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Impacts of Environmental Targets on the Livestock Sector: An Assessment Tool Applied to Italy

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Abstract: Environmental and climate targets are becoming very relevant policy objectives for European agriculture. The introduction of environmental targets could have important impacts on production, land use and economic dimensions of the EU agricultural sector. The livestock sector is influenced doubly, considering crop cultivation and livestock-rearing activities and their interactions. This study assesses the impacts on Italian livestock farms from the implementation of some environmental targets set by the Farm to Fork strategy, i.e., reducing the use of chemical inputs for forage crops and antimicrobials for livestock. An agroeconomic supply model based on microdata from the Farm Accountancy Data Network is used to evaluate the impacts on production, land use and socio-economic outcomes. Results show an increase of feed purchases to maintain livestock numbers in all farm types, while limiting the use of chemical inputs for forage crops. Adding limitations on the use of antimicrobials, livestock number decreases in all farm types, but especially in those rearing granivores. Negative economic impacts are particularly observed in farms of small and medium economic size. The highest reduction of labor employment occurs in farms of large economic size. Results could support policymakers' decisions in setting measures that aid transition towards more sustainable farming systems.

Keywords: farm to fork; livestock sector; mathematical programming model; environmental targets; impacts evaluation

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1. Introduction

In December 2019, the European Commission presented the European Green Deal as directly connected with the Commission's strategy to implement the United Nations' 2030 Agenda [1]. Signed in 2015 by 193 Member States of the United Nations, the 2030 Agenda states that the objectives set for sustainable development have a global validity and concern and involve all countries and components of society. It encompasses 17 Sustainable Development Goals (SDGs), expected to guide the actions of the international community in the coming years. SDGs refer to a set of development issues that consider the three dimensions of sustainable development—economic, social and ecological—in a balanced way, aiming to end poverty, fight against inequality, tackle climate change, and build peaceful societies that respect human rights [2]. The 2030 Agenda offers a vision of agricultural and food sectors as keys for sustainable development and explicitly mentions their role in Target 2.4. The latter asks to "ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality". Then, the Communication from the Commission on its "Farm to Fork (F2F) strategy" further strengthened the efforts for building a fair, healthy, and environmentally friendly agricultural and food system [3]. In fact, the F2F strategy aims to accelerate transition to a sustainable food system. In its application to the agricultural sector, this translates into a complex set of challenging goals, to be simultaneously reached by farming activities. These are in fact primarily requested to exert a neutral or positive environmental impact contributing to mitigate climate change while adapting to it, also through the reversal of biodiversity loss. Meeting these issues, the agricultural sector should be able to ensure food security, nutrition and public health. It should simultaneously preserve food affordability and generate fairer economic returns, fostering the competitiveness of the EU supply sector and promoting fair trade. The F2F strategy asks for precise constraints to be respected by 2030 to reach the environmental goals. These consist in halving the use and risk of chemical and hazardous pesticides, reducing by 20% the use of fertilizers, halving the sales of antimicrobials for farmed animals and aquaculture, and increasing by 25% organically farmed land in the EU. The feasibility of respecting these constraints while preserving the social and economic sustainability of farming activities is a hot research topic to which this study aims to contribute. Undoubtedly, ensuring the vitality and competitiveness of the EU agricultural sector is also pivotal in ensuring food security and food affordability, and ultimately the achievement of the same environmental goals of the F2F strategy as well. Multidisciplinary analyses are necessary to consider the various aspects regarding the use of natural resources, but at the same time productive and socio-economic outcomes [4,5].

Economic models can be used to conduct multidisciplinary analyses. Specifically, the microeconomic approach of mathematical programming models allows the technical aspects of agricultural production and of resource use to be considered [6]. The mathematical programming models can be classified into three groups: a. agroeconomic supply models (e.g., FSSIM, EFEM, FARMIS, AGRITALIM); b. Partial Equilibrium models (e.g., CAPRI, GLOBIOM, ESIM); Computable General Equilibrium models (e.g., GTAP, MAGNET). Some of these models use data from the Farm Accountancy Data Network (FADN), such as FSSIM, EFEM, FARMIS, AGRITALIM and CAPRI models [7,8]. Moreover, some of them use the Positive Mathematical Programming (PMP) to calibrate the models to the situation observed in the baseline, such as FSSIM, FARMIS, AGRITALIM and CAPRI models.

More in depth, the microeconomic approach of PMP models allows the technical aspects of agricultural production and of resource use to be considered, calibrating perfectly to observed production activities [9–11]. Thus, in this study, we use a PMP model called "AGRIcultural TerritoriAL tIme econoMic" (AGRITALIM). The objective is to assess the impacts on Italian livestock farms arising from the implementation of some of the environmental targets set by the F2F strategy. In particular, the focus here is on the reduction of chemical fertilizers, pesticides and antimicrobials used. The analysis is based on current production practices and technologies, as well as market and political frameworks observed in the baseline.

Modelling the supply side of production fits into our scope since, although the F2F strategy encompasses many aspects of the entire agricultural supply chain, we focus only on agricultural production. In fact, as in other studies in the field, the aspects we consider are more suitable to be implemented in an economic model and are well defined under the proposed F2F targets [12]. Thus, this study is not an impact assessment of the entire F2F strategy, as it does not include all the measures considered by the strategy (e.g., consumption changes, reduction of food waste, logistics and marketing). It focuses only on some quantitative targets clearly assessed by the F2F strategy for some agricultural inputs, which can quite easily be simulated by our model.

