BAE
Bio-based and Applied Economics

AIEAA
ASSOCIAZIONE ITALIANA DI
ECONOMIA AGRARIA E APPLICATA

Citation: Baldi, L., Calzolai, S., Arfini, F., & Donati, M. (2024). Predicting the effect of the Common Agricultural Policy post-2020 using an agent-based model based on PMP methodology. *Bio-based and Applied Economics* 13(4): 333-351. doi: 10.36253/bae-14592

Received: April 6, 2023
Accepted: March 27, 2024
Published: December 31, 2024

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Editor: Simone Cerroni

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Predicting the effect of the Common Agricultural Policy post-2020 using an agent-based model based on PMP methodology

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Abstract. The objective of this study is to perform an ex-ante assessment of the potential impacts of agro-environmental measures included in the post-2020 Common Agricultural Policy (CAP), by estimating farmers' responsiveness in adopting organic agricultural practices and an eco-scheme that incentivises extensive forage systems. This research is conducted by means of an Agent-Based Model (ABM), based on Positive Mathematical Programming (PMP), implemented in GAMS. The ABM facilitates the simulation of interaction among farmers, allowing for an analysis of farm heterogeneity. The PMP methodology adds a non-rational dimention to the farmers' economic drivers. The model is calibrated using 2019 Farm Accountancy Data Network (FADN) data specific to the Emilia Romagna region in Italy. Our findings reveal significant impacts on land use, with a notable decrease in cereal cultivation in favour of protein and fodder crops. Moreover, structural shifts are observed, notably a decrease in the number of small-scale farms. We also assess environmental and economic implications, observing a modest reduction in CO_2 equivalent emissions per hectare, an increase in water demand, and an overall economic stability among farms, as indicated by changes in gross margin per hectare.

Keyword: CAP Reform, Agent Base Model, Land use, Structural change, CO2 Emission.
JEL Codes: C61, Q15, Q18, Q52.

1. INTRODUCTION

Since its first implementation in the early 1960s, the Common Agricultural Policy (CAP) has greatly impacted European Union agriculture, driving farm behavior through subsidies, direct and indirect payments, production constraints, and trade regulations. The CAP objectives have gradually moved from strengthening agricultural production to providing public goods through different reforms. However, despite the environmental principles embedded in the CAP regulations, as from the Fischler reform in 2003, the intensification of agricultural practices has progressively eroded several criti-

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cal environmental components such as climate, water quality, pollination, biodiversity, physical and psychological well-being, as well as cultural heritage (European Environmental Agency 2019; Nègre, 2022). These developments have had significant repercussions on the provisioning of ecosystem services. The "greening" measures introduced in the 2014-2020 CAP reform proved inadequate to meet social demand for an EU agriculture more aware of its role in enhancing regulatory and cultural services (Cortignani & Dono, 2019; Alons, 2017). The CAP post-2020 reform aimed to redress past failures in meeting EU Green Deal objectives and following targets established by the Farm-to-Fork and Biodiversity strategies. The new green CAP architecture is based on eco-schemes, one of the most important innovations introduced by the CAP post-2020 reform, which obliges Member States to allocate at least 25% of first pillar payments to measures beneficial for the environment and the climate. Strategic Plan regulations limit eco-schemes to active farmers, which can apply voluntarily (European Commission 2020).

During the last decade, several economic models have been developed to help policymakers and stakeholders to evaluate CAP greening mechanisms from an ex-ante perspective. The main results provided by CAPRI, PASMA, and IFM-CAP models suggested that the CAP measures generating environmental benefits are not as effective as expected (Solazzo et al., 2016). A recent ex-post analysis confirmed these results (Bertoni et al., 2021). This empirical evidence supports the idea that economic modelling is a useful decision tool for designing more effective agricultural policies, increasing researcher and policymaker interest in in-depth impact assessment of agricultural policies at the farm scale (Kremmydas et. al 2018).

The aim of this paper is to present an ABM, based on Positive Mathematical Programming, for conducting an ex-ante impact evaluation of the agri-environmental measures incorporated into the post-2020 Common Agricultural Policy (CAP). This evaluation entails a comparative static exercise, whereas we equate the baseline scenario with two simulated scenarios wherein farmers receive the organic payments or the payment for extensive forage systems, if economically viable. The baseline scenario also represents the counterfactual scenario, enabling the evaluation of the impacts of a particular policy (where farmers receive basic coupled and decoupled payments) against alternative policies. The model employed is static in the sense that it evaluates the initial sample at a particular moment in time and compares it to the same sample where farmers have altered their behaviour to maximize their utility function due to different payment conditions. The quadratic functions, commonly used in dynamic models to capture temporal dynamics, are introduced, in this study, with the PMP to represent nonlinear relationships between variables at a specific point in time. Positive Mathematical Programming is widely used in agricultural policy assessment (Howitt, 1995; Britz et al., 2012; Solazzo et al., 2014; Reidsma et al., 2018; Matthews, 2022). A distinctive feature of PMP is its ability to recover important entrepreneurial decision variables, such as hidden costs related to past farming experience, risk attitude, and production expectations, useful for simulating more realistic behaviours, not solely driven by economic rationale. In this research, the PMP model is an agent-based model (ABM) which can capture interactions between farms in the use of scarce resources. ABMs are better suited to fulfilling important disaggregated specifications, to capturing farm heterogeneity at the regional level, and considering interaction between farmers in the use of scarce resources. They bring substantial innovations to mathematical programming models (Reidsma et al. 2018; Berger & Troost 2014).

Integrating positive mathematical programming (PMP) techniques within ABMs provides a rigorous framework for modelling agents' decision-making processes, particularly with respect to optimising their behavior subject to constraints and policy incentives. PMP helps in simulating how agents respond to policy changes based on economic principles represented by explicit and implicit variable cost. Moreover, the integrated methodology of ABMs and PMP enables the assessment of ex-ante agricultural policies by examining their potential effects on farmers' behaviour related to agricultural production choices, land use, structural adjustments, as well as their environmental and economic impacts, supporting policymakers in making informed decisions while considering farms heterogeneity.

That said, Implementing ABMs with PMP requires detailed data on agent characteristics, preferences, decision rules, and interactions, which can be challenging to obtain, especially at fine spatial scales. Limited or inaccurate data may lead to uncertainty and biases in model outcomes. ABMs can become highly complex, particularly when modelling large-scale agricultural systems with numerous interacting agents and processes. Calibrating such models to real-world data and ensuring their validity and reliability can be time-consuming and computationally intensive.

With over one million hectares of UAA (8.6% of national UAA), in 2016 Emilia Romagna accounts for respectively 10.9% (€3,221.91 million) and 15.17% (€2,292.83 million) of Italian crop production and animal value, making this region one of the most productive agricultural areas in Italy. Moreover, for the same reference year, 55% of agricultural land is under high intensity input agricultural practices, 37% under medium intensity and 8% under low intensity input practices.

Agricultural activities have a strong climate-change impact, accounting in Europe for 10% of total Greenhouse Gases emission (Eurostat 2022). Italy is the fifth largest contributor, after France, Germany, Spain and Poland, emitting 8% of total agricultural GHGs.

Not surprisingly, the high level of agricultural productivity and related impacts, as well as the consolidated presence of industrial and logistic infrastructures, heavy urbanization, and the peculiar geographical conformation of the Po Valley, make Emilia Romagna, together with the other three regions of the Valley – Lombardia, Piemonte and Veneto, the most polluted and impacted areas in Italy (Raffaelli et al. 2020).

This study is organised as follows. The materials and methods section presents the characteristics of the farm sample and discusses how PMP is particularly suitable for developing ABM models. The policy scenario section describes the main agricultural policy instruments used in the simulation, and the results are discussed in the last section.

2. METHODOLOGY AND DATA

2.1. Agent-based models and PMP

A key feature of ABMs is their capacity to evaluate the interactions between agents (farms) and to describe the impact on land use and structural change according to the structure, productivity, efficiency, and spatial heterogeneity of the agents in their territory (Reidsma et al., 2018). Agents can represent different individual farms, entrepreneurs, or aggregated entities, such as farm types.

