEP project. A review of the real use of the indicators by the models at the end of the project will provide a final evaluation of their usefulness.

The largest challenge ahead for the MIND STEP modellers is the data availability to assess many of the indicators in the framework, particularly the environmental and social. According to our literature review, the EU Farm Accountancy Data Network (FADN) has currently the larger potential to assess farm-level sustainability across all three dimensions on an EU-wide basis, despite being primarily oriented towards economic issues. FADN main advantages are that it collects data annually across a

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 817566.

range of indicators at farm level and enables temporal assessment of trends. Other promising sources are IACS and LPIS. However our literature review also identifies limitations of these data sources and how some MS collect additional data beyond the legal requirement. Such data are however only available within the relevant national FADN databases and are not provided to the European Commission. Therefore, MIND STEP will need to utilise FADN data in combination with additional data from sources other than FADN, available at national, EU or international level. Kelly et al (2018) provide examples of how MS have conducted supplementary data collection to build on the existing FADN data, and developed novel methods to study farm-level sustainability.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 817566.

6. ACKNOWLEDGEMENTS

This Deliverable was developed as part of the H2020 MIND STEP project, which received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

7. REFERENCES

Areal F J, Jones P J, Mortimer S R, Wilson P. (2018) Measuring sustainable intensification: combining composite indicators and efficiency analysis to account for positive externalities in cereal production. Land Use Policy 75: 314–326.

Bartolini, F., Vergamini, D., Longhitano, D., Povellato, A. (2021) Do differential payments for agri-environment schemes affect the environmental benefits? A case study in the North-Eastern Italy. Land Use Policy 107 doi 10710.1016/j.landusepol.2020.104862

Bartolini, F; Bazzani, GM; Gallerani, V; Raggi, M; Viaggi, D. (2007) The impact of water and agriculture policy scenarios on irrigated farming systems in Italy: An analysis based on farm level multi-attribute linear programming models. Agricultural Systems doi 10.1016/j.agsy.2006.04.006

Brennan, M., Hennessy, T., Dillon, E. (2020) Towards a better measurement of the social sustainability of Irish agriculture. International Journal of Sustainable Development doi 10.1504/IJSD.2020.115229

COM (2006) Communication from the Commission to the Council and the European Parliament - Development of agri-environmental indicators for monitoring the integration of environmental concerns into the common agricultural policy {SEC(2006) 1136} COM/2006/0508 final.

Czubak, W; Pawlowski, KP (2020) Sustainable Economic Development of Farms in Central and Eastern European Countries Driven by Pro-investment Mechanisms of the Common Agricultural Policy. Agriculture-Basel doi 10.3390/agriculture10040093

Dora, M; Levente, H; Katalin, B; Zsolt, B; Paulina, J; Laszo, P; Balazs, S. (2015) Farm-level environmental performance assessment in Hungary using the Green-point system. Studies in agricultural economics doi 10.7896/j.1426

Ehrmann, M. (2010) Assessing ecological and economic impacts of policy scenarios on farm level. Paper Presented at the 50 st Annual Conference of the German Association of Agricultural Economists (GEWISOLA). Braunschweig, Germany, September 29-October 1 doi 10.22004/ag.econ.93949

Ehrmann, M. (2008) Comparing sustainable value approach, data envelopment analysis and indicator approaches-An application on German dairy farms. Paper Presented at the 12th Congress of the European Association of Agricultural Economists (EAAE), Ghent, Belgium doi 10.22004/ag.econ.44140

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Gomez-Limon, JA; Riesgo, L. (2009) Alternative approaches to the construction of a composite indicator of agricultural sustainability: An application to irrigated agriculture in the Duero basin in Spain. Journal of Environmental Management doi 10.1016/j.jenvman.2009.05.023

Gras R., Benoit M., Deffontaines J.P., Duru M., Lafarge M., Langlet A.,Osty P.L. (1989) Le fait technique en agronomie, Activité agricole,concepts et méthodes d'étude, Institut National de la RechercheAgronomique, L'Hamarttan, Paris, France.

Grzelak, A; Guth, M; Matuszczak, A; Czyzewski, B; Brelik, A (2019) Approaching the environmental sustainable value in agriculture: How factor endowments foster the eco-efficiency. Journal of Cleaner production doi 10.1016/j.jclepro.2019.118304

Hanley, N; Acs, S; Dallimer, M; Gaston, KJ; Graves, A; Morris, J; Armsworth, PR. (2012) Farm-scale ecological and economic impacts of agricultural change in the uplands. Land use policy doi 10.1016/j.landusepol.2011.10.001

Kelly E., Latruffe L., Desjeux Y., Ryan M., Uthes S., Diaza-bakana A., Dillon E., Finn J. (2018) Sustainability indica-tors for improved assessment of the effects of agricultural policy across the EU: Is FADN the answer? Ecological Indicators 89: 903–911.

Latruffe, L., Mann, S. (2015) Is part-time farming less subsidised? The example of direct payments in France and Switzerland. Cahiers Agriculture doi 10.1684/agr.2015.0732

Lehtonen, H; Aakkula, J; Rikkonen, P. (2005) Alternative agricultural policy scenarios, sector modelling and indicators: A sustainability assessment. Journal of Sustainable Agriculture doi 10.1300/J064v26n04_06

OECD (2001) Environmental Indicators for Agriculture. Volume 3 – Methods and Results. OECD, Paris.

Pesti, C., Keszthelyi, S. (2009) Additional Environmental Data in Hungarian FADN – Analysis of Crop Farms. Landbouw-Economisch Instituut (LEI), The Netherlands, pp. 86–93 (Report No . 2009-085)

Poppe, K; Vrolijk, H; Dolman, M; Silvis, H. (2016) FLINT - Farm-level Indicators for New Topics in policy evaluation: an introduction. Studies in agricultural economics doi 10.7896/j.1627

Quemada, M; Lassaletta, L; Jensen, LS; Godinot, O; Brentrup, F; Buckley, C; Foray, S; Hvid, SK; Oenema, J; Richards, KG; Oenema, O (2020) Exploring nitrogen indicators of farm performance among farm types across several European case studies. Agricultural systems doi 10.1016/j.agsy.2019.102689

Reig-Martinez, E; Gomez-Limon, JA; Picazo-Tadeo, AJ (2011) Ranking farms with a composite indicator of sustainability. Agricultural Economics doi 10.1111/j.1574-0862.2011.00536.x

Rey, PJ; Manzaneda, AJ; Valera, F; Alcantara, JM; Tarifa, R; Isla, J; Molina-Pardo, JL; Calvo, G; Salido, T; Gutierrez, JE; Ruiz, C (2019) Landscape-moderated biodiversity effects of ground herb cover in olive groves: Implications for regional biodiversity conservation. Agriculture Ecosystems & Environment doi 10.1016/j.agee.2019.03.007

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Syp, A; Osuch, D (2018) Assessing Greenhouse Gas Emissions from Conventional Farms Based on the Farm Accountancy Data Network. Polish Journal of Environmental Studies doi 10.15244/pjoes/76675

Tzilivakis, J; Lewis, KA. (2004) The development and use of farm-level indicators in England. Sustainable Development doi 10.1002/sd.233

Tzouramani, I; Mantziaris, S; Karanikolas, P (2020) Assessing Sustainability Performance at the Farm Level: Examples from Greek Agricultural Systems. Sustainability doi 10.3390/su12072929

Uthes, S; Kelly, E; Konig, HJ (2020) Farm-level indicators for crop and landscape diversity derived from agricultural beneficiaries data. Ecological Indicators doi 10.1016/j.ecolind.2019.105725

Van Asseldonk, M; Tzouramani, I; Ge, L; Vrolijk, H (2016) Adoption of risk management strategies in European agriculture. Studies in agricultural economics doi 10.7896/j.1629

Van Wenum, J., Buys, J., Wossink, A. (1999) Nature quality indicators in agriculture. In: Brouwer, F., Crabtree, B. (Eds.), Environmental Indicators and Agricultural Policy, CABI Publishing, Wallingford.

