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## The importance of wooden biomass in the transition to a bioeconomy in Latvia

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**Abstract.** The EU Green Deal advocates decarbonising the EU's energy sector, largely by transitioning to renewable sources. Latvia aims to increase the share of renewable energy production in total energy production to 50% by 2030 (it was 39% in 2017), prioritising biomass from forests and wood for bioenergy. This paper evaluates increasing the tax on non-biobased energy use alongside implementing a subsidy for biobased energy use, particularly from wood biomass, to promote the substitution of the first by the latter as a step towards climate neutrality and energy self-sufficiency. Furthermore, it examines technological advancements in the bioenergy sector as an alternative instrument. Using an applied general equilibrium model and 2015 supply and use data, the study allows for substitution between domestic and imported inputs and between the non-biobased and biobased energy product. Given Latvia's heavy reliance on imported fossil fuels, these measures could lead to a 58% increase in bioenergy production compared to 2015, reducing CO<sub>2</sub> emissions by 0.3–1.7%, and reducing non-biobased energy imports by 2.5–4.2%.

**Keywords:** biobased energy, non-biobased energy, product tax, subsidy.

### 1. INTRODUCTION

The transition from a fossil-based economy to a biobased economy is considered a priority to mitigate the effects of climate change in the European Union (EU). The EU Green Deal states that the EU has to become climate neutral by 2050 (EC b, n.d.). This requires the EU to reduce net greenhouse gas (GHG) emissions to zero. Carbon dioxide (CO<sub>2</sub>) remains the main greenhouse gas emitted through human activities, and most CO<sub>2</sub> emissions come from the energy sector: electricity, heating, and transport. Therefore, one of the main actions proposed in the Green Deal is to decarbonise the EU's energy sector, largely through the transition of the generation of power from fossil-based to renewable sources. The Latvian government follows this action with the intention to increase the production of energy from renewable sources to 50% of the total energy production in 2030 (it was 39% in 2017). To achieve this goal, an emphasis will be placed on sourcing biomass from the forest and wood industry to be used for the production of biobased

energy (EM, 2019). The reason for this focus is that the production and use of other renewable energy products are small. For example, in 2015 91.7% of the use of renewable energy was from biomass from forests and wood, for hydropower, this was 7.7% and for wind 0.6%.

As a reaction to the Russian invasion of Ukraine, the European Commission introduced the REPowerEU plan in March 2022 outlining measures to drastically reduce Russian gas imports and achieve independence from Russian fossil fuels before the end of the decade. The key elements in this plan are diversifying supplies, reducing demand, and increasing the production of green energy in the EU. This is expected to accelerate the green transition by reducing GHG emissions, reducing dependency on imported fossil fuels, and protecting the EU against price hikes on the energy market (EU Commission, 2022).

Economic instruments like taxes on fossil fuels and subsidies on biobased energy production or use can contribute to achieving the goals of the Green Deal and the REPowerEU plan. Since fossil fuels are non-renewable and GHG emissions are harmful to the environment, a product tax can help in reducing its demand and supply, as it increases the net price demanders pay and decreases the price suppliers receive. Product subsidies for biobased energy have the opposite effect. Moreover, product taxes and subsidies can stimulate the development and use of more sustainable technologies (Wolfson & Koopmans, 1996).

A tax on fossil energy can – in addition to the reduction in emissions – lead to an increase in welfare if it reduces the tax distortions caused by other taxes (“second best effect”). If this happens, then we speak of a ‘double dividend’ (see De Mooij, 2002 and Goulder, 1995). A potential double dividend can be an extra incentive to introduce a tax on fossil energy use.

In Latvia, the forest sector is one of the cornerstones of the economy. Forestry, wood processing and furniture manufacturing contributed 5.1% to GDP, 5.4% to total employment and 20.7% to exports in 2018 (AM - Ministry of Agriculture, 2022). Furthermore, the forest area covers 52% of the country’s territory and this is expanding. It has doubled since 1935 due to farm abandonment that resulted in the conversion of cropland fields into young forests (Fonji & Taff, 2014). The increase in forest area is expected to continue because of purposeful afforestation, as well as through the continued natural overgrowth of forest on non-agricultural lands. Moreover, wooden biomass is increasing annually due to more sustainable forest management in recent decades (Lazdiņš et al., 2019). This opens possibilities for further increase in the use of wooden biomass in the production of biobased energy.

The aim of this paper is to investigate the potential of taxes, subsidies, and technological change to increase the share of biobased energy production in Latvia. More specifically, it assesses the effect of an increase in the tax on non-biobased energy use and the implementation of a subsidy on biobased energy use, especially from wooden biomass, to facilitate the substitution of the first for the latter as a step in the transition of Latvia’s economy towards climate neutrality and self-sufficiency of energy. Moreover, the paper assesses the effects of technological change in the industry producing biobased energy. Such a technological change in the production of biobased energy is instrumental for a successful transition of the energy sector. To this end, the EU and the Latvian government will stimulate technological change as part of the Green Deal using € 4.4 billion from EU funds for Latvia between 2021 and 2027 (FM, n.d.).

The paper uses an applied general equilibrium (AGE) model based on the model developed by Komen and Peerlings (1999) to achieve the aim. Their model included greenhouse gas emissions and policy scenarios to reduce these emissions. However, it did not distinguish between non-biobased and biobased energy, nor did it include biomass. Especially in the 1980s and 1990s AGE models were used to assess different policy issues, e.g., agricultural policy reform, environmental taxation, etc. (for an overview, see Bergman, 1990; Gunning & Keyzer, 1995; Robinson, 1989). Policy issues simulated with AGE models reflect relatively large shocks to an economy, as AGE models explicitly model the economy as a whole. Calculating the effects of large shocks cannot be done using a partial equilibrium model given that these models assume too many variables (e.g. wages, interest, etc.) exogenous. The transition towards climate neutrality and energy self-sufficiency can be considered as a large shock to the Latvian economy. Data come from the supply and use tables for 2015 and national accounting data from the Latvian Central Statistics Bureau (CSB). It is assumed that a nested production structure allows for explicit imperfect substitution between domestic and imported inputs in energy production to account for Latvia’s current dependence on imported fossil fuels. By increasing the use of (domestically produced) wooden biomass in the energy sector through a tax on the use of non-biobased products and a subsidy on the use of the biobased products, the amount of CO<sub>2</sub> emissions from fossil energy and the dependence on fossil energy imports are expected to reduce. The technological change is expected to lead to similar effects. To the best of our knowledge, this is the first application of an AGE model to Latvia and the first AGE analysis to investigate the effects of the Green Deal.

The remainder of the paper is structured as follows. Section 2 describes the energy and forestry sectors and policies of Latvia. Section 3 presents the AGE model. The data are described in Section 4. Section 5 presents and discusses the results of the model. Section 6 concludes and provides a general discussion.

## 2. ENERGY AND FORESTRY SECTORS, AND POLICIES

Latvia is highly dependent on imports of fossil fuels. Table 1 shows that oil products and natural gas are not produced in the country. Electricity is produced mostly domestically, partly from fossil fuels and partly from renewable energy sources.

