ECOWHEATALY

Evaluation of policies for enhancing sustainable wheat production in Italy

Work Package 1: Setting the scene: information gathering

Task report 1.1

The Italian wheat production system: data, farm types and green policies

www.ecowheataly.it

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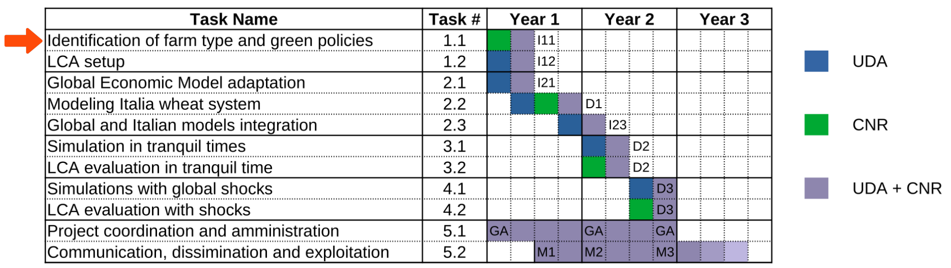

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The partners in the project are:
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The content of this document is the result of the worked developed by the partners in the context of the project.

DISCLAIMER

The Italian wheat production system: data, farm types and green policies

Contents

Executive Summary

This report presents the results of **Task 1.1 of the ECOWHEATALY project**, which aims to construct a detailed empirical representation of the Italian wheat production system and to provide the data foundation for the simulation of environmental policies affecting the sector.

The task has three main objectives. First, it collects and harmonizes farm-level data describing wheat production in Italy. Second, it identifies representative farm types reflecting the heterogeneity of production practices across farms. Third, it reviews and analyses the main environmental policy instruments affecting wheat farming within the framework of the Common Agricultural Policy (CAP).

The empirical analysis is primarily based on the **RICA/FADN (Farm Accountancy Data Network)** database, which provides detailed microeconomic information on Italian farms, including production levels, input use, revenues, and production costs. These data are complemented with additional sources required for environmental assessment and life-cycle analysis. To facilitate the integration of these heterogeneous datasets, a dedicated database structure has been developed within the ECOWHEATALY project. The data are processed through Python scripts and organized into a structured **JSON-based database**, allowing flexible access and integration with simulation models and life-cycle assessment (LCA) modules.

Using these data, the report develops a classification of Italian wheat farms based on their production characteristics and input intensity. A clustering procedure identifies three broad groups of farms that differ in their levels of input use, production intensity, and environmental pressure. These representative farm types provide a simplified but realistic representation of the structural diversity of the Italian wheat sector and will be used in the subsequent simulation exercises of the project.

The report also reviews the main **green policy instruments** affecting wheat production under the CAP framework, including Eco-scheme 4 and agri-environmental measures such as SRA19 and SRA20. These policies aim to reduce the environmental impact of agriculture by encouraging crop diversification, reducing pesticide use, and lowering overall input intensity. A preliminary economic framework is introduced to illustrate how these policy measures may influence farmers' production decisions through changes in revenues, costs, and subsidies.

Overall, Task 1.1 provides the empirical and methodological basis for the subsequent stages of the ECOWHEATALY project. By combining detailed farm-level data, representative farm types, and a structured policy analysis, the report establishes the analytical foundation required to simulate the environmental and economic effects of green agricultural policies on the Italian wheat sector.

1 Datasets

1.1 FADN-RICA

The ECOWHEATALY project leverages the Farm Accountancy Data Network (FADN), an annual sample survey established by the European Economic Commission, which serves to define the Community Agricultural Policy. Originally, the surveys had served as an important means of appraising the income of agricultural holdings. Subsequently, there has been an increasingly uses to gauge the broader impacts and accomplishments of the Common Agricultural Policy.

Overall, the FADN surveys collect quantitative insights into agricultural practices, incomes, and expenses at the individual farm level. The list of variables included in FADN can be found in the document "Definitions of Variables used in FADN standard results" by the committee for the Farm Accountancy Data Network (FADN). The document is available upon subscription to the group at europa.eu homepage. Alternatively, the document is freely available at:list of FADN variables. Additional details on variables available in FADN can be found in Neuenfeldt and Gocht (2014), who provide a handbook on FADN use.

Presently, there are ongoing works to include sustainable aspects into FADN. The results will be the Farm Sustainability Data Network (FSDN) (FSDN homepage) (Vrolijk and Poppe, 2021).

There exist various national accounting networks headed by FADN with their own characteristics. The Italian counterpart of FADN, known as RICA (Agricultural Accounting Information Network), is administered by the Council for Agricultural Research and Economics (CREA). This system annually collects survey data on approximately 12,000 farms, with over 3000 of them identified as wheat producers. The RICA dataset represents the only harmonized source of microeconomic data on the economic functioning and economic-structural dynamics of companies operating in the agricultural sector. It provides quantitative insights into agricultural practices at the individual farm level, covering all regions of Italy. Currently, the RICA provides, on average, national coverage of 95% of the Utilised Agricultural Area, 97% of the value of Standard Production, 92% of Work Units, and 91% of Livestock Units.

1.2 The RICA dataset

One of the ECOWHEATALY partners (CREA-PB) is responsible for collecting and organizing data on the Italian agriculture sector for the RICA database, and then providing the Italian data to FADN. However, the data gathered by CREA-PB are more detailed than those supplied to FADN. The tables shown in Figure 1, taken from the RICA variables webpage, can be used for this comparison. The full list of available tables and related variables is available at the (link to the RICA homepage). Given the extensive nature of the data, much of which does not need to be included in the database, we recommend that readers seeking comprehensive information about RICA refer to the online source.

1.2.1 Data Retrieving and Exploration

In the RICA database, collected data are organized into one-to-multiple relational databases comprising multiple tables. Complete access to the data for scientific purposes is free, subject to authorization by the CREA. Once authorization is obtained,

The numbers of GAIA	EU-FADN	IT-FADN
Types of accounting records, divided into **80** types of accounting transactions	<20	30
Accounts managed directly by user	0	80
Types of agricultural machinery and equipment *(farm tractor, farm kit, tank car, etc.)*	0	300
Types of farm buildings *(starehouse, stalls, greenhouse, dung-hill, silos etc.)*	0	70
Types of soil *(physical characteristics and fertility)*	0	20
Crop species *(arable land and arbored)*and **6800** cultivars	<100	380
Animal species and categories	<30	100
Breeds*/attitude:beef, milk, mixed, eggs, etc.)*	<10	290
Types of crop products *(primary and processed - combinz crop-prod over **1.055** case)*	<50	54
Types of livestock products *(primary and processed)*	<10	35
Categories of technical inputs *(fertilizers, crop protection, feed, motor fuels, seeds, etc.)*	<25	110
Types of public aid *(investments subsidies and annual payments)*	<300	500
Variables	1000	>2500

Some technical data	EU-FADN	IT-FADN
Georeferencing farms	✔	✔
Irrigated UAA	✔	✔
Volumes of irrigated water for single crops and fert-irrigation		✔
Amount of N, P, e K used in the farm level	✔	✔
Unit of N,P e K used in a single crop		✔
Use of protection crop for single cultivar (tokicity class		✔
Energt crops use	✔	✔
Type land use (minimum tillahe / no-tillage)		✔
Cover crop (es. date of seeding - date of harvest		✔
Environmental constraints - water directive UE	✔	✔
Environmental constraints - nature 2000 areas (SPA - SCI)		✔
Certification systems of the productive process (BIO, POD, PGI, etc.)		✔

Figure 1: Comparison of variables included in the Italian and EU Farm Accountancy Data Network (FADN).

users can query the database, apply filters, and download the selected data as CSV files. In our case, we applied two filters restricting the data to common wheat and durum wheat, and organized the data as tables for the entire available period (2008-2022) across the entire national territory. Within each table, the key variable `Cod_Azienda` allows for tracking individual farms across all Excel files. Additionally, `Cod_Specie_vegetale` or `ID_SPECIE_VEG` identifies the crop type (3 for durum wheat, 4 for common wheat). These key variables, along with `Anno` (year), enable the extraction of data specific to each farm, crop, and year across different tables.

To pinpoint and identify variables suitable for the ECOWHEATALY project, partners convened in an online meeting, overseen by CNR-IBE, with the partnership of CREA-PB. Following the meeting, the partners collaboratively identified the main variables essential for the task and subsequently requested CREA-PB to retrieve data spanning the period from 2008 to 2022. Noteworthy variables for the present task include the quantity of **fertilizers** and **pesticides** used, water consumption, and energy utilization, along with metadata such as cultivated area, production quantity, type of management, and any kind of certifications, as well as any costs incurred by the farm.

The subset of RICA chosen for the ECOWHEATALY project comprises several CSV files (Table 1), each detailing a multitude of economic, productive, or environmental variables. Given the extensive nature of these variables, which exceeds the practicality of including them as a table in this report, we encourage readers seeking the comprehensive list to refer to the RICA website.

Since each file holds many variables, more or less useful for the scope of the ECOWHEATLY project, the first step was to explore the full list of variables to identify the useful ones (Figures 2 and 3).

Proceeding with a precautionary approach, Figures 2 and 3 show both the variables

File name
Aziende_grano.csv
Colture_grano.csv
Fertilizzanti_grano.csv
Fitofarmaci_grano.csv
Aiuti_grano.csv
Bilancio_grano.csv
Certificazioni_grano.csv

Table 1: List of selected tables from the RICA dataset (data only for wheat species).

that are considered certainly useful (orange cells in Figures 2 and 3) for the project and the other potentially useful.

Variabili	Aiuti_cereali.xlsx	Certificazione_cereali.xlsx	Colture_cereali.xlsx
Anno	Anno	Anno	Anno
Cod_Azienda	Cod_Azienda	Cod_Azienda	Cod_Azienda
Ricavi_Totali_Aziendali	Cod_Tipo_Aiuto	Cod_Tipo_Certificazione	ID_SPECIE_VEG
PLV_Colture	Tipo_Aiuto_Concesso	Tipo_Certificazione	Specie_Vegetale
Aiuti_EU		Cod_Oggetto	Modalità_Coltivazione
Costi_Correnti		Oggetto	ID_MOD_COL
Fertilizzante			SUPERFICIE_UTIL
Antiparassitari_Disserbanti			PLV
Acqua_Elettricità_e_Combustibili			Acqua
Valore_Aggiunto			Certificazioni
Reddito_Operativo			Energia
Aiuti_Pubblici_Conto_Capitale			*Concimi*
Aiuti_altri			*Difesa*
Reddito_Netto			Costo_Lav_Macchine
Farm_Net_Value_Added			Ore_Macchina
Margine_Operativo_Lordo			QT_PROD_PRINC

Figure 2: List of variables of interest for Ecowheataly subset from the RICA.

It's crucial to highlight that the files Colture_grano.csv, Fertilizzanti_grano.csv, and Fitofarmaci_grano.csv contain the key variable Specie_vegetale, enabling a unique association of the other entries in the files (e.g., quantity distributed per hectare, crop surface, etc.) specifically with wheat cultivation. Conversely, in files lacking this key variable, it becomes possible to establish a comprehensive profile of the entire company (thanks to the Cod_Azienda variable), irrespective of whether it cultivates multiple plant species or engages in diversified production activities.

Among the available data, both continuous and categorical data are present. Examples of continuous data are the number of pesticides and fertilizers used; examples of categorical data are the type of cultivation (organic or not) and the type of incentives acquired. For the purpose of data exploration, Figures 4 and 5 offer the full list of categorial data for the variables summarized in Figures 2 and 3.

From the table of Figure 4, it emerges that there exists a classification system adopted by the FADN, in Certificazioni_grano.csv, which assigns to each farm the one among the following categories: Organic, Good Agricultural Practice, Good agri-environmental conditions, Cultivation on organic sur-

Fitofarmaci_cereali.xlsx	Aziende_cereali.xlsx	Fertilizzanti_cereali.xlsx
Anno	Anno	Anno
Cod_Azienda	Cod_Azienda	Cod_Azienda
Cod_Specie_Vegetale	Cod_Provincia	Cod_Specie_Vegetale
Specie_Vegetale	Provincia	Specie_Vegetale
Cod_Modalità_di_Coltivazione	Sigla_Prov	Modalità_Coltivazione
Modalità_Coltivazione	Regione	Cod_Modalità_di_Coltivazione
Produzione Industriale	Cod_Zona_Altimetrica_3	Produzione Industriale
Classe_di_Tossicità	Produzione_Standard_Aziendale	Quantità_distribuita
Quantità_distribuita	Diversificata	Valore_del_distribuito
UM	Biologica	UM
SAU	KW_Macchine	Quantità_azoto_distribuita
Quantità_distribuita_per_Ha	Profilo_Strategico	Quantità_fosforo_distribuita
		Quantità_potassio_distribuita
		Superficie_della_coltura

Figure 3: List of useful variables within the subset of RICA. Note that cultivation practice corresponds only to open field for cereals.

faces, Cultivation on organic surfaces in conversion, and Conventional (yellow cells in Figure 4). Although this classification suggests that it is possible to proceed with the activities of ECOWHEATALY without the need for a cluster analysis, this is not feasible as the number of farms with this classification will prove to be very scarce (see Table 2). In addition, we found an inconsistency in the certifications. Many farms change the type of certification (from one type to another, from one type to no certification) and from one year to the next.

Year	N. of farms producing wheat	N. of farms with certificate
2008	3699	237
2009	3277	109
2010	3500	104
2011	3288	106
2012	3645	116
2013	3497	74
2014	3267	75
2015	3173	52
2016	3495	88
2017	3420	91
2018	3570	129
2019	3415	171
2020	3427	174
2021	3661	261

Table 2: List of farms in the RICA dataset with a certificate of clear type of greening management (data only for wheat species).