Waarts, Y. (2007) Indicators for agricultural policy impact assessment - the case of multifunctional beef production. In: Mander Ü., Wiggering H., Helming K. (eds) Multifunctional Land Use. Springer, Berlin, Heidelberg doi 10.1007/978-3-540-36763-5_17

Westbury, D.B., Park, J.R., Mauchline, A.L., Crane, R.T., Mortimer, S.R. (2011) Assessing the environmental performance of UK arable and livestock holdings using data from the Farm Accountancy Data Network (FADN). Journal of Environmental Management doi 10.1016/j.jenvman.2010.10.051

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

APPENDIX 1 LIST OF INDICATORS SELECTED FROM THE REVIEWED DATASETS

INDICATOR THEMES	Agri-environmental indicators (EUROSTAT)	CAP indicators					COMBINED LIST OF AGRICULTURAL POLICY INDICATORS	MIND STEP specific indicators	POLICY AND MIND STEP COMBINED LIST
		Impact	Context	Indicator name	Result	Indicator name	Indicator name	Indicator name	Indicator name
General	1. Agri-environmental comm						Agri-environmental commitments		Agri-environmental commitments
	9. Land use change						Land use change		Land use change
								Land cover	Land cover
	10.1 Cropping patterns						Cropping patterns		Cropping patterns
								Area harvested per crop	Area harvested per crop
								Area harvested - rainfed	Area harvested - rainfed
								Area harvested - irrigated	Area harvested - irrigated
	11.1 Soil cover						Soil cover		Soil cover
	12. Intensification/extensific		C.33	Farming intensity			Farming intensity		Farming intensity
								Feed use (ruminant meat, non-ru	Feed use (ruminant meat, non-rumi
	13. Specialisation						Specialisation		Specialisation
	14. Risk of land abandonmer						Risk of land abandonment		Risk of land abandonment
Energy	8. Energy use		C.44	Energy use ir	R.16	Energy sa	Energy use in agriculture, forestry and foo		Energy use in agriculture, forestry an
	24. Production of renewable	I.12	C.43	Production c	R.15	Investmer	Production of renewable energy from agric		Production of renewable energy fror
GHG emissions	19. Greenhouse gas emissio	I.10	C.45	Greenhouse			Greenhouse gas emissions from agricultur	Total GHG emissions	Greenhouse gas emissions from agri
					R.12	Share of a	Share of agricultural land under commitme		Share of agricultural land under com
					R.13	Share of l	Share of livestock units under support to r		Share of livestock units under suppo
					R.14	Share of a	Share of agricultural land under commitme		Share of agricultural land under com
					R16a	Share of f	Share of farms benefitting from CAP invest		Share of farms benefitting from CAP
								Carbon demand	Carbon demand
								Carbon price	Carbon price
Air quality	18. Ammonia emissions	I.14	C.45	Ammonia en	R.19	Share of a	Share of agricultural land under commitme		Share of agricultural land under com
Water quality	5. Mineral fertiliser consump				R.20	Share of a	Share of agricultural land under managem		Share of agricultural land under mar
								Fertiliser Nitrogen	Fertiliser Nitrogen
	10.2 Livestock patterns		C.21	Livestock un	R.22a	Share of l	Share of livestock units (LU) under support		Share of livestock units (LU) under su
				Livestock density			Livestock density		Livestock density
	11.3 Manure storage						Manure storage		Manure storage
	15. Gross nitrogen balance	I.15	C.40	Gross nutrie	R.21	Share of a	Gross nutrient balance – nitrogen		Gross nutrient balance – nitrogen
	16. Risk of pollution by phos		C.40	Gross nutrie			Gross nutrient balance – phosphorus		Gross nutrient balance – phosphoru:
	27.1 Water Quality - Nitrate	I.16		Nitrates in g			Nitrates in ground water		Nitrates in ground water
	27.2 Water Quality - Pesticid						Water Quality - Pesticide pollution		Water Quality - Pesticide pollution

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Water quantity and availabil	7. Irrigation	I.17		Water use in	R.22	Share of i	Water use in agriculture		Water use in agriculture
	20. Water abstraction						Water abstraction		Water abstraction
	Water Exploitation Index plu	I.10	C.20	Volume of w			Volume of water applied to soils for irrigat		Volume of water applied to soils for
Soil quality and fertility	11.2 Tillage practices						Tillage practices		Tillage practices
	26. (Archive) Soil quality						Soil quality		Soil quality
	Soil organic carbon content	I.11	C.41	Soil organic			Soil organic carbon in agricultural land		Soil organic carbon in agricultural la
	[Crop diversity]								
	[Peatland areas]								
					R.18	Share of a	Share of agricultural land under managem		Share of agricultural land under mar
Soil erosion	21. Soil erosion	I.13	C.42	Soil erosion			Soil erosion by water		Soil erosion by water
Biodiversity and landscapes	2. Agricultural areas under N		C.34	Farming in N			Farming in Natura 2000 areas		Farming in Natura 2000 areas
	22. Genetic diversity				R.28	Area in N	Genetic diversity		Genetic diversity
	23. High Nature Value farmla				R.27	Share of a	High Nature Value farmland		High Nature Value farmland
					R.27a	Share of f	Share of farms benefitting from CAP invest		Share of farms benefitting from CAP
	25. Population trends of farr	I.18	C.35	Farmland bi			Farmland birds index (FBI)		Farmland birds index (FBI)
		I.19		Percentage c			Percentage of species and habitats of Com		Percentage of species and habitats o
	28. (Archive) Landscape - sta	I.20		Agricultural	R.29	Share of a	Agricultural land covered with landscape f		Agricultural land covered with lands
					R.17	Area supp	Area supported for afforestation and crea		Area supported for afforestation and
		I.26		Antimicrobia	R.36	Share of l	Share of livestock units concerned by supp		Share of livestock units concerned b
Reduce the use of pesticides	17. Pesticide risk	I.27		Risk and imp	R.37	Share of a	Share of agricultural land concerned by su		Share of agricultural land concerned
	4. Area under organic farmir	I.17a	C.19	Agricultural	R.39	Share of U	Share of Utilised Agricultural Area (UAA) s		Share of Utilised Agricultural Area (U
	6. Consumption of pesticide						Consumption of pesticides		Consumption of pesticides
Animal welfare					R.38	Share of l	Share of livestock units covered by suppor		Share of livestock units covered by s
Employment rate		I.14	C.05	Percent emp			Percent employed in rural areas compared		Percent employed in rural areas com
			C.17	Agricultural			Agricultural holdings (farms)		Agricultural holdings (farms)
			C.22	Farm labour force			Farm labour force		Farm labour force
			C.23	Age structur			Age structure of farm managers		Age structure of farm managers
		I.21		New farm managers			New farm managers		New farm managers
Farm income		I.4		by type of farming			farm income by type of farming		farm income by type of farming
				by region			farm income by region		farm income by region
		I.16	C.08	GDP per cap			GDP per capita in PPS in rural areas as a pe		GDP per capita in PPS in rural areas a
				by farm size			GDP by farm size		GDP by farm size