To meet the objectives set by the EU in the Green Deal and international commitments (see Table 2), the Latvian government drafted the *National Energy and Climate Plan 2021–2030*. The long-term goal of the plan is to promote the development of a climate-neutral economy in a sustainable, competitive, cost-effective, secure, and market-based way by improving energy security and public welfare. To achieve this goal, it is necessary: ‘1) *To promote the efficient use of resources, as well as their self-sufficiency and diversity; 2) To ensure a significant reduction in the consumption of resources, in particular*

*fossil and unsustainable resources, and a simultaneous transition to sustainable, renewable and innovative use of resources, ensuring equal access to energy for all sections of society; 3) To stimulate research and innovation that contributes to the development of a sustainable energy sector and the mitigation of climate change’* (EM - Ministry of Economics, 2019).

One of the goals of the *National Energy and Climate Plan* is to increase the share of renewable energy sources in Latvia. The plan includes the so-called ‘tax greening’ (“polluter pays principle”), where the focus is on taxes such as excise, value added, vehicle, electricity, and natural resource taxes. However, to our knowledge, these have not been implemented by the beginning of 2025.

The transition from a fossil-based economy to a biobased economy is especially relevant for the forest sector in Latvia. The forest sector is expected to contribute to this transition through the replacement of fossil fuels and non-renewable products with forestry-based products (Kröger & Raitio, 2017). In addition to being used in the production of traditional wood-based products, such as furniture, wooden biomass is increasingly being used in energy generation and in the production of textiles, bioplastics, chemicals, and intelligent packaging, and is also contributing to the construction sector (Hetemäki et al., 2017; Hurmekoski et al., 2018).

**Table 1.** Energy production, imports, exports and domestic consumption in Latvia, 2020.

Product	Production	Imports	Exports	Domestic consumption
Oil products, thousand Euro <sup>1</sup>	-	726.56	145.64	542.4
Natural gas, million Euro	-	433.74	0.00	433.74
Electricity, million Euro	181.86	137.71	84.02	235.55

<sup>1</sup> Production plus imports does not add up to domestic consumption and exports because of changes in stocks and statistical issues. Source: CSB, 2021a, 2021b, 2021c.

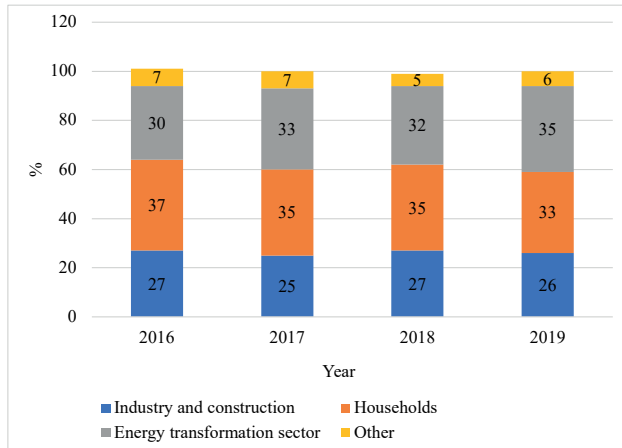
**Table 2.** EU and Latvia’s energy policy indicators and targets

Indicator/target	EU’s target, 2030	Latvia’s actual value in 2017	Latvia’s target, 2030	Latvia’s target, 2050
Reducing GHG emissions (% to 1990) (LULUCF* excluded)	-40	-57	-65	Climate neutrality (irreducible GHG emissions are compensated by LULUCF sector)
Reducing GHG emissions (% to 1990) (LULUCF included)	-	-	-38	
Energy produced from RES**, share of gross final consumption (%)	32	39	50	-
Share of imports in gross domestic energy consumption (%)	-	44.1	30–40	-

\* Land Use, Land Use Change and Forestry.

\*\* Renewable energy sources.

Source: EM, 2019.



**Figure 1.** Wooden Biomass Consumption in Energy Production in Latvia 2016–2019 (%). Source: AM, 2022.

One fifth of the forest stands in Latvia is in the age of mature and old-growth (CSB, 2021d). The CO<sub>2</sub> sequestration capacity of old trees is relatively low, hindering the fulfilment of the Green Deal targets making them a potential feedstock to produce biobased energy.

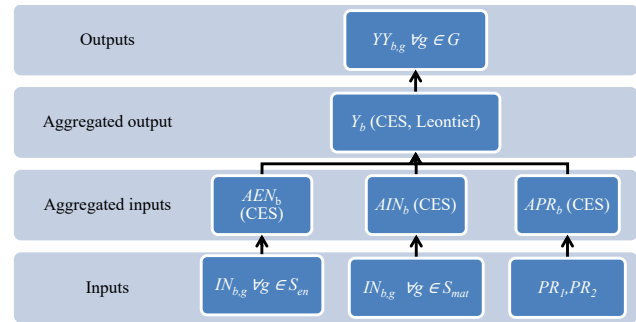
According to data from the EU Bioeconomy Monitoring System Dashboard (EC, n.d.), 58.5% of wooden biomass in Latvia is used in the production of bioenergy and 41.5% is used as materials in manufacturing in 2015. The largest share of wooden biomass in energy production was taken by firewood (30% of the total consumption of energy sources) in 2018, followed by briquettes, pellets, wood scraps, and wood chips. The largest consumers of wooden biomass are households followed by the energy transformation sector (Figure 1).

### 3. MODEL

This section describes the AGE model developed and applied in this paper. The model is based on the model of Komen and Peerlings (1999). Their model included greenhouse gas emissions and policy scenarios to reduce these emissions. However, it did not distinguish between non-biobased and biobased energy. We present the model in Section 3.1 and discuss the modelling of taxes, subsidies, and technological change in section 3.2. A full description can be found in Appendix A.

#### 3.1. General description

An AGE model describes an economy as a whole and is therefore useful to analyse large shocks to the

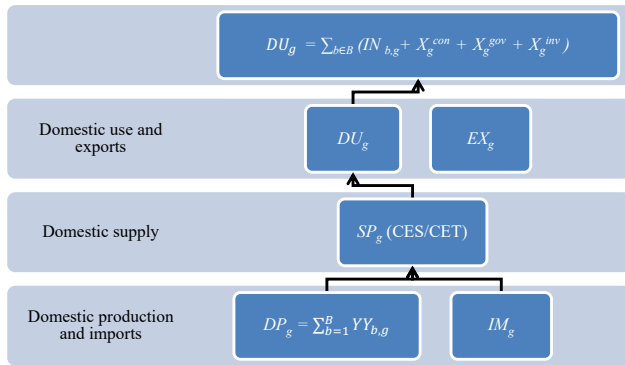


**Figure 2.** Production of industry b. Where:  $IN_{b,g} \forall g \in S_{en}$ : use of energy commodity  $g$  as an intermediate input in industry b. Commodities are in the set  $S_{en}$  of energy intermediate inputs.  $IN_{b,g} \forall g \in S_{mat}$ : use of commodity  $g$  as an intermediate input in industry b. Commodities are in the set  $S_{mat}$  of non-energy intermediate inputs.  $PR_1, PR_2$ : labour ( $j=1$ ) and capital ( $j=2$ ) used in industry b.  $AEN_b$ ,  $AIN_b$ , and  $APR_b$ : aggregate energy, aggregate intermediate and aggregate primary input use, respectively, in industry b.  $Y_b$ : aggregate output in industry b.  $YY_{b,g}$ : output  $g$  of industry b. Source: Authors' elaboration.

economy that affect, through market linkages, all the economy's actors (i.e. industries, households, government). It mainly consists of demand and supply functions of commodities and factor inputs, and income formation and distribution equations (Dervis et al., 1982). The developed model contains 60 commodities and 60 industries including both a non-biobased and biobased energy commodity and industry. However, one industry can produce more than one commodity, and one commodity can be produced by more than one industry. Industries are assumed to minimise costs as they face a constant returns to scale nested Constant Elasticity of Substitution (CES) production function (see, e.g. Arrow et al., 1961; Sato, 1967).