The ability of ABMs to capture the interactions between farmers can be leveraged under the assumption of non-full rationality in production preferences. This can be done because farmers tend to maximize their utility function, rather than their profit function (Nolan et al., 2009; Kremmydas et. al 2018). This is plausible only if agents represent individual farm-households, in which family structure and other individual characteristics are particularly important in determining transaction costs affecting the economic objective to be maximized. Decisions are based on production factor endowment and level of technological knowledge, as well as the perception of economic and technical risks.The literature provides some attempts to measure the effect of CAP provisions through ABM-type models, such as AgriPoliS (Happe et. al 2004), MP-MAS (Schreinemachers and Berger, 2011), and RegMAS (Lobianco & Esposti, 2010), however none of them is associated with the PMP. Linking Agent-Based Models (ABMs) with Mathematical Programming (MP) models offers the advantage of creating micro-level models that can depict technological variations based on the structural characteristics of farms. For more insights into the different types of ABMs, Kremmydas et al. (2018) have conducted a systematic literature review on ABMs for evaluating agricultural policies. The integration between ABM and PMP models enables the optimization of the cost function for each farm within the sample. This optimization takes into consideration the unique characteristics and behaviors of individual farmers, starting from the observed optimal scenario. The cost function is hypothesized to be a quadratic functional form in output quantities: $C(x) = x'Qx/2$, where the Q matrix is symmetric and positive semidefinite. Additionally, this integration allows for the simulation of structural and technological changes, such as changes in farm size or the potential abandonment of farm activities. An ABM based on PMP can estimate these choices by simulating land exchange, the introduction of new activities and changes in agricultural management practices. Aggregating these results can provide a useful and solid insight into the general trend of the agricultural sector at regional, national, and international levels.

PMP is generally used as a straightforward calibration technique as seen in the CAPRI model, where specific technical coefficients are applied. In this study, the PMP methodology employed for calibration is based on farm marginal costs, which consider accounting costs c and the marginal implicit cost λ, intended as "transaction costs", or socio-economic costs (Anderson et al., 1985), perceived by the farmers. These costs are estimated under economic constraints using the dual property of a profit maximisation problem implicit in the model. This results in shadow prices linked to production activities that precisely equate to the combined total of the estimated accounting cost and the estimated differential marginal costs. The estimated accounting cost corresponds to the farm accounting values, whereas the estimated differential marginal costs can be viewed as the opportunity cost linked to each activity. The estimated differential marginal cost, usually referred as hidden cost, represents the portion of the estimated total marginal cost not documented in the farm accounting sheet but taken into account by farmers when formulating production plans (Cesaro and Marongiu, 2013). The hidden costs refer to the specific and individual opportunity costs that each farmer considers when deciding whether to introduce a given crop in the production plan. These hidden costs incorporate the specific and individual opportunity costs that each farmer weighs when determining whether to incorporate a particular crop into the production plan. These costs are important not only for the marginal cost calculation but also for the calibration. It is for this reason that the PMP guarantees that the cost estimates obtained can be used for reproducing the basic production situation, enabling the assessment of each farm's response within the sample to the policy measures implemented.

Although there is no theoretical rationale requiring a specific functional form for farmers' reactions, the quadratic form is employed in this study because it is widely used in Agricultural Economics and inherently represents the cost function. Additionally, the Cholesky decomposition ensures to obtain a symmetric and positive semidefinite matrix.

2.2. The model structure

AGRISP (Agricultural Regional Integrated Simulation Package), the model described in this paper, is a supply ABM, based on the PMP approach, which models farm-holders as agents and analyzes the impact of new CAP measures on agents' behaviours related to land use, gross margin, carbon emission, and water consumption. AGRISP is implemented in GAMS (GAMS 2023) and articulated in a calibration module and a simulation module, depicted in Figure 1.

The exact production level for each farm is estimated with the "self-selection". A detailed explanation of self-selection rules and a comparison between the farm and frontier cost functions can be found in Paris and Arfini (Paris & Arfini, 2000).

Leveraging on the self-selection process, in AGRISP, agents belonging to a specific regional farm sample can exchange production techniques or adopt new agricultural practices, if experimental research makes technical information available.

This is accomplished through the use of a common frontier-cost function, shared at the regional level, estimated using the PMP and which incorporates the costs associated with all crops and cultivation techniques, and the deviation of each individual farm from this function (Arfini and Donati 2012). The common frontier-cost function serves as a link among the farms in the sample. The deviation from the common cost function is regarded as a basis for comparing costs and profitability among the farms included in the sample.

The introduction of a subsidy or a tax, which triggers changes in output prices of variable costs, leads farms to different cost-efficiency crop or techniques combination, as result of the optimization run in the simulation phase. This can be viewed as a form of "social learning process" or, more accurately, as an exchange of technical and economic information made available, because observed, in the sample. The interconnectedness stems from the fact that all farms are aware of the potential techniques available. The latent technologies or crops are those options that agents could potentially adopt but remain "unused" by a farm due to their lack of economic viability within a particular simulated scenario.. Supports coupled to a specific technique or tied to the acreage can alter the economic ratios among various production plans. As a result, farm holders may choose to adopt a new crop or technology from the array of agronomic techniques practiced by the farms in the sample, originally latent in their production plan, and their decision is influenced not only by the accounting cost but also by the utility cost unique to each farm.

Following calibration, the simulation module assesses the repercussions of alternative policy scenarios by leveraging the positive information embedded in the nonlinear cost function and employing a set of hypothetical behavioural rules. These agent-based rules offer a more realistic representation of the interactions among farms, encompassing resource exchange, as well as the choices made by the farmers regarding different agricultural practices, taking into account the specific social and family characteristics. More specifically, as argued by Möhring et al., farm dynamism is correlated with the farm holder's age and successors' presence (Möhring et al. 2016).

The authors of this study make the assumption that once farmholders reach the age of 65, they are more inclined to reduce farm activity rather than expand it. Likewise, it is assumed that farms with holders aged 65 or older, without successors, are unlikely to lease additional hectares or opt for the conversion of farms from conventional to organic practices. Farmers over 65 are more likely to rent out their land, totally or partially. In the model, the complete rental of land is regarded as equivalent to abandoning the farming activity. On the other hand, if the holder is younger than 65 or the possibility of a generational renewal exists, they may consider expanding the farming activity by leasing additional land from neighboring farms or transitioning from conventional to organic practices.. It is important to highlight that all these decisions are contingent upon cost-effectiveness. Therefore, the economic cost function that needs to be optimized incorporates factors such as the cost of land rental and the supplementary expenses associated with converting and sustaining organic crops.

The equations associated with the key characteristics of the model are outlined below, and more details