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Training/education	3. Farmers' training level and		C.24	Agricultural			Agricultural training of farm managers		Agricultural training of farm manage
		I.1		Share of CAP			Share of CAP budget for knowledge sharin		Share of CAP budget for knowledge s
					R.1	Share of f	Share of farmers receiving support for adv		Share of farmers receiving support fo
					R.3	Share of f	Share of farmers benefitting from support		Share of farmers benefitting from su
					R.5	Share of f	Share of farms with CAP risk management		Share of farms with CAP risk manage
					R.9	Share of f	Share of farmers receiving investment sup		Share of farmers receiving investmer
					R.10	Share of f	Share of farmers participating in supporte		Share of farmers participating in sup
					R.24	Share of f	Share of farmers receiving support for adv		Share of farmers receiving support fo
Agricultural productivity		I.6	C.27	Total factor			Total factor productivity in agriculture		Total factor productivity in agricultu
								Crop yield	Crop yield
								Crop yield - rainfed	Crop yield - rainfed
								Crop yield - irrigated	Crop yield - irrigated
								Climate change shifter on crop yi	Climate change shifter on crop yield
								Livestock yield (endogenous)	Livestock yield (endogenous)
				Labour productivity			Labour productivity in agriculture		Labour productivity in agriculture
			C.14	in agriculture			Labour productivity in forestry		Labour productivity in forestry
			C.15	in forestry			Labour productivity in food industry		Labour productivity in food industry
								Shadow price of land	Shadow price of land
Agricultural trade		I.7	I.06	Agricultural			Agricultural imports and exports		Agricultural imports and exports
								Real export price	Real export price
Other gainful activities			C.30	Tourism infr			Tourism infrastructure		Tourism infrastructure

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

APPENDIX 2 - DRAFT INDICATOR FRAMEWORK

The indicators are grouped by sustainability IMPACTS and THEMES. The indicators marked in black belong to the lists of the Common Agricultural Policy and Agri-environmental indicators (EUROSTAT), and those marked in red are indicators available from the MIND STEP models.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME
Economic			
	Agricultural productivity	1	Total factor productivity in agriculture
		2	Crop yield
		3	Crop yield - rainfed
		4	Crop yield - irrigated
		5	Climate change shifter on crop yield
		6	Livestock yield (endogenous)
		7	Labour productivity in agriculture
		8	Labour productivity in forestry
		9	Labour productivity in food industry
	Farm income/GDP	10	Farm income by type of farming
		11	Farm income by region
		12	GDP per capita in PPS in rural areas as a percent of other areas and EU average
		13	GDP by farm size
	Other gainful activities	14	Tourism infrastructure
	Structural change	15	Agricultural holdings (farms)
		16	Age structure of farm managers
		17	New farm managers
	Land prices	18	Shadow price of land
	Agricultural trade	19	Agricultural imports and exports
		20	Real export price
Environmental			
	Agri-environmental commitments	21	Agri-environmental commitments
	Land cover/Land use	22	Land use change
		23	Land cover
		24	Cropping patterns
		25	Area harvested per crop
		26	Area harvested - rainfed

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME
		27	Area harvested - irrigated
		28	Soil cover
		29	Farming intensity
		30	Specialisation
		31	Risk of land abandonment
	Feed use	32	Feed use (ruminant meat, non-ruminant, dairy)
	Energy	33	Energy use in agriculture, forestry and food industry
		34	Production of renewable energy from agriculture and forestry
	GHG emissions	35	Greenhouse gas emissions from agriculture
		36	Share of agricultural land under commitments to improve climate adaptation
		37	Share of livestock units under support to reduce GHG emissions and/or ammonia, including manure management
		38	Share of agricultural land under commitments to reducing emissions, maintaining and/or enhancing carbon storage (permanent grassland, agricultural land in peatland, forest, etc.)
		39	Share of farms benefitting from CAP investment support contributing to climate change, mitigation and adaptation, and to renewable energy or biomaterials production
		40	Carbon demand
		41	Carbon price
	Air quality	42	Share of agricultural land under commitments to reduce ammonia emission
	Nutrient (N,P) balance	43	Nitrogen from fertilisers
		44	Share of livestock units (LU) under supported commitments to improve environmental sustainability
		45	Livestock density
		46	Manure storage
		47	Gross nutrient balance – nitrogen
		48	Gross nutrient balance – phosphorus
	Water quality	49	Share of agricultural land under management commitments for water quality
		50	Share of livestock units under supported commitments to improve environmental sustainability
		51	Nitrates in ground water
		52	Water Quality - Pesticide pollution
	Water quantity and availability	53	Water use in agriculture
		54	Water abstraction
		55	Volume of water applied to soils for irrigation purposes

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 817566.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME
	Soil quality and fertility	56	Tillage practices
		57	Soil quality
		58	Soil organic carbon in agricultural land
		59	Share of agricultural land under management commitments beneficial for soil management
	Soil erosion	60	Soil erosion by water
	Biodiversity and landscapes	61	Farming in Natura 2000 areas
		62	Genetic diversity
		63	High Nature Value farmland
		64	Share of farms benefitting from CAP investment support contributing to biodiversity
		65	Farmland birds index
		66	Percentage of species and habitats of Community interest related to agriculture with stable or increasing trends
		67	Agricultural land covered with landscape features
		68	Area supported for afforestation and creation of woodland, including agroforestry
		69	Share of livestock units concerned by supported actions to limit the use of antibiotics (prevention/reduction)
	Pesticide use	70	Share of agricultural land concerned by supported specific actions which lead to a sustainable use of pesticides in order to reduce risks and impacts of pesticides
		71	Share of Utilised Agricultural Area supported by the CAP for organic farming maintenance or conversion
		72	Consumption of pesticides
	Animal welfare	73	Share of livestock units covered by supported action to improve animal welfare
Social			
	Employment	74	Percent employed in rural areas compared to national and other area rates for same age and sex classes
		75	Farm labour force
	Training and education	76	Agricultural training of farm managers
		77	Share of CAP budget for knowledge sharing and innovation
		78	Share of farmers receiving support for advice, training, knowledge exchange, or participation in operational groups to enhance economic, environmental, climate and resource efficiency performance
		79	Share of farmers benefitting from support to precision farming technology through CAP
		80	Share of farms with CAP risk management tools

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME
		81	Share of farmers receiving investment support to restructure and modernise, including to improve resource efficiency
		82	Share of farmers participating in supported Producer Groups, Producer Organisations, local markets, short supply chain circuits and quality schemes
		83	Share of farmers receiving support for advice/training related to environmental-climate performance

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

APPENDIX 3 - MINDSTEP QUESTIONNAIRE ON INDICATORS

1. COMPLETENESS OF THE INDICATOR LIST TO COVER POLICY SCENARIOS

We have grouped the **policy scenarios** identified in the first stakeholder workshop into three groups (Table 1).