In particular, two scenarios are simulated: (i) the reduction by 20% of fertilizer use and the reduction by 50% of more hazardous pesticides; (ii) the additional 50% reduction in expenditure for veterinary antimicrobials. Impacts are evaluated in terms of production quantities, land use changes, and economic and social results.

This research adds to other studies conducted in recent years on the targets of the Farm to Fork strategy [8,13–18]. Besides representing a further contribution to this topic, the research aims to deepen some aspects that in previous analyses were not fully developed. In fact, one focus is on the livestock sector, highlighting the trade-off between objectives of economic performance and environmental sustainability for the different types of farms (cattle, sheep, pigs, poultry) and production (milk, meat, other). Moreover, the livestock sector is an interesting subject of analysis for its connection both with land use (forage crops) and administration of antimicrobials, which allows us to analyze and deepen some issues. The first issue concerns the risk of a further exposure of the livestock sector to feed production from third countries, in an international context shaken by war with supply limitations and high prices. Another issue concerns the potentially drastic land use changes affecting large rural areas. From the environmental side, these could bring relevant benefits for some areas (consequent to grassland expansion). However, negative impacts could occur on the cultivation of crops (e.g., leguminous crops) that improve soil structure and fertility and that are better suited to arid areas and drought-prone regions. From the economic side, negative impacts on production chains of the territories are in addition foreseen, with relevant impacts on a sector that is pivotal in ensuring employment and incomes in rural areas.

Moreover, the modelling approach brings some innovative aspects. The AGRITALIM model includes all the farms of the Italian FADN database, which gathers more detailed information on crop and livestock production techniques, such as unitary use of inputs (e.g., nitrogen, phosphorus, potassium, water, labor, etc.). In addition, data used to build the model are updated to the last available year in the FADN database (to date, 2020). This allows a better representation of the current situation, especially in terms of the structural and productive characteristics of farms and production techniques. In addition, the AGRITALIM model is able to simulate very detailed results, which in this study refer to the different livestock farm types, as well as to their land size and economic size. Finally, the model maximizes farm operating income and therefore also allows changes in the elements of fixed capital to be considered, taking into account the annual depreciation of their total value.

The rest of the paper proceeds as follows: Section 2 presents the data and the model used. Section 3 shows the results and Section 4 discusses them. Then, Section 5 presents some conclusions. Table 1 shows the detailed abbreviations and definitions most used in the paper.

Table 1. List of abbreviation and acronyms most used in the paper.

Abbreviation	Definition
AGRITALIM	AGRIcultural TerritoriAL tIme econoMic
F2F	Farm to Fork
FADN	Farm Accountancy Data Network
LSU	Livestock Units
PMP	Positive Mathematical Programming
UAA	Utilized Agricultural Area

2. Materials and Methods

2.1. Data and Sample Used

Data used are those derived from the Italian FADN, which is the only harmonized microeconomic database merging data on farm structure, input use, output produced and economic variables. Moreover, the use of the FADN database allows some proxies of environmental pressure (e.g., input use) to be linked to economic indicators and economic and environmental performances to be appraised at the farm level. Farms are selected to take part to the FADN survey based on sampling plans established at the regional level in the EU. The survey sample is randomly drawn from the structural survey of the Italian National Institute of Statistics and provides representative data along three dimensions: geographical region (location), economic size and farm specialization [19]. The survey does not cover all farms, but only those which, due to their size, can be considered to be professional and market-oriented (i.e., with a standard output higher than 8000 euros per year); consequently, the FADN sample is not fully representative of the entire national agricultural sector.

The whole Italian FADN sample of livestock farms referred to up to 2020 (the most recent available) is considered in this study, to ensure the representativeness of the exercise in all the three dimensions sampled. Summary statistics on FADN microdata are reported in the following Table 2, which distinguishes among farm type, economic and land size.

Table 2. Description of farm sample for farm types, economic size and agricultural area extension: number of farms (farms in n°), Utilized Agricultural Area (UAA in hectares), Livestock Units (LSU in n°), Operating Income (OI in 000 €), Labour Employment (LE in 000 hours).

	Farms	**UAA**	**LSU**	**OI**	**LE**
			Farm Type		
Dairy cattle	933	40.191	99.782	76.869	2.964
Beef cattle	487	22.737	35.849	21.349	866
Dairy & beef	153	7.717	9.282	4.947	297
Sheep	578	28.316	23.153	15.414	1.284
Sheep & cattle	46	2.548	2.331	1.077	110
Goat	58	2.854	1.145	578	99
Mix. ruminants	71	3.630	2.394	1.181	136
Pigs breeding	22	909	8.954	3.701	53
Pigs fattening	176	7.304	56.675	23.149	365
Pigs br. & fat.	19	554	3.975	1.631	65
Laying hens	57	665	15.185	14.448	123
Poultry meat	193	2.686	6.225	25.901	224
Hens & poultry	15	99	10.981	1.109	31
Mix. granivores	26	649	2.885	1.776	53
			Economic size		
Large	1.531	89.532	247.931	178.359	4.287
Medium	1.076	29.405	28.912	14.232	2.103
Small	227	1.924	1.971	541	279
			UAA size		
<5 ha	194	379	15.609	13.493	225
5–15 ha	640	4.686	41.413	25.151	1.161
15–40 ha	899	18.922	66.900	44.394	2.094
>40 ha	1.101	96.872	154.893	110.095	3.188
Total	2.834	120.860	278.815	193.133	6.669

Source: Authors' elaborations.