Figure 2 shows that for industry b, the intermediate energy intermediate inputs ( $IN_{b,g} \forall g \in S_{en}$ ), material intermediate inputs ( $IN_{b,g} \forall g \in S_{mat}$ ) and primary inputs ( $PR_1, PR_2$ ) are aggregated into 3 aggregate inputs respectively. This is done using 3 CES functions, each with their own substitution elasticity. The aggregate inputs are then aggregated into an aggregate output ( $Y_b$ ) using a CES function with again its own substitution elasticity. The aggregated output is then divided into different outputs ( $YY_{b,g}$ ) using a Leontief transformation function (i.e., using fixed ratios).

At the highest level, outputs are produced by an aggregate energy input, an aggregate intermediate input, and an aggregate factor input. At the lowest level, the aggregate energy input is composed of a biobased and a non-biobased energy input. The aggregate intermediate input is composed of 58 non-energy intermediate inputs.



**Figure 3.** Supply and use of commodity  $g$ . Where:  $DP_g$  : domestic production of commodity  $g$ .  $IM_g$  : imports of commodity  $g$ .  $SP_g$  : total supply of the commodity  $g$ .  $DU_g$  : domestic use of the commodity  $g$ .  $EX_g$  : exports of commodity  $g$ .  $IN_{b,g}$ : intermediate input demand of commodity  $g$  in industry  $b$ .  $X_g^{con}$ : private household demand of commodity  $g$ .  $X_g^{gov}$ : public household demand of commodity  $g$ .  $X_g^{inv}$ : investment demand of commodity  $g$ . Source: Authors` elaboration.

The aggregate factor input is composed of labour and capital. Cost minimisation leads to the demand for energy intermediate inputs, non-energy intermediate inputs, labour and capital.

Figure 3 shows that in the next step of the model, the outputs produced by different industries are aggregated commodity by commodity. Aggregation gives domestic production ( $DP_g$ ) of a commodity  $g$ . Domestic production competes with imports of the same commodity ( $IM_g$ ). This competition can be seen as an aggregation into total supply ( $SP_g$ ) using a CES production function. The total supply is then disaggregated using a CET transformation function into domestic use ( $DU_g$ ) and exports ( $EX_g$ ). CES production and CET transformation functions imply that with profit maximisation relative prices determine demand and supply, respectively.

Domestic use equals the sum of intermediate demand ( $\sum_{b \in B} IN_{b,g}$ ), private household demand ( $X_g^{con}$ ), public household demand ( $X_g^{gov}$ ) and investment demand ( $X_g^{inv}$ ).

The model includes one private household that supplies labour and capital to the industries and receives income in return. Capital and labour are assumed to be imperfectly mobile between industries. We also assume one aggregated public household (i.e., government). Consumption of commodity  $g$  by the private and public household follows from maximising a CES direct utility function given an income constraint. The CES utility function used implies an income elasticity of one. In addition, as a consumer, the public household imposes taxes and redistributes income. A fixed share of both

private and public household income is saved. Savings together with the (minus) surplus on the balance of trade equal investment. Investment demand is modelled using a Leontief production function implying that the demand for an individual commodity is proportional to total investment (Komen & Peerlings, 2001).

The model also includes greenhouse gas emissions that are proportionally linked to the production of an industry ( $Y_b$ ).

### 3.2. Taxes, subsidies, and technological change

All transactions in the model can be potentially taxed or subsidised. Taxes can be divided into product and non-product taxes (including subsidies). The latter are levied on income, the first on transactions of commodities. Product taxes drive a price wedge between the demand and the supply price. In the model, we use ad valorem taxes on demand (see Equation 1).

$$P_{demand} = (1 + tax_{rate})P_{supply} \tag{1}$$

A tax increases the price demanders must pay and decreases the price suppliers receive; a subsidy does the opposite.

This paper also examines the effects of Hicks neutral technological change in the biobased energy industry. Hicks neutral technological change implies that with the same level and ratio between (all) inputs, more biobased energy can be produced. Equation 2 shows a CES input demand function. In the case of a Hicks neutral technological change, the exogenous scale parameter  $\Gamma$  increases. We include the Hicks neutral technological change in the aggregate demand functions (see Figure 2) of the biobased energy industry. Hicks neutral technological change implies that input demand ( $x_n$ ) and cost of production decrease given a level of output *ceteris paribus*. However, in the AGE model, the *ceteris paribus* assumption does not hold, as Hicks neutral technological change lowers the price of wooden biomass as less is needed to produce biobased energy, making it more attractive to demand. Therefore, technological change in the production of biobased energy leads to an increase in the demand for wooden biomass and a lower price for biobased energy. In addition, the lower price of biobased energy leads, because of substitution, to a reduction in the demand for non-biobased energy by all demanders. The degree of substitution between biobased energy and non-biobased energy depends on the degree of substitution (i.e. substitution elasticity) between both in the different industries.

$$x_n(\cdot) = y \cdot \Gamma^{-1} \cdot \alpha_n^\sigma \cdot w_n^{-\sigma} \cdot \left( \sum_{n=1}^N \alpha_n^\sigma \cdot w_n^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}}$$

$$n = 1, \dots, N \quad (2)$$

where:  $x_n$  - conditional demand for input  $n$ ,  $y$  - output,  $w_n$  - price of input  $n$ ,  $\sigma$  - substitution elasticity,  $\Gamma$  - scale parameter and  $\alpha_n$  - distribution coefficient of input  $n$ .

#### 4. DATA

The model uses the supply and use tables (SUT) at the basic prices from Latvia's Central Statistical Bureau for 2015 (CSB Latvia, 2016). A supply table shows in its columns the supply of commodities by the different industries and by imports in an economy for a given period. A use table shows in its columns the use of commodities by type of use. Therefore, the use table reveals in its columns the input structure of each industry and the demand for individual commodities by the different final demand categories (Eurostat, 2008). Due to a lack of data, some industries and commodities are aggregated. The data set used in modelling contains 60 commodities and 60 industries (see Appendices B and C).

Furthermore, we use Latvia's 'energy SUT' in terajoules from Eurostat's 2015 Physical Energy Flow accounts (Eurostat, 2021) with energy commodities supplied/used by industries to split commodity *Electricity, gas, steam and air-conditioning* of the SUT in non-biobased and biobased *Electricity, gas, steam and air-conditioning*, respectively. We consider energy commodities wood, wood waste and other solid biomass, liquid fuels, and biogas as biobased energy commodities. Other energy commodities are fossil-based or renewable energy sources that are not biobased. This implies, for example, that electricity and heat are non-biobased energy products, but they can be produced using both the biobased and non-biobased product.

The two energy commodities are used to calculate the shares of biobased and non-biobased energy commodities in the commodity and industry '*Electricity, gas, steam and air-conditioning*' in the SUT, respectively. According to the data of Physical Energy Flow accounts, 7.47% of the total energy supplied and 5.88% of the total energy used comes from biobased energy commodities.

### 5. SCENARIOS AND RESULTS

#### 5.1. Scenarios

In the Base scenario, the model calculates back the actual situation of the Latvian economy in 2015. This

includes a product tax of 17% for all energy commodities - biobased and non-biobased - since all energy producers pay the tax.