Certificazione_cereali.xlsx	Aziende_cereali.xlsx	Aiuti_cereali.xlsx
Tipo_Certificazione	Zona_Altimetrica_3	Tipo_Aiuto_Concesso
Altra tipologia di certificazione	Collina	Aiuti UE alla produzione (I Pilastro)
Biologica	Montagna	Aiuti UE allo sviluppo rurale (II Pilastro)
Buona Pratica Agricola	Pianura	Aiuti di Stato (compresi regionali e locali)
Buone condizioni agroambientali	nan	Tipo_Politica
Ciclo di vita del prodotto (UNI EN ISO 14040 LCA)	Forma_Giuridica	Altre 1° Pilastro
Coltivazione su superficie biologica	Altra associazione riconosciuta e non	Altre 2° Pilastro
Coltivazione su superficie biologica in conversione	Altra forma giuridica non profit (Fondazione)	Asse 1 - Competitività
Convenzionale	Altra forma giuridica profit (Consorzio)	Asse 2 - Ambiente
Denominazioni di Origine Protetta (DOP)	Altra tipologia	Asse 3 - Diversificazione
EMAS	Associazione di prodotti	Asse 4 - Leader
Filiera legno per imballaggi (PEFC)	Cooperativa sociale	Interventi regionali e altri
Forniture prodotti agroalimentari a GDO (BRC	Cooperative (a responsabilità limitata o illimitata)	Interventi statali
HACCP	Ditta individuale	Ortofrutta
ISO-VISION	Ente pubblico	Seminativi e altri
Indicazione Geografica Protetta (IGP)	Società a responsabilità limitata (S.r.l.)	Viticoltura
Marchio collettivo privato (consorzio agroalimentare	Società in accomandita per azioni (S.a.p.a.)	Zootecnia
Marchio di impresa	Società in accomandita semplice (S.a.s.)	Zucchero e tabacco
Marchio di impresa registrato	Società in nome collettivo (S.n.c.)	Oggetto_Contributo
Marchio di qualità alimentare/superiore (es. OGM free)	Società per azioni (S.p.a.)	Animali da vita
Mista (alcuni processi biologici altri convenzionali)	Società semplice	Animali giovani e da ingrasso
Prodotto agroalimentare tradizionale iscritto nel registro del MIPAAF	Biologica	Attrezzature dei centri aziendali
Prodotto biologico	N	Azienda in complesso
Prodotto biologico da superficie in conversione	S	Colture erbacee
Prodotto tradizionale	Profilo_Strategico	Fabbricati e manufatti
Produzione integrata certificata (Marchi regionali	Convenzionali Grandi	Non specificati
Ridotto impatto ambientale	Convenzionali Piccole	Piantagioni agricole
Rintracciabilità della filiera agro-alimentare (UNI EN ISO 22005)	Differenziate	Piantagioni forestali
Rintracciabilità interaziendale (UNI EN ISO 11020)	Differenziate e Diversificate	Prodotti animali e trasformati
Sistema comunitario di ecogestione e audit EMAS	Diversificata	Prodotti vegetali e trasformati
Sistema di gestione ambientale (UNI EN ISO 14001)	Micro	Terreni agricoli e forestali
Sistema di gestione della sicurezza in campo alimentare (UNI EN ISO 22000)		
Sistema di gestione per l'autocontrollo igienico dei prodotti e dei processi (UNI EN ISO 10854)		
Sistema di gestione per la qualità (UNI EN ISO 9001/Vision 2000)		
Sistema di qualità nazionale zootecnia		

Figure 4: Exploded list of categorical variables present in the RICA subset. The yellow cell represents the classification system identified within the FADN dataset that is consistent with the goal of the Ecowheataly Project.

Fertilizzanti_cereali.txt	Fitofarmaci_cereali.txt
Produzione Industriale	
Altri concimi e fertilizzanti	Acaricida
Ammendanti e correttivi	Anticrittogamico
Concimi a base di microelementi solidi	Bagnante, coadiuvante
Concimi fluidi	Coadiuvante
Concimi minerali solidi	Diserbante
Concimi organo minerali solidi	Fitoregolatore
Fertilizzanti tipo humus	Geodisinfestante
Letame di altri animali	Insetticida
Letame di bovini, bufali ed equini	Molluschicida, nematocida, rodenticida
Letame di granivori	Repellente
Letame di ovicaprini	
UM	
HL	
QL	

Figure 5: Exploded list of categorical variables present in the RICA subset.

2 The Ecowheataly dataset

Starting from the RICA Excel files, we built a dedicated dataset with the relevant variables for the project. The database aims to gather variables from the various Excel files into a single source.

This document describes the Ecowheataly JSON Database (hereinafter, the EWJS database) and the overall procedure used to populate it. As part of the Ecowheataly project, the EWJS database stores the data needed to conduct the project's activities in a format suitable for carrying out the Life Cycle Assessment (LCA) of wheat cultivation using the Brightway LCA software framework (see Task 1.2).

2.1 Ecowheataly database as JSON file format

A JSON database is a type of NoSQL (Not Only SQL) database that stores data in JSON (JavaScript Object Notation) format. JSON is a lightweight, human-readable data interchange format that uses key-value pairs to represent data. In a JSON database, data organization does not require a predefined schema, such as the classic columns-and-rows format. This means each document (JSON object) can have a different structure, which can be easily adjusted without complex migrations. Indeed, JSON databases typically have a Hierarchical Structure, namely nested data structures in which objects can contain arrays and other objects.

The choice of the JSON format for the EWJD lies in two main reasons:

1. the source data (i.e., the RICA dataset) contains a foreign key that allows multiple observations per farm, year, and variable (e.g., pesticide application). This structure, often referred to as a one-to-many relationship, is common in relational databases like RICA. However, it can pose challenges for statistical analyses that often require one-to-one relationships. The JSON format, due to its hierarchical structure and ability to represent complex data structures, is well-suited for managing relationships like one-to-many.

2. Some modern LCA tools and APIs require JSON due to its lightweight nature and compatibility with web applications. Specifically, the Brightway LCA Software Framework used to perform the LCA within this project is one of them. Details on the implementation of the Brightway LCA framework with input data from the RICA are presented in Task 1.2.

2.1.1 EWJS population

From the RICA tables listed in Table 1, two filters were applied to restrict the data to common and durum wheat crops. The data encompass the entire available time period from 2008 to 2022. Within each table, the key variable `Cod_Azienda` allows for tracking individual farms across all Excel files. Additionally, `Cod_Specie_vegetale` or `ID_SPECIE_VEG` identifies the crop type (3 = durum wheat, 4 = common wheat). These key variables, along with `Anno` (year), enable the extraction of data specific to each farm, crop, and year across different tables. Consequently, the *Python* script for populating the EWJS (`01_create_jspndatabase_for_lca.py`) employs iterative processes over these three essential keys to extract RICA data and populate the EWJS.

The selected tables provide data on agricultural practices essential to conducting a Life Cycle Assessment (LCA) of the environmental impacts of wheat production. These variables include:

- Fertilizer and Pesticide Use
- The quantities of fertilizers and pesticides applied, directly sourced from the RICA
- Machinery Fuel Consumption: estimated fuel consumption for agricultural machinery

To enhance the LCA results and facilitate general statistical analysis, additional variables have been extracted from the selected tables and included in the EWJS. These include:

- cultivated area
- crop production quantity
- farm standard output

The EWJS database is provided in the `ecowheataly_database.json` file. The data structure of each farm is presented as in Figure 6.

First, the Tables were imported as tabular dataframes using the *Pandas library*. From the imported `Aziende.csv` file, unique farm codes were extracted and listed. These codes serve as the keys for the first hierarchical level of the database, which is initialized as a dictionary in Python 3. A total of 14.691 unique farm codes resulted. Accordingly, the first hierarchical level of the EWJS database contains 14,691 entries, each accessible by the farm code in string format. The list of variables included in the EWJS database is reported in the table of Figure 7.

Each entry at this level includes general information from `Aziende.csv`, such as the region (corresponding to the Nomenclature of Territorial Units for statistics (NUT) at level 2 (NUT2)), province (NUT3), as well as the agronomic region (Quaresima

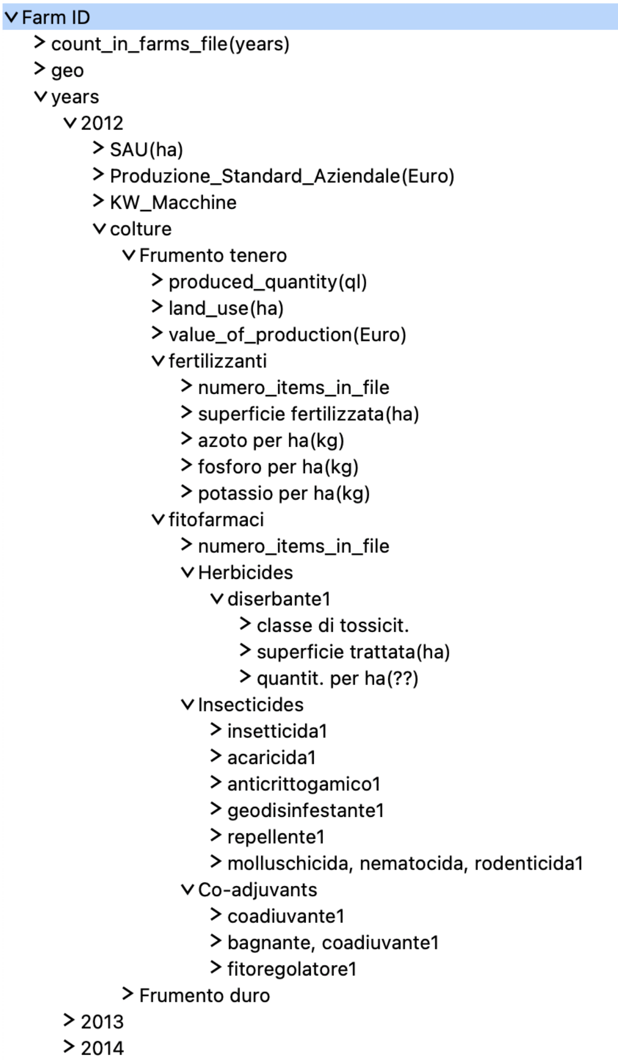


Figure 6: The structure of the Ecowheataly database (figure obtained by using the *pyjsonviewer* software).

et al., 2024) where the farm is located. Additionally, the farm's technical-economic orientation is included. The RICA system classifies farms into eight broad TEO categories, which include farms specialized in arable crops, horticulture, permanent crops, herbivores, granivores, polyculture, polybreeding, and mixed cultivation and breeding (see this link). At the same hierarchical level, the key `years` is a dictionary that contains additional farm-level structural and agronomic data, further categorized by crop type (durum wheat or common wheat). These keys are optional, meaning data exists only for the years and crop types with available information.

For each year, farm structural data are extracted from `Aziende.csv` and include: a) the whole farm acreage, b) the standard gross output, and c) the power supplied by driving machines (regardless of ownership title, excluding passive subcontracting).

Agronomic data for specific crop types (durum wheat or common wheat) are grouped under the corresponding keys. Crop-specific data stored at this level were extracted by `Colture.csv` and include: the crop produced quantity (quintals), the crop-specific cultivated area (crop acreage), and the estimated hours of machines used per hectare. The ratio of production quantity to cultivated area equals crop yield.

The hierarchical level of specific crops also includes data about fertilizers and pesticides. The fertilizer level collects data from the `Fertilizzanti.csv` file on the fertilized area and the quantities of nitrogen, phosphorus, and potassium distributed throughout the crop's life cycle. The total amount of these nutrients applied per hectare is calculated by summing across all treatments. Fertilizer data are predominantly in solid form (98%) and are expressed in quintals. Less than 2% of the fertilizers are in liquid form, measured in hectoliters. Observations involving liquid fertilizers have been excluded to avoid aggregation errors.

The phytosanitary level collects data from the `Fitofarmaci.csv` file on the phytosanitary treatment. Specifically, the extracted data includes the quantities of herbicides, insecticides, and fungicides. Each phytosanitary type stores hierarchical data, whose key for access represents the phytosanitary's toxicity level. The toxicity level, if present, determines the area subject to phytosanitary treatments and the quantity distributed. If multiple treatments of the same type are applied using products with the same toxicity class, the entries are aggregated by averaging the relevant values. However, if treatments involve products with different toxicity classes, separate entries will be recorded in the dataset for each toxicity class.

Overall, this hierarchical dataset provides a detailed view of farm operations, with optional data points based on availability. The structure allows for flexibility in capturing information at varying levels of detail, from general farm-level data to specific crop- and treatment-related data. The inclusion of optional keys ensures that the dataset can handle missing or incomplete data while still maintaining a coherent structure for analysis.

3 Data for LCA in RICA

The LCA method, along with the implementation strategy in open-source software, is fully described in the report of Task 1.2. However, in this section, we present data from the RICA database used to complete the Life Cost Inventory required for applying the LCA method.