The sample consists of 2834 farms, extending over a UAA of 120,860 ha, of which 41% is located in Northern Italy, 15% in Central Italy and 44% in Southern and Insular Italy. The number of total LSU is 278,815, of which 63% is reared in Northern Italy; the total amount of operating income is €193,132,934, of which 60% is produced in Northern Italy. Overall land use characterizing the sample includes the following forage crops: pasture (53,702 ha), cereals (19,216 ha), forage leguminous (14,805 ha), grain leguminous (2906 ha), other forage crops (23,263 ha). The main productions reused for animal feeding are silage (335,175 tons) and hay (168,329 tons); other productions are grain (50,523 tons) and green grass (36,975 tons). Feed purchases on the market reach 463,061 ton, of which 79% are in Northern Italy.

In terms of land size, 39% of farms have an acreage of more than 40 ha, while only 7% have less than 5 ha. With reference to the type of livestock specialization, more than half of the farms are cattle farms (two thirds of which are specialized in milk production and the remaining part in fattening activities); more than 20% of farms are sheep and goat farms. The remaining farms are mainly specialized in rearing hens and poultry (9.4%), and in pig reproduction and fattening (7.7%). Cattle farms are particularly concentrated in Northern Italy (32%), sheep and goat farms in Central, Southern and Insular Italy (19.5%), while pig and chicken farms are uniformly distributed throughout the national territory.

2.2. AGRITALIM Model

The AGRITALIM model is an agroeconomic supply model that represents the entire FADN sample of Italian farms [8]. The model is calibrated with the PMP approach that perfectly calibrates the model to baseline (in this study, year 2020) and avoids adding ad hoc constraints and over-specialized responses of the model to policy changes. Moreover, a PMP model can be built and calibrated using a very simplified farm database, based only on production levels (e.g., land use and quantities production) and the main economic information related to production processes (e.g., output prices and variable costs). In fact, even in the presence of limited data, a PMP model guarantees the reconstruction of the variable costs structure, the substitutability relationships between processes as well as the representation of the farm productions, and then the use to carry out analysis ex-ante [9–11]. The mathematical representation of the AGRITALIM model is shown in Appendix A.

The objective function maximizes operating income, and the model variables are the hectares of crops and the number of animals. The main constraints of the model refer to land, labor and water. Regarding labor and water, the hours of labor and quantity of water pumping are additional variables. Another variable concerns the possibility of purchasing feeds on the market, considering that the latter can integrate self-production from cropping activities into animal feeding. The model also allows to add an area of fixed capital (acreage of tree crops and areas for animal) in the simulation phase, and then additional depreciation rates are considered in terms of costs. The operating income considers elements of market, production function and policy. Market prices refer to outputs, to some inputs for crop production (e.g., fertilizers, pesticides) and to all additional inputs purchased on the market (labor, feed, energy for water pumping). Production functions consider the relationships between quantity of inputs used and output obtained. The quantities of inputs needed per unit of production activities (matrix of technical coefficient) are used in the specification of the constraints and determine the needs in terms of land, labor, water, feeding and structures. Total needs must respect the availability of resources, with the possibility of additional variables [8].

Compared to other models described in the literature, the AGRITALIM model has some innovative aspects. Specifically, the model is very detailed from a territorial point of view, considering NUTS2 and NUTS3 areas and altimetric levels. Furthermore, the model considers all Italian farms of the FADN sample and allows the various groups of farm typologies to be represented in terms of production orientation, dimensional economic and land classes. In addition, the model has been recently integrated by adding data regarding expenditure for veterinary products and with an ad hoc methodology to estimate agricultural greenhouse gas emissions at farm level [18].

2.3. Simulations Performed

The AGRITALIM model, implemented with the abovementioned integrations, was used to carry out two different simulations based on the F2F strategy.

At present, there is no indication of how the proposed F2F targets will be applied at European or Member State level, and whether these targets will operate at the level of a single farm or at some level of farm aggregation (e.g., regional, national, etc.). In this exercise, we have assumed that the targets are applied at the farm level; thus, from a mathematical point of view, the reduction constraints act on the single farms. Although this might be the most restrictive approach, with no possibility of compensation between more efficient and less efficient farms, this approach was preferred here. In fact, it mimics some other policies already applied for input reduction, which are mainly based on standards at the individual farm level (e.g., the Nitrate Directive). However, it is important to underline that the simulations performed have no intention of proposing political measures, but to quantify the impacts at the farm level, based on conditions of the market and technologies observed in the baseline. This allows to understand which farms and sectors could be most affected by environmental targets and to give indications on strategies and policy measures.

The first simulation (2T) concerns two specific targets of the F2F strategy, regarding the reduction of the use of mineral fertilizers (−20%), and of pesticides classified as very toxic, toxic and harmful (−50%). The information on the quantities of fertilizers and pesticides actually applied to crops derives directly from FADN records at the farm level. The second simulation (3T) additionally considers the reduction of expenditure on antimicrobials (−50%). Table 3 summarizes the simulations performed.

Table 3. Characteristics of the simulated scenarios.