Table 1. Composition of the scenario groups. The scenarios are policy scenarios identified by the MIND STEP stakeholders in the first workshop that can be potentially modelled in MIND STEP.

SCENARIO GROUPS	ID	SCENARIOS
Climate change action	1	Simulate the adoption of a carbon border tax adjustment
	2	Simulate the adoption of subsidies targeted to climate change mitigation
	3	Impact of different GHG mitigation measures (i.e. constraints on livestock numbers and/or on nutrient disposal)
	4	Create incentives to increase carbon sinks by farmers (and measure the impact of different land use options)
	5	Create incentives for energy transition in agriculture (e.g. renewables)
	6	Simulate the adoption of emission trading systems between farms
	7	Creating markets for ecosystem services (carbon sequestration)
	8	Simulate the impact on the agricultural sector of changes in diets (e.g. reduction of meat consumption)
Preserve biodiversity, ecosystem services and environmental care	9	Mandatory reduction of pesticides use by 50%
	10	Mandatory 25% of UAA cultivated with organic farming methods
	11	Adoption of collective payments to farmers (territorial approach to environmental care) (e.g.: new approaches to nutrient policies or agri-environmental payments)
	12	Create incentives linked to the environmental footprint of agricultural activities
	13	Increased use of EU subsidies for various types of agri-environmental measures (including x% of the farm area for public good use, especially for arable farms)
	14	Simulate land use changes derived from different livestock management options (e.g. more grazing, constraints on feed, constraints on livestock numbers, etc.)
	15	Creating markets for ecosystem services

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Competitiveness in the agricultural sector	16	Model the removal of first pillar direct payments
	17	Model a further full decoupling of first pillar payments
	18	Model a fundamental change in the distribution of direct payments (i.e. linkage of payment to farm labour rather than to farm area or other parameters)
	19	Model a re-coupling of the First Pillar Payments to public goods and ecosystem services
	20	Simulate other re-instrumentation for the first pillar payments
	21	Model the adoption of publicly supported risk management tools (i.e. subsidised income stabilisation tools)
	22	Simulate the adoption of supply chain management tools such as contracting and producers' organisations
	23	Model an increased use of subsidies for innovation adoption (precision agriculture, conservation agriculture, 5g, robotics, Artificial Intelligence, Blockchain, etc.)

The **indicator list** combines:

- indicators used to assess the impact of EU agricultural policy, including the Common agricultural policy Context, Result and Impact indicators from the 2014-2020 period (DG AGRI) https://agridata.ec.europa.eu/extensions/DataPortal/cmef_indicators.html , and Agri-environmental indicators (EUROSTAT) https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicators

- indicators used in the MIND STEP models.

The consolidated indicator list includes 83 indicators grouped by themes, covering economic, environmental and social issues relevant for the scenarios. They are now listed in Annex 2 (in the questionnaire the list was included at the end).

QUESTION 1: Does the list of indicators in Annex 1 cover the main impacts expected in the scenario groups? Please provide your answers below.

SCENARIO GROUPS	YES	NO	If NO, which indicators are you missing?
Climate change action			
Preserve biodiversity, ecosystem services and environmental care			
Competitiveness in the agricultural sector			

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

2. RELEVANT INDICATORS

QUESTION 2: Which 10 indicators (from Annex 1 or proposed by you) are those that you consider more meaningful to describe the scenario impacts on **climate change**? Please explain why in the Comments column.

Indicator ID or name	Comments

QUESTION 3: Which 10 indicators (from Annex 1 or proposed by you) are those that you consider more meaningful to describe the scenario impacts on **biodiversity, provision of ecosystem services and environmental care**? Please explain why in the Comments column.

Indicator ID or name	Comments

QUESTION 4: Which 10 indicators (from Annex 1 or proposed by you) are those that you consider more meaningful to describe the scenario impacts on **competitiveness in the agricultural sector**? Please explain why in the Comments column.

Indicator ID or name	Comments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

3. NUMBER OF INDICATORS PER SCENARIO

Consider as example the (Farm to Fork) scenario “**mandatory reduction of the use of chemical pesticides in the EU by 50 percent by 2030**”.

QUESTION 5: How many indicators do you think are needed to analyse the economic, environmental and social impacts? Please mark with “X” the selected option.

- Less than 9
- Between 9 and 15
- More than 15

QUESTION 6: Which ones?

That was the last of our questions.

Thank you very much for your time!

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 817566.

APPENDIX 4 - LIST OF THE CORE STAKEHOLDER GROUP MEMBERS

	Name	Organisation
1	David Baldock	IEEP
2	Robert Finger	ETH
3	Christopher Genillard	Genillard & Co Consultant Company
4	Reina Groen	Province of Flevoland (NL)
5	Eva Iglesias Martinez	CEIGRAM
6	Simon Kay	EC DG CLIMA
7	Jussi Lankoski	OECD
8	Simon Schlüter	German farmer association in Brussels
9	Ben Van Doorslaer	EC DG AGRI
10	Stefan Van Merrienboer	Rabobank

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

APPENDIX 5 - AGENDA OF THE SECOND STAKEHOLDER WORKSHOP

Modelling Individual Decisions to Support the European Policies Related to Agriculture
MIND STEP (817566)

AGENDA

2nd Stakeholder Workshop

22 April 2021

Objectives of the stakeholder workshop

- to get feedback on the completeness and relevance of the indicator framework to estimate the impacts of the policy scenarios
- to illustrate the use of the MINDSTEP toolbox for selected policy scenarios

Time	Topic	Lead partners and presenters
9:30	Welcome and introduction to the workshop	John Helming
9:35	Introduction of participants	Paolo Sckokai
9:40	Policy scenarios and indicators (including outcomes of the questionnaire)	Silvia Coderoni Marta Pérez-Soba
10:00	Discussion 1	Paolo Sckokai
10.40	Break	
11:00	Illustration on how MINDSTEP toolbox will model the selected policy scenarios	John Helming Marc Müller Hugo Storm
11:20	Discussion 2	Paolo Sckokai
11:50	Concluding remarks	Marta Pérez-Soba
12:00	End of Workshop	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

APPENDIX 6 LIST OF FARM INDICATORS REPORTED IN THE LITERATURE REVIEW

The references are ordered chronologically with the most recent publication date first.