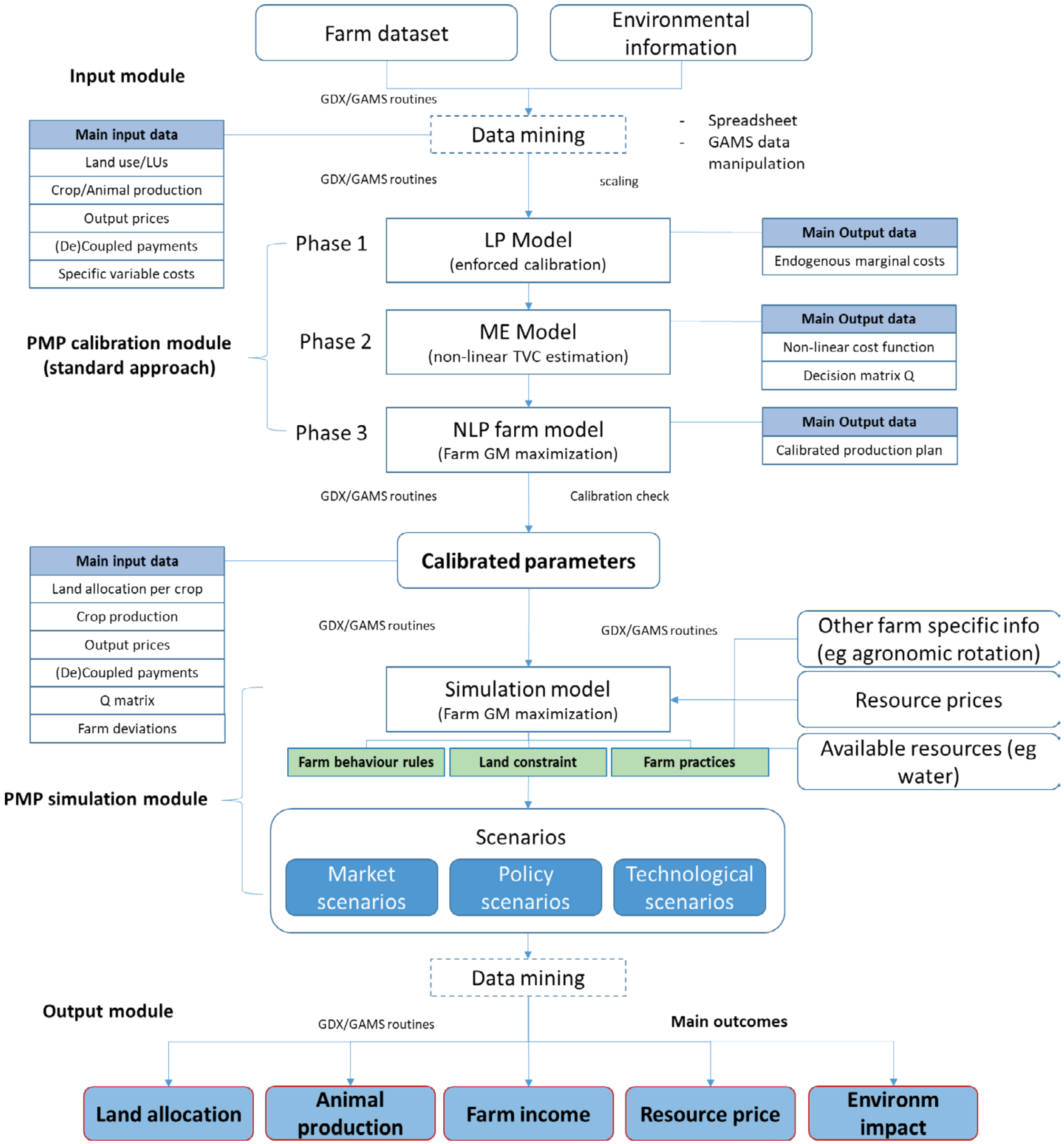

Figure 1. Model Structure. Source: authors' own elaboration.

on the implementation of the policy instruments can be found on the Appendix 1. The interactions between agents (1-3), related to the adoption of a specific production plan, are given by sharing the same frontier-cost function (Q) plus a deviation (u) and the adoption of the self-selection rule (4-5) by the n_{th} farm. The self-selection allows for the replication of the observed production plan through a comparison between the marginal cost of the current activity (or technology) and the average cost of a new activity or technology, which is defined within the Q matrix as latent activity or technology.

$$(p'_n x_n - {}^1/_2 x'_n \hat{Q}_n x_n - u_n x_n) \tag{1}$$

$$A_n x_n \leq b_n \tag{2}$$

$$x_n \geq 0 \tag{3}$$

To simulate the fact that not all farms in the sample cultivate all the crops encountered in the region two sets of constraints are postulated.

The first set deals with the crops, which are produced, and, thus, the marginal cost relation is an equation:

$$mc_{nk} \mid x_{Rk} > 0 \ \lambda_{nk} + c_{nk} = Q_k x_{Rn} + u_{nk} \text{ if the } k^{-th} \text{ activity is produced, k=1, …, J}_\text{n} \tag{4}$$

where mc_{nk} is the marginal cost for the n^{-th} farm associated with the k^{-th} activity.

The second set of constraints deals with the activities which are not produced by the n^{-th} farm, in which case the marginal cost relation is a weak inequality with respect to the level of the frontier-cost function:

$$mc_{nk} \mid x_{Rk} = 0 : \underline{\lambda}_{nk} + \underline{c}_{nk} \leq Q_k x_{Rn} + u_{nk} \text{ if the } k^{-th} \text{ activity is not produced, } k = 1,\ldots,Jn \tag{5}$$

R is the level of production observed for activity **k** and the vector u_{nk} assumes the role of indexing the cost function with the farm n specific characteristics.
λ represents the implicit component of the marginal cost associated to the production of the activity k by the farm n.

Restrictions (4) and (5) enable farmers also to select possible production activities from all activities present in the region among the activities observed in the first phase of the PMP (Paris and Arfini, 2000).

In the case of conversion to organic farming, equations (1-3) are replaced by Equations (6-8).

$$p'_c x_c + p'_g x_g - {}^1/_2 \, [x_c \ \ x_g] \ Q_{cg} \ [x_c \ x_g] \tag{6}$$

$$S.t. \quad A_c x_c + A_g x_g \leq b \tag{7}$$

$$A_{nc} x_{nc} \cdot A_{ng} x_{ng} \leq 0 \tag{8}$$

Any farm using conventional technology (c) can convert to organic technology (g) if it is more profitable.

In the Italian FADN, information regarding the agronomic management practice (organic or conventional) is provided for each farm. From this information the average costs, yield and output prices of the organic production are extrapolated. When a farm converts to organic farming those values are applied for the crops included in its production plan. Appendix 1 explains the operational implementation of the conversion from conventional to organic agriculture in the simulation phase.

The objective function, with the non-linear cost component, takes advantage of the self-selection property, allowing the substitution of technology or crops based on the cost information provided in the Q_{cg} matrix.Consequently, farms that decide to convert to organic farming change their production plan and cost structure.

Equations (9-14) represent and rules related to the exchange of the land factor between agents. Setting j activities, n and m farm holdings exchange land between each other. Equation 9 indicates that the available utilised area is equal to the available area plus the rented-in land minus the rented land. Equations (9 - 14) indicate that a farmer can either rent or rent out land, and that the total amount of rented land must be equal to the total rented-out land at the agrarian region level.. More precisely constraint (9) requires that the total land allocated to the different crops **j** (j = 1, … ,J), must be less than or equal to the observed total available land at the j farm level, $\mathbf{b}_n$, plus the land rented ($\mathbf{Z}_n$) minus the land rented out ($\mathbf{V}_n$).

$$A_{nj} x_n \leq b_n + Z_n - V_n \tag{9}$$

The land rented is represented as:

$$Z_n = \sum_m ZZ_{nm} \tag{10}$$

and the land rented out is represented as:

$$V_m = \sum_n VV_{nm} \tag{11}$$

where $\mathbf{ZZ}_{nm}$ and $\mathbf{VV}_{nm}$ are the matrix tracing the transfer of land for each pair of farms for renting and renting out, respectively. Furthermore, for each pair of farms, the land rented by one farm must be equal to the land out by the other, as follows:

$$ZZ_{nm} - VV_{nm} = 0 \quad \forall n \neq m \tag{12}$$

To avoid a given farm renting and renting out land at the same time, a specific constraint has been added:

$$Z_n \cdot V_n = 0 \tag{13}$$

Finally, to ensure that the exchange of land is consistent with the total available land at regional level, we establish that the total land rented must be equal to the total land rented out:

$$\sum_n Z_n = \sum_n V_n \tag{14}$$

Therefore, we assume that the exchange of land is limited to the farms located in the same agrarian region. Each farm has a marginal cost level, estimated with the PMP, beyond which acquiring additional land provides no further advantage. Introducing a price shock or a policy incentive can lead to a change in the shadow price of land for a specific farm. However, the land rental price remains constant, as it is treated as exogenous to the model and is assumed to be uniform throughout the Emilia-Romagna region.

Agents' interactions are regulated by the behavioural rules already mentioned in the previous section and here summuarised: i) Conventional farmers older than 65 and without successors cannot move to organic practices; ii) Farms are only allowed to exchange land within the agrarian regions where they operate; iii) Farmers older than 65 and without successors cannot rent land.

The input level is calculated based on the spending on purchased inputs, both for crops and livestock, per hectare of UAA. The inputs are purchased fertilizers and soil improvers, plant protection products, other means for protection, bird scarers, anti-hail shells, frost protection and purchased feed.