Scenario Description	Short Name	Fert.	Pest.	Antimicr.
Fertilizers and pesticides	2T	−20%	−50%	
+ expenditure for antimicrobials	3T	−20%	−50%	−50%

Source: Authors' elaborations.

3. Results

Results of the simulated scenarios are shown in Tables 4–6. Each table is divided into three sections—livestock farms for typology (Section 1), class of economic size (Section 2) and class of land size (Section 3)—and also reports overall impacts on the whole sample in the last row. Impacts are expressed in terms of percentage variations over the baseline.

Table 4 shows the impacts on the number of LSU reared, quantity of self-produced fodder and grain to be reused in animal feeding, and quantity of feeds purchased on the market.

Table 4. Percentage variation of livestock units, feed self-production and purchases.

	Livestock Units		Farm Forages		Farm Grains		Purchased Feed	
	2T	3T	2T	3T	2T	3T	2T	3T
	Farm Type							
Dairy cattle	−1.4	−32.9	−9.5	−27.7	−12.5	−29.7	12.8	−39.5
Beef cattle	−2.7	−32.8	−7.3	−25.4	−20.8	−29.6	7.4	−50.9
Dairy & beef	−0.6	−27.7	−12.5	−39.3	−9.0	−16.3	22.2	−35.8
Sheep	−0.3	−35.8	−5.5	−27.3	−9.5	−14.2	15.6	−62.7
Sheep & cattle	−0.2	−18.4	0.0	−2.6	−3.8	−4.4	0.4	−31.1
Goat	−0.5	−31.1	−11.3	−32.0	−7.9	−22.5	2.2	−44.1
Mix. ruminants	0.0	−30.6	0.4	−10.4	−0.5	−0.5	0.6	−20.3
Pigs breeding	−0.8	−47.6	−10.5	−38.7	−20.6	−8.4	1.0	−53.3
Pigs fattening	−0.1	−40.6	−0.4	−2.3	−14.5	−17.2	2.8	−45.2
Pigs br. & fat.	−0.9	−42.7	−11.4	−34.8	−6.3	−6.6	2.2	−50.5
Laying hens	0.2	−42.3	−15.4	−28.3	−12.0	−7.0	0.9	−41.3
Poultry meat	0.1	−43.8	−5.7	−15.2	−8.4	−19.5	0.6	−47.7
Hens & poultry	0.4	−50.0	−38.2	−23.6	−22.2	−28.4	7.8	−51.6
Mix. granivores	0.6	−42.9	0.0	−8.0	−13.5	−18.1	0.8	−36.8
	Economic size							
Large	−0.1	−27.7	−9.1	−28.5	−14.7	−21.8	7.9	−45.5
Medium	0.6	−19.4	−5.1	−19.4	−11.6	−19.5	6.0	−24.0
Small	0.2	−37.2	−3.7	−16.1	−5.1	−16.7	6.9	−17.0
	UAA size							
<5 ha	−0.4	−36.9	−7.0	−11.7	−14.2	−13.7	0.6	−36.9
5–15 ha	−1.3	−35.3	−10.8	−23.3	−11.6	−19.4	4.8	−40.6
15–40 ha	−1.2	−39.0	−9.0	−25.7	−20.1	−26.7	9.9	−41.7
>40 ha	−0.7	−38.2	−8.4	−28.7	−13.5	−20.7	8.2	−46.6
Total	−0.2	−34.9	−8.7	−27.6	−14.5	−21.6	7.7	−44.0

Source: Authors' elaborations.

Table 5. Percentage variation of UAA for group of crops.

	Cereal Crops		**Leguminous Crops**		**Other Forage Crops**		**Meadows & Pastures**	
	2T	3T	2T	3T	2T	3T	2T	3T
	Farm Type							
Dairy cattle	−16.3	−16.8	−8.2	−7.2	−10.5	−22.1	0.0	−16.7
Beef cattle	−17.9	−17.1	−4.6	−1.2	−11.8	−16.7	−0.3	−12.7
Dairy & beef	−5.3	−1.7	−3.7	−2.0	−9.3	0.9	0.2	−18.3
Sheep	−15.9	−10.5	−3.5	−5.0	−8.3	−18.9	1.3	−19.9
Sheep & cattle	−10.1	−11.8	−0.2	−0.7	−0.9	6.1	0.1	−2.7
Goat	−10.8	−9.8	−11.7	−19.9	−17.9	−29.7	0.3	−14.3
Mix. ruminants	−2.1	−2.1	−0.3	2.1	−1.7	−3.3	0.1	−18.1
Pigs breeding	−15.6	−9.6	−26.4	−36.8	1.0	1.0	0.0	−3.8
Pigs fattening	−18.2	−18.2	−9.0	8.5	−13.3	−17.1	8.3	−3.6
Pigs br. & fat.	−26.6	−29.9	−2.0	−1.2	−6.5	48.0	0.0	−0.6
Laying hens	−20.9	−8.0	−13.0	−5.8	−15.5	2.2	−5.9	40.4
Poultry meat	−21.8	−21.9	−13.4	−10.0	−8.8	−8.3	−5.6	−16.1
Hens & poultry	−18.3	−22.8	−7.8	2.0	0.0	0.0	0.0	0.0
Mix. granivores	−9.1	−8.5	−7.1	8.3	−12.7	−17.2	0.0	6.5
	Economic size							
Large	−17.3	−16.1	−7.2	−5.7	−10.4	−19.9	0.5	−15.1
Medium	−12.3	−9.6	−3.8	−0.5	−6.5	−4.8	0.1	−18.2
Small	−12.3	−15.1	−5.2	−0.2	−9.4	−14.1	0.2	−9.9
	UAA extension							
<5 ha	−17.4	−17.2	−14.7	−12.7	−4.7	−9.4	−8.9	1.0
5–15 ha	−15.4	−14.8	−9.0	−6.9	−11.7	−16.2	−1.3	−4.9
15–40 ha	−18.6	−16.6	−5.6	−4.9	−10.9	−17.2	0.4	−10.5
>40 ha	−16.3	−15.2	−6.7	−4.6	−9.3	−17.7	0.4	−16.8
Total	−16.7	−15.4	−6.7	−4.8	−9.8	−17.5	0.4	−16.1