ID	Authors	Year	Article Title	Source Title	DOI	Policy	Indicators	Number of single indicators	Sustainability dimensions	Data used	Scale
1	Bartolini, F., Vergamini, D., Longhitano, D., Povellato, A.	2021	Do differential payments for agri-environment schemes affect the environmental benefits? A case	Land Use Policy	10.1016/j.landusepol.2020.104862	CAP Agrienvironment climate scheme (AECS)	A composite indicator on extensification based on different dimensions of farming, management, cropping, and livestock, and two relevant domains of the definition of High Nature Value farming (land use and farm biodiversity). Includes 8 single indicators: Permanent grassland (% UAA), Number of crops, Livestock units per forage area, Feed expenses per hectare, Irrigated UAA, Set aside, Pesticide expense per hectare and Fertiliser expense per hectare.	8	ENV	FADN	Veneto region (North-eastern Italy)
2	Czubak, W; Pawlowski, KP	2020	Sustainable Economic Development of Farms in Central and Eastern European Countries Driven by	Agriculture-Basel	10.3390/agriculture10040093	CAP (pro-investment mechanisms in second pillar)	1) Investment subsidies. 2) Productive input resources: Utilized agricultural area, Labor input, Total fixed assets other than land. 3) Outputs: Productivity of land, Productivity of labor, Productivity of capital, Profitability of land, Profitability of labor, Profitability of capital.	10	ECO	FADN	Farms in Central and Eastern European Countries
3	Tzouramani, I; Mantziaris, S; Karanikolas, P	2020	Assessing Sustainability Performance at the Farm Level: Examples from Greek Agricultural Systems	Sustainability	10.3390/su12072929	CAP 2021-2027	**ECONOMIC** (7): Total output/total input, Total subsidies/family farm income, (Family farm income/family work unit)/reference income, Farm net value added. **ENVIRONMENTAL** (5): GHG emissions from farms, Percentage of farm UAA with nitrate risk, Water consumption per kg of product, Farm gate N-balance, Pesticide usage. **SOCIAL** (5): Advisory contacts per year per holding, Degree of agricultural training of the manager, Total labor in annual working units, Satisfaction with quality of life, Social diversfication index.	17	ECO, ENV, SOC	FLINT and FADN	Greece
4	Brennan, M., Hennessy, T., Dillon, E.	2020	Towards a better measurement of the social sustainability of Irish agriculture	International Journal of Sustainable Development	10.1504/IJSD.2020.115229	CAP 2021-2027	**SOCIAL INTERNAL** (7): Farmer wellbeing, Household vulnerability, Education level, High age profile, Isolation, Work-life balance, Succesion. **SOCIAL EXTERNAL** (11): 1) Animal wellbeing (health and welfare): Feeding and nutrition, Mortality rate, Somatic cell count, Age/quality of buildings, Duration of grazing; 2) Community wellbeing: Multifunctionality (contribution to rural economy), Availability of services, Food safety, Heritage and cultural values, Consumer perceptions and concerns.	18	ENV, SOC	National datasets	Ireland
5	Uthes, S; Kelly, E; Konig, HJ	2020	Farm-level indicators for crop and landscape diversity	Ecological Indicators	10.1016/j.ecolind.2019.105725	CAP	Index of crop diversity (Shannon Index), Number of crops with a share of > 5% in arable farm area, Median parcel size, Edge density (mean ratio of perimeter and surface area of land parcels), Share of landscape features in total farm area.	5	ENV	IACS	Germany
6	Quemada, M; Lassaletta, L; Jensen, LS; Godinot, O; Brentrup, F;	2020	Exploring nitrogen indicators of farm performance among farm types across several European	Agricultural systems	10.1016/j.agsy.2019.102689		Nitrogen use efficiency, N surplus and N output in agricultural products.	3	ENV	Farm-level data collected through surveys	1240 farms from Atlantic, Continental and Mediterranean Europe
7	Grzelak, A; Guth, M; Matuszczak, A; Czyzewski, B; Brelik, A	2019	Approaching the environmental sustainable value in agriculture: How factor endowments	Journal of Cleaner production	10.1016/j.jclepro.2019.118304	CAP	A composite indicator on Environmental Sustainable Value (ESV): Capital: total fixed assets (value of land, permanent crops & quotas), Labour input and Land (total utilised agricultural area). Calculate ESV, using as environmental pressures: Stock density per ha, Mineral fertilisers use , Plant protection products, Total use of energy, Utilised agricultural area minus woodland area.	8	ECO, ENV	FADN	25 EU member countries, excluding Cyprus, Malta and Croatia

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

ID	Authors	Year	Article Title	Source Title	DOI	Policy	Indicators	Number of single indicators	Sustainability dimensions	Data used	Scale
8	Rey, PJ; Manzaneda, AJ; Valera, F; Alcantara, JM; Tarifa, R; Isla, J; Molina-Pardo, JL; Calvo, G; Salido, T; Gutierrez, JE; Ruiz, C	2019	Landscape-moderated biodiversity effects of ground herb cover in olive groves: Implications for regional biodiversity conservation	Agriculture Ecosystems & Environment	10.1016/j.agee.2019.03.007	CAP Agrienvironmental scheme (AES)	Indices of species richness for birds, ants and herbs.	3	ENV	Field surveys	Southern Spain
9	Syp, A; Osuch, D	2018	Assessing Greenhouse Gas Emissions from Conventional Farms Based on the Farm Accountancy Data Network	Polish Journal of Environmental Studies	10.15244/pjoes/76675	CAP	GHG emission sources considered were linked to the following FADN data: Animal numbers, Nitrogen quantities, Crop area, Crop yield, Urea quantities, and Fuel quantities.	6	ENV	FADN	Poland
10	Van Asseldonk, M; Tzouramani, I; Ge, L; Vrolijk, H	2016	Adoption of risk management strategies in European agriculture	Studies in agricultural economics	10.7896/j.1629	CAP	Indicators for adoption rates of risk management instruments: Insurance contracts, Price contracts, Off-farm income, Other types risk of reduction measures, and Other gainful activities	5	ECO	FLINT database from 821 farmers	8 EU Member States
11	Latruffe, L., Mann, S.	2015	Is part-time farming less subsidised? The example of direct payments in France and Switzerland.	Cahiers Agriculture	10.1684/agr.2015.0732	CAP	Household incomes (including farm and off-farm incomes)	2	ECO	FADN, French tax records	France
12	Dora, M; Levente, H; Katalin, B; Zsolt, B; Paulina, J; Laszo, P; Balazs, S	2015	Farm-level environmental performance assessment in Hungary using the Green-point system	Studies in agricultural economics	10.7896/j.1426	CAP	18 indicators to assess soil degradation from which the first 13 are calculated at field level and only 4 are at the farm level to assess the diversity of crop production: Proportion of legumes in crop structure, Proportion of cereals and maize, Average plot size and Diversity of crop structure.	4	ENV	National datasets	Hungary
13	Hanley, N; Acs, S; Dallimer, M; Gaston, KJ; Graves, A; Morris, J; Armsworth, PR	2012	Farm-scale ecological and economic impacts of agricultural change in the uplands	Land use policy	10.1016/j.landusepol.2011.10.001	CAP	7 indicators of biodiversity based on Total avian species richness and Individual and Total bird densities.	7	ENV	Farm surveys	UK upland farms