To provide environmental impact assessment, we integrated the Italian FADN data with environmental information on greenhouse gas (GHG) emission factors and water consumption for the different crops. GHG emissions from agricultural activities were estimated by applying the ICAAI methodology (Impronta Carbonica dell'Azienda Agricola Italiana), developed by CREA-PB, following the guidelines provided by the IPCC for establishing a national inventory of greenhouse gas emissions (Coderoni and Vanino, 2022; IPCC, 2008). This procedure, already implemented by Solazzo et al. (2016) assumes that the amount of atmospheric emissions is linearly related to the level of economic activity, and the emission factors considered for the agricultural sector are carbon dioxide, methane and nitrous oxide, expressed in ton CO2eq per hectare or head of livestock. The conversion factors referred to the 100-year Global Warming Potential and are provided by the Fourth Assessment Report of the IPCC (2007), following Equation (15):

$$CO_2eq = CO_2 + 298 \cdot N_2O + 25 \cdot CH_4 \tag{15}$$

More in detail, carbon dioxide emissions comprise emissions due to mechanical cropping operations (Ribaudo 2011) and soil organic carbon (SOC) estimation; methane emissions are due to livestock enteric fermentation and rice cultivation; nitrogen emissions include animal manure management, synthetic fertilizer application and atmospheric deposition (Solazzo et al. 2016).

Table 1. Crop aggregation.

Macrocategory	Aggregated Crops
Cereals	wheat, barley, rice, sorghum, other cereals
Forages	alfalfa, forage maize, other forages
Proteic/Oilseeds	sunflower, soja, protein crops, other oilseeds
Maize	maize
Meadows Pastures	meadows and pastures
Indutrial tomato	industrial tomato
Other industrial crops	beetroot, potato

The water consumption measurement uses the Water Footprint Network, based on the extensive work of Mekkonnen and Hoekstra (Mekonnen and Hoekstra 2010) that estimates the water footprint of 147 crops and over 200 products, and which also calculates the water footprint at national and sub-national level of each crop worldwide. The concept of Water Footprint was previously introduced by Hoekstra in 2002 in order to assess the direct and indirect use of freshwater resources along a production chain (Hoekstra and Hung 2002), as a sum of i) Blue water, surface water or groundwater for irrigation; ii) Green water, the water naturally embedded in the rhizosphere and available for plant assimilation; iii) Grey water, the volume of water necessary to dilute ecotoxic compounds (mainly used in crop protection) to restore specific quality standards.

Results are analised using the aggregation depicted in Table 1.

2.3. Data

The economic agents in the model are the individual farms included in the "Rete di Informazione Contabile Agricola" (RICA or FADN) database, which has been operational in Italy since 1968. This database is managed by CREA and provides data for the year 2019. The initial sample is specific to the Emilia-Romagna (NUTS2) Region and comprises 739 farms out of the nearly 11,000 sampled farms across Italy. Since RICA assigns a sample weight to each farm to ensure it is representative of the entire population, the weighted sample corresponds to a total of 40,753 farms. Table 2 illustrates the distribution of farms based on their size class (measured in hectares) and their management practices, which can be either conventional or organic.

The set of farm data includes information on geographical location (region, province, altitude, agrar-

Table 2. Number of Farms according to size class (ha) and management practices.

Size (ha)	Conventional Farms		Organic Farms		Total	
	Initial Sample	Weighted Sample	Initial Sample	Weighted Sample	Initial Sample	Weighted Sample
< 10	246	17,312	23	1,397	269	18,710
10-20	120	7,714	17	1,950	137	9,664
20-50	152	5,975	34	1,610	186	7,585
50-100	68	2,197	25	964	93	3,160
100-300	47	1,249	3	92	50	1,342
> 300	1	51	3	61	4	112
total	634	34,499	105	6,074	739	40,573

Table 3. Farms per age and size class, based on management practices.

Holder's Age	Conventional Farms			Organic Farms			Total	% Organic Farms
	≤40	41–64	≥65	≤40	41–64	≥65	-	Size class
% Age class/Farm type	6.81	46.55	46.64	15.02	64.31	20.67	-	-
< 10	1,122	7,470	8,721	159	1,034	205	18,710	3.44%
10-20	230	3,350	4,134	283	1,293	375	9,664	4.81%
20-50	525	3,235	2,215	130	1,001	478	7,585	3.97%
50-100	439	1,112	645	340	481	142	3,160	2.37%
100-300	34	842	374	-	52	41	1,342	0.23%
> 300	-	51	-	-	46	15	112	0.15%
Total	2,350	16,059	16,089	913	3,906	1,255	40,573	14.97%

ian zone), agricultural practices (conventional, organic), household characteristics (age and gender of the farm holder, number of potential farm holder's successors), land use, specific production costs per crop (cost of seeds, fertilizers, pesticides, energy, water), gross total product, and CAP payments. Table 3 depicts the heterogeneity of the sample based on class of age, per farm size and percentage of organic farms, that represent almost 15% of the farms population in Emilia Romagna.

Within the sample, the average age of the landholders is 61 for conventional farms and 54 for organic farms. The "agrarian region" spatial definition is a peculiarity of the FADN and it further segments Italian provinces (NUTS3) based on geographical location and altitude range. Although similar to the European sampling, the Italian FADN is notably more comprehensive, considering over 2,500 variables for each sampled farm, in contrast to the European FADN, which only takes into account approximately 1,000 variables (CREA-PB 2021).

Table 4 detailed the observed land use in Emilia Romagna region in the year 2019.

The prevailing land use relates to cereals (33.26% of the total Utilized Agricultural Area (UAA)) followed by forage (33.17%); meadows and pastures count for 10.54% of the regional UAA.

2.4. Policy scenarios

To model how farmers respond to the adoption of organic agricultural practices and eco-scheme, two scenarios are implemented in AGRISP and evaluated through a comparative static analysis. More specifically, we compare the baseline scenario, represented by the calibrated FADN data for the year 2019, wherein farmers receive the basic coupled and decoupled payments, with the simulated scenario. Greening measures of the previous CAP reform: crop diversification, maintenance of permanent grassland, and the establishment of Ecological Focus Areas are simulated (European Commission 2017) are also included in the baseline.

The two CAP post-2020 scenarios implemented in the simulation module of AGRISP are:

1. the "Organic" scenario, where payments are made to encourage farm holders to adhere to organic agricultural practices in order to increase the area

Table 4. Land Use in thousands of hectars.

Land Use (1000 ha)	Cereals	Forages	Proteic/ Oilseeds	Maize	Meadows Pastures	Industrial Tomato	Other Industrial Crops	Total
Conventional	263	230	52	81	45	23	35	729
Organic	46	78	10	5	53	3	4	199
Total	309	308	62	87	98	26	39	928
%	33.26%	33.17%	6.64%	9.33%	10.54%	2.82%	4.24%	

under organic agriculture to 25%, according to the Farm to Fork strategy target (Appendix 1). Regional payments for organic crops are listed in the RDP of Emilia Romagna (DG AGRI 2021). In this scenario farmers will opt for organic farming if economically convenient, considering transition costs, organic yield and prices for organic products.

2. the "Eco-Scheme" scenario simulates the 4th eco-scheme in the Italian National Strategic Plan (MASAF 2022). It envisages incentives in the form of additional payment of 110 €/ha added to the basic payment, for an extensive forage system. In our model, we consider the crop category "Meadows and Pastures" as eligible for this payment. The "Eco-Scheme" scenario is added to the subsidy foreseen to support the conversion to the organic agronomic management practice.

The ABM rules and the PMP methodology integrated in the AGRISP model trigger farm owners' decisions on farm organisation, including factors such as land endowment and utilisation. This is achieved by optimising the individual utility functions of each farm, which subsequently influence the environmental impact and the overall regional gross margin.

Other models can be used to perform similar comparative analysis, such as partial equilibrium models based on farm types (e.g. CAPRI), providing a macroeconomic perspective by analysing the interactions between supply and demand in agriculture. However, these models can offer insights into how policies affect market equilibrium, prices and production but do not consider the farms heterogeneity.

As noted above (Equations 9 - 14), in both scenarios farmers can exchange land according to specific agent-based constraints that trace a one-to-one relationship between all the farms included in the sample, in the sense that each farm has the option to rent or rent out arable land with the other farms located in the same agrarian region. Farmers exchange land as a way of making optimal use of their resources. Farmers can adopt different structural strategies, such as leasing out their land and exiting the market entirely, or alternatively, they may choose to lease out only a portion of their land while continuing their farming activities.

The rental price for land is not resulting from a land market equilibrium but is assumed to remain fixed at 690€/ha. This price is derived from the "Survey on the Land Market" conducted by CREA-PB (2019) in Emilia Romagna.