Name	Description	Source Table and related item in the RICA
Farmcode {}	unique numeric code associated with the sampled farm	Aziende.csv (item ID_AZIENDA)
region	Name of the region (NUT level 2)	Aziende.csv (item "Regione")
province	Name of the province (NUT level 3)	Aziende.csv (item "Provincia"
agronomic_region	Agronomic Region where the farm is located	Aziende.csv (item "Regione Agraria")
technical-economic_orientation	Technical-Economic Orientation of the farm	Aziende.csv (item "PoloOTE"
years {}	*The dataset includes a dictionary of years (e.g., 2008, 2009, 2010), with data only being present for years where information is available.*	
farm acreage:	The total Area of the farm, measured in hectares	Aziende.csv (item "SAU")
standard gross output	The estimated economic size of the farm for that year	Aziende.csv (item "Produzione Standard Aziendale" before 2024, then "RLS_PS").
KW machines	The total power (in kilowatts) supplied by the machines used on the farm.	Aziende.csv (item "KW macchine")
durum_wheat {} / common_wheat {}	*Crop-Specific Data for durum or common wheat: for each year, if data is available, the dataset may include information on specific crops*	
produced quantity	the total production of the crop, measured in quintals.	Colture.csv (item "T_PROD_PRINCIPALE")
crop acreage	agricultural land dedicated to the crop cultivation, measured in hectares.	Colture.csv (item "SUPERFICIE_UTIL")
hours_of_machine_ha	the estimated hours of machine use per hectare for that crop	Aziende.csv, Colture.csv
Fertilizers {}	*If data on fertilizers uses are available for a given year, information of quantities are included*	
fert area	The average area subject to the fertilizer treatments, in hectares	Fertilizzanti.csv
Nitrogen_ha	The amount of nitrogen applied per hectare.	Fertilizzanti.csv (item "Azoto_ad_ettaro") as sum of all the products applications
Phosphorus_ha	The amount of phosphorus applied per hectare.	Fertilizzanti.csv (item "Fosforo_ad_ettaro") as sum of all the products applications
Potassium_ha	The amount of potassium applied per hectare.	Fertilizzanti.csv (item "Potassio_ad_ettaro") as sum of all the products applications
Phytosanitary {}	*If data on phytosanitary uses are available for a given year, information of quantities grouped by toxicity and phytosanitary types are included:*	Fitofarmaci.csv (item "Produzione Industriale" to identify the product type)
- Herbicide {}	Contains details about herbicide applications grouped into class of toxicity.	
- Fungicide {}	Contains details about fungicide applications, grouped into class of toxicity.	
- Insecticide {}.	Contains details about insecticide applications, grouped into class of toxicity	
Class of toxicity: **0 {}** = caution handle with care **1 {}** = very toxic (T+) **2 {}** = Toxic (T) **3 {}** = harmful (Xn) **4 {}** = Irritating (Xi)		Fitofarmaci.csv (item "Classe di Tossicità" to identify the class of toxicity)
distributed_quantity_ha	The quantity of the treatments distributed per hectare.	Fitofarmaci.csv (item "Quantità_distribuita_per_Ha"). Data are aggregated (summed) for class toxicity
phyto_area	The average area subject to the treatments, in hectares.	Fitofarmaci.csv (item "SAU"). Data are averaged for class toxicity

Figure 7: List of variables included in the Ecowheataly database (EWJS).

3.1 Machinery use

We develop our LCI for agricultural machinery by employing the use time. This figure, namely the hours of machinery use directly available for each crop in the RICA (in particular, in the `colture.csv` file), concerns only the farm's owned machines. Data on third-party supplied machinery is also available at the crop level as the total amount for this type of expense. We could trace back the time of third-party machinery use, dividing the total expenditure by the service hourly cost. Unfortunately, this hourly cost is not available in the RICA. However, the `aziende.csv` file includes two useful variables: the hourly opportunity cost of human labor and machinery use. These variables are normally used to value the owner's work and the proprietary machinery used. The RICA glossary specifies that a third-party operation is performed by third-party personnel using their company-owned machine. Therefore, we add up the two previously identified opportunity costs to obtain a starting point for an estimation of the third-party machinery hourly cost. We increase this amount by 30% to account for taxes, machinery movement, and other costs.

The equation to compute the number of machine use hours is:

$$H^{mac} = H^{mac}_{own} + \underbrace{\frac{C_{tp}}{(c^l + c^{mac})(1+t)}}_{H^{mac}_{tp}}$$

where

- H^{mac}_{own}: hours of use of owned machines (available in `colture.csv` as `Ore_Macchina`)
- C_{tp}: cost for third party sevices (available in `colture.csv` as `Contoterzismo`)
- c^l: hourly opportunity cost of human labor (available in `aziende.csv` as `Costo_Opp_Lavoro_Uomo_Orario`)
- c^{mac}: hourly opportunity cost of machinery (available in `aziende.csv` as `Costo_Opp_Lavoro_Macchina_Orario`)
- t: third-party service supplier's markup (taxes, transport, etc.) (parameter we set to 0.3)
- H^{mac}_{tp}: hours of use of third-party machines.

Finally, we divide by the cultivated area to obtain the hours of machinery use per hectare:

$$h^{mac} = \frac{H^{mac}}{SAU}$$

where

- SAU: hectares of cultivated area (available in `colture.csv` as `SUPERFICIE_UTIL`)

3.2 Fertilizers

Among others, the RICA includes detailed information on fertilizers (see the table in Figure 7). The file has one record for each different composition of applied fertilizers. Therefore, given a farm, a year, and a crop, several records can be found (one for each different fertilizer). Each record includes, among many other variables,

- the quantity of nitrogen per hectare (available in the `fertilizzanti.csv` as `Azoto_ad_ettaro`)
- the quantity of phosphorus per hectare (available in the `fertilizzanti.csv` as `Fosforo_ad_ettaro`)
- the quantity of potassium per hectare (available in the `fertilizzanti.csv` as `Potassio_ad_ettaro`)

We report in the Ecowheataly database the sum of these three variables taken across all the records for each farm, in each year, but taking hard and soft wheat one by one. In addition, we record the surface of the crop, which is available in the `fertilizzanti.csv` as `Superficie_della_coltura`.

3.3 Pesticides

Usetox is the main tool to evaluate the effects of using chemicals (see this link). The aim of *Usetox* is to provide for each chemical the characterization factors to evaluate its potential impact on two aspects: human health and the environment. This is done both at the midpoint and endpoint level Frantke (2019).

The list of studied chemicals increases progressively. However, we want to highlight that studying a new chemical means analyzing a very complex system where all the possible paths of the chemical molecule from its use to its disappearance have to be considered. Figure 8 gives an idea of the multiple aspects that are considered to evaluate, for example, human exposure.

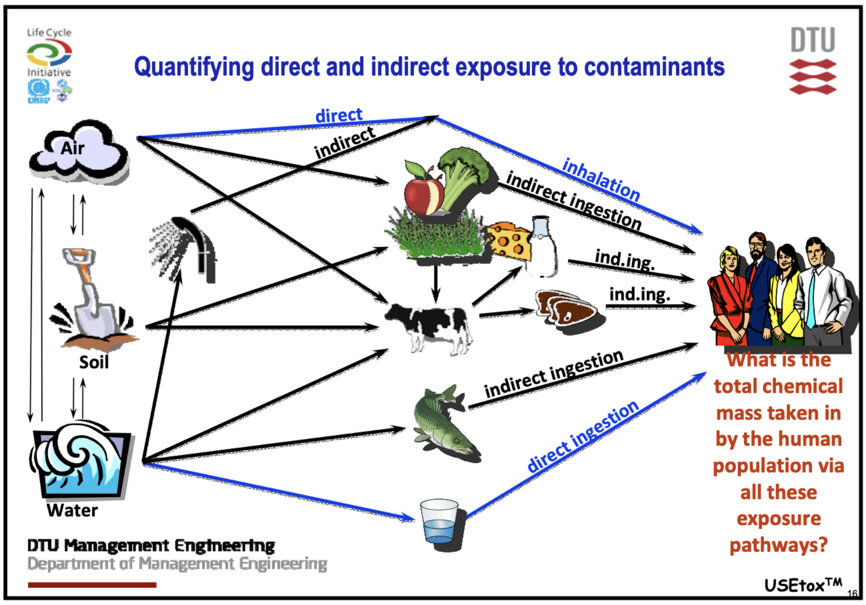


Figure 8: Human exposure to contaminants (credit to usetox.org).

The RICA database provides data on pesticides in the `fitofarmaci.csv` file. Our analysis has to be based on the following available variables:

- toxicity classification (available as `Classe_di_Tossicit\'a`)
- type, i.e.. herbicide, insecticide, fungicide, . . . (available as `Produzione_Industriale`)
- applied quantity per hectare (available as `Quantit\'a_distribuita_per_Ha`).

Toxicity classification is:[1]

Unfortunately, the RICA dataset does not specify the active ingredients in each pesticide. Therefore, we do not have enough information for a standard LCA analysis of pesticides.

In an attempt to trace the active ingredients, we use the Fitogest® database where detailed information on pesticides available in Italy is recorded and can be accessed at: https://fitogest.imagelinenetwork.com/it/.

This website has a search tool. When the product search is specified, it is possible to use the advanced search, where several choices are available. Once the "ongoing crop" option is chosen, a list of crops becomes available, and the wheat items (hard and soft) are among them. We leave the following choices at their default value and jump to the classification part, where toxicity level/type can be selected. The choice interface is reported in Figure 9:

Figure 9: Web interface for choicing the toxicity class of pesticides at https://fitogest.imagelinenetwork.com/it/.

Unfortunately, there is a mismatch between the RICA and the Fitogest classifications. A European directive, which implies changes in pesticide classification, came into force in June 2015. For coherence with previously recorded data, the RICA reports the old classification, while Fitogest®database, being a picture of the current market, reports the newer one. Although a one-to-one correspondence is not possible, a possibility to link the two classifications is provided in this document, where we found the picture of Figure 10.

Our strategy was to:

- select products with the GHS06 pictogram in Fitogest, evaluate their active ingredients, and use them for RICA classes *T+* and *T*
- select products with the GHS07 pictogram in Fitogest, evaluate their active ingredients, and use them for RICA class *Xn*
- select products with the GHS05 pictogram in Fitogest, evaluate their active ingredients, and use them for RICA class *Xi*
- select products with the sentence "attenzione manipolare con prudenza" in Fitogest, evaluate their active ingredients, and use them for the corresponding RICA class.

The type of pesticides considered also has some mismatches. We identified several

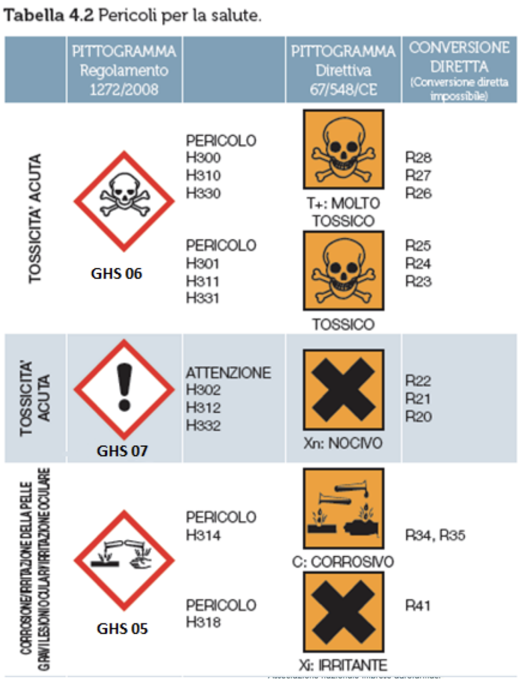


Figure 10: Classes of equivalence between older and newer toxicity classification.

Fitogest®+	RICA
Acaricida, Anticrittogamico	
Acaricida, Diserbante, Insetticida	
Acaricida, Insetticida	Acaricida
Anticrittogamico	Anticrittogamico
	Bagnante, coadiuvante
	Coadiuvante
Diserbante	Diserbante
Diserbante, Fitoregolatore	
Fitoregolatore	Fitoregolatore
	Geodisinfestante
Insetticida	Insetticida
Molluschicida	Molluschicida, nematocida, rodenticida

Table 3: Correspondences of pesticide types between Fitogest®+ and RICA.

correspondences that are reported in Table 3 :

For each correspondence, we selected in Fitogest the products having given characteristics in RICA (for example "Diserbante nocivo"), and we analyzed the most frequent composition of these products. The result for our example is

[1] Search for "Classe di tossicità dei fitofarmaci" under letter C of RICA glossary available at https://rica.crea.gov.it/APP/glossario/index.php.

- 12 pesticides are composed of MCPA (Sale)
- 11 pesticides are composed of Clodinafop-propargyl and Cloquintocet-mexil
- 6 pesticides are composed of 2,4-D (Sale) and MCPA (Sale)

We then analyzed the concentrations and the recommended quantities starting from the first item. In our example, we find that producers of pesticides having MCPA (Sale) as a unique active ingredient recommend 800-1000g per hectare. Making the simplifying assumption that the farmers in RICA use the most frequent active ingredients makes it possible to perform the pesticide LCA analysis. Performing the analysis in types and toxicity level, we obtained the most frequent active ingredients in pesticide types (Table 4).

	prudenza	irritante	nocivo	tossico
Acaricida		Sali di potassio degli acidi grassi		
Anticrittogamico	Zolfo	protioconaziolo (2)	Tebuconazolo	
Diserbante	Glifosate	2,4 D (Sale)(3)	MCPA (Sale)	
Fitoregolatore		Clormequat	Trinexapac etile	
Insetticida		Deltametrina	Deltametrina	Pirimicarb
Molluschicida & co	Fosfato ferrico	Metaldeide		

Table 4: Most frequent active ingredients in pesticide types.

Once we have identified the active ingredient, we trace back the names of products containing the ingredient. We consulted the producer's documentation to trace back the quantity of active ingredients per hectare recommended for wheat. The results of this process are reported in Table 5.

type	tox level	active ing	product	quantity	concentration	active ing per ha
acaricida	irritante	sali di potassio degli acidi grassi	flipper	4-10l/ha	479,8g/l	1920-4800g/ha
anticrittogamico	prudenza	zolfo	cosavet df edge	3-8 kg/ha	80%	2400-6400g/ha
anticrittogamico	irritante	protioconazolo	pecari 300	0.65l/ha	300g/l	195g/ha
anticrittogamico	nocivo	Tebuconazolo	ares 430 sc	0.58l/ha	430g/l	250g/ha
diserbante	prudenza	Glifosate	clean-up	1-4-6-12l/ha	360g/l	360-4320g/ha
diserbante	irritante	2,4 D (sale)	pimiento 600	0.6-1.2l/ha	600g/l	360-720g/ha
diserbante	nocivo	MCPA (sale)	erbitox m pro	1.6-2l/ha	500g/l	800-1000g/ha
Fitoregolatore	irritante	clormequat	stabilan	2-3.5l/ha	461g/l	922-1613.5g/ha
Fitoregolatore	nocivo	Trinexapac etile	moddus	0.5l/ha	250g/l	125g/ha
Insetticida	irritante	Deltametrina	antal	0.3-0.5l/ha	25g/l	7.5-12.5g/ha
Insetticida	nocivo	Deltametrina	antal	0.3-0.5l/ha	25g/l	7.5-12.5g/ha
Insetticida	tossico	Pirimicarb	aphox 50	260g/ha	50%	130g/ha
Molluschicida	prudenza	Fosfato ferrico	ferrex	6kg/ha	25g/kg	150g/ha
Molluschicida	irritante	Metaldeide	luma-kl	7kg/ha	50g/kg	350g/ha

Table 5: Names of products and active ingredients composition.