#### Scenario I

In Scenario I, we introduce an arbitrary 25% tax on non-biobased energy demand and a subsidy of 10% for biobased energy demand replacing the 17% tax on both products in the Base scenario (see Equation 1 and equations A.29-A.33 in Appendix A).

#### Scenario II

In Scenario II, a 25% Hicks neutral technological change in the biobased energy production industry is introduced in the Base scenario, where the scale parameter  $\Gamma$  in eq. (2) is increased by 25%. This scenario reflects the technological change in new technologies producing biobased energy that is partially stimulated by government investment from EU funds. The 25% is selected because it leads to a similar increase in the production of biobased energy as in Scenario 1.

#### 5.2. Results

Table 3 shows the outcomes of both scenarios. It is important to note that all price changes are relative to the price numeraire chosen, which is the exchange rate in our case.

#### Scenario I

Table 3 shows that due to the switch to the subsidy (10%) on biobased energy, its production increases with 57.8%. Table 3 also shows that due to the tax (25%) on non-biobased energy, the price of non-biobased energy increases for buyers (8.3%). Moreover, production in the non-biobased energy industry decreases (-6.0%). This leads to a reduction in the value added (-2.9%) of this industry. Non-biobased energy is substituted by biobased energy in all industries where the degree of substitution depends on the substitution elasticity between non-biobased and biobased energy. In the model, we assume that this substitution elasticity is large ( $\sigma = 1.5$ ), implying that the degree of substitution is large (see Table A3). In all industries, we see therefore a reduction in the demand of non-biobased energy and an increase in the use of biobased energy. Overall, the use of energy falls between 1-3% (a reduction of  $AENb$ ; see Figure 2). The increase in biobased energy production (57.8%) leads to a reduction in imports of biobased energy products (i.e. natural gas and oil) of 4.2%, making Latvia less dependent on energy imports. However, the subsidy on non-biobased energy increases the imports of this prod-

**Table 3.** Scenario results compared to initial values (i.e., Base scenario)

	Initial values	Scenario I: Tax and subsidy (% change)	Scenario II: Technological change (% change)
Production* and value added** in million euro of the base year			
Production of non-biobased energy industry ( $Y_b$ )	1,766.3	-6.0	-1.2
Production of biobased energy industry ( $Y_b$ )	110.3	57.8	57.9
Forestry production ( $Y_b$ )	938.9	-0.3	-0.1
Value added in non-biobased energy industry ( $APR_b$ )	663.6	-2.9	-0.8
Value added in biobased energy industry ( $APR_b$ )	34.2	27.7	10.3
Value added in forestry ( $APR_b$ )	352.8	-0.2	-0.1
Prices (index, so no unit)			
Price of non-biobased energy production (price of $DP_g$ )	1.00	1.2	-0.8
Price of biobased energy production (price of $DP_g$ )	1.00	9.4	-28.1
Price of non-biobased energy demand (price of $DU_g$ )	1.17	8.3	-0.8
Price of biobased energy demand (price of $DU_g$ )	1.17	-16.1	-28.8
CO <sub>2</sub> emissions*** in 1000 tons			
CO <sub>2</sub> emissions in non-biobased energy industry	1,757,841	-6.0	-1.2
Total CO <sub>2</sub> emissions	6,937,629	-1.7	-0.3
Tax revenue in million euro (nominal)		(M euro)	(M euro)
Product tax paid on non-biobased energy product	293.7	411.1	287.7
Product tax paid on biobased product	23.7	-21.9	24.5
Welfare in million euro of the base year		(M euro)	(M euro)
Laspeyers index		63.5	61.9

\* Note: quantities are expressed in million euros for the base year 2015. This implies that initial supply prices (indices) are equal to 1; the initial price for energy demanders is equal to 1.17 due to the 17% tax on energy demand.

\*\* Value added equals the value of capital and labour.

\*\*\* Excluding CO<sub>2</sub> emissions from biobased energy commodities that are assumed to be climate neutral.

Source: Authors' elaboration.

uct (64.4%). However, these imports are still very small. Table 3 shows a 1.7% reduction in CO<sub>2</sub> emissions assuming CO<sub>2</sub> emissions from the biobased energy product to be zero (i.e. being climate neutral). The reduction largely follows from the reduced use of non-biobased energy products (5.7%). Despite this reduction, the target of 50% energy from biobased sources is not reached.

Overall, there is a welfare gain (63.5 million euros) in Scenario I, where we measured welfare as private, public, and investment demand changes in prices of the base year. The welfare gain results from a reduction in already existing distortions by introducing the subsidy for biobased products (replacing the 17% tax) and increasing the tax on non-biobased products (from 17% to 25%). Therefore, there is a double dividend. However, whether the double dividend exists depends on the level of tax and subsidy. Sensitivity analyses show that larger taxes and subsidies create welfare losses and that especially the subsidy helps to reduce already existing distortions. Table 3 shows that the increase in tax revenue from the product-related tax on non-biobased energy

production (117.4 million euro) is larger than the cost of the switch from the tax to the subsidy for the biobased product (45.6 million euro).

#### Scenario II

Table 3 shows that Hicks neutral technological change of 25% (Scenario II) results in a reduction in the price of biobased energy (-28.1%) and therefore, an increase in production (57.9%) and value added (10.3%) in the biobased energy industry. This leads to a substitution away from non-biobased energy and a reduction in the production (-1.2%) and value added (-0.8%) in the non-biobased energy industry. Also, in this scenario, import of the biobased energy product fall (-2.5%). The lower price of the biobased energy product decreases imports of the biobased energy product (-12.4%). Again, imports are very small. Compared to Scenario I, the reduction in CO<sub>2</sub> emissions is smaller (0.3% versus 1.7%) because the price and production of non-biobased products changes less, and therefore, less substitution takes place. The welfare increase is similar to the welfare

increase in Scenario I (61.9 million euros). This welfare gain results from the fact that fewer inputs are needed in the production of biobased energy. This shows the attractiveness of technological change. However, in this scenario, technological change is 'free', and this is, of course, not true.

Overall, one can conclude that the effects for the Latvian economy are not large. Important reasons for this are the fact that the biobased energy industry is small and even a large growth in production (57.8% and 57.9% in Scenario I and II respectively) does not create a substantial change. Another reason is that in the AGE model factor inputs are mobile between industries making that labour and capital moving out of industries affected negatively by the scenarios can be used elsewhere in the economy leading there to higher production and value added. Finally, the AGE model allows for substitution because of relative price change, again smoothing the effect for the economy as a whole.

## 6. CONCLUSIONS AND DISCUSSION

This paper aims to assess the effect of a tax on non-biobased energy demand and a subsidy on biobased energy demand replacing a lower tax on both to facilitate the substitution of the first for the latter as a step in the transition of Latvia's economy towards climate neutrality and energy self-sufficiency. Furthermore, the effects of Hicks neutral technological change in the biobased energy industry are examined. The paper uses an applied general equilibrium (AGE) model to assess the effects of a tax, subsidy, and technological change given the expected economy-wide effects and interest in national emissions and welfare.

The paper finds that a tax in combination with the subsidy indeed has the expected effects. The Green Deal proposed decarbonisation of the economy by transitioning from fossil-based to renewable sources in energy production. Latvia aims to increase the share of renewable energy production in total energy production to 50% by 2030 (it was 39% in 2017), focussing on the use of wooden biomass in energy production. According to the results of the model, the supply of the biobased energy commodity has increased by 57.8%. However, measures are insufficient to deliver the target, climate neutrality, and energy self-sufficiency. However, there is an overall welfare gain in both Scenario I and Scenario II. So, Scenario I reduces existing distortions in Latvia's economy (i.e., double dividend). Scenario II (technological change in the biobased energy industry) leads to a similar increase in the production and use of biobased energy.