Source: Authors' elaborations.

There appears, with evidence, the very different magnitude of the impacts predicted for the two scenarios. Under the 2T scenario, constraints on the use of fertilizers and pesticides impose limits on cropping activities, but shortcomings in feed self-production are compensated for by their purchase. This makes it feasible to keep almost unchanged the number of animals reared. However, this prediction does not account for the possible increase of feed prices consequent to the increase of feed purchases throughout the national territory. Price increases could hamper the feasibility of this response of farms to the applied constraints. Instead, the additional constraint of halving the use of veterinary antimicrobials, under the 3T scenario, imposes reductions on the number of LSU, if alternative (and less drastic) options are not undertaken by farmers. This explains the much stronger impacts of the 3T scenario on the considered variables.

Under the 2T scenario, the different extent of the impacts among farm typologies in self-production and purchase of feeds can be explained, considering the different level of reliance on purchases that characterizes ruminant- and monogastric-rearing farms. In fact, cattle-, sheep- and goat-rearing activities are largely based on self-production, through farm cropping activities, of the feeds necessary to meet animals' requirements, nearly limiting purchase only to concentrates. On the contrary, pigs, hens and poultry farms typically make large use of purchased grains and concentrates. This is why imposing restrictions on cropping activities determines the impacts on feed purchases of very different extents between these two groups of farm typologies, even in the face of comparable reductions in self-production. Focusing on the 3T scenario, the greater the rearing intensity (characteristic of pigs, hens and poultry farms, which typically use more antimicrobials), the greater the extent to which reduction of number of LSU occurs, as expected. More mild, though far from negligible, are the impacts predicted for ruminant-rearing farms. The consequent reduction of feed requirements determines a drop of feed self-production, and to a greater extent of feed purchases.

Table 6. Percentage variation of operating income and labor employment.

	Operating Income		**Labour Employment**	
	2T	3T	2T	3T
	Farm Type			
Dairy cattle	−3.8	−25.5	−3.6	−26.3
Beef cattle	−3.1	−13.9	−3.5	−18.9
Dairy & beef	−5.9	−17.3	−3.5	−21.4
Sheep	−2.5	−21.6	−2.5	−25.6
Sheep & cattle	−0.9	−38.4	−1.3	−14.9
Goat	−2.8	−20.9	−2.7	−20.7
Mix. ruminants	−0.5	−19.7	−1.4	−21.7
Pigs breeding	−3.2	−33.0	−3.7	−14.8
Pigs fattening	−2.2	−14.0	−8.1	−23.7
Pigs br. & fat.	−1.8	−26.8	−4.7	−32.6
Laying hens	−0.5	−12.9	−2.4	−13.1
Poultry meat	−0.8	−2.3	−7.1	−16.7
Hens & poultry	−0.6	−11.6	−0.5	−41.3
Mix. granivores	−1.9	−15.6	−5.4	−23.4
	Economic size			
Large	−2.7	−17.1	−4.4	−24.3
Medium	−2.7	−33.0	−2.1	−22.8
Small	−6.4	−35.8	−2.7	−19.7
	UAA extension			
<5 ha	−0.4	−10.1	−3.6	−21.2
5–15 ha	−1.7	−15.4	−3.2	−22.9
15–40 ha	−3.7	−22.6	−4.0	−24.8
>40 ha	−2.9	−18.2	−3.7	−23.6
Total	−2.7	−18.3	−3.7	−23.7

Source: Authors' elaborations.

Moving on to consider economic size regardless of farm typology, reductions affecting feed self-production under the 2T scenario have an extent proportional to farm size. The latter is often related to the level of intensity of cropping activities and translates into the increase in feed purchases. Instead, the constraints on antimicrobials imposed simulating the 3T scenario determine the strongest reduction of the number of LSU in small farms. The decrease of self-production activities occurs once again with an intensity proportional to farm economic size, affecting in particular forage production in large farms. The strong drop in feed purchases occurring in the latter, even in face of a slighter reduction of the number of LSU than that occurring in small farms, is indicative of the larger recourse to this form of supply made by these farms.

In classifying farms based on their land size, no univocal considerations can be made considering the 2T scenario. For instance, the most significant decrease affects forage self-production in farms of between 5 and 15 hectares, and grain self-production in those between 15 and 40 hectares. The latter are also characterized by the highest increase in feed purchases. Comprehensibly, this might suggest that no univocal relation exists between land size and level of intensity of cropping activities. A relation seems to emerge under the 3T scenario between land size and intensity of rearing activities. In fact, more relevant reductions occur for all the considered variables in farms of larger extension (above 15 hectares) than in the smaller ones.