Some active ingredients fall in more than one toxicity class. In this case, we search for less-used ingredients that better reflect the toxicity class. This task was particularly demanding for Deltametrina (insecticide). So, we decided to use it both for the irritant and nocive levels.

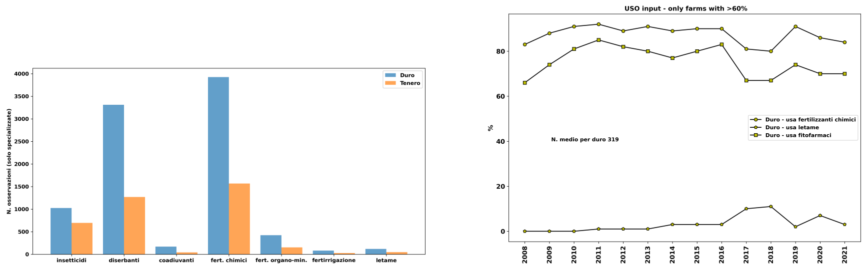
4 Identification of farm types

To account for the heterogeneity of Italian wheat farms, we conducted a clustering analysis using data from the Farm Accountancy Data Network (FADN). The Italian FADN (RICA) dataset includes information on 8,218 farms and 15 years of observations. The objective of this step is to identify homogeneous groups of farms characterized by similar production practices and environmental impacts, which will then be used to evaluate the environmental and economic effects of alternative policy scenarios. To this end, we adopted three different approaches, described in the following subsections.

4.1 Hierarchical clustering analysis of farm types

The first clustering procedure relies on farm-level variables related to input use and environmental pressures. An initial overview of the input use adopted by Italian farms specialized in durum and soft wheat cropping is presented in Figure 11. It clearly shows that the main inputs used in production are nitrogen, herbicides, and insecticides.

For the clustering analysis, the following variables are considered: fertilizer and pesticide use, water consumption, and energy consumption. These indicators capture the main dimensions of production intensity and environmental impact in cereal farming.



(a) (b)

Figure 11: Main dimensions of input use in cereal farming: (a) soft and durum, (b) only durum wheat.

Firstly, the variables were normalized to remove scale effects and ensure comparability across farms. A hierarchical clustering algorithm was then applied using a distance metric based on the multidimensional similarity between farms. The hierarchical approach allows the progressive aggregation of farms into clusters according to their similarity, producing a dendrogram that highlights the structure of the farm population.

The clustering results are presented in Figure 12 and 13. They suggest the presence of three main farm typologies that differ significantly in their use of agricultural inputs and production strategies:

- **Intensive farms**: characterized by a relatively high use of fertilizers, pesticides, and energy inputs. These farms typically aim at maximizing productivity but are associated with higher environmental pressures (G1 and G2).
- **Sustainable farms**: characterized by moderate input use and more balanced production practices. These farms represent an intermediate production system combining relatively good productivity with lower environmental impacts (G3).

- **Organic farms**: characterized by minimal use of chemical inputs and production practices consistent with organic agriculture standards. These farms generally exhibit lower environmental pressures but may also present lower yields compared to intensive systems (G4).

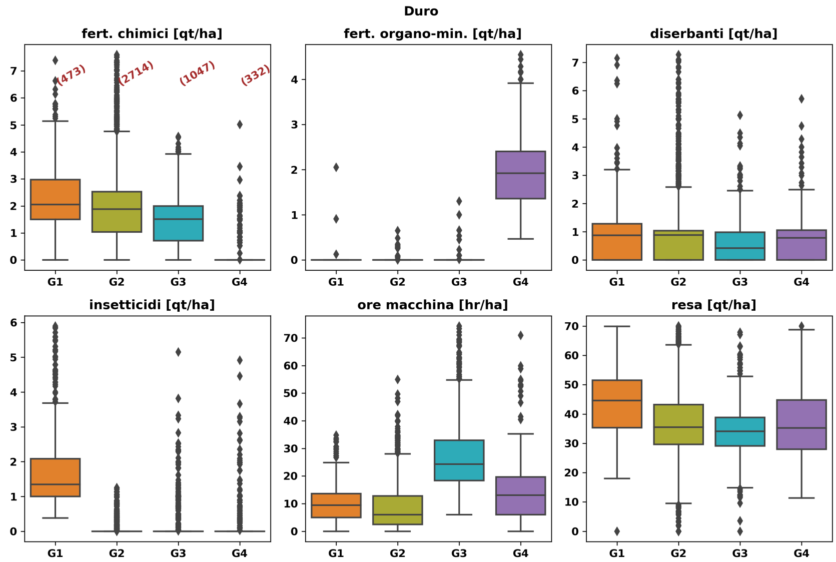


Figure 12: Hierarchical clustering of input use in cereal farming.

4.2 Reduced K-means cluster analysis of durum wheat in 2016

We also focused on the farm practices in 2016 using a different clustering method: the reduced k-means. In particular, the analysis considers variables describing fertilizer application (nitrogen, phosphorus, and potassium per hectare) as well as machinery use measured in hours per hectare as key dimensions of the production technology adopted by farms.

Before clustering, the variables were normalized to remove scale differences and ensure comparability across farms. The clustering algorithm was then applied to the standardized dataset to identify groups of farms characterized by similar combinations of input use.

The clustering solution identifies three distinct farm groups. The distribution of farms across clusters is highly asymmetric: cluster 1 includes 1461 farms (79.45% of the sample), cluster 2 includes 241 farms (13.10%), and cluster 3 includes 137 farms (7.45%).

To assess whether the clusters capture meaningful differences in production practices, an analysis of variance (ANOVA) was performed for several agronomic indicators. The results show statistically significant differences across clusters for all the considered variables, confirming that the clustering procedure successfully separates farms with different input intensities (see Figure 15).

For nitrogen fertilization, the overall mean application is 74 kg per hectare, while cluster averages are 64 kg/ha in Cluster 1, 135 kg/ha in Cluster 2, and 75 kg/ha in

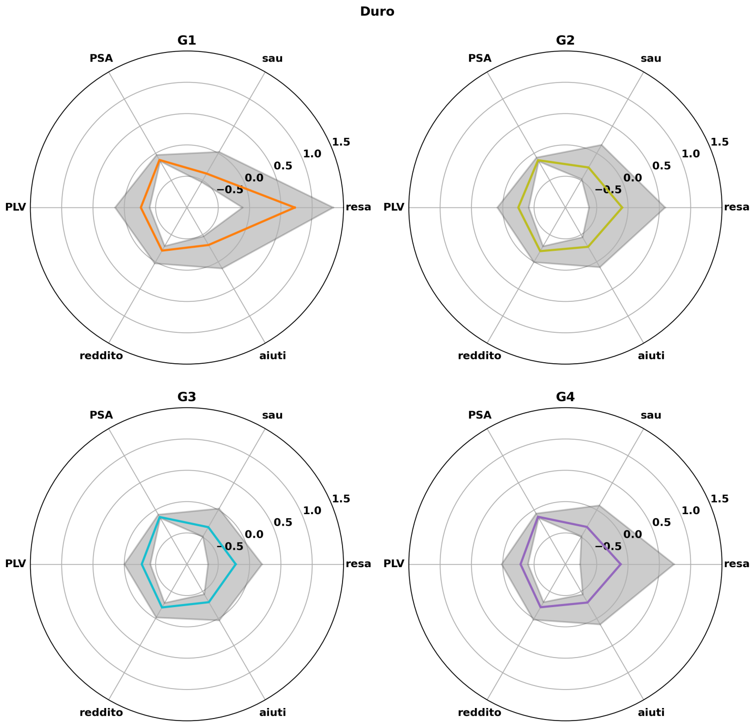


Figure 13: Profile of input use clusters in cereal farming.

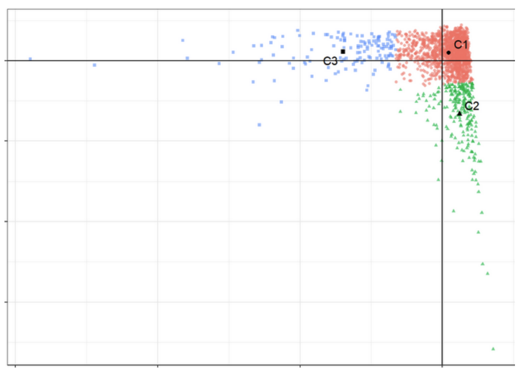


Figure 14: Reduced k-means clustering in wheat farming (2016).

Cluster 3. The differences across clusters are highly significant ($p < 2 \times 10^{-16}$).

A similar pattern emerges for phosphorus use. The overall mean is approximately 25.6 kg per hectare, with cluster means equal to 22 kg/ha for Cluster 1, 49 kg/ha for Cluster 2, and 20 kg/ha for Cluster 3. The differences across clusters are again statistically significant.

Potassium application also varies across clusters, with mean values of 9.45 kg/ha, 23.5 kg/ha, and 8.3 kg/ha for c Clusters 1, 2, and 3, respectively, compared to an overall mean of 11.2 kg/ha.

Finally, machinery use provides a further dimension of differentiation between farm types. The average machinery use is 19.4 hours per hectare, while cluster averages are 14.6 hours/ha in Cluster 1, 53.5 hours/ha in Cluster 2, and 10.6 hours/ha in Cluster 3. These differences are statistically significant and highlight substantial heterogeneity in production technology across farms.

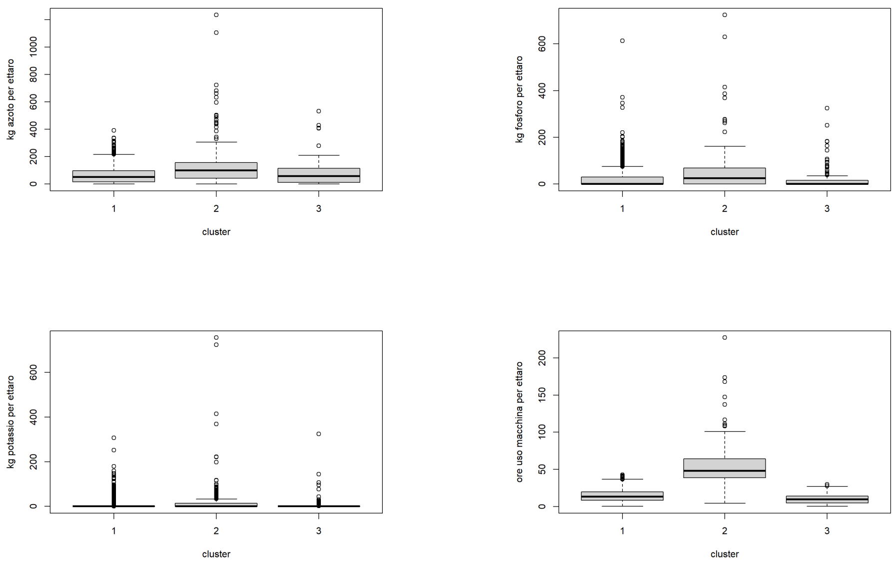


Figure 15: Reduced k-means clustering of input uses in 2016.

Taken together, these results suggest the presence of three distinct production systems. Cluster 2 represents a group of highly intensive farms characterized by very high levels of fertilization and mechanization. Cluster 1 corresponds to farms with intermediate levels of input use and represents the dominant production structure in the dataset. Cluster 3 appears to represent lower-input systems, characterized by relatively limited fertilizer and machinery use.

4.3 Multidimensional k-means cluster analysis of durum wheat in 2016

A third clustering method was applied to compare the identification of representative farm types obtained through the reduced k-means method in Section 4.2. For the purpose of the clustering analysis, the illustrative application focuses on the year 2016 and considers the subset of 1,915 farms producing durum wheat.

A structured data pipeline was implemented to ensure the quality of the clustering results. The first step consisted of anomaly detection aimed at removing extreme observations that could distort distance-based clustering algorithms. Outliers were identified using the Isolation Forest algorithm, which is well-suited for multivariate datasets. This procedure reduced the sample from 1,915 to 1,748 farms, corresponding to a reduction of approximately 8.7% of observations.

Feature engineering was then applied to construct relevant indicators describing production intensity. Different from the k-reduced method applied in Section 4.2, the clustering inputs were defined as ratios with respect to crop yield in order to normalize input use by production performance. Furthermore, the three main nutrients were grouped into a unique variable. Thus, the variables used in the clustering include: herbicide use intensity relative to yield, total nutrient inputs per hectare (nitrogen, phosphorus, potassium), and operational efficiency measured by machine hours per hectare.

Moreover, to ensure comparability across variables with different scales, all inputs were standardized using a standard scaling transformation:

$$x_i' = \frac{x_i - \mu}{\sigma}$$

This normalization improves the performance of distance-based clustering algorithms.

The clustering stage was implemented using the K-means algorithm. The optimal number of clusters was determined using the elbow method, which evaluates the reduction in within-cluster inertia as the number of clusters increases. The elbow criterion identifies the value of K beyond which the marginal improvement in cluster compactness becomes limited.