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

ID	Authors	Year	Article Title	Source Title	DOI	Policy	Indicators	Number of single indicators	Sustainability dimensions	Data used	Scale
14	Westbury, D.B., Park, J.R., Mauchline, A.L., Crane, R.T., Mortimer, S.R.	2011	Assessing the environmental performance of UK arable and livestock holdings using data from the Farm Accountancy Data Network (FADN).	Journal of Environmental Management	10.1016/j.jenvman.2010.10.051	CAP/Agrienvironmental schemes	Two different Assessment Criteria Matrices were created for the arable and livestock farm types and populated using indicators derivable from FADN data. Indicator selection for the matrices was based on the availability of FADN data combined with knowledge of the environmental impacts of farming practices relevant to each of the three issues: natural resource protection (NR), biodiversity conservation (B), and protection of landscape character (L). **For arable farms** - 1) NR: Protection of groundwater quality - *Fertiliser units per ha UAA and Crop protection costs per ha UAA* ; Protection of groundwater quantity - *% of UAA that is irrigated* ; Energy consumption - *Electricity costs and machinery, heating and vehicle fuels and oil per ha UAA* . 2) B: Intensity of crop husbandry - *Fertiliser units per ha UAA* , *Crop protection costs per ha UAA* , *Crop diversity (Shannon Diversity)* , *% of spring crops* , Land use diversity - *Land use diversity (Shannon diversity)* ; Provision of woodland habitats - *% of total farm area that is woodland* 3) L: Provision of woodland habitats - *% of total farm area that is woodland* ; Evidence of uncultivated land - *% of total farm as uncropped land (including fallow and set-aside)* ; Land use diversity - *Land use diversity (Shannon diversity)* . **For livestock farms** 1) NR: Protection of groundwater quality - *Fertiliser units per ha UAA* and *Average number of grazing livestock units per hectare of forage* ; Protection of groundwater quantity - *Water units per hectare UAA* ; Energy consumption - *Electricity costs and machinery, heating and vehicle fuels and oil per hectare UAA* . 2) B: Intensity of livestock production - *Fertiliser units per ha UAA, Average number of grazing livestock units per hectare of forage, Percentage of grassland area that is temporary grassland* , Provision of semi-natural grassland habitats - *Percentage of UAA that is classified as rough grazing* ; Land use diversity - *Land use diversity (Shannon diversity)* ; Provision of woodland habitats - *% of total farm area that is woodland* 3) L: Provision of woodland habitats - *% of total farm area that is woodland* ; Provision of semi-natural grassland habitats - *% of UAA that is classified as rough grazing* ; Land use diversity - *Land use diversity (Shannon diversity)* .	11 (arable farms) 8 (livestock farms)	ENV	FADN	UK
15	Reig-Martinez, E; Gomez-Limon, JA; Picazo-Tadeo, AJ	2011	Ranking farms with a composite indicator of sustainability	Agricultural Economics	10.1111/j.1574-0862.2011.00536.x	CAP	**ECONOMIC** (3)**: In**come of agricultural producers, Contribution of agriculture to GDP, Insured area. **ENVIRONMENTAL** (5): Soil cover, Nitrogen balance, Pesticide risk, Energy balance, Environmental subsidy areas. **SOCIAL** (4): Agricultural employment, Work-force stability, Risk of abandoning agricultural activity, Economic dependence on agricultural activity.	12	ECO, ENV, SOC	database of 163 farms	Spanish Northern Plateau
16	Ehrmann, M.	2010	Assessing ecological and economic impacts of policy scenarios on farm level.	Paper Presented at the 50 st Annual Conference of the German Association of Agricultural Economists (GEWISOLA). Braunschweig, Germany, September 29-October 1.	10.22004/ag.econ.93949	CAP	Impact indicators. **ECONOMIC** (8)**:** Production Value (of the whole farm or different production lines), Use of intermediate products, Subsidies, Income, Cash flow (income minus depreciation), Change of the owner's capital (based on withdrawals and contributed capital), Profit rate (income in relation to operation income), Farm capital profitability (remuneration of used production factors <> opportunity costs). **ECOLOGICAL** (6): Nitrogen balance, Phosphorus balance, Potash balance, Ammonia emissions, Humus balance (carbon fixed in organic matter), Shannon Weaver index.	14	ECO, ENV	FADN , national data	Germany
17	Pesti, C., Keszthelyi, S.	2009	Additional Environmental Data in Hungarian FADN – Analysis of Crop Farms.	Landbouw-Economisch Instituut (LEI), The Netherlands, pp. 86–93 (Report No . 2009-085).			Indicators to analyse crop farms: Nutrient balances, Proportion of organic manure in the nutrient supply.	2	ENV	FADN,national data	Hungary

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

ID	Authors	Year	Article Title	Source Title	DOI	Policy	Indicators	Number of single indicators	Sustainability dimensions	Data used	Scale
18	Gomez-Limon, JA; Riesgo, L	2009	Alternative approaches to the construction of a composite indicator of agricultural sustainability: An application to irrigated agriculture in the Duero basin in Spain	Journal of Environmental Management	10.1016/j.jenvman.2009.05.023	CAP and WFD	Indicators to quantify the sustainability of irrigated agriculture at farm level based on OECD (2001). **ECONOMIC** (4) Total gross margin, Profit, GDP contribution, Public subsidies. **ENVIRONMENTAL** (6): Landscape and Biodiversity - Agro-biodiversity (number of diffferent crops in the farm), Soil cover; Water use - Water use; Fertilizers and pesticides - Nitrogen balance, Energy balance, Pesticide risk. **SOCIAL** (2): Total labour, Seasonal labour emplyment.	12	ECO, ENV, SOC	Data collected through a farmers survey	Spain (Duero basin)
19	Ehrmann, M.	2008	Comparing sustainable value approach, data envelopment analysis and indicator approaches-An application on German dairy farms.	Paper Presented at the 12th Congress of the European Association of Agricultural Economists (EAAE), Ghent, Belgium.	10.22004/ag.econ.44140	CAP	**ECONOMIC** (7)**:** Income per annual working unit (AWU), Profit ratio, Remuneration of factors, Net debt service, Change of owner's equity both per ha and per AWU, Net investment per AWU, Farm net value added per ha. **ENVIRONMENTAL** (5)**:** **N**utrient balances, Soil organic matter balance, Pesticide use, Crop diversity, Median field size.	12	ECO, ENV	FADN, national data	Germany
20	Bartolini, F; Bazzani, GM; Gallerani, V; Raggi, M; Viaggi, D	2007	The impact of water and agriculture policy scenarios on irrigated farming systems in Italy: An analysis based on farm level multi-attribute linear programming models	Agricultural Systems	10.1016/j.agsy.2006.04.006	CAP and WFD	Indicators aimed at quantifying the impact of the scenarios on different aspects of sustainability relevant for irrigated farming systems. **ECONOMIC** (2): Farm profit, Farm contribution to GDP; **ENVIRONMENTAL** (4): Biodiversity (Genetic diversity - number of species cultivated on the farm), Water use (Water use), Nutrients and pollutants (Nitrogen balance, Pesticide risk); **SOCIAL** (1): Farm employment.	7	ECO, ENV, SOC	National datasets	Italy
21	Waarts, Y.	2007	Indicators for agricultural policy impact assessment - the case of multifunctional beef production	Multifunctional Land Use: Meeting Future Demands for Landscape Goods and Services	10.1007/978-3-540-36763-5_17	CAP	Large set of indicators to quantify the impact of future CAP reforms on beef production. Focus on policy relevant Non Commodity Outputs with respect to beef production. **ECONOMIC** (3): Average size of (livestock) farms, Farm income, Specialisation/diversification. **ENVIRONMENTAL** (17+): Environmental quality - *Fertilizer use* (e.g. farm gate N balance), *Energy use, Pesticide consumption, Soil quality, Soil erosion, Organic matter content, Soil compaction, Ammonia emissions, GHG emissions* , Water quality (*Nitrate leaching*), Water availability (*Ground water supply*); (agro)Biodiversity - *Natural Capital Index, Pan European Common Bird Indicator; Landscape and land use* - Habitats (*Corridors* , e.g. length, number of corridors; *Habitat size*), *Land use intensity, Changes in land use patterns* . **SOCIAL** (9+): *Farm buildings and farm structures, Traditional farming practises* , Social infrastructure (*Population density* , e.g. age structure, gender structure), *Labour employed in agriculture* , Animal welfare (*Access to outdoor areas for animals*), *Non farming activities (Income derived from diversification and activities in other sectors* e.g. tourism), Recreation in rural areas (*Total tourist spending in the region*), *Healthy food/food safety (* e.g. mycotoxins, contamination with pesticide residues, nitrates).	>29	ECO, ENV, SOC	Not all the proposed indicators had available data, and therefore the authors recommended one indicator per category, except for biodiversity with two indicators	Case study regions in Denmark, France, Germany, Hungary, Italy, Poland and Slovakia.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