Because in Scenario II the prices of non-biobased energy are affected less than in Scenario I, its production and use fall less leading to a lower reduction in CO<sub>2</sub> emissions. Although the welfare gain is similar to the gain in Scenario I, Scenario II ignores the costs of technological change and does not explicitly include the incentives needed to implement it.

To our knowledge, there are no prior studies on the use of wooden biomass for bioenergy production in Latvia. While there are studies of the AGE model on energy taxes, they are not recent. For example, Komen and Peerlings (1999) analysed the effect of an energy tax on small users in the Netherlands using 1990 data. They only find a double dividend in the case of small tax rates. Goulder (1995) discusses the double dividend in more detail, coming to the same conclusion. Welfare effects found by Komen and Peerlings (1999) are also small, like in our case. This is largely due to the substitution possibilities economy-wide and fixed endowments of labour and capital in combination with factor mobility in the models used.

This study has three main caveats. First, Latvia devised an action plan in 2019, and is currently undergoing upgrading procedure, although the exact measures are largely unknown. Therefore, it is not possible to calculate the effects of actual policies. This research can contribute to the formulation of such policies. Second, data on energy use and supply are largely aggregated and had to be disaggregated for this study. This involved arbitrary choices. This emphasises the importance of data collection. Related to this, in the base year there is hardly and use of other renewable energy sources than biomass from forests and wood. Wind and solar energy are negligible, although there is some hydropower. It is to be expected that the share of wind and solar energy will grow, requiring that in future research they must be considered separate energy products. Finally, an AGE model is a powerful tool to analyse the economy-wide effects of policies but also comes at a price. For example, the level of aggregation is high, for example, it distinguishes not between, e.g. electricity and heat production. Despite these caveats, this study contributes to the discussion of the transition of the Latvia's economy towards climate neutrality and energy self-sufficiency.

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## Input interactions and structural dynamics in Greek agriculture productivity

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**Abstract.** This study examines the impact of fixed capital, variable inputs, and labor on agricultural output in Greece from 1981 to 2021 using a Cobb-Douglas equation. It also investigates changes over time through the Bai-Perron structural changes method, confirming a structural break in 2006. From 1981 to 2005, labor and fixed capital had positive elasticities, contributing positively to agricultural production but with decreasing returns to scale. Post-2006, labor and fixed capital exhibited negative elasticities, indicating inefficiencies, while variable inputs retained positive elasticity. This shift suggests an increased influence of variable inputs on production after 2006. The findings highlight the need for continuous monitoring and analysis of agricultural factors to enhance sector competitiveness and sustainability, providing insights for policy design and implementation aimed at agricultural development.

**Keywords:** Agriculture productivity growth, input-output analysis, Cobb - Douglas function, Greek agriculture.

### 1. INTRODUCTION

Agricultural production processes require not only the optimal use and combination of inputs, but also the effective utilization of other aspects such as technological innovations, the experience and ability of those employed in the agricultural sector, and consideration of elements related to the economic circumstances that characterize economies both individually and globally. Moreover, unprecedented economic, social, and environmental conditions, particularly financial crises, income inequalities among farmers and consumers, and climate change, have shaped a complex environment for agricultural production. Based on the above reasoning, decisions are formulated regarding the appropriate quantities and types of production factors, with the ultimate goal of achieving economic efficiency in the agricultural sector. Decisions about input use are not purely technical; they also reflect agriculture's continuous endeavors to adapt strategically to shifting economic, environmental, and technological conditions. As farmers face extensive changes in market conditions, technological capabilities, and political regulations, the

selection of production factors must be performed while considering their interaction.

In this context, capital is a decisive factor for agricultural production, fulfilling a dual role as a source of financing and as a shaper of production processes. Technological progress and innovation require frequent investments in fixed capital, such as equipment and machinery. These investments aim to improve efficiency along with the use of and promote sustainable production methods (Crespi & Zuniga, 2012; Gann, 2000) in most sectors, hence also in including agriculture. In addition, labor productivity is a fundamental determinant for the efficient implementation of agricultural activities, influencing output quantity and quality, as well as the associated production costs. The latter are also affected by the quality of inputs utilized (Akram et al., 2019), such as fertilizers, pesticides and seeds, as well as land rental expenses, payments to dependent labor (Jayachandran, 2006), and intermediate consumption elements in general. The selection of the amount of labor and variable inputs used in the production process, is influenced by the potential provided by existing fixed capital, highlighting the interaction between these elements.

The Cobb-Douglas production function is considered a useful tool for modeling the interaction between factors of production, as it expresses the relationship between the quantity of production outputs and the inputs used in it. The efficiency of the Cobb-Douglas function, lies in its ability to reliably represent the production process. It estimates the contribution of each input to the total output, the returns to scale, the marginal productivity of production factors, and their marginal rate of substitution (Fuss & McFadden, 1978). The application of the Cobb-Douglas function to agricultural production has been intensely researched, as it captures the relationship between inputs and output, while simultaneously offering simplicity and flexibility in modeling.

To better understand the suitability of the Cobb-Douglas production function for analyzing agricultural productivity and the influence of different production factors on output, a number of empirical studies are reviewed. Within this framework, Armagan & Ozden (2007) argue that the Cobb-Douglas production function estimation is suitable for the efficient analysis of agricultural activities, as it is characterized by ease of calculations and the capability of statistical testing of production flexibilities, pointing out that this approach addresses the concept of productivity and efficient use of inputs, through the integration of the output function based on the inputs used. Faruq-Uz-Zaman (2021) further endorses the Cobb-Douglas production function, highlighting its practical value in estimating marginal productivity and

assessing input efficiency. Using data related to crop production in Bangladesh, the author employed inputs such as land area under cultivation, the proportion of the population engaged in agriculture, household spending as a proxy for capital input, fertilizer usage per hectare, and total cultivated land under irrigation to estimate impacts on agricultural output. The results indicated inefficiency in input use, with negative returns to scale (elasticity of -0.977), primarily due to the negative marginal productivity of cultivated land and labor, highlighting the non-rational use of the aforementioned production factors.

Echevarria (1998) confirmed the negative effect of labor growth on agricultural production using data from 1971 to 1991 for Canada. By employing the Cobb-Douglas equation, she compared the agricultural sector with services and industry, determining a reduced need for labor in agriculture and the particular importance of using technological innovations, as they positively affect productivity. Mundlak et al. (1999) used panel data from 1967 to 1992 for 57 countries, suggesting that agricultural production should rely to a greater extent on its extensive industrialization. They argued that output is relatively less influenced by labor changes than by capital, and that efficient production methods reduce labor needs, indicating a shift towards labor-reducing technology.

Yuan (2011) used data from 1999 to 2008 for Hebei Province, China. The study estimated a Cobb-Douglas production function with independent variables including cultivated land area, effective irrigation area, chemical fertilizer usage, agricultural machinery power, rural electricity consumption, and manpower. Effective irrigation area was identified as the most significant contributor to agricultural output, exerting a positive sign, followed by chemical fertilizer usage and farm labor. Cultivated land area, electricity consumption, and farm machinery power also showed a positive impact on output, though to a lesser extent, with overall input elasticity indicating decreasing returns to scale, with a value of 0.56.