Based on this procedure, the optimal number of clusters was identified as $K = 8$. The choice was further supported by validation metrics such as inertia stabilization and moderate internal cohesion measured through silhouette statistics.

The resulting clustering solution reveals substantial heterogeneity in production practices across farms. Larger clusters tend to exhibit relatively moderate and homogeneous behaviour in terms of input use relative to yield. For example, clusters with approximately 364 farms (around 20.8% of the sample) show similar and balanced production practices.

In contrast, smaller clusters capture more extreme production profiles. Some clusters contain only about 66 farms (3.8% of the sample) and exhibit markedly different ratios of herbicide use, nutrient inputs, or machine hours relative to output.

The multidimensional clustering structure can be interpreted through one-dimensional projections of key variables. For instance:

- Herbicide intensity relative to yield shows moderate behaviour in larger clusters, while smaller clusters exhibit higher dispersion.
- Nutrient inputs relative to yield reveal that large clusters display comparable and relatively efficient input-output relationships.
- Machine hours per hectare relative to yield indicate that the largest cluster (approximately 414 farms, 23.7%) combines relatively intensive mechanization with higher productivity.

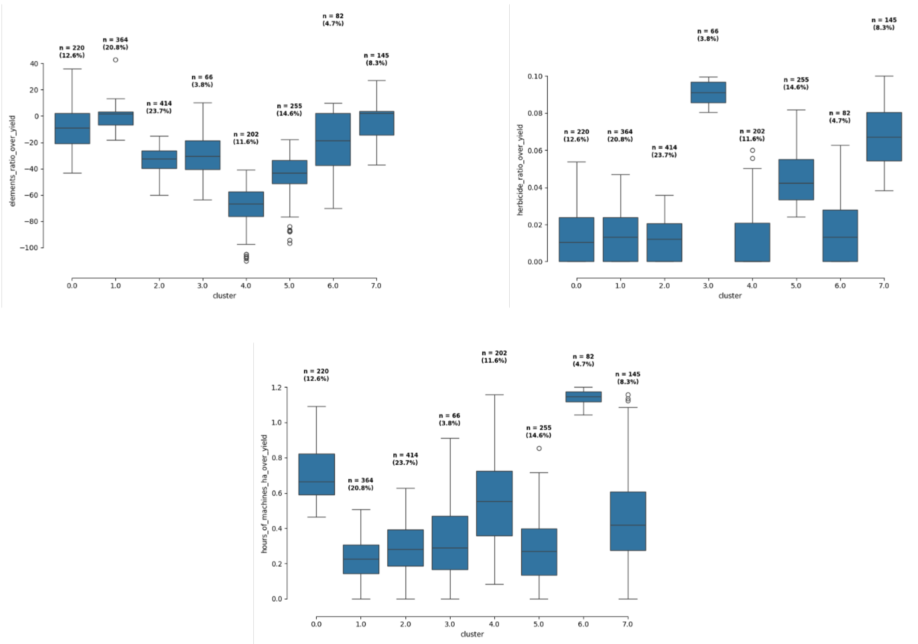


Figure 16: Multidimensional k-means clustering of input uses in 2016 (”Elementi totali” corresponds to grouped values of nitrogen, phosphorus, and potassium per hectare).

5 Green Policies

5.1 The Common Agricultural Policy (CAP) 2023-27 of the European Union

On the 1st January 2023, the Common Agricultural Policy (CAP) 2023-27 entered into force in the EU. The CAP focuses on 10 specific objectives, aligned with common EU goals for social, environmental, and economic sustainability in agriculture and rural areas (Fig. 17).

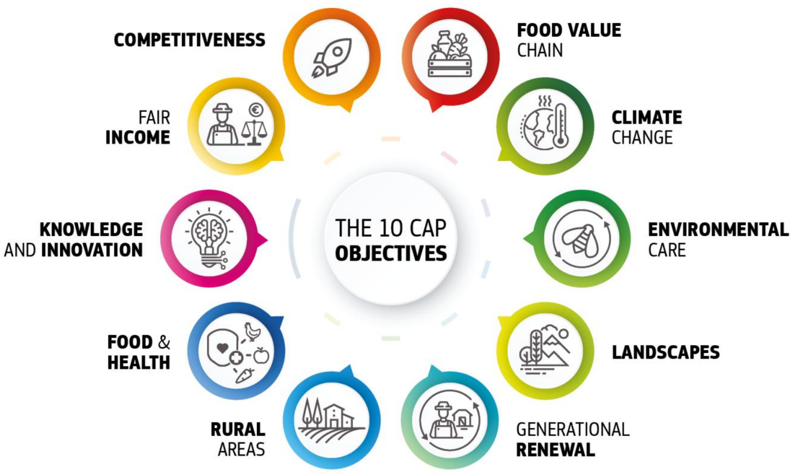


Figure 17: The 10 CAP objectives.

The CAP has three main aims: a) improving green practices, b) improving fairness, and c) improving competitiveness.

5.1.1 The Green Architecture of the CAP 2023–2027

Particularly important for the project is the CAP Green Architecture; the details can be retrieved from this publication. The Green Architecture gathers the instruments through which the CAP goals tied to the environment and sustainability, namely climate change, environmental care, and landscapes (see Figure 17), can be achieved.

The Green Architecture constitutes the environmental and climate-related framework of the Common Agricultural Policy (CAP) 2023–2027. Rather than constituting a separate policy, it integrates environmental objectives directly into the overall CAP structure, aligning agricultural support with the European Green Deal.

The Green Architecture is organized as a multi-layered system composed of three complementary instruments.

First, *conditionality* establishes a mandatory baseline for all beneficiaries of CAP payments. Farmers must comply with statutory management requirements and the

Good Agricultural and Environmental Conditions (GAEC), which cover soil protection, crop rotation, biodiversity conservation, and water management. Conditionality represents the minimum environmental standard required to access direct payments.

Second, *Eco-schemes*, financed under Pillar I of the CAP, provide annual voluntary payments to farmers adopting environmentally beneficial practices. These include crop diversification, reduced use of chemical inputs, soil cover, and extensive grazing systems. At least 25% of the direct payments budget is allocated to Eco-schemes, strengthening the environmental orientation of income support.

Third, *agri-environment-climate commitments* under Pillar II (rural development) support multiannual environmental engagements that exceed baseline requirements. These include interventions such as organic farming, pesticide reduction, and sustainable nutrient management.

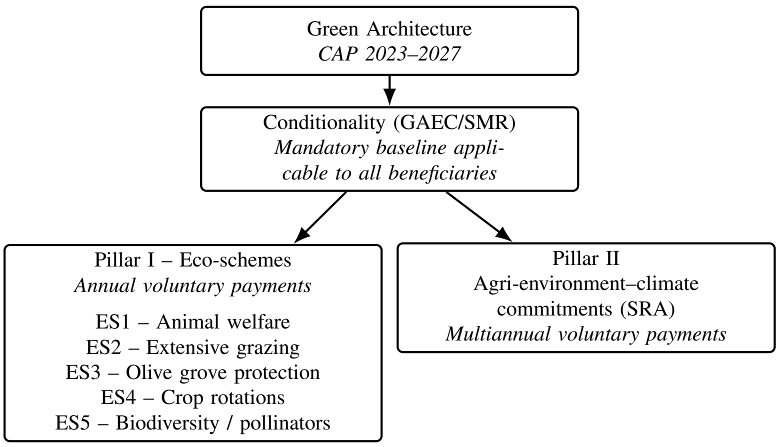


Figure 18: Green Architecture of the CAP 2023–2027.

Together, these three components form an integrated policy structure that combines mandatory standards with voluntary incentive mechanisms. The Green Architecture, therefore, operationalizes environmental objectives within the CAP, influencing farmers' production decisions through regulatory constraints and economic incentives.

5.1.2 From CAP to national strategic plans

Each EU member country develops a National Strategic Plan that takes into account national needs and capabilities and fully integrates with CAP. An overview of this approach can be found here.

National strategic plans must mirror the CAP objectives. They also have to implement green architecture to achieve climate and environmental objectives.

5.2 The Italian National Strategic Plan

The Italian National Strategic Plan (PSP[2].) The 2023-2027 was approved by the European Commission on the 2nd December 2022 (links to the approved version can be found here and here, or directly from the pdf).

[2]PSP is the acronym of *Piano Strategico PAC*, the Italian for PAC Strategic Plan, where PAC in turn is the acronym of *Politica Agricola Comune*, the Italian for Common Agricultural Policy

The Italian strategic plan for the agricultural system identifies 10 specific objectives derived from three general and one horizontal objectives (Fig. 19).

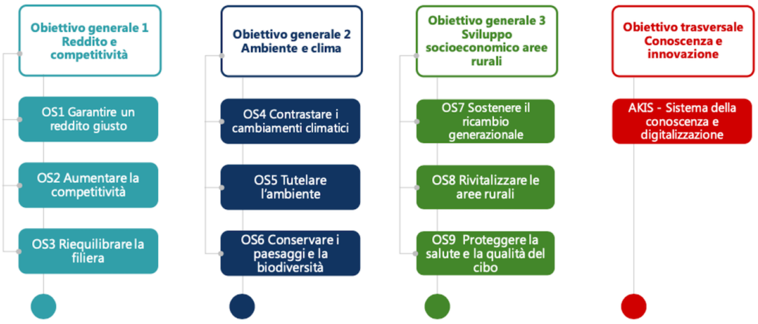


Figure 19: The 10 objectives of the Italian National Strategic Plan.

In addition, the links between the UN Sustainable Development Goals, the Italian general strategy, and the ten specific objectives are reported in Figure 20).

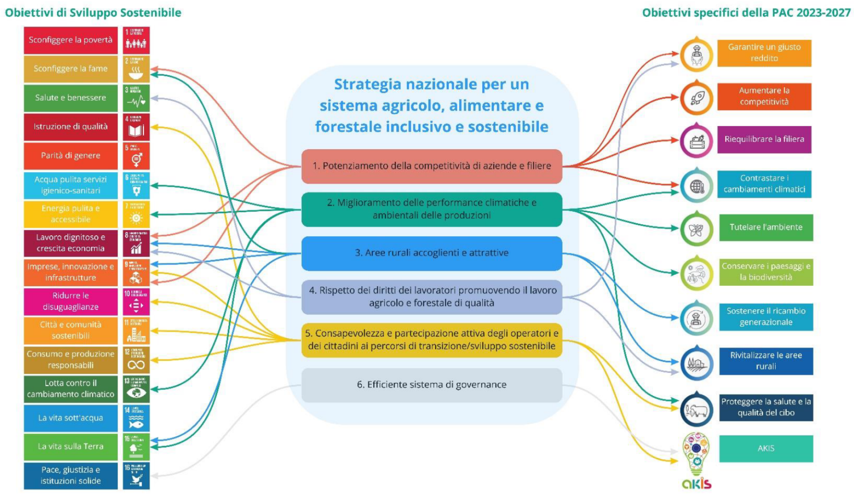


Figure 20: The objectives of the Italian National Strategic Plan under the UN Sustainable Development Goals. Credit to https://www.reterurale.it/ pag. 21).

The specific objectives of the Italian strategic plan (PSP) are described in the policy briefs available at `www.reterurale.it/PAC_2023_27/PolicyBrief`. To explore the PSP, visit also the PSPexplorer, furthermore good overviews are available at this website and in this document.

Finally, a visual representation of the measures included in the Italian strategic plan, PSP 2023-27, is shown in Figure 21.

Particularly relevant for the ECOWHEATALY project are the measures:

1. Direct Payment → coupled payment → crops → durum wheat

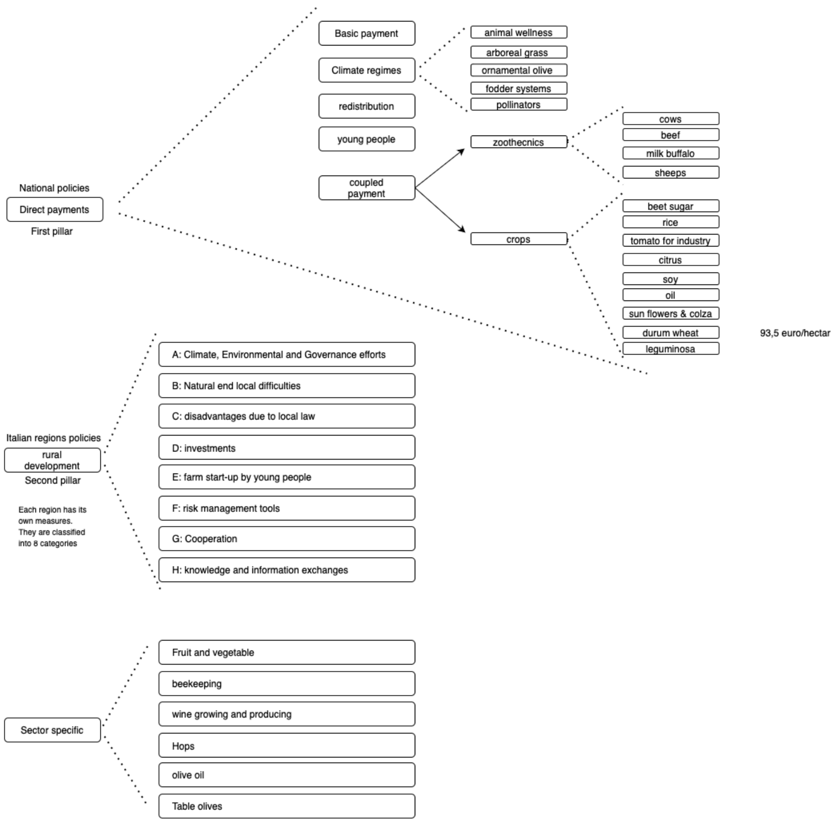


Figure 21: Measures included in the Italian strategic plan PSP 2023-27.