ID	Authors	Year	Article Title	Source Title	DOI	Policy	Indicators	Number of single indicators	Sustainability dimensions	Data used	Scale
22	Lehtonen, H; Aakkula, J; Rikkonen, P	2005	Alternative agricultural policy scenarios, sector modelling and indicators: A sustainability assessment	Journal of Sustainable Agriculture	10.1300/J064v26n04_06	CAP	Total and individual number of animal units(bovine, pig and poultry); Total cultivated area, Set-aside, Unused, Grassland and Grain area; Nitrogen and Phosphorus balances on cultivated area; Agricultural income; Profitability coefficient of agricultural production; Labour hours in agriculture; Agricultural income per hour of labour.	15	ECO, ENV	National datasets	Finland
23	Tzilivakis, J; Lewis, KA	2004	The development and use of farm-level indicators in England	Sustainable Development	10.1002/sd.233	not specified	Indicators, mostly showing changes over time. **RURAL ECONOMY:** 1. Agricultural assets and liabilities, 2. Age of farmers, 3. Proportion of area tenanted, 4. EU producer support, 5. Payments for agrienvironmental activities, 6. Income from farming, 7. Average earnings, 8. Agricultural productivity, 9. Agricultural employment. **FARM MANAGEMENT:** 10. Adoption of management systems (non-government organization membership), 11. Conversion to organic farming, 12. Knowledge of codes of practice. **INPUT USE**: 13. Pesticides in rivers, 14. Pesticides in groundwater, 15. Quantity of pesticides used, 16. Area treated with pesticides, 17. Pesticides residues in food, 18. Nitrate and phosphorus losses, 19. Phosphorus levels in soils, 20. Manure management, 21. Ammonia emissions, 22. Methane and nitrous oxide emissions, 23. Direct energy consumption. **RESOURCE USE**: 24. Indirect energy inputs, 25. Water for irrigation, 26. Organic matter content of soil, 27. Heavy metals in topsoil, 28. Area of agricultural land, 29. Change in land use, 30. Planting of non-food crops. **CONSERVATION VALUE:** 31. Land committed to conservation, 32. Features, 33. Area of cereal margins environmental management, 34. Area of semi-natural, 35. Population of farm birds.	35	ECO, ENV, SOC	National datasets	UK

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

APPENDIX 7 - INDICATOR FRAMEWORK

The indicators are grouped by sustainability IMPACTS and THEMES. The indicators marked in black belong to the lists of the Common Agricultural Policy and Agri-environmental indicators (EUROSTAT), those marked in red are indicators available from the MIND STEP models, and in blue are the indicators reported in the papers selected in the literature review, identified by their ID number (see Appendix 6).

Impacts	INDICATOR THEMES	ID	INDICATOR NAME	REFERENCES (ID number – see Appendix 6) OF THE PAPERS FROM THE LITERATURE REVIEW
Economic				
	Agricultural productivity	1	Total factor productivity in agriculture/ Production Value (of the whole farm or different production lines)	2, 16, 23
		2	Crop yield	
		3	Crop yield - rainfed	
		4	Crop yield - irrigated	
		5	Climate change shifter on crop yield	
		6	Livestock yield (endogenous)	
		7	Labour productivity in agriculture	2
		8	Labour productivity in forestry	
		9	Labour productivity in food industry	
		10	Capital productivity	2
	Farm income/GDP	11	Farm income by type of farming	11, 15, 21, 22, 23
		12	Farm income by region	11, 15, 16, 21, 22, 23
		13	Specialisation/diversification	21
		14	Income per annual working unit (AWU)	19, 22, 23
		15	Total gross margin	18
		16	Cash flow (income minus depreciation)	16
		17	Change of the owner's capital (based on withdrawals and contributed capital)	16, 19
		18	GDP per capita in PPS in rural areas as a percent of other areas and EU average	
		19	GDP by farm size	
		20	Contribution of farm/agriculture to GDP	15, 18, 20
		21	Profitability of land	2, 20
		22	Profitability of labour	2, 20
		23	Profitability of capital (remuneration of used production factors <> opportunity costs)	2, 16, 20
		24	Profit rate (income in relation to operation income)	16, 18, 19, 22
		25	Total fixed assets other than land	2
		26	Public/EU subsidies (investment, etc.)	2, 16, 18, 23
		27	Net investment	19

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME	REFERENCES (ID number – see Appendix 6) OF THE PAPERS FROM THE LITERATURE REVIEW
		28	Remuneration of factors	19
		29	Feed expenses per hectare	1
		30	Pesticides expenses per hectare	1
		31	Fertilisers expenses per hectare	1
	Other gainful activities	32	Tourism infrastructure	10, 21
	Structural change	33	Agricultural holdings (farms)	
		34	Conversion to organic farming	23
		35	Average size of (livestock) farms	21
		36	Proportion of area tenanted	23
		37	Age structure of farm managers	4, 23
		38	New farm managers	
		39	Succession	4
	Land prices	40	Shadow price of land	
	Agricultural trade	41	Agricultural imports and exports	
		42	Real export price	
	Farm economic performance	43	Total output/total input	3
		44	Total subsidies/family farm income	3
		45	(Family farm income/family work unit)/reference income	3
		46	Capital; total fixed assets (value of land, permanent crops & quotas)	7
		47	Farm net value added	3, 19
	Indicators for adoption rates of risk management instruments	48	Insurance contracts	10
		49	Insured area	15
		50	Price contracts	10
		51	Off-farm income	10, 11
		52	Other types risk of reduction measures	10
		53	Other gainful activities	10
Environmental				
	Agri-environmental commitments	54	Agri-environmental commitments	23
	Land cover/Land use	55	Land use change	21, 23
		56	Land cover	
		57	Land use diversity (Shannon diversity)	14