3. DISCUSSION OF RESULTS

The "Organic" scenario and the "Eco-Scheme" scenario are executed using the calibrated 2019 Italian FADN data, and subsequently compared to the baseline, which does not incorporate any agent-based or policy constraints. The main emerging phenomena are: (i) The impact on land use, including technological changes for conversion to organic farming; (ii) The structural changes recorded in total number of farms per sized-class and in terms of farm holder age ; (iii) The environmental impact related to the carbon emissions and water consumption; (iv) The impacts on farmers' gross margin.

3.1. Impacts on land use

The impact of the two scenarios on land use has been analysed both in total hectares allocated and as a percentage (*Table* 5). Cereals, the less profitable crops, decrease overall by 13.74% in the Organic scenario and by 13.90% in the Eco-scheme one respectively. Meadows and pastures experience a modest decrease in the organic scenario, but the eco-scheme subsidy helps bring production back up slightly. All other crop categories show an increase. Among them, protein/oleaginous crops reveale the highest rise, with an increase of 8.58% for the Organic scenario and 8.59% for the Eco-scheme scenario. The greening requirement leads to land set-aside of 0.28% on "Organic" and 0.27% in "Eco-scheme" farms.

Additional elaboration is provided for each class of dimension concerning the four crops that exhibit higher

Table 5. Impact on land use, per crop in hectares and in %.

Crops	Land allocation in hectares per crop			Land allocation in % per crop		
	Baseline	Organic	Eco-scheme	Baseline	Organic	Eco-scheme
Cereals	308,691.60	181,205.60	179,665.30	33.27	19.53	19.36
Forages	307,796.00	331,914.00	333,666.00	33.17	35.77	35.96
Protein/oleaginous	61,604.60	141,340.40	141,267.40	6.64	15.23	15.22
Maize	86,561.00	90,632.00	88,917.00	9.33	9.77	9.58
Meadows Pastures	97,817.00	93,449.00	97,454.00	10.54	10.07	10.50
Industrial tomato	26,184.00	32,444.00	33,143.00	2.82	3.50	3.57
Other industrial crops	39,318.80	54,361.80	51,379.50	4.24	5.86	5.54
Greening	-	2,620.70	2,475.40	0.00	0.28	0.27
Total	927,973.00	927,967.50	927,967.60	-	-	-

variation: cereals, forage, protein/oleaginous crops, and industrial tomatoes (Figure 2). Delving into the results we notice that the decrease in cereal production is mostly accentuated in the small medium-sized farms (under 100 hectares), whereas the decrease is of lower intensity in farms between 100 and 300 ha and almost not relevant in farms over 300 ha. This could be explained with the fact that cereals are typically grown on large plots of land, and they tend to require less labor and inputs per unit of land compared to other crops. Large-scale cereal farms may have specialised equipment and processes optimised for extensive agriculture, making it less practical or economical to switch to different crops or practices and they may have more stable market contracts or subsidies that incentivise the continuation of existing cereal production methods. In smaller to medium-sized farms, the decrease in cereal production could be more pronounced when switching to organic or eco-schemes due to the relative increase in labor and management required for these practices. Smaller farms might not benefit from economies of scale in the same way larger operations do and may feel the shifts in practice more acutely.

For farms under 50 hectares there is no incentive to increase the production of forage. This is probably due to the relatively low amount of the subsidy for conversion to organic (only 120€/ha for alfalfa and other forage) that the Eco-scheme scenario is not able to counterbalance. However, for larger farms (50 hectares and above), the trend reverses, with the forage under Organic and Eco-scheme scenarios having more allocated land than in Baseline, with the largest increases seen in the 100-300 hectares size class. This could also be driven by the concentration of the dairy farms in class 3-5 (86.33%), which may have further interest in forage.

Strong positive shift towards protein/oleaginous crops production is reported in both the Organic and the Eco-scheme scenarios consistently across all farm sizes, suggesting that farmers find agroecological practices economically viable for these products, notably more profitable. This might be due to more favorable subsidies for these crops (351€/ha) or higher market price for organic products. The percentage increase in land allocation is higher in larger farms, especially in those over 300 hectares. This could be due to the greater financial resilience of larger farms, allowing them to take on the risk of transition and the associated costs more readily than smaller farms. Also for these crops, data suggests significant economies of scale for larger farms, more likely to distribute the costs and labor required for organic farming more efficiently. The total increase of around 129% for both Organic and Eco-scheme scenarios is particularly notable. It underscores a widespread and significant adoption of these practices across the sector.

A remarkable increase is depicted for smaller farms (<10 hectares) in the Organic and Eco-scheme scenarios for industrial tomatoes, which might be due to the high subsidy of 427€/ha. This makes it financially attractive for smaller operations to switch to these practices. Medium-sized farms (10-50 hectares) also show substantial increases for both scenarios. This could suggest that the subsidy is sufficient to cover the additional costs of transitioning and that the market for organic or eco-friendly tomatoes is strong. There's a notable decrease in land allocation for farms larger than 300 hectares, where there's no activity in the Organic and Eco-scheme scenarios. This stark contrast to other size classes might be influenced by several factors, including the possibility that farms producing industrial tomatos practice more intensive farming and consequently have relatively smaller size. Tomato cultivation typically involves higher costs for seeds, fertilizers, pesticides, and water. They also require careful management and more labor for tasks like pruning,

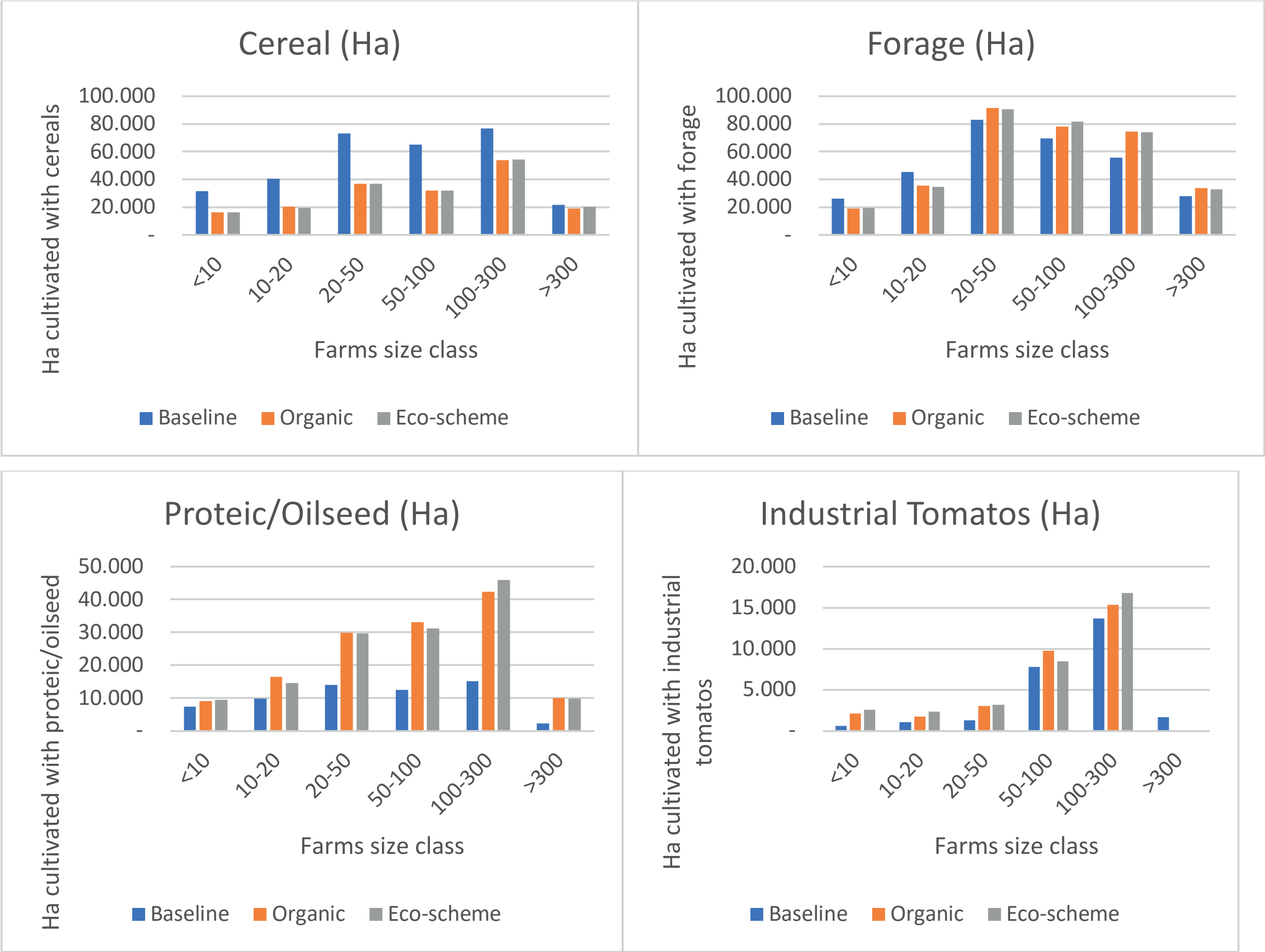

Figure 2. Land use per crop and per scenario.