Dawson & Lingard (1982), investigate the relationship between various input factors and total revenue in agricultural output using a Cobb-Douglas production function. The study employs Ordinary Least Squares and covariance analysis to estimate the elasticities and marginal productivity of labor, total wage-bill, machinery costs, livestock costs, crop costs, general farming costs, rent, and land area, which are set as independent variables, using total revenue as the dependent variable. The results emphasize the special role of labor and raw materials, as their increase leads to improved productivity, while a similar but less important effect is observed with investments in fixed capital. Nevertheless, decreasing returns on the scale of variable inputs are observed, indicating a rela-

tively reduced efficiency in the use of production factors.

A study by Ghoshal & Goswami (2017), referring to the efficiency of agricultural production in regions of India using Stochastic Frontier Analysis with the use of the Cobb-Douglas production function, in panel data for the period from 2005 to 2014, found matching results. The average annual efficiency ranged from 0.376 to 0.882 across different regions of the country, also indicating inefficiency in the use of production inputs, with the fertilizers and pesticides being the most important variable inputs for increasing output. Additionally, the presence of a comprehensive public infrastructure network, specifically the total state road length per unit of cultivated area, had a positive impact on output. This finding is consistent with that of Mamatzakis (2003), who studied the Greek agricultural sector from 1960 to 1995 using the I3SLS method to estimate a translog cost function. The study indicated that improvements in public infrastructure, reduce marginal variable costs and positively impact productivity advancement.

The present study investigates how the main production factors, namely, fixed capital, variable inputs and labor, have jointly shaped the growth of Greek agricultural output over the past four decades amid evolving technological advances, macroeconomic shocks, and Common Agricultural Policy regimes. To this end, a modified Cobb-Douglas specification, incorporating capital-labor and capital-intermediate input interactions, is estimated and subjected to sequential structural-break analysis to identify and date any endogenous shifts in factor productivity. At the second level, the resulting factor elasticities are compared to chart the evolution of input returns over time, to derive evidence-based insights into how structural shifts reallocate productivity patterns, which can inform the design of policy measures to strengthen sectoral efficiency and resilience.

The paper is organized as follows. Section 2 discusses the evolution of Greek agriculture in relation to CAP Common Agricultural Policy reforms and macroeconomic shocks. Section 3 provides an overview of the data employed and details the empirical methodology adopted. Section 4 summarizes the estimation results derived from the empirical analysis. Section 5 derives policy implications from the results, and section 6 presents concluding comments.

## 2. COMPETITIVENESS AND PRODUCTIVITY CHALLENGES IN GREEK AGRICULTURE

Greece's entry into the European Economic Community in 1981 and the immediate adoption of the Com-

mon Agricultural Policy, is widely credited with transforming Greek agriculture. Previously characterized by small-scale, family subsistence farming, the Greek rural economy began shifting towards market-oriented production after the accession (Caraveli, 2000). Tangible improvements in farm incomes and rural development were evident by the late 1970s following Greece's EU membership, as CAP price guarantees initially boosted agricultural revenues (Christou & Sarris, 1980). Today, the CAP continues to shape and control the framework of operation and activity in the agricultural sector. Over approximately four decades of CAP implementation, significant changes have been observed in the Greek rural economy. The most noteworthy of these changes concern employment, production structure, prices, and rural incomes. Common Agricultural Policy implementation resulted in substantial improvements in producer incomes through subsidies and played a key role in rural development. However, according to Haniotis (2024), CAP revisions have often exacerbated structural issues in Greek agriculture, including uneven distribution of subsidies, a lack of a functional Farm Advisory System, and slow adaptation to market-oriented reforms, which have limited Greece's ability to align production with market demands and compete internationally.

The 1980s, according to historical data from the Hellenic Statistical Authority (ELSTAT, 1980–2006), stand out as the most prosperous decade for Greek agriculture, marked by high real producer prices and strong overall production value. Following this prosperous period, production volumes stabilized in the 1990s, while real prices gradually and steadily declined. Building on the changes, the 2003 reform of the Common Agricultural Policy, which decoupled subsidies from actual output, brought a significant shift to the Greek agricultural landscape by weakening the link between support and production. As noted by Psaltopoulos et al. (2006), policy adjustments altered the rural economic environment and had uneven effects across regions, adding a layer of instability to production outcomes. The global financial crisis of 2008 compounded these challenges, and by 2011, the value of agricultural production had fallen to its lowest level in decades (Eurostat, 2024). At the same time, falling consumer demand and financial pressure on households caused a deeper contraction in agricultural output, revealing the level that agricultural sector was exposed to wider economic disruptions (Konstantinidis, 2016).

As reported by the Greek GSEE-ADEDY Labor Institute (2002), labor productivity during the 1980s increased at an annual rate of 4.9%. In the 1990s, it stabilized at slightly higher levels, despite a significant

reduction in the workforce from 31.6% of the total personnel in Greece in 1980 to 18.0% in 2000. Between 2000 and 2010, the agricultural labor force in Greece experienced a cumulative decline of 22.1%, equivalent to a compound annual decrease of 2.5%. Over the same period, the branch's gross value added receded from €7.49 billion to €6.52 billion, a drop of 13.0% (1.4% per year) (ELSTAT, 2024). Simultaneously, the 2007 financial shock, coupled with the decrease in private investments in agriculture, resulted in low overall performance of the primary sector. Although agriculture still absorbed 11.0% of national employment, it generated barely 3.5% of GDP, a mismatch that steadily eroded its competitiveness (Kassimis & Papadopoulos, 2013). These challenges have persisted in the long term, leading the country to exhibit a consistent trade deficit in agricultural products, which ranged from -1.5 to -2.8 billion euros annually throughout the mid-2010s and up to date (ELSTAT, 2014-2023). As a result, in 2024, Greek agriculture contributes only 3.8% to the country's national GDP, with an average of approximately 3.6% for the 2020s, which is significantly lower than the 6.9% contribution recorded in 1995 and the average of around 4.6% during the 2000s (Eurostat, 2024), suggesting the sector's reduced competitiveness within the national economy.

As productivity trends downward and a significant portion of the workforce departs the agricultural sector, further contraction of production is likely. Kalfas et al. (2024) emphasize that addressing productivity and workforce challenges requires substantial investment in infrastructure, supportive policies, and farmer education to facilitate the adoption of modern practices and enhance sector performance. Hence, enhancing competitiveness in the agricultural sector remains a key challenge for the future of Greek agriculture, as these factors determine its ability to penetrate international markets.

### 3. Materials & Methods

Data were collected from the European Commission's Directorate General for Economic and Financial Affairs (AMECO) database on an annual basis, covering the period 1981–2021. The regression model used is based on a production function that reflects the impact of labor and production cost on agricultural output. These factors interact separately with capital, allowing for a detailed analysis of their combined effects on the production process. This relationship is formulated as a modified Cobb–Douglas production function, expressed by the following equation:

$$Y = A \cdot (LK)^{\alpha_L} \cdot (CK)^{\alpha_C} \quad (1)$$

where Y defines agriculture output in real prices, L represents labor in terms of employed persons, C defines agri-

cultural sector's variable costs as the aggregate of land rental expenses, hired-labor wages and intermediate consumption, K stands for the agriculture sector fixed capital in real prices and A captures total factor productivity.