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME	REFERENCES (ID number – see Appendix 6) OF THE PAPERS FROM THE LITERATURE REVIEW
		58	Cropping patterns	
		59	Planting of non-food crops	23
		60	Utilised Agricultural Area/ Utilised Agricultural Area minus woodland area	2, 7, 22, 23
		61	Area harvested per crop	9, 22
		62	Area harvested - rainfed	
		63	Area harvested - irrigated	1, 14
		64	Set aside/ % of total farm as uncropped land (including fallow and set-aside)	1, 14, 22
		65	Soil cover	15, 18
		66	Farming intensity	
		67	Specialisation	
		68	Risk of land abandonment	
		69	Permanent grassland	1
	Feed use	70	Feed use (ruminant meat, non-ruminant, dairy)	
	Energy	71	Energy use in agriculture, forestry and food industry/ Fuel quantities/	7, 9, 21, 23
		72	Electricity costs and machinery, heating and vehicle fuels and oil per ha UAA	14
		73	Energy balance	15, 18, 23
		74	Production of renewable energy from agriculture and forestry	
	GHG emissions	75	Greenhouse gas emissions from agriculture/farms	3, 9, 21, 23
		76	Share of agricultural land under commitments to improve climate adaptation	
		77	Share of livestock units under support to reduce GHG emissions and/or ammonia, including manure management	
		78	Share of agricultural land under commitments to reducing emissions, maintaining and/or enhancing carbon storage (permanent grassland, agricultural land in peatland, forest, etc.)	
		79	Share of farms benefitting from CAP investment support contributing to climate change, mitigation and adaptation, and to renewable energy or biomaterials production	
		80	Carbon demand	
		81	Carbon price	
	Air quality	82	Share of agricultural land under commitments to reduce ammonia emission	
		83	Ammonia emissions	16, 21, 23
	Nutrient (N,P) balance	84	Nitrogen from fertilisers	
		85	Share of livestock units (LU) under supported commitments to improve environmental sustainability	
		86	Livestock density	7, 9

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME	REFERENCES (ID number – see Appendix 6) OF THE PAPERS FROM THE LITERATURE REVIEW
		87	Total and individual number of animal units (bovine, pig and poultry)	22
		88	Livestock units per forage area	1, 14
		89	Manure management and storage	23
		90	Gross nutrient balance – nitrogen (farm gate)/ N surplus and N output in agricultural products	3, 6, 9, 15, 16, 17, 18, 19, 20, 21, 22, 23
		91	Gross nutrient balance – phosphorus	16, 17, 19, 21, 22, 23
		92	Gross nutrient balance – potash	16, 17, 19,21
		93	Nitrogen use efficiency	6
		94	Mineral fertilisers use	7, 14, 21
		95	Organic fertilisers use/urea quantities/manure proportion	9, 14, 17, 21
	Water quality	96	Share of agricultural land under management commitments for water quality	
		97	Share of livestock units under supported commitments to improve environmental sustainability	
		98	Nitrates in ground water	21
		99	Percentage of farm UAA with nitrate risk	3
		100	Water Quality - Pesticide pollution	
	Water quantity and availability	101	Water use in agriculture/ Volume of water applied to soils for irrigation purposes/Water consumption per kg of product	3, 14, 18, 20, 23
		102	Water abstraction/Ground water supply	21
	Soil quality and fertility	103	Tillage practices	
		104	Soil quality	21
		105	Soil organic carbon in agricultural land	16, 19, 21, 23
		106	Share of agricultural land under management commitments beneficial for soil management	
		107	Diversity of crop production	12
		108	Soil compaction	21
	Soil erosion	109	Soil erosion by water	21
	Biodiversity and landscapes	110	Farming in Natura 2000 areas	
		111	Genetic diversity /Number of crops/ Index of crop diversity (Shannon Index)/ Number of crops with a share of > 5% in arable farm area/Proportion of legumes in crop structure/proportion of cereals and maize/% spring crops	1, 5, 12, 14, 16, 18, 19, 20
		112	Median parcel size	5, 12, 19
		113	Edge density (mean ratio of perimeter and surface area of land parcels)	5
		114	High Nature Value farmland	
		115	Share of farms benefitting from CAP investment support contributing to biodiversity	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME	REFERENCES (ID number – see Appendix 6) OF THE PAPERS FROM THE LITERATURE REVIEW
		116	Farmland birds index	21, 23
		117	Percentage of species and habitats of Community interest related to agriculture with stable or increasing trends/ Indices of species richness for birds, ants and herbs/ Total avian species richness and Individual and Total bird densities	8, 13
		118	Natural Capital Index	21
		119	Land committed to conservation	23
		120	Agricultural land covered with landscape features / Share of landscape features in total farm area/	5, 23
		121	% of total farm area that is woodland	14
		122	Area supported for afforestation and creation of woodland, including agroforestry	15
		123	Share of livestock units concerned by supported actions to limit the use of antibiotics (prevention/reduction)	
		124	Percentage of grassland area that is temporary grassland	14
		125	Percentage of UAA that is classified as rough grazing	14
	Pesticide use	126	Share of agricultural land concerned by supported specific actions which lead to a sustainable use of pesticides in order to reduce risks and impacts of pesticides	
		127	Share of Utilised Agricultural Area supported by the CAP for organic farming maintenance or conversion	15
		128	Consumption of pesticides	3, 19, 21, 23
		129	Area treated with pesticides	23
		130	Crop protection costs	14
		131	Plant protection products	7
		132	Pesticide risk	18, 20
		133	Pesticides in rivers	23
		134	Pesticides in groundwater	23
	Animal wellbeing (health and welfare)	135	Share of livestock units covered by supported action to improve animal welfare	15
		136	Feeding and nutrition	4
		137	Mortality rate	4
		138	Somatic cell count	4
		139	Age/quality of buildings	4
		140	Duration of grazing	4
		141	Access to outdoor areas for animals	21
Social				
	Employment	142	Percent employed in rural areas compared to national and other area rates for same age and sex classes	
		143	Farm labour force	2, 3, 7, 15, 18, 20, 21, 22, 23

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Impacts	INDICATOR THEMES	ID	INDICATOR NAME	REFERENCES (ID number – see Appendix 6) OF THE PAPERS FROM THE LITERATURE REVIEW
		144	Seasonal labour employment	18
		145	Work-force stability	15
		146	Risk of abandoning agricultural activity	15
		147	Economic dependence on agricultural activity	15
	Training and education	148	Agricultural training of farm managers	3
		149	Share of CAP budget for knowledge sharing and innovation	
		150	Share of farmers receiving support for advice, training, knowledge exchange, or participation in operational groups to enhance economic, environmental, climate and resource efficiency performance	23
		151	Share of farmers benefitting from support to precision farming technology through CAP	
		152	Share of farms with CAP risk management tools	
		153	Share of farmers receiving investment support to restructure and modernise, including to improve resource efficiency	
		154	Share of farmers participating in supported Producer Groups, Producer Organisations, local markets, short supply chain circuits and quality schemes	
		155	Share of farmers receiving support for advice/training related to environmental- climate performance	3
	Quality of life	156	Satisfaction with quality of life	3
		157	Social diversification index	3
		158	Farmer wellbeing	4
		159	Household vulnerability	4
		160	Education level	4
		161	Work-life balance	4
	Community wellbeing	162	Multifunctionality (contribution to rural economy)	4
		163	Availability of services	4
		164	Food safety/ Pesticides residues in food	4, 21, 23
		165	Heritage and cultural values	4
		166	Consumer perceptions and concerns	4

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.