trellising, and harvesting. Intensive crops like tomatoes are often grown in smaller areas with a higher yield per hectare and are more labor-intensive than extensive crops. The increase in Organic and Eco-scheme scenarios for the 50-100 and 100-300 hectares classes is lower compared to the smaller farms, and this could be because these larger operations might already be producing at scale, and the relative benefit of the subsidy is lower compared to their overall operations. Despite the differences in subsidies, the overall trend shows that there is a significant move towards Organic and Eco-scheme practices across most crop types and farm sizes. The data for the Industrial Tomato crop, especially the impressive increases in the smaller size classes, shows that when subsidies are perceived as significant and worthwhile, they can be a powerful motivator for changing farming practices. However, for larger farms, especially those over 300 hectares, the current subsidy rates and perhaps other factors related to scale, market dynamics, or the specifics of tomato cultivation may not provide enough incentive for a shift to Organic or Eco-scheme practices.

Overeall organic land increases significantly in the Organic scenario (+43% at aggregated level) but is lower at (+35% at aggregated level) for the Eco-scheme. Looking at the impact of the two payments schems per class of dimension (Figure 3) we notice that the more reactive are the medium size farms, particularly those in the class 100-300 ha. It's worth mentioning that the significant rise in organic surface area within this category might be attributed to the absence of a cap on the subsidies that farms can request.

3.2. Structural changes

The impact of the scenarios on the number of farms, in terms of farm size, is illustrated in Figure 4.

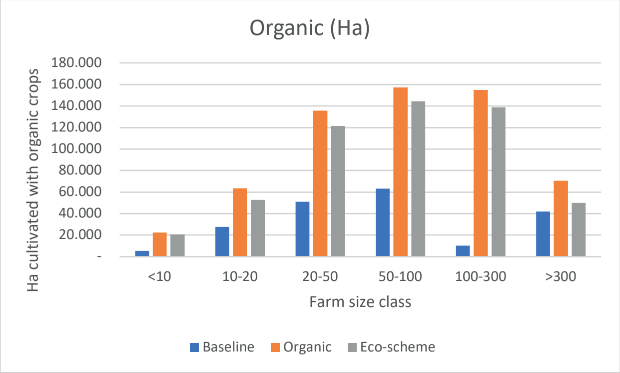

Figure 3. Changes in hectares cultivated under organic farming per scenario and size class.

Table 6. Impact of scenarios on number of farms (weighted).

Farm size class	Baseline	Organic	Eco-scheme
< 10	18710	15368	15297
10-20	9664	8465	8387
20-50	7585	6852	6852
50-100	3160	3053	3159
100-300	1342	1342	1342
> 300	112	112	112

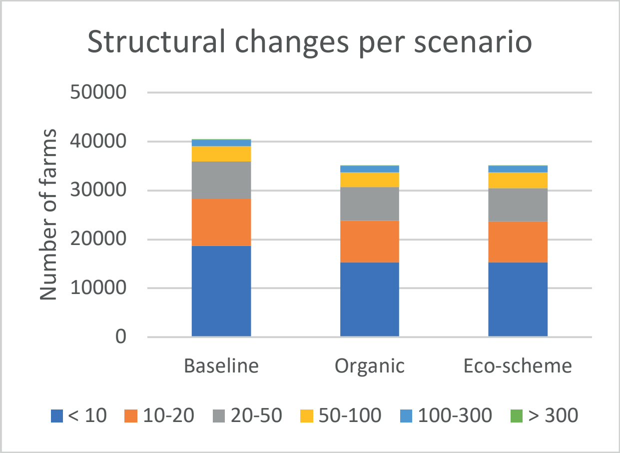

Figure 4. Structural changes according to farm size in ha.

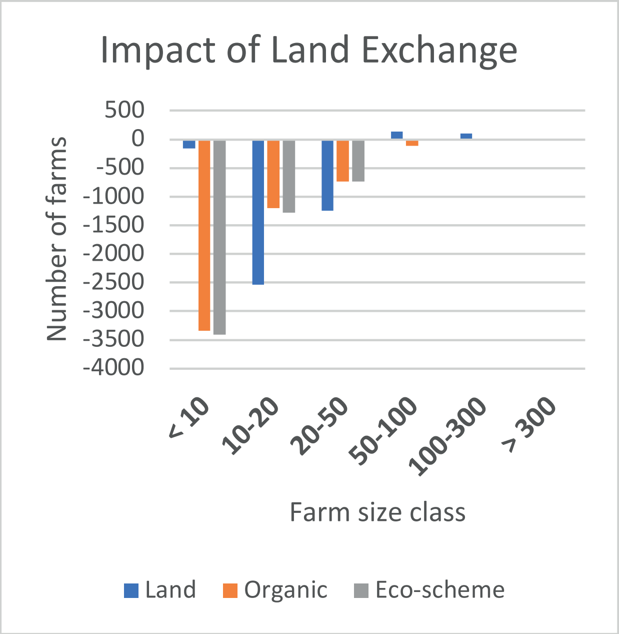

Figure 5. Effect of land exchange on number of farms per size class (in ha) compared to Baseline.

Overall, there is a noticeable decline in the weighted figures, showing a drop of 5,381 units for the Organic scenario and a drop of 5,325 units for the Eco-scheme scenario. (Table 6).

The farms appearing to be the most affected are the smaller ones, with a decrease of 18% in farms smaller than 10 hectares, a 13% decrease in the class with a UAA of 10-20 hectares, and a 10% decrease for farms smaller than 50 hectares altogether (Figure 4).

The activation of the land exchange constraints, allowing for land rental, as highlighted in Figure 5, emerges as the primary trigger for this structural transformation in the scenarios. However, there is an exception with very small farms (less than 10 hectares), where the incentives for organic conversion and eco-scheme 4 do not seem adequate to support them.

These phenomena might be explained with the fact that small farm holders are more likely to leave the market, while big farms tend to consolidate. For small farms, with shadow prices lower than market prices, it becomes more economically efficient to lease out their land rather than continue farming. We can make the assumption that larger farms exhibit greater resilience, as they can capitalize on their economies of scale, as well as on the subsidies tied to their larger land holdings.

From an age-based analysis, and considering the initial agronomic practices of the sample, results reveal (Figure 6) that young farm holders (aged below 40), who represent only a small portion, experience a slight increase in the size class of less than 10 hectares, in conventional farming, due to the impact of the land exchange rules. However, their overall decrease remains relatively stable. Within the organic compart the decline is perceivable in the smaller size class


Age under 40 - Conventional Farms

Age under 40 - Organic Farms

Age 41-64 - Conventional Farms

Age 41-64 - Organic Farms

Age above 65 - Conventional Farms

Age above 65 - Organic Farms

Figure 6. Variation in number of farms per size class and age range.

(less than 10 hectares) and in the 10-20 hectare range, primarily influenced by land exchange. In the 50-100 hectare class instead, incentives have a minor but still positive effect.

In the age range of 41-64, the land exchange rules contribute to a decrease in the number of very small farms, while subsidies help retain some of the 10-20 hectare farms in the market. For organic farms in this same age range, subsidies appear to be beneficial in the 20-50 hectare size class, although the impact of land exchange still remains a significant driver in reducing the number of small farms.