The above functional form implies that capital acts not as an isolated input but as a productivity amplifier, influencing the effectiveness of labor and cost via the LK and CK interaction terms. The parameters  $\alpha_L$  and  $\alpha_C$  therefore represent the output elasticities with respect to the labor–capital and cost–capital interactions respectively, as specified below:

$$\varepsilon_L = \frac{\partial Y}{\partial L} \cdot \frac{L}{Y} = A \alpha_L \cdot (LK)^{\alpha_L-1} \cdot (CK)^{\alpha_C} \cdot K \cdot \frac{L}{A \cdot (LK)^{\alpha_L} \cdot (CK)^{\alpha_C}} = \alpha_L \quad (2)$$

$$\varepsilon_C = \frac{\partial Y}{\partial C} \cdot \frac{C}{Y} = A \alpha_C \cdot (LK)^{\alpha_L} \cdot (CK)^{\alpha_C-1} \cdot K \cdot \frac{C}{A \cdot (LK)^{\alpha_L} \cdot (CK)^{\alpha_C}} = \alpha_C \quad (3)$$

Since (1) can be rewritten as:

$$Y = A \cdot L^{\alpha_L} \cdot C^{\alpha_C} \cdot K^{\alpha_L + \alpha_C} \quad (4)$$

the output elasticity with respect to capital  $\varepsilon_K$  is presented as the aggregate of the interaction elasticities:

$$\varepsilon_K = \frac{\partial Y}{\partial K} \cdot \frac{K}{Y} = A \cdot L^{\alpha_L} \cdot C^{\alpha_C} \cdot (\alpha_L + \alpha_C) \cdot K^{\alpha_L + \alpha_C - 1} \cdot \frac{K}{A \cdot L^{\alpha_L} \cdot C^{\alpha_C} \cdot K^{\alpha_L + \alpha_C}} = \alpha_L + \alpha_C \quad (5)$$

To estimate the impact of labor, production cost and capital on agricultural output via Ordinary Least Squares, the modified Cobb–Douglas production function is transformed to a log-linear model:

$$\ln(Y) = \beta_0 + \beta_1 \cdot (\ln L + \ln K) + \beta_2 \cdot (\ln C + \ln K) + u \quad (6)$$

where u is the disturbance term,  $\beta_1 = \alpha_L$ ,  $\beta_2 = \alpha_C$  and  $\beta_1 + \beta_2 = \alpha_L + \alpha_C$ .

Hence, the parameter estimates directly reflect the output elasticities of the labor–capital and cost–capital interactions, illustrating how shifts in capital intensity condition the productivity of both labor and intermediate inputs and thus affect overall output.

To accommodate non-constant elasticities and endogenous complementarity, the specification follows Thompson (2014) in treating capital as a productivity amplifier. In the form given in (1), this entails that both the marginal product of labor,  $\frac{\partial Y}{\partial L}$ , and the marginal product of intermediate inputs,  $\frac{\partial Y}{\partial C}$ , are functions of the capital stock K, thereby endogenizing substitution elasticities and capturing evolving input complementarities.

The traditional Cobb–Douglas form imposes two restrictive assumptions that are crucial for understand-

ing its limitations: (i) unit elasticity of substitution ( $\sigma=1$ ) between every input pair; and (ii) full separability, meaning the marginal product of each factor does not depend on the level of any other factor (Arrow et al., 1961). Induced-innovation theory, however, challenges these assumptions by predicting that when relative factor prices change, firms will direct technical change toward the now-cheaper factor, thereby endogenously altering the productivity of both capital and labor (Acemoglu, 2002). Thus, a standard Cobb–Douglas cannot capture complementarity or allow its intensity to adjust, which is necessary to account for economic changes such as mechanization, CAP-subsidy regimes, and rising production costs that have fundamentally transformed agriculture over the past decades.

By contrast, the CES specification of Arrow et al. (1961) relaxes the unit-substitution assumption by permitting  $\sigma \neq 1$ , yet it still constrains that elasticity to remain constant over time. The translog function, as introduced by Christensen et al. (1973), affords full flexibility, but at the expense of estimating  $\frac{n(n+3)}{2}$  parameters, a complexity that induces high covariance among regressors, leading to multicollinearity and unstable estimates (Berndt & Christensen, 1973).

Semi-flexible, interaction-augmented specifications provide a balanced alternative to the rigid Cobb–Douglas and the overly complex translog forms. Thompson (2014) evaluated three competing models: a log-linear Cobb–Douglas, a full translog, and a two-interaction ‘physical production function’, which is specified as follows:

$$Y = A \cdot (LK)^{a_L} \cdot (EK)^{a_E} \tag{7}$$

where L denotes labor, K capital, E energy, and A total factor productivity, demonstrating that this specification outperforms both the log-linear Cobb–Douglas and the translog by treating capital as a productivity amplifier, thereby introducing spill-over effects to labor and energy that vary with the level of the capital stock.

Based on the above, the study adopts Thompson’s (2014) specification by replacing the energy term (E) with sector-specific variable costs (C). This approach preserves log-linearity, allows for the direct interpretation of each exponent as an output elasticity, endogenizes substitution elasticities, and captures evolving capital–input complementarities.

Additionally, given the frequent complex changes in the relationship between agricultural outputs and production inputs in the agricultural sector, due to factors such as rapid technological progress, climate change, and other environmental factors, as well as the application of differentiated policies and changing demand

needs, it is necessary to study and detect the presence of structural changes in this sector. In this direction, the Bai-Perron Multiple Structural Changes Linear Estimation (Bai & Perron, 2003) is applied, which detects the presence of endogenous structural breaks, under the following model specification:

$$y_t = x_t' \beta_j + z_t' \delta + u_t, \text{ for } t = T_{j-1} + 1, \dots, T_j, j = 1, \dots, m + 1 \tag{8}$$

where  $y_t$  denotes the dependent variable at time  $t$ ,  $x_t$  represents a vector of covariates with regime-specific coefficients  $\beta_j$ ,  $z_t$  comprises covariates with time-invariant coefficients  $\delta$  and the error term  $u_t$  captures stochastic disturbances. The model partitions the data into  $m + 1$  distinct regimes, defined as intervals  $(T_{j-1}, T_j)$  between structural breakpoints, where each regime  $j$  maintains constant parameters  $\beta_j$ , while allowing coefficients to shift across regimes.

Initially, the hypothesis of zero versus a fixed number of up to five breaks, and zero versus an undetermined number of up to five breaks (Bai & Perron, 1998) is tested, followed by testing  $l$  versus  $1 + l$  breaks (Bai & Perron, 2003), a procedure that is particularly suitable for small samples, as outlined in detail by Antoshin et al. (2008). The test statistics are calculated as follows:

$$\text{Test statistic : } \frac{RSS_0 - RSS_1}{\sigma^2} \tag{9}$$

where  $RSS_0$  is the residual sum of squares under the null hypothesis (fewer breaks),  $RSS_1$  is the residual sum of squares under the alternative hypothesis (more breaks) and  $\sigma^2$  is the variance of the residuals.

For sequential testing of breaks, the approach involves two steps. In the first stage, the null hypothesis of no structural breaks versus the alternative of  $m$  breaks is tested, using the  $supF(m)$  test, defined as the maximum F-statistic across all possible break points  $T_1$  through  $T_m$ :

$$supF(m) = \max \{F_{T_1}, F_{T_2}, \dots, F_{T_m}\} \tag{10}$$

Subsequently, the hypothesis of  $l$  versus the alternative of  $l + 1$  structural breaks is examined using the  $supF(l + 1|l)$  statistic, which evaluates whether the inclusion of an additional break significantly improves the model fit, defined as:

$$supF(1 + l|l) = \frac{T - l(p+q)}{q} \cdot \frac{RSS_l - RSS_{1+l}}{RSS_{1+l}} \tag{11}$$

where  $p$  is the number of parameters in  $\beta$ ,  $q$  is the number of parameters in  $\delta$ ,  $T$  is the sample size,  $RSS_l$  is the residual sum of squares with  $l$  breaks and  $RSS_{1+l}$  is the residual sum of squares with  $1 + l$  breaks.