2. Direct Payment → Climate regimes (implementing pillar 1 of Green Architecture: Eco-schemes, especially 4 and 5)

3. Rural development → Climate, environmental and governance efforts (implementing pillar 2 of Green Architecture).

Of course, enhanced conditionality is compulsory to obtain basic direct payments and those related to rural development.

5.3 Eco-schemes

At the heart of the new approach to enhancing environmental sustainability are eco-schemes, instruments that reward farmers who adopt environmentally beneficial practices. Eco-schemes consist of annual payments granted to farmers who voluntarily implement sustainable practices. Each EU member state has designed its own system in accordance with its national priorities. In Italy, the challenge is to balance productivity with environmental protection in a landscape dominated by cereal crops. The Italian PSP includes five main eco-schemes, at least three of which directly affect wheat:

Eco-scheme 1: maintenance of permanent grasslands in vulnerable areas;

Eco-scheme 2: grass cover in orchards and vineyards;

Eco-scheme 3: integrated and organic farming practices;

Eco-scheme 4: conservation tillage and minimal soil disturbance;

Eco-scheme 5: biodiversity enhancement through flower strips and crop rotations.

Cereal farms can benefit by adopting longer rotations, winter cover crops, or reduced tillage. According to CREA (2024), around 40% of durum wheat in southern Italy and 25% of soft wheat in the north are potentially eligible for eco-schemes 3, 4, and 5. Such practices improve:

- soil health by reducing erosion and increasing organic matter;
- water efficiency, thanks to better retention capacity;
- climate resilience, by mitigating yield losses during drought;
- biodiversity, encouraging pollinators and beneficial insects.

Participation in eco-schemes brings environmental benefits and financial incentives to farmers. Payments range from €60 to €120 per hectare, depending on region and practice. However, studies by ISMEA (2024) and CREA (2025) show that transition costs — new machinery, seeds, and monitoring systems — can offset early gains. Larger farms with technical support or digital tools can treat eco-schemes as medium-term investments. Smaller producers, however, still face obstacles posed by bureaucracy and fragmented regulations.

The main issues observed in Italy during the 2023–2024 PAC campaign include:

1. regional disparities in implementation and control;
2. payment delays;
3. uncertainty about compatibility with other subsidies (organic, rural development, supply chains);
4. difficulty in measuring environmental outcomes.

The key challenge is impact verification. Without measurable indicators, eco-schemes risk becoming more administrative than transformative. In 2025, the European Commission launched a mid-term review of the CAP, proposing to: 1) integrate carbon and biodiversity credits into CAP payments; 2) simplify procedures through data sharing and blockchain tools; 3) create adaptive climate eco-schemes linked to measurable results (e.g., organic matter increase, input reduction).

6 Economic Assessment of Selected CAP 2023–2027 Measures: A Cost–Benefit and Risk Framework

In this section, we develop a formal Cost-Benefit framework to evaluate three policy instruments included in the Italian PSP under the Common Agricultural Policy (CAP) 2023–2027:

1. Eco-scheme 4 (crop rotation),
2. Measure SRA20 Sustainable Nutrient Management (contributing to European indicator R.22), and
3. Measure SRA19 Sustainable and Reduced Use of Pesticides (contributing to European indicator R.24 reduction of risk from pesticide use).

The analysis focuses on per-hectare profitability, incorporating input savings, compliance costs, yield effects, and risk-adjusted expected returns.

Let farm profit per hectare without policy participation be:

$$\pi_0 = p_w \cdot y - c(\mathbf{x}) \tag{1}$$

where p_w is the wheat price, y the yield, $\mathbf{x}$ is the vector of input quantities (fuel, fertilizers, pesticides and others), and $c(\mathbf{x})$ is the cost function.[3] Participation in a policy measure modifies both costs and production:

$$\pi_1 = p_w \cdot (y + \Delta y) - c(\mathbf{x} + \Delta \mathbf{x}) + S \tag{2}$$

where Δy is the change in yield (positive or negative), $\Delta \mathbf{x}$ the change in input use, and S the direct payment per hectare. Therefore, the net benefit of participation is: $\Delta\pi = \pi_1 - \pi_0$. By formally rewriting the Cost–Benefit decomposition, we have:

$$\Delta\pi = S + p_w \cdot \Delta y - [c(\mathbf{x} + \Delta \mathbf{x}) - c(\mathbf{x})] \tag{3}$$

Thus, participation is economically justified if:

$$S + p_w \cdot \Delta y \geq \text{Marginal Cost Savings or Increases}$$

However, it is worth to taking into account the expected value under uncertainty because yield effects are uncertain. Let Δy be a random variable, then the expected profit change becomes as follows:

$$\mathbb{E}[\Delta\pi] = S + p_w \cdot \mathbb{E}[\Delta y] - \mathbb{E}[\Delta c] \tag{4}$$

Under Equation 4, the participation by the farmer to the greening measure is optimal if $\mathbb{E}[\Delta\pi] > 0$.

[3] Refer to Deliverable D1 appendix for a detailed description

6.1 Risk-Adjusted Evaluation

In addition, we can consider the farmer's propensity to the risk by including it in the Equation 4 the expected utility. Let farmer utility be $U(\pi)$ with $U' > 0, U'' < 0$. Using a second-order Taylor approximation, the expected utility can be written as follows:

$$\mathbb{E}[U(\pi)] \approx U(\mathbb{E}[\pi]) - \frac{1}{2}U''(\mathbb{E}[\pi]) \cdot \text{Var}(\pi) \tag{5}$$

It is clear from Equation 5 that policies increasing variance (e.g., reduced pesticide intensity) impose a risk penalty. Thus, the risk-adjusted net benefit becomes:

$$\Delta\pi^{RA} = \mathbb{E}[\Delta\pi] - \frac{1}{2}\gamma \cdot \Delta\text{Var}(\pi) \tag{6}$$

where γ is the Arrow-Pratt coefficient of absolute risk aversion.

Finally, the break-even condition for the adoption of a green measure by a farmer is encountered when the minimum payment S^* satisfies the following equation:

$$S^* = \mathbb{E}[\Delta c] - p_w \cdot \mathbb{E}[\Delta y] \tag{7}$$

or, under risk aversion, the following equation:

$$S^*_{RA} = S^* + \frac{1}{2}\gamma \cdot \Delta\text{Var}(\pi) \tag{8}$$

Thus, policies increasing production risk require higher compensation.

6.2 Application to Italian PSP Measures (with an Illustrative Example)

This section provides an illustrative per-hectare calibration for wheat. The goal is to translate the Cost-Benefit expressions into interpretable magnitudes. All values are indicative and should be replaced with farm-specific data (yields, prices, and regional payment rates).

6.2.1 Baseline: wheat gross margin

Let us define the baseline wheat profit per hectare as in the Equation 9:

$$\pi_0 = p_w \cdot y - (c_{\text{fert}} + c_{\text{pest}} + c_{\text{ops}}) \tag{9}$$

where p_w is the price of durum wheat, y the yield, c_{fert}, c_{pest}, and c_{ops} are the fertilizer, pesticide, and other operating costs, respectively.

As an illustrative example, let us assume:

- Price: $p_w = 240$ €/t
- Yield: $y = 6.0$ t/ha
- Fertilizer cost: $c_{\text{fert}} = 230$ €/ha
- Pesticide cost (product + application): $c_{\text{pest}} = 90$ €/ha
- Other variable operating costs: $c_{\text{ops}} = 520$ €/ha

Then, we obtain the baseline of the wheat gross margin to be as follows:

$$\pi_0 = 240 \cdot 6.0 - (230 + 90 + 520) = 1440 - 840 = 600 \text{ €/ha}$$

6.3 Eco-scheme 4: rotation constraint (two-year average)

Eco-scheme 4 under the CAP 2023–2027 introduces a crop rotation requirement aimed at enhancing agronomic sustainability and environmental performance. Its introduction reflects a structural shift in EU agricultural policy from income-based support toward performance-based environmental payments.

Wheat monoculture can emerge as a privately optimal strategy under standard profit-maximization behavior. If the expected gross margin of wheat exceeds that of alternative rotational crops, a rational farmer will allocate land predominantly to wheat. Moreover, specialization may reduce average production costs due to economies of scale in machinery use, storage, marketing channels, and managerial expertise. Wheat markets are typically liquid and well integrated into international trade, reducing marketing uncertainty relative to niche or break crops. In the presence of fixed costs and risk aversion, diversification may imply duplication of fixed inputs and exposure to less predictable price dynamics. As a result, short-run private strategy may favor monoculture even when long-term soil quality deteriorates. This divergence between short-run private profitability and long-run environmental sustainability provides the economic foundation for policy intervention.

Continuous cereal monoculture generates well-documented agronomic drawbacks, including soil nutrient depletion, pathogen accumulation, and increased weed resistance (Bullock, 1992; Smith et al., 2008). Conversely, crop rotation mitigates these effects by:

- Interrupting pest and disease cycles,
- Enhancing soil organic matter,
- Improving nitrogen-use efficiency,
- Increasing biodiversity and ecosystem resilience.

Leguminous crops contribute to biological nitrogen fixation, reducing the need for synthetic nitrogen inputs and lowering nitrate leaching into groundwater (Drinkwater et al., 1998). These environmental benefits align with the EU objective of reducing fertilizer use and greenhouse gas emissions.

Eco-scheme 4 is consistent with the European Green Deal and the Farm to Fork Strategy, which aim to reduce nutrient losses and chemical pesticide use while increasing carbon sequestration in agricultural soils (European Commission, 2019, 2020). Rotational systems contribute to:

- Lower nitrous oxide emissions,
- Improved soil carbon storage,
- Greater resilience to climatic shocks.

Thus, the measure integrates climate mitigation and adaptation objectives within income support mechanisms.

From a microeconomic perspective, monoculture may represent a privately optimal strategy in the short run but generates negative environmental externalities over time. Let soil quality Q_t evolve as:

$$Q_{t+1} = Q_t - \delta M_t + \gamma R_t$$

where:

- M_t = monoculture intensity,
- R_t = rotation effort,
- $\delta > 0$ captures degradation,
- $\gamma > 0$ captures soil regeneration.

Farmers maximize discounted profits:

$$\max \sum_{t=0}^{\infty} \beta^t \pi_t(Q_t)$$

If farmers place a low weight on future soil degradation (low β), soil conservation is underprovided relative to the social optimum. This creates an intertemporal externality (Arrow and Kurz, 1970).

Eco-scheme 4 introduces a per-hectare payment S that increases the private return to rotation, thereby partially internalizing the externality:

$$\pi_t^{policy} = \pi_t + SR_t$$

The policy aims to restore alignment between private and social optima.

Highly specialized cereal systems exhibit higher vulnerability to:

- Disease outbreaks,
- Input price shocks,
- Climate variability.

Crop diversification reduces yield variance and income volatility (Lin, 2011). From a risk-adjusted perspective, rotation can lower the variance of farm income:

$$\Delta Var(\pi) < 0$$

thereby increasing expected utility for risk-averse farmers.

Under CAP 2023–2027, at least 25% of Pillar I payments are allocated to Eco-schemes. Eco-scheme 4 reflects:

- The transition from decoupled income support to environmental conditionality,
- The operationalization of the Green Deal objectives within direct payments,
- The integration of climate policy into agricultural subsidies.

It represents a shift toward results-oriented agricultural policy design.

Eco-scheme 4 was introduced to correct environmental externalities associated with cereal monoculture, enhance soil sustainability, support climate mitigation objectives, and increase systemic resilience. From an economic standpoint, it functions as a Pigouvian-type transfer designed to internalize long-term soil and biodiversity benefits within farm-level decision-making.

6.3.1 Policy Design and Eligibility Conditions

Participation in Eco-scheme 4 requires farmers to implement crop rotation practices on eligible arable land. The specific conditions are defined in the Italian CAP Strategic Plan and may vary slightly across regions, but the core requirements include:

- Adoption of crop rotations involving at least two or more different crops over consecutive years.
- Avoidance of continuous monoculture systems.
- Inclusion of crops that improve soil fertility or contribute to nitrogen fixation, such as legumes.
- Compliance with minimum agronomic standards regarding soil management and crop diversification.

Payments are granted annually on a per-hectare basis. In Italy, the payment level typically ranges from approximately 100 to 120 euros per hectare, depending on the type of cropping system and regional context.

6.3.2 Economic Interpretation

From an economic perspective, Eco-scheme 4 is an incentive mechanism that compensates farmers for adopting crop rotations that may yield lower short-term profitability than monoculture systems.

Let the farmer's baseline profit function be defined as:

$$\pi = pY(N, H, I) - c_N N - c_H H - c_I I,$$

where $Y(\cdot)$ denotes the production function and N, H, and I represent nitrogen, herbicide, and insecticide inputs respectively.

Participation in Eco-scheme 4 introduces a payment P_{ES4} conditional on the adoption of crop rotation practices:

$$\pi = pY(N, H, I) - C(N, H, I) + P_{ES4}.$$

However, crop rotation requirements may also influence production decisions through agronomic mechanisms.

First, rotations can modify the productivity of inputs by improving soil fertility and nutrient cycling:

$$Y = Y(N, H, I \mid R),$$

where R represents the rotational system.

Second, rotations can reduce pest and weed pressure, potentially lowering the optimal use of chemical inputs:

$$H^*(R) < H^*(\text{monoculture}), \qquad I^*(R) < I^*(\text{monoculture}).$$

Finally, the inclusion of nitrogen-fixing crops in the rotation may reduce the optimal nitrogen application required in subsequent cereal crops.

6.3.3 Implications for Production Decisions

Eco-scheme 4 affects farmers' decisions primarily through changes in cropping systems rather than through direct restrictions on input use. By incentivizing crop rotations, the policy indirectly influences the optimal levels of nitrogen fertilizers and plant protection products.

In cereal-based systems, such as wheat production, crop rotations that incorporate legumes or other break crops can increase soil nitrogen availability and reduce pest and weed incidence. As a result, farmers may require lower applications of both fertilizers and pesticides.