Farmers aged 65 or older, constituting 43% of the initial sample, appear to be the less responsive to change triggered by subsidies, with a slight exception for conventional farms in the 10-50 hectare range. The primary factor leading to the decrease in the number of very small conventional farms is the opportunity to exchange land.

If the total Utilized Agricultural Area (UAA) is assumed constant, the average farm size increases from the 31 hectares in the "Baseline" to the 41 and 40 hectares in "Organic" and "Eco-scheme" scenarios. This result is consistent with the ongoing trend according to the 7th General Census of Agriculture (ISTAT 2022).

Census results depict an overall decrease in the number of farms, while across all regions of Italy, farm sizes are increasing, which confirms that incentives to counter the disappearance of small farms need to be well-planned.

3.3. Environmental impacts

The environmental impact of the CAP post-2020 reform on climate change can be evaluated in terms of GHG emissions per agricultural activity. GHG emissions are measured in CO_2 equivalent. Implementing subsidies to support organic agriculture, in this research, leads to a total reduction of almost 6% of tons of CO_2 equivalent emitted at the regional level, resulting in a total reduction of 1,294 thousand and 1,297 thousand respectively for scenario Organic and Eco-scheme at the regional level (Table 7), confirming that organic practices impact less on the climate than conventional ones (Holka et. al 2022).

In line with these results is the average carbon emission per hectare (Figure 7). Carbon footprint aggregated per crop shows that the reduction in emissions is mainly due to the reduction of cereal cultivation (-11%), while there is a slight increase in emissions related to forage, protein crops and oilseeds.

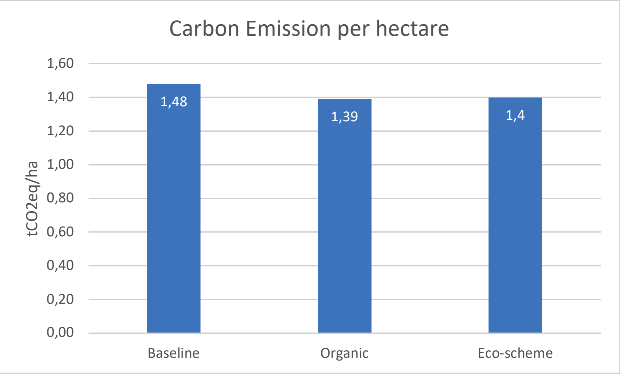

Figure 7. Average carbon emission (tCO2eq) per hectare.

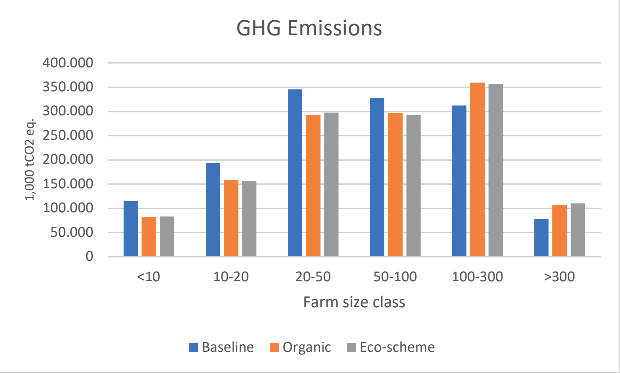

Figure 8. GHG Emissions (ton of CO2 equivalent) per class of farm size.

The per farms-size analysis of the evolution of the GHG emissions across scenarios depicts (Figure 8) how the implemented policies generally lead to a significant reduction in CO_2 equivalent emissions across most farm sizes, with the exception of the largest farm size category (above 100 hectares), where emissions actually increase. This suggests that while subsidy-driven policies can effectively reduce GHG emissions in smaller to mid-sized farms, their impact on larger farms may require additional considerations or tailored approaches. The results underline the importance of carefully designing agricultural subsidies to ensure they achieve desired environmental outcomes across all farm sizes. It may also point towards the need for diversified strategies that cater specifically to the operational and environmental conditions of different farm sizes.

Table 7. Carbon Emission in 1,000 tCO2 equivalent aggregated per crop.

	Baseline	Organic	Eco-scheme
Cereals	493.22	290.93	290.67
Forages	184.15	196.02	198.88
Proteic/oilseeds	54.05	126.34	126.31
Maize	305.00	319.34	313.30
Meadows Pastures	219.08	209.29	218.26
Industrial tomato	55.34	68.57	70.04
Other industrial crops	62.90	83.81	79.58
Total	1,373.75	1,294.30	1,297.04

Unlike carbon emission, water resources are in general strongly affected by the transition to organic production. Water consumption in the Organic scenario increases by 9,4% (Figure 9), which is mainly due to the decrease in cereal production, offset by an increase in oilseeds and protein crops.

Forage cultivation consumes the most water of all crops, accounting for over 60% of the regional water footprint. The result is coherent with the fact that alfalfa is one of the most widespread crops in Emilia Romagna (Solazzo et al. 2016).

However, if we delve further in the results per farm size, we note that for farms smaller than 20 hectares, both subsidy scenarios lead to a reduction in water consumption, suggesting that the adoption of organic and eco-friendly practices can effectively decrease water usage in smaller scale operations. For farm sizes larger than 20 hectares, both subsidy scenarios result in an

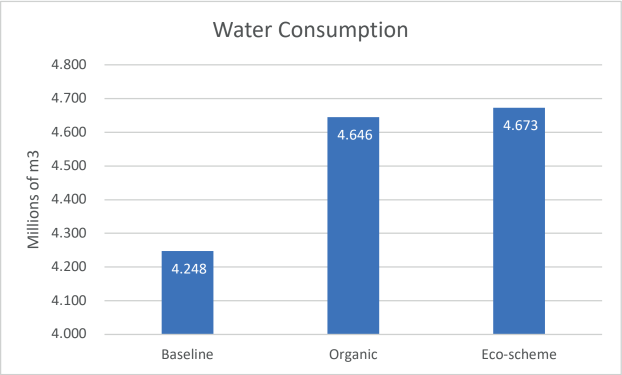

Figure 9. Water consumption (m3) per hectare.

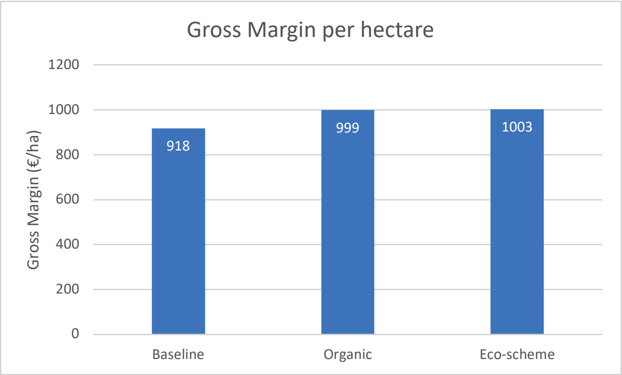

Figure 10. Gross margin variation.

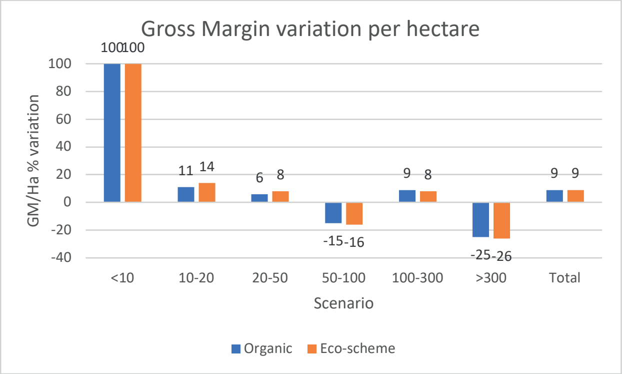

Figure 11. Gross margin variation per ha according to size class compared to baseline scenario.

increase in water consumption. This trend is especially pronounced in the largest farm size category (100-300 hectares), which could reflect the more water-intensive nature of some organic and eco-friendly practices, or possibly the increased water requirements for these practices to be effective at a larger scale.

The results indicate that while subsidy-driven policies can support water conservation in smaller farms, they may exacerbate water use in larger operations. This could have significant implications for water resources management, especially in regions facing water scarcity. These findings underscore the importance of designing agricultural subsidies and practices that are tailored to farm size and local water availability conditions. Policies should consider the varying impacts of organic and eco-friendly practices on water consumption across different farm sizes to ensure sustainable water use.