The following Table 5 reports, for completeness of information, the changes in land use occurring under the two simulations.

Analyzing overall impacts, the acreage of cereals and (although at a lower extent) of leguminous crops is similarly reduced under the two scenarios; instead, impacts are very different for other forage crops, meadows and pastures.

The strong reduction of cereals under the 2T scenario is explained by their higher need of inputs than the other crops. Instead, as expected, nearly no change is forecast for the acreage of meadows and pastures, which require very low amounts of fertilizers and pesticides. Acreage reduction of leguminous crops under the 2T scenario contrasts with the need to encourage local production of protein forage crops. This could be of primary interest for making farmers more independent of purchased feed and could also provide agronomic benefits to cropping systems and increase EU protein self-sufficiency [20].

Completely different are the impacts under the 3T scenario, as a consequence of the reduction of LSU: very relevant reductions affect meadows, pastures and other forage crops, while the impacts predicted under the 2T simulation for cereals and leguminous crops are even mitigated, to balance the reduction of the other crops.

Very heterogeneous impacts are predicted among the different farm typologies, also considering the class of their economic and land size. Naturally, this determines the changes already evidenced in feed self-production, thus in feed purchase, but requires further insights going beyond the purposes of the present study. Consequently, we postpone this analysis to a future study going into greater depth in these aspects. Here, it is worth highlighting that the trend of a decrease in cropping activities, if no alternative strategy is undertaken to cope with the simulated constraints, is destined to generate phenomena of land abandonment. These will have to be necessarily managed to avoid serious consequences in terms of protection against land degradation.

Table 6 presents the results of examinations reporting the impacts predicted under the two scenarios on operating income and labor employment, which gives a measure of the social repercussions to be expected.

First looking at the overall results, similar considerations can be made to those exposed in commenting on Table 4, about the very different magnitude of the impacts predicted under the two scenarios. In specialized livestock farms, most of the income derives from rearing activities, which also absorb a very relevant share of farm labor. Thus, comprehensibly, the strongest impacts have to be expected under the 3T scenario, although these are not negligible in the 2T scenario. It should be highlighted that in both scenarios operating income reduces at a lower extent than labor employment. The reduction of cropping and rearing activities leads labor requirements to drop, and the expulsion of seasonal and temporary labor mitigates the reduction of operating income.

Similar considerations can be made in analyzing the impacts on the different farm typologies, particularly under the 3T scenario. Here the consistent reduction of the number of LSU (shown in Table 4) involves a huge decrease in labor requirements. Despite its social costs, labor expulsion is the main determinant in mitigating the negative impacts predicted on operating incomes, which are in fact about half the percentage of those predicted on LSU. The measure to which this occurs in the single farm typologies depends on how much rearing (and cropping) activities are labor-intensive, suggesting that labor productivity might also be involved.

Considering farms' economic size regardless of their typology, it should be noted that, in particular under the 3T scenario, the worst economic impacts affect medium and small farms, also because the high rate of feed self-production (evidenced in Table 4) prevents labor expulsion.

With reference to the analysis of the impacts considering the UAA size, univocal considerations cannot instead be made. In fact, the greatest economic impacts are evidenced in farms of intermediate extension, thus confirming that acreage extension in itself is not directly indicative of farming intensity and of farm economic size.

4. Discussion

The present study highlights the impacts that might affect the Italian livestock sector achieving some environmental targets set by the European F2F strategy. The latter consists of reducing the use of fertilizers and pesticides (2T scenario) and additionally reducing veterinary antimicrobials (3T scenario). The simulations were performed through the AGRITALIM model, which currently does not consider possible technological innovations and alternative production techniques, specific for the livestock sector. These could help to mitigate the impacts; therefore, managing to account for them represents the main goal of forthcoming AGRITALIM model developments.

However, results provide guidance to policymakers on the farm typologies that are likely to be most affected and on the potential impacts on production and land use if adequate policies of support are not adopted. In fact, especially under the 3T scenario, results highlight that important reductions might affect operating income. These are a consequence of the decrease of cropping activities (already appreciable under the 2T scenario), and of the numerical drop of reared LSU. These results are consistent with evidence from recent studies simulating F2F strategy reduction targets from the agricultural supply side in Italy and in other European Countries, although not specifically referring to the livestock sector [4,8,13–17].

Thus, the indications provided by this study can be used for targeting policy design to the single typologies of livestock activities, which is necessary given the variability of the impacts evidenced among the latter. This is essential also to ensure that the transition is not made at the expense of the profitability of the agricultural sector [14]. If this happened, no benefits for the global environment could even be created, since economic losses might occur on such a scale as to lead to relocating more intensive and polluting activities to other parts of the world. In this case, the achievement of any environmental purpose would be jeopardized [21]. Furthermore, land abandonment consequent to the decrease of cropping activities, if no alternative actions are undertaken with the support of agricultural policies, might result in a serious threat to the protection from land degradation. In this case as well, the objective of environment preservation would be compromised by the risks linked to the loss of territorial management and supervision, instead guaranteed by agricultural activities.