From a microeconomic perspective, the policy therefore alters both the production technology and the set of feasible cropping strategies available to the farmer.

6.3.4 Payment Structure and Participation Conditions

Eco-schemes are annual voluntary commitments under Pillar I of the CAP. Farmers may decide each year whether to participate in the scheme, provided that they comply with the eligibility conditions and declare the relevant areas in their annual CAP application.

Payments are granted on a per-hectare basis for eligible arable land and remain conditional on compliance with the scheme's agronomic requirements for the relevant production year.

Unlike agri-environment–climate commitments under Pillar II, eco-schemes do not require multiannual contracts. However, farmers must still comply with the specified conditions during each year in which they claim the payment.

6.3.5 Eligible Crops and Scope of Application

Eco-scheme 4 primarily targets arable cropping systems. The measure applies to a broad range of crops typically cultivated in rotation.

Cereal systems. Cereal crops such as durum wheat, soft wheat, barley, and maize represent the main production systems affected by the measure. In these systems, crop rotations play a central role in maintaining soil fertility and controlling pests and diseases.

Break crops and legumes. Leguminous crops, oilseeds, and other break crops are frequently included in rotation systems promoted under the scheme. These crops contribute to improved nitrogen cycling and soil structure.

Mixed cropping systems. The scheme may also apply to mixed cropping systems where farmers combine different arable crops across consecutive years.

Although Eco-scheme 4 does not impose direct restrictions on input use, the adoption of crop rotations typically reduces chemical input requirements and improves nutrient efficiency. For this reason, the measure plays a complementary role within the CAP Green Architecture, interacting with other interventions such as SRA19 and SRA20 that directly target pesticide and nutrient use.

6.3.6 An illustrative example

Eco-scheme 4 requires a rotational crop on the same parcel within a two-year window. Thus, the risk might arise from variability in the profitability of rotational crops. Let us define the profit variation as in the Equation 10:

$$\Delta\pi = S_{Eco4} + \frac{\underbrace{GM_{wheat} - GM_{wheat}}_{\text{year 1}} + \underbrace{GM_{rotation} - GM_{wheat}}_{\text{year 2}}}{2} = \\ = S_{Eco4} + \frac{GM_{rotation} - GM_{wheat}}{2} \quad (10)$$

where S_{Eco4} is the direct payment for Eco-scheme 4 measure adoption, $GM_{rotation}$ is the gross margin obtainable from the coupled crop, and GM_{wheat} is the wheat gross margin.

In our illustrative example, we assume that:

- Direct payment: $S_{\text{Eco4}} = 58$ €/ha/year
- Wheat gross margin in wheat year: $GM_{\text{wheat}} = 600$ €/ha (from above)
- Rotational crop gross margin (legume/break crop year): $GM_{\text{rot}} = 520$ €/ha

and the average profit change results in:

$$\Delta\pi_{\text{Eco4}} = S_{\text{Eco4}} + \frac{GM_{\text{rot}} - GM_{\text{wheat}}}{2} = 58 + \frac{520 - 600}{2} = 58 - 40 = 18 \text{ €/ha/year}$$

Since the parcel alternates in a two-year cycle, the break-even point requires:

$$0 = S_{\text{Eco4}} + \frac{GM_{\text{rot}} - GM_{\text{wheat}}}{2} \Rightarrow GM^*_{\text{rot}} = GM_{\text{wheat}} - 2S_{\text{Eco4}}$$

With $GM_{\text{wheat}} = 600$ and $S_{\text{Eco4}} = 58$:

$$GM^*_{\text{rot}} = 600 - 116 = 484 \text{ €/ha}$$

In our illustrative example, Eco-scheme 4 remains profitable if the gross margin of the rotational crop is at least about 484 €/ha (or if rotation benefits raise the effective two-year average to that level).

The interpretation is that Eco-scheme 4 remains profitable in this calibration, but the net gain is small if the rotational crop has a markedly lower gross margin than wheat. If rotational agronomy improves wheat performance (e.g., lower N needs, lower disease pressure), GM_{rot} should be interpreted as *including* that benefit, raising $\Delta\pi_{\text{Eco4}}$. This possibility is particularly applicable in the case of Ecowheataly, where the effect of green measure adoption is assessed using LCA.

As reported in the manual (Ministero dell'agricoltura, 2025), in 2025, the allocation of public funds under the Eco-scheme 4 measure for arable crops at the regional level is shown in the table in Figure 22.

6.4 SRA19: Reduction of Pesticide Use under the Italian CAP Strategic Plan

The intervention SRA19 ("Reduction of pesticide use") is part of the agri-environment–climate commitments implemented under Pillar II of the Italian CAP Strategic Plan (2023–2027). It aims to reduce the environmental and health risks associated with plant protection products by incentivizing farmers to decrease pesticide intensity and adopt reinforced integrated pest management (IPM) practices.

TABELLA 11: DISTRIBUZIONE DELLE SUPERFICI PAGATE AF 2025

Regione e P.A.	Output realizzato AF 2925 al 31/08/2025 (ha)	AF 2025 Output realizzato rispetto al totale (%)	Superfici a seminativi - Censimento 2020 (ha)	Ripartizione superfici a seminativi Anno 2020 (%)	Eco 4 su totale superfici a seminativo Censimento 2020 (%)
Abruzzo	55.511,8	2,1%	174.222,0	2,4%	31,9%
Basilicata	146.463,0	5,6%	275.949,0	3,8%	53,1%
Bolzano	2,0	0,0%	16.927,0	0,2%	0,0%
Calabria	65.288,5	2,5%	166.052,0	2,3%	39,3%
Campania	100.646,5	3,9%	263.030,0	3,7%	38,3%
Emilia-Romagna	408.232,9	15,6%	863.473,0	12,0%	47,3%
Friuli-Venezia Giulia	16.579,9	0,6%	158.130,0	2,2%	10,5%
Lazio	157.611,0	6,0%	373.256,0	5,2%	42,2%
Liguria	154,9	0,0%	11.898,0	0,2%	1,3%
Lombardia	17.866,1	0,7%	759.385,0	10,5%	2,4%
Marche	209.876,8	8,0%	367.921,0	5,1%	57,0%
Molise	64.069,2	2,5%	132.873,0	1,8%	48,2%
Piemonte	89.554,6	3,4%	574.904,0	8,0%	15,6%
Puglia	193.429,3	7,4%	668.153,0	9,3%	28,9%
Sardegna	263.304,2	10,1%	479.692,0	6,7%	54,9%
Sicilia	309.433,1	11,9%	687.615,0	9,6%	45,0%
Toscana	291.088,6	11,2%	440.829,0	6,1%	66,0%
Trento	103,0	0,0%	8.511,0	0,1%	1,2%
Umbria	134.116,7	5,1%	200.601,0	2,8%	66,9%
Valle d'Aosta	1,0	0,0%	2.124,0	0,0%	0,0%
Veneto	86.555,4	3,3%	573.869,0	8,0%	15,1%
Totale	2.609.888,4	100%	7.199.414,0	100,0%	36,3%
Spesa programmata AF 2025 (€)	162.662.927,0				
Spesa erogata AF 2025 (€)	166.793.057,7				
Spesa erogata AF 2024 (€)	194.308.720,2				

Figure 22: Contribution allocated to farmers in terms of hectares admitted to Eco-scheme 4 measure (data by AGEA Coordinamento).

6.4.1 Policy Design and Eligibility Conditions

SRA19 is a voluntary, multiannual commitment typically lasting five years. Participating farmers must maintain the declared eligible area for the entire duration of the contract. The intervention requires a measurable reduction in pesticide use relative to a baseline, which may be defined at the farm level or in accordance with regional technical standards.

In practice, eligibility conditions generally include:

- A reduction in pesticide use intensity (often in the range of 20–30% compared to baseline levels or regional reference values).
- Adoption of reinforced integrated pest management practices, including monitoring of pest populations, application of treatment thresholds, and prioritization of low-impact active substances.
- Maintenance of updated treatment records (farm logbooks) and compliance with traceability requirements.
- In some cases, restrictions or prohibitions on specific high-risk active substances.

Payments are granted on a per-hectare basis and are intended to compensate farmers for additional management costs, potential yield reductions, and increased production risk. For arable crops, including cereals, support levels typically range from 70 to 120 euros per hectare, depending on the region and crop type.

6.4.2 Economic Interpretation

From an economic perspective, SRA19 represents a contractual agri-environmental scheme that combines conditional payments with production constraints. Unlike unconditional income support, the measure is explicitly linked to a quantifiable environmental outcome: a reduction in pesticide use or in risk indicators.

Let H denote herbicide use and I insecticide use. The farmer's profit function can be written as:

$$\pi = pY(N, H, I) - c_N N - c_H H - c_I I,$$

where $Y(\cdot)$ is the production function and c_j are input prices. Under SRA19, the farmer receives a per-hectare payment P_{SRA19} conditional on compliance with pesticide reduction requirements.

The policy can be represented in three modelling approaches:

Quantity constraint (regulatory interpretation)

$$H \leq \bar{H}, \quad I \leq \bar{I},$$

where $\bar{H}$ and $\bar{I}$ represent reduced application thresholds (e.g., 80% of baseline use).

Conditional payment

$$\pi = pY(N, H, I) - C(N, H, I) + P_{SRA19} \cdot \mathbf{1}\{H \leq \bar{H}, I \leq \bar{I}\},$$

where $\mathbf{1}\{\cdot\}$ is an indicator function capturing compliance.

Implicit compliance cost

$$c_H \to c_H + k_H, \quad c_I \to c_I + k_I,$$

where k_j represents additional management and monitoring costs associated with reinforced IPM.

6.4.3 Implications for Production Decisions

SRA19 affects farmers' optimal input choices by increasing the relative cost of chemical control or by constraining the set of feasible input combinations. In a standard profit-maximization framework, the policy is expected to reduce optimal levels of H and I, potentially affecting yields depending on the elasticity of substitution between chemical inputs and other agronomic practices.

Because SRA19 is a multiannual commitment, it may also influence risk exposure and dynamic adjustment decisions. If yield variability increases under reduced chemical intensity, the scheme implicitly involves a risk-sharing component, partially compensated by the per-hectare payment.

Overall, SRA19 can be interpreted as a targeted environmental contract that internalizes part of the external costs associated with pesticide use through a combination of conditional payments and production constraints.

6.4.4 Payment Structure and Early Withdrawal Conditions

SRA19 is implemented as a multiannual agri-environment–climate contract, typically lasting five years. Payments are granted on an annual per-hectare basis and are conditional upon verified compliance with the prescribed commitments in each reference year. Beneficiaries must annually declare the eligible area and demonstrate adherence to the required pesticide-reduction targets and integrated pest management practices. Therefore, although the commitment is multiannual, financial transfers are disbursed annually and remain contingent on continued compliance.

The payment level is designed to compensate farmers for additional management costs, potential yield reductions, and increased production risk associated with reduced pesticide intensity. As in other Pillar II interventions, the support does not represent unconditional income support but rather a contractual remuneration for the provision of environmental services.

Early withdrawal from a commitment generally incurs financial penalties. In cases of voluntary termination without a justified cause, the beneficiary is typically required to reimburse payments received in prior years, and additional administrative penalties may apply. The contract is therefore binding for the entire commitment period, creating an intertemporal obligation.

Exceptions may apply under duly recognized cases of force majeure (e.g., natural disasters, severe illness, expropriation, or death of the beneficiary), in which case reimbursement obligations may be waived.

From an economic perspective, this structure introduces lock-in effects and intertemporal constraints, as participation entails both annual conditional payments and potential repayment liabilities upon premature exit.

6.4.5 Eligible Crops and Scope of Application

The SRA19 intervention ("Reduction of pesticide use") applies to a broad range of crops under the Italian CAP Strategic Plan (2023–2027). The measure is designed as a cross-cutting agri-environment–climate commitment targeting farming systems where the use of plant protection products is relevant and where measurable reductions in pesticide intensity can be achieved.

In practice, the intervention generally covers three main crop groups.

Arable crops. Seminative crops are among the main categories eligible for the measure. These include cereals such as durum wheat, soft wheat, maize, and barley, as well as oilseeds (e.g., sunflower and rapeseed), protein crops, and grain legumes. Within this group, cereals are particularly relevant for the implementation of SRA19 because herbicides and fungicides are commonly used to control weeds and diseases. As a result, reductions in pesticide intensity can be directly targeted through changes in crop management practices.

Permanent crops. SRA19 is also applicable to permanent crop systems, including vineyards, olive groves, fruit orchards, and citrus plantations. In these production systems, pesticide use can be relatively intensive, and the adoption of reinforced integrated pest management practices may significantly reduce environmental risks.

Specialized and horticultural crops. In some regional implementations, horticultural crops and other specialized high-value crops may also be eligible. However, the specific eligibility rules and payment levels can vary across regions, reflecting differences in production systems and baseline pesticide use.

Although the intervention is not crop-specific, its effectiveness and economic relevance depend on the intensity of pesticide use in the baseline production system. In arable systems characterized by significant use of herbicides and fungicides, such as durum wheat production, SRA19 provides a direct incentive to modify input use and adopt alternative pest management strategies. Consequently, the measure can be interpreted as affecting the optimal use of chemical inputs in the farmer's production decision.

6.4.6 An illustrative example

The average profit change due to the adoption of a measure such as R.22 can be described as in Equation 11:

$$\Delta\pi = S_{R22} + Savings_{fertilizer} - Compliance\ Costs \pm Yield\ Effect \tag{11}$$

where S_{R22} denotes the direct payment for the adoption of the R.22 measure.