The increased water consumption under both scenarios for larger farms highlights the need for comprehensive environmental assessments of subsidy programs. Ensuring that efforts to reduce one form of environmental impact do not inadvertently increase another is crucial for the overall sustainability of agricultural practices.

3.4. Economic results

Gross margin per hectare increases in both “Organic” and “Eco-scheme” scenarios. The increase of 8.8% in the “Organic” scenario, corresponding to 81€/ha, can be attributed to the implementation of subsidies for organic farming conversion. Adding to these subsidies the payment for extensive forages leads to an overall increase in gross margin of 9.2% (85€/ha) (Figure 10).

Looking at gross margin relative variation according to size class (Figure 11), less economically efficient farms are those with an UAA over 300 Ha, followed by those between 50 and 100 Ha. All the other classes show an increase in the gross margin per hectare.

4. DISCUSSION AND CONCLUSION

In this study, the application of the agent-based methodology within the AGRISP model has proven to be an effective tool for quantifying the supply-side impacts of CAP measures. Methodologically, AGRISP introduces unique features to capture the diverse characteristics of farms, their decisions, and interactions within their economic and social contexts. It facilitates predictions of the effects of CAP reform at a granular level, including individual farms, and enables analysis at both territorial and sectoral levels. The social variables, such as family structure and farmers’ age, are taken in consideration in the model through the definition of specific rules, to characterise the behaviour of the entrepreneur. The choice of the social variables and the socio-structural rules in this paper was made to assess how the CAP strategies may benefit young farmers, however, other socio-structural rules linked to the characteristics of the agricultural family business can be included.

Another innovative feature is the capabilities of simulating the farmers' attitude to change their production plans or their production factors endowment. In order to model farmers' willingness to make changes, the PMP methodology was employed to calculate the marginal cost of individual agricultural productions and the constraining factor, represented by the availability of land. Comapring costs with alternative options acts as a benchmark for farmers when considering the adoption of new technologies and adjustments to their farm structure. Furthermore, the PMP methodology coupled with the self-selection process, enables agents to adapt their production plans by broadening their decision-making options, incorporating production methods and technologies employed by other farms in the sample, as well as considering new production technologies that may emerge due to policy interventions. Consequently, farmers can introduce new processes or modify production intensity, when these choices prove to be more advantageous. Using this approach, AGRISP enabled the simulation of the transition to organic farming in response to the introduction of additional payments and the Eco-scheme 4.

The analysis of the model results may highlight which farm categories are advantaged and which are penalised when policy measures are implemented, whether they are designed for specific production categories or are applicable to all farms across the agricultural region.

Micro-based farm models, capable of simulating farmers' behaviour and their aptitude to change production plans under economic, market, technological and environmental scenarios, are becoming increasingly important, however supply-side farm models, while accurately simulating the entrepreneur's strategies, have the limitation of assuming the farm as a "closed" production system whose decisions consider only the production resources available. Nontheless, the exchange of production factors between farmers, particularly land, in order to adjust to fluctuations in their marginal value, allows the sample's dynamics to be brought closer to reality.

The results illustrated in this paper showing how less efficient farmers rent out land to more productive ones, enabling the latter to expand their operations and leverage economies of scale and scope, well reproduce the decline in number of farms depicted in the most recent Italian agricultural census.

Furthemore, our preliminary results show that the ambitious objectives of the new CAP reform would have significant impacts on land use as well as non-negligible effects on climate change mitigation and water resource consumption.

The complexity of the new CAP, due to potential contradicting objectives such as competitiveness and environment sustainability, requires careful ex-ante evaluation of the possible outcome.

This study reveals that the subsidies allocated to organic farming conversion and the Italian Eco-scheme 4, applied to the Emilia-Romagna FADN sample (2019), may lead to:

1. a considerable decrease in the number of small farms,
2. a shift from cereal cultivation towards protein and feed crops,
3. a substantial economic stability among farms, measured by changes in gross margin per hectare,
4. a modest reduction in CO_2 equivalent emissions per hectare, and
5. an increased demand for water resources.

Overall, the effect appears to be positive in terms of CO_2 reduction. However, concerns are raised by the further increase of capital-intensive agriculture at detriment of small farms.

This work presents some results aggregated at the regional level, but further analysis could be done to highlight findings at the sub-regional level, to suggest more targeted actions able to consider the individual characteristics of different rural areas, allowing, for instance, different payment scheme better calibrated to the territorial conditions and specific regional policy objectives.

To conclude, it is noteworthy that like any modeling approach, ABMs with PMP involve simplifications and assumptions about agents' behavior, market dynamics, policy implementation, and other factors. These assumptions may not always hold true in practice, leading to potential limitations in the model's predictive accuracy and generalizability across different contexts. Integrating variuos modeling approaches could provide a comprehensive assessment of agricultural policies, taking into account farm heterogeneity, farmers' cost and risk perceptions, and the dynamic nature of production decisions and techniques. Collaboration between interdisciplinary teams of researchers and stakeholders is essential to develop and apply these models effectively in policy analysis and decision-making processes.

ACKOWLEDGMENTS

This research was funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 816078 for the AGRICORE Project

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APPENDIX 1 – CONVERSION TO ORGANIC PRACTICE SCENARIO

List of indexes, parameters, and variables:

Indexes

$n = (1,2,\ldots,N)$: index of farm

$j = (1,2,\ldots,J)$: index of crop

$k = (1,2,\ldots,K)$; $k = j$: index of crop

Parameters

pc_{nj}: output prices for conventional crops

pb_{nj}: output prices for organic crops

sh_{nj}: specific crop payment (€/ha)

shb_{nj}: specific payment for organic crops (€/ha)

SFP_n: single farm payment including basic and greening payments

r: rent price for land (€/ha)

Q_{jk}: matrix Q

u_{nj}: farm deviations

AB_{nj}: technical coefficients for organic crops

Ac_{nj}: technical coefficients for conventional crops

Variables

GM_n: gross margin

xh_{nj}: land use
xhc_{nj}: land use for convention crops
xhb_{nj}: land use for organic crops
xc_{nj}: production for conventional crops
xb_{nj}: production for organic crops
V_n: land rented
Z_n: land leased

List of relevant equations:

1) Constraint linking land allocation to conventional and organic practices
$xhc_{nj} + xhb_{nj} = xh_{nj}$
$\forall n$ [conventional AND ((with farm owner ≤ 65 years) OR (with farm owner > 65 years AND with successor))]: Δj

2) Constraint ensuring the total conversion by crop
$xhc_{nj} \cdot xhb_{nj} = 0$
$\forall n$ [conventional AND ((with farm owner ≤ 65 years) OR (with farm owner > 65 years AND with successor))]: Δj

3) Constraint linking organic land allocation and organic production
$Ab_{nj} \cdot xb_{nj} = xhb_{nj}$
$\forall n$ [conventional AND ((with farm owner ≤ 65 years) OR (with farm owner > 65 years AND with successor))]: Δj

4) Constraint linking conventional land allocation and conventional production
$Ac_{nj} \cdot xc_{nj} = xhc_{nj}$
$\forall n$ [conventional AND ((with farm owner ≤ 65 years) OR (with farm owner > 65 years AND with successor))]: Δj

5) Objective function at the farm level

$$\begin{aligned}&\sum_j \left(pc_{nj} xc_{nj}\right) + \sum_j \left(pb_{nj} xb_{nj}\right) + \sum_j \left(shb_{nj} xhb_{nj}\right) + \sum_j \left(sh_{nj} xh_{nj}\right) + SFP_n + \\ &+ \left(V_n - Z_n\right) r + \\ &- \frac{1}{2} \sum_j \sum_k \left(xc_{nj} Q_{jk} xc_{nk}\right) - \sum_j \left(u_{nj} xc_{nj}\right) + \\ &- \frac{1}{2} \sum_j \sum_k \left(xb_{nj} Q_{jk} xb_{nk}\right) - \sum_j \left(u_{nj} xb_{nj}\right) = GM_n\end{aligned}$$

$\forall n$ [conventional AND ((with farm owner ≤ 65 years) OR (with farm owner > 65 years AND with successor))]: Δj