Another relevant aspect to consider, also in light of the great relevance in the 2023–2027 CAP programming, regards the social implications linked to the achievement of environmental targets. The critical aspects to consider are mainly two. First, the reduction of the hours of agricultural labor, in those Italian territories where no concrete employment alternative exists in other sectors, might increase the unemployment rate to socially and economically unsustainable levels. Second, the drop of remuneration for family labor, consequent to such large income reductions, might seriously undermine rural livelihoods and the economic sustainability of agricultural activities [22].

5. Conclusions

This study has presented an evaluation of the likely impacts on the Italian livestock sector from the adoption of some environmental targets envisaged by the F2F strategy. Environmental constraints set by this policy might produce evident economic and social implications, although their extent is differentiated by farm typology and size. However, it is worth highlighting that the impacts simulated by the AGRITALIM model are those to be expected under observed crop production techniques which currently make use of mineral fertilizers and chemical pesticides. In order to seek alternatives to the use of chemical pesticides that maintain farmers' incomes, the F2F strategy stresses the approach of integrated pest management (IPM). The latter is aimed at promoting greater use of safe alternative ways for protecting harvests from pests and diseases and encouraging the adoption of agronomic approaches such as crop rotation and mechanical weeding [3]. Weed control is a fundamental practice for ensuring satisfying crop performances. It is possible through mechanical methods also on maize [23], which in many areas of Italy represents the core of forage cropping systems. Crop rotation is complementary to mechanical methods for weed control and also plays a pivotal role in non-chemical (or low-chemical) strategies of pest management, which is why it is mandatory in integrated production systems. However, in the Po Valley (the largest maize cultivation district in Italy and Europe) about a quarter of maize extension was cultivated in single succession, and IPM found application on less than a quarter until quite recently [24].

With reference to the patterns of land use change, the large decline in cereals extension simulated by reducing the use of fertilizers and pesticides is not counteracted by an appreciable expansion of meadows and pastures. Shortcomings in forage and feed production on farm, consequent to the decline of cropping activities, can only be compensated for by an increase in purchases. However, cropland conversion to meadows and pastures would bring a significant contribution to EU mitigation strategies in terms of carbon sequestration. New Rural Development Programs (2023–2027) ensure CAP payments for conversion, so it will be of interest to implement AGRITALIM model with these payments. Although studies assessing the F2F strategy have reported positive effects of the strategy in terms of mitigation, changes in land use practices up to now have remained unexplored [25].

Even before the European Green Deal and the elaboration of the F2F strategy, Domínguez et al. [26] evidenced the importance of subsidizing farmers' investments in valid technologies to pursue climate-change mitigation goals. Using the CAPRI model, the reference for ex-ante evaluation of European agricultural policies, they warned about important production impacts affecting especially the EU livestock sector, if future environmental policy targets were set in absence of this support. Moreover, decreases in internal production, which are implicit in the case of non-adoption of technology improvements, could be partially offset by production increases in other parts of the world. The consequent phenomena of carbon leakage would hamper EU mitigation efforts at a global scale, but could be significantly reduced by subsidizing the adoption of technologies that allow agricultural production to be preserved. These provisions are reflected in the results of Fellmann et al. [27], simulating through CAPRI model the impacts of unsubsidized adoption of mitigation technologies. In that case as well, increases in imports and decreases in exports induced production increases in non-EU countries, associated with considerable leakage effects. With specific reference to the Italian livestock sector, the present study fully confirms the abovementioned evidence, simulating the impact of reaching EU environmental targets with current production technologies.

Ultimately, in order to allow the agricultural sector to tackle food security, economic profitability and global environmental change, a sustainable intensification process seems to be needed, i.e., the production of more food with lower resource inputs and emissions [28]. The differentiated impacts suggest that policies aimed at pursuing sustainable intensification in the agricultural sector cannot be undifferentiated. Instead, they should aim to accompany the transition towards a more sustainable agricultural sector and consider the different capacities of agricultural systems to respond to these challenges [29].

With reference to the limitations of this study, some issues are worth mentioning here. First, the study does not want to propose an evaluation of the F2F targets applied to the Italian agricultural sector, but limits itself to appraising the possible impact of the imposition of some of the F2F environmental targets on the supply side of production. As such, the study does not consider all the measures and tools that the F2F strategy wishes to implement in the food sector (e.g., demand-side measures). Equally, the possible increase in yields given by improved biodiversity or innovation adoption was not taken into account. Moreover, the use of Common Agricultural Policy subsidies to favor the transition towards more sustainable practices was not considered. Indeed, this might have led to an overestimation of impacts, as transition could be effectively accompanied by subsidies to support economic resilience of the farms. The latter could compensate for income losses due to the adoption of more sustainable practices or encourage farmers' investments in mitigation technologies. In any case, subsidies should be particularly oriented to the most affected farm typologies and sustain the effective targets (i.e., those for which synergies are exploited). Finally, the model uses data from the latest database available in terms of years (at the time of writing, the year 2020). Therefore, new market scenarios causing significant changes and impacts on the agricultural sector, begun in 2021 and continuing with Russian-Ukrainian conflict, are not considered.

Besides, the current modelling tool needs improvements. The model does not consider innovative technologies and farm practices that could contribute to the achievement of the environmental targets while minimizing the impacts on production.

For example, the adoption of digital technologies can improve animal welfare, thus limiting the use of antimicrobials without relevant reductions of LSU. Similarly, the use of techniques and instruments in the preventive phase can also limit the negative impacts. In all cases, however, policy measures are needed to incentivize investments, in the case of digital technologies, and to support higher variable costs, in the case of prevention activities.