Let us build an illustrative example by assuming that:

- Direct payment: $S_{\text{R22}} = 110$ €/ha/year
- Nitrogen reduction: $\Delta N = -30$ kg N/ha
- Nitrogen unit cost: $c_N = 1.4$ €/kg N $\quad\Rightarrow\quad$ fertilizer saving $= 42$ €/ha
- Compliance and advisory costs: $C_{\text{comp}} = 55$ €/ha/year
- Expected yield effect: $\mathbb{E}[\Delta Y] = -0.03$ t/ha (small under-fertilization risk)

Then, we can compute the average profit change:

$$\Delta\pi_{\text{R22}} = S_{\text{R22}} + Savings_{\text{fert}} - C_{\text{comp}} + p \cdot \mathbb{E}[\Delta Y]$$

$$\Delta\pi_{\text{R22}} = 110 + 42 - 55 + 240 \cdot (-0.03) = 97 - 7.2 = 89.8 \text{ €/ha/year}$$

Since the break-even expected yield penalty (in t/ha) solves $\Delta\pi = 0$, we obtain:

$$0 = S_{\text{R22}} + Savings_{\text{fert}} - C_{\text{comp}} + p \cdot \mathbb{E}[\Delta Y] \Rightarrow \mathbb{E}[\Delta Y]^* = -\frac{S_{\text{R22}} + Savings_{\text{fert}} - C_{\text{comp}}}{p}$$

$$\mathbb{E}[\Delta Y]^* = -\frac{110 + 42 - 55}{240} = -\frac{97}{240} \approx -0.404 \text{ t/ha}$$

Thus, R.22 remains profitable unless expected yield losses exceed roughly 0.40 t/ha under these assumptions. In this calibration, R.22 yields a robust positive profit effect, primarily driven by payment effects and moderate input savings.

6.5 SRA20: Sustainable Nutrient Management under the Italian CAP Strategic Plan

The intervention SRA20 ("Sustainable nutrient management") is part of the agri-environment–climate commitments implemented under Pillar II of the Italian CAP Strategic Plan (2023–2027). The measure aims to reduce the environmental impacts associated with excessive nutrient use, particularly nitrogen and phosphorus, by encouraging farmers to adopt more efficient fertilization practices and to implement improved nutrient management plans.

Excessive nutrient applications in agriculture are a major source of environmental externalities, including nitrate pollution of groundwater, eutrophication of surface waters, and greenhouse gas emissions such as nitrous oxide (N_2O). SRA20 addresses these issues by incentivizing farmers to optimize fertilizer application in accordance with crop needs and soil conditions.

6.5.1 Policy Design and Eligibility Conditions

SRA20 is a voluntary multiannual commitment, typically lasting five years. Farmers who participate in the scheme must maintain the declared eligible area under the commitment for the full contractual period and comply with specified nutrient management practices.

Eligibility conditions generally include the following requirements:

- Preparation and implementation of a farm-level nutrient management plan based on soil analysis and crop nutrient requirements.
- Reduction in nitrogen application relative to baseline practices or regional technical standards (often around 15–20% compared to conventional fertilization levels).
- Adoption of precision fertilization techniques or decision support systems that improve nutrient use efficiency.
- Maintenance of detailed fertilization records documenting quantities, timing, and types of fertilizers applied.

Payments are granted on a per-hectare basis and are intended to compensate farmers for the additional management effort, monitoring costs, and potential yield risks associated with reduced fertilizer use. For arable crops, including cereals, support levels generally range from 60 to 100 euros per hectare, depending on the region.

6.5.2 Economic Interpretation

From an economic perspective, SRA20 can be interpreted as an agri-environmental contract that modifies farmers' optimal fertilization decisions by introducing both incentives and constraints on nutrient use.

Let N denote nitrogen input. The farmer's baseline profit function can be written as:

$$\pi = pY(N, H, I) - c_N N - c_H H - c_I I,$$

where $Y(\cdot)$ is the production function and c_j denote input prices.

Under SRA20, the farmer receives a per-hectare payment P_{SRA20} conditional on compliance with sustainable nutrient management requirements.

The policy can be represented in three modelling approaches.

Quantity constraint (fertilizer cap)

$$N \leq \bar{N},$$

where $\bar{N}$ represents a reduced fertilization threshold (for example, 80–85% of baseline nitrogen application).

Conditional payment

$$\pi = pY(N, H, I) - C(N, H, I) + P_{SRA20} \cdot \mathbf{1}\{N \leq \bar{N}\},$$

where $\mathbf{1}\{\cdot\}$ captures compliance with the fertilization constraint.

Implicit management cost

$$c_N \to c_N + k_N,$$

where k_N represents additional management costs associated with nutrient planning, monitoring, and compliance with technical standards.

6.5.3 Implications for Production Decisions

SRA20 directly affects farmers' optimal nitrogen application decisions. By imposing upper bounds on fertilization or increasing the effective cost of nitrogen use, the policy encourages farmers to move closer to agronomically optimal nutrient levels rather than economically excessive applications.

In a standard profit-maximization framework, the policy tends to reduce optimal nitrogen input N, potentially affecting crop yields depending on the marginal productivity of fertilizer and the responsiveness of the production function. However, improvements in nutrient-use efficiency and better application timing may partially offset yield losses.

Moreover, because nitrogen is a key driver of greenhouse gas emissions and water pollution, reductions in N also generate environmental benefits in terms of lower nitrate leaching and reduced N_2O emissions.

6.5.4 Payment Structure and Early Withdrawal Conditions

As with other agri-environment–climate commitments under Pillar II, SRA20 is implemented through a multiannual contract, typically lasting five years. Payments are disbursed annually on a per-hectare basis and remain conditional on verified compliance with the prescribed commitments in each year.

Beneficiaries must declare eligible areas annually and provide documentation demonstrating the implementation of nutrient management plans and compliance with fertilization limits. The payment level compensates farmers for additional management costs, possible yield adjustments, and increased agronomic risk associated with reduced fertilizer use.

Early withdrawal from the commitment generally entails financial consequences. In cases of voluntary termination without justified cause, farmers are typically required to reimburse payments received in previous years, and additional administrative sanctions may apply. Exceptions may be granted under recognized cases of force majeure.

From an economic perspective, the multiannual structure introduces an intertemporal commitment similar to that of other agri-environmental schemes, creating a lock-in effect that influences farmers' participation decisions.

6.5.5 Eligible Crops and Scope of Application

The SRA20 intervention applies to a wide range of crops within the Italian CAP Strategic Plan (2023–2027). The measure targets farming systems where fertilizer management plays a key role in determining both productivity and environmental impact.

Arable crops. Seminative crops are among the main groups eligible for the intervention. This includes cereals such as durum wheat, soft wheat, maize, and barley, as well as oilseeds and protein crops. In these systems, nitrogen fertilization is a key determinant of yield, making them particularly relevant for implementing sustainable nutrient management practices.

Permanent crops. In some regional implementations, the intervention may also apply to permanent crops such as vineyards, olive groves, and fruit orchards, where nutrient management planning can improve fertilizer efficiency and reduce environmental risks.

Specialized crops. Horticultural and intensive production systems may also be eligible depending on regional implementation rules.

Although the intervention is not crop-specific, its economic relevance is particularly strong in nitrogen-intensive production systems such as cereal cultivation. In these systems, SRA20 directly influences farmers' fertilization strategies and, consequently, the optimal choice of nitrogen input in production decisions.

6.5.6 An illustrative example

The average change in profit from adopting a measure such as R.24 is given by Equation 12, assuming that the variance may increase under stochastic pest pressure.

$$\Delta\pi = S_{R24} + Savings_{pesticides} - Technology\ Costs \pm Yield\ Risk \qquad (12)$$

As an illustrative example, let us assume that:

- Direct payment: $S_{\text{R24}} = 100$ €/ha/year
- Pesticide saving (product + fewer passes): $Savings_{\text{pest}} = 35$ €/ha/year
- Technology/DSS + training costs (annualized): $C_{\text{tech}} = 60$ €/ha/year
- Expected yield effect: $\mathbb{E}[\Delta Y] = -0.02$ t/ha (risk of occasional under-control)

Then:

$$\Delta\pi_{\text{R24}} = S_{\text{R24}} + Savings_{\text{pest}} - C_{\text{tech}} + p \cdot \mathbb{E}[\Delta Y]$$

$$\Delta\pi_{\text{R24}} = 100 + 35 - 60 + 240 \cdot (-0.02) = 75 - 4.8 = 70.2 \text{ €/ha/year}$$

The break-even point for assessing the advantage of measure adoption can be computed as follows:

$$\mathbb{E}[\Delta Y]^* = -\frac{S_{\text{R24}} + Savings_{\text{pest}} - C_{\text{tech}}}{p} = -\frac{100 + 35 - 60}{240} = -\frac{75}{240} \approx -0.313 \text{ t/ha}$$

7 Green Policies Affecting Wheat Production Outside the CAP

Environmental policies targeting agricultural production are not limited to the European Union. Several major wheat-producing countries have introduced policy instruments to reduce the environmental impact of crop production while maintaining agricultural productivity. These policies often focus on improving nutrient management, reducing pesticide use, and promoting soil carbon sequestration. Although their designs vary across countries, they share the objective of encouraging more sustainable farming practices in input-intensive cropping systems, such as wheat production.

7.1 Canada

Canada has introduced several policy initiatives to reduce greenhouse gas emissions from agriculture while maintaining competitiveness in cereal production. A central element of Canadian policy is the objective of reducing emissions from nitrogen fertilizers, which are a major source of agricultural greenhouse gases through nitrous oxide (N_2O) emissions. The Canadian government has established a national target to reduce emissions from fertilizer use by improving nitrogen-use efficiency (Agriculture and Agri-Food Canada, 2022). Programs such as the *On-Farm Climate Action Fund* support farmers in adopting improved fertilizer management practices, including soil testing, variable-rate application, and optimized fertilizer timing.

7.2 Australia

Australia has implemented one of the most developed policy frameworks for agricultural carbon sequestration through the *Carbon Farming Initiative* and the subsequent *Emissions Reduction Fund*. These programs allow farmers to generate carbon credits by adopting practices that increase soil carbon storage or reduce agricultural emissions (Australian Government, 2015). Farmers implementing eligible practices can generate Australian Carbon Credit Units (ACCUs), which can be sold either to the government or on voluntary carbon markets. In cereal systems, such as wheat production, these policies create an additional revenue stream associated with environmentally beneficial farming practices.

7.3 United States

In the United States, environmental objectives in agriculture are largely pursued through voluntary conservation programs administered by the United States Department of Agriculture (USDA). Programs such as the *Environmental Quality Incentives Program* (EQIP) and the *Conservation Stewardship Program* (CSP) provide financial incentives for farmers adopting environmentally beneficial practices (USDA, 2022). These programs support practices relevant to wheat production, including improved nutrient management, reduced tillage, and integrated pest management.

7.4 China

China has also implemented policies to reduce the environmental impacts of agricultural intensification. One notable initiative is the national strategy to achieve "zero growth" in fertilizer use, which promotes more efficient nutrient management through improved agronomic practices and technological innovation (Zhang et al., 2015). Given the large scale of cereal production in China, including wheat cultivation, these policies aim to improve nutrient efficiency while maintaining food security objectives.

Table 6 summarizes the main policy instruments affecting wheat production in major producing countries.

Country	Policy / Program	Policy Instrument	Target Inputs	Economic Mechanism
European Union	CAP Green Architecture	Payments and conditionality	N, pesticides	Subsidies and compliance rules
Canada	Fertilizer Emission Reduction Target	Nutrient management programs	N	Incentives for nitrogen efficiency
Australia	Carbon Farming Initiative / ERF	Carbon credits	Soil carbon, N	Carbon market payments
United States	EQIP / CSP Conservation Programs	Cost-sharing payments	N, pesticides	Adoption incentives
China	Fertilizer Reduction Program	Input reduction policy	N	Efficiency targets and extension services

Table 6: Green policy instruments affecting wheat production in major producing countries.

8 Conclusions

This report presented the results of Task 1.1 of the ECOWHEATALY project, whose objective is to build a detailed empirical representation of the Italian wheat production system and to provide the data and methodological basis for the subsequent simulation of environmental agricultural policies.

The analysis relied primarily on farm-level information from the RICA/FADN database, which offers detailed microeconomic data on Italian agricultural holdings, including production levels, input use, revenues and production costs. These data were combined with additional information required for environmental assessment and life-cycle analysis. In order to integrate these heterogeneous sources, a dedicated database structure was developed within the project. The resulting ECOWHEATALY database organizes farm-level information in a structured JSON format, allowing flexible access to the data and facilitating its integration with simulation models and environmental assessment tools.

A key contribution of this task is the identification of representative farm types within the Italian wheat sector. Using information on production practices and input intensity, a clustering procedure was applied to group farms into a limited number of representative categories. The resulting farm types capture the main sources of heterogeneity in wheat production systems, particularly in terms of input use, production intensity and potential environmental pressure. This typology provides a simplified but realistic representation of the sector, which will serve as a basis for the simulation exercises developed in the following stages of the project.

The report also reviewed the main environmental policy instruments currently affecting wheat production under the Common Agricultural Policy (CAP), including Eco-scheme 4 and agri-environmental measures such as SRA19 and SRA20. These policies aim to promote more sustainable agricultural practices through incentives for crop diversification, reductions in pesticide use and lower input intensity. A preliminary economic framework was introduced to illustrate how these policy instruments may affect farmers' production choices through their impact on revenues, costs and subsidy payments.

Overall, the results of Task 1.1 provide the empirical and analytical foundations required for the next phases of the ECOWHEATALY project. The database construction, the identification of representative farm types and the characterization of the policy environment together create the necessary conditions for developing simulation models capable of analysing the economic and environmental impacts of green agricultural policies on the Italian wheat sector.

Future tasks of the project will build on this framework by integrating the farm typology into simulation models and life-cycle assessment tools in order to evaluate the effects of alternative policy scenarios. In this way, the ECOWHEATALY project aims to contribute to a better understanding of how agricultural policy can reconcile economic viability of farms with environmental sustainability in the wheat production system.

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