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Appendix A. Mathematical Representation of the AGRITALIM Model

Appendix A.1. Objective Function

$\max Z = \mathrm{GPS} + \mathrm{CAP} + \mathrm{RCA} - \mathrm{VC} - \mathrm{QC} - \mathrm{EXL} - \mathrm{FP} - \mathrm{PW} - \mathrm{DRO} - \mathrm{DRNI}$
Operating income = Z
Gross Saleable Production = GPS = $pc \quad yc \quad XC + pm \quad ym \quad XA + revnm \quad XA$
CAP payments = CAP = $dp + cpc \quad XC + cpa \quad XA$
Revenues from Complementary Activities = RCA
Variable Costs = VC = $pfp \quad qfp \quad XC + acc \quad XC + aca \quad XA$
Quadratic Costs = QC = $\frac{1}{2} XC' \, Q \, XC + \frac{1}{2} XA' \, Q \, XA$

External Labor = EXL = $ph \, XH$
Feed Purchased = FP = $pf \, XF$
Pumped Water = PW = $pw \, XW$
Depreciation Rates Observed = DRO
Depreciation Rates New Investments = DRNI = $drtc \, ADTC + drsf \, ADSF$

Variables
XC = hectares of crops
XA = number of animals
XH = hours of labor
XF = quantity of feed
XW = quantity of water pumping

ADTC = additional area of tree crops
ADSF = additional area of stables and facilities

Market
pc = prices of crops
pm = prices of milk
pfp = prices of factors of production (fertilizers, pesticides)
ph = prices of external labor
pf = prices of feed purchased
pw = prices of water pumped
drtc = depreciation rates of new investments (tree crops)
drsf = depreciation rates of new investments (animals)

Production function
yc = yields of crops
ym = yields of milk
qfp = quantities of factors of production (fertilizers, pesticides)

Common Agricultural Policy payments
dp = decoupled payments
cpc = coupled payments for crops
cpa = coupled payments for animals

Revenues and average costs
revnm = revenues from other animal products no milk (meat, eggs, honey, . . .)
acc = average costs for crops (per hectare)
aca = average costs for animals (per number)

Appendix A.2. General Constraints

$$\sum_j XC_{j,n} \leq ald_n \quad \forall n$$

$$\sum_j ml_{j,n} XC_{j,n} + \sum_{ja} ml_{ja,n} \quad XA_{ja,n} \leq alb_n \quad \forall n$$

$$\sum_j mw_{j,n} XC_{j,n} \leq awt_n \quad \forall n$$

$$\sum_{jt} \quad XC_{jt,n} \leq atc_n + ADTC_n \quad \forall n$$

$$\sum_{ja} msf_n XA_{ja,n} \leq asf_n + ADSF_n \quad \forall n$$

$$\sum_{ja} mf_n \quad XA_{ja,n} \leq afp_n + XF_n \quad \forall n$$

$$\sum_{jan} rc_n \quad XA_{jan,n} \geq \sum_{jap} XC_{jap,n} \quad \forall n$$

Sets shown in the mathematical representation
j = types of crops
n = farms
ja = types of animals
jt = tree crops
jan = types of animals non-productive
jap = types of animals productive

Other sets (not shown in the mathematical representation): geographical area [NUTS 2 and NUTS 3], altimetric level, types of cultivation (field, vegetable garden, greenhouse), following crops, main vegetable product, animal production, time

Matrix coefficients
ml = labor (manual and mechanical) needs per each crop and animal
mw = water needs per each irrigated crop
msf = square meter of stables and facilities per each animal
mf = feed needs for each animal

rc = ratio between productive and non-productive animals

Availabilities
ald = land availability per each farm
alb = labor availability per each farm
awt = water availability per each source (e.g., water users' association, well, . . .) and farm
atc = tree crops area per each farm
asf = total square meter of stables and facilities
afp = quantity of feeds produced in farm

Appendix A.3. Constraints on Use of Chemical Inputs

$$\sum_{j,tf} qfp_{j,tf,n} \quad XC_{j,n} \leq 0.8 \quad QF_n^0 \quad \forall n$$

$$\sum_{j,tp,tc} qfp_{j,tp,tc,n} \quad XC_{j,n} \leq 0.5 \quad QP_n^0 \quad \forall n$$

$$QF_n^0 = \sum_{j,tf} qfp_{j,tf,n} \quad XC_{j,n}^0 \quad \forall n$$

$$QP_n^0 = \sum_{j,tp,tc} qfp_{j,tp,tc,n} \quad XC_{j,n}^0 \quad \forall n$$

Sets
tf = types of fertilizers (e.g., solid minerals)
tp = types of pesticides
tc = toxicological classes (e.g., very toxic, toxic and harmful)

Matrix coefficients, availabilities and variables
qfp = quantities of factors of production (fertilizers, pesticides)
QF^0 = quantity of fertilizers used in the baseline
QP^0 = quantity of pesticides used in the baseline
XC^0 = hectares of crops observed in the baseline

Appendix A.4. Constraints on Antimicrobials Expenditure

$$\sum_{ja} antexp_{ja,n} \quad XA_{ja,n} \leq 0.5 tantexp_n^0 \quad \forall n$$

Matrix coefficients and availabilities
antexp = antimicrobials expenditure for animal
$tantexp^0$ = total antimicrobials expenditure for farms observed in the baseline

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