The structural change points were detected using the Bayesian Information (BIC) (Yao, 1998) and modified Schwarz (LWZ) (Liu, 1997) criteria, in order to achieve the optimal choice of the number of structural changes incorporated in the regression model. The final selection of the optimal model is achieved based on the criterion that provides the lowest critical value threshold, and then the linear regression model is estimated for each possible period of structural change.

#### 4. RESULTS

In Figure 1, time trends of output, fixed capital, employed persons, and variable costs for the Greek agriculture sector (1980–2020) are presented. Initially, a significant increase in agricultural output and fixed capital of the Greek agriculture sector occurred during the 1980s and up to 1995. This was likely related to the introduction of new technologies and improvements in the management of European resources, which indicate the adoption of strategies for the development of the agricultural

sector and the industrialization of production, leading to the transformation of the capital/labor ratio. To provide more detail, the average growth rate of agricultural output for the period 1981–1995 is 2.24%, with an overall percentage change of 34.69% in 1995 compared to 1981. Additionally, the average and total increase in fixed capital for the same period is 1.84% and 28.21%, respectively. This suggests a potential relationship between invested capital and agricultural output, possibly indicating increasing returns to scale. The trend of increasing capital intensity and decreasing labor intensity in agricultural production is evident. This is confirmed by a decrease in the number of individuals employed in the agriculture sector at an average rate of 2.24% per year, resulting in an overall reduction of 27.80% in the total number of farmers, equivalent to 292,200 individuals. In contrast to the trends in output and capital, production costs increased significantly by 3.09% per year and 50.30% overall by 1995 compared to 1981.

During the 1996–2006 period, agricultural output growth reversed, resulting in a total decline of 10.22%. This was mainly due to a 14.41% reduction in agricul-

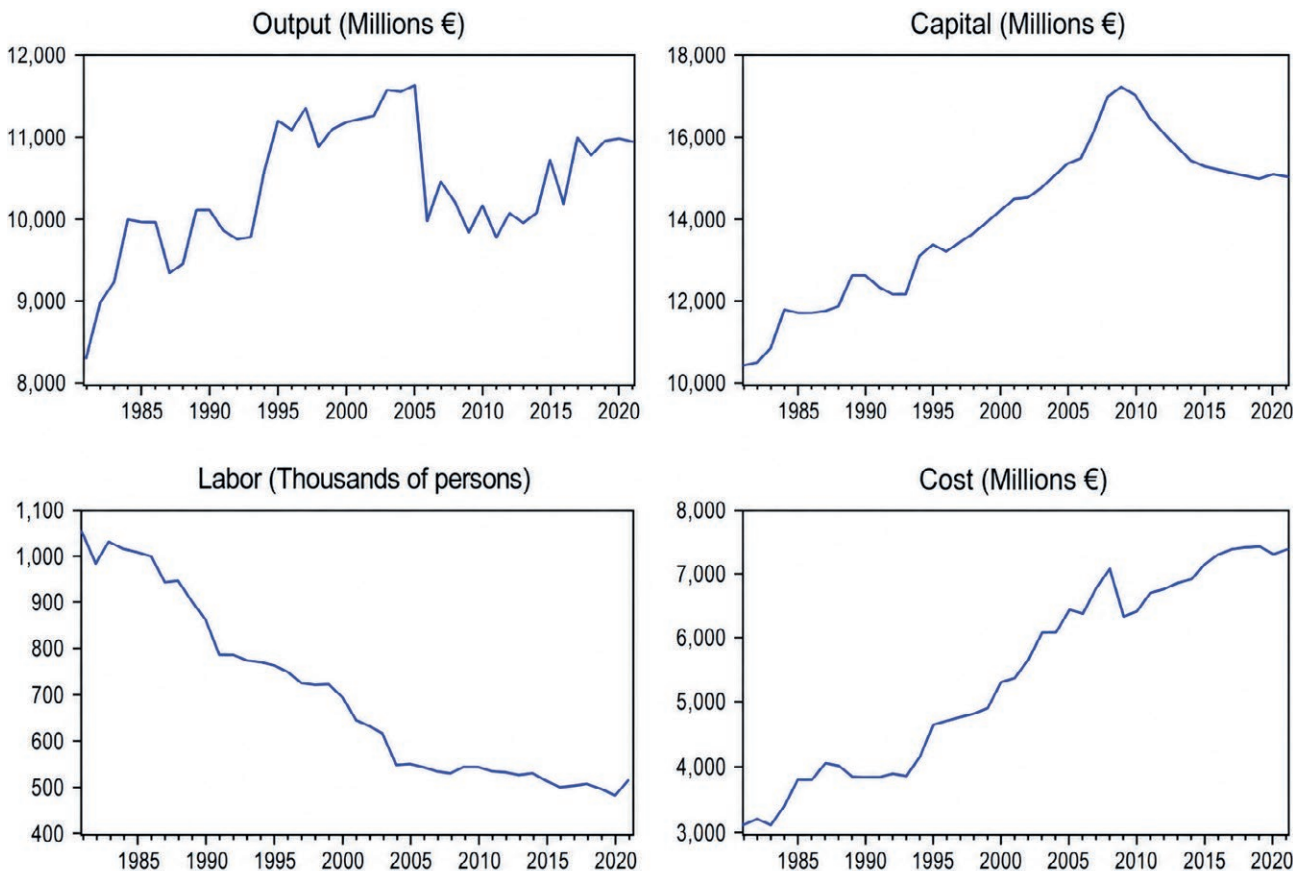


Figure 1. Time trends.

tural product in 2006 compared to 2005, and an average negative change of 0.95%. In contrast, while capital experienced a decelerated average annual growth of 1.34% and a total growth of 16.95%, employment decreased significantly by 27.35% from 1996 to 2006, at a constant annual rate of 2.90%. On the contrary, production costs continued their upward trend, increasing by 35.11% in 2006 compared to 1996. In 2007, as the global economic crisis emerged, a decline in agricultural output to its average levels during the 1990s and a total reduction of 6.04% is observed. During the years 2007–2009, fixed capital increased by 11.52% compared to the pre-crisis period. However, variable costs decreased less proportionally than the reduction in output, reflecting the negative effects of the crisis on the agricultural sector.

After the crisis period, agricultural output is observed to recover with a slow growth rate of 0.95% per year, failing to reach pre-crisis levels. These recovery efforts are accompanied by a reduction in fixed capital by 11.66% in 2021 compared to 2009, with an annual decrease of 1.12%, and an average increase in production costs of 1.26% annually. Thus, the compensation of fixed capital and variable inputs of production is linked to the stabilization of agricultural output. Finally, the number of individuals employed in the agricultural sector shows relative stability after the negative economic conditions of the period 2007-2009, decreasing by 15,500 individuals in 2021 compared to 2007 at a rate of 2.92%, demonstrating the long-term effect of the economic crisis on employment.

The Spearman correlation matrix (Table 1) reveals statistically significant linear relationships between agricultural production, fixed capital, employment, and variable costs, providing insights into the dynamics of agricultural productivity. The positive correlation between agricultural output and capital ( $\rho = 0.338$ ,  $p = 0.031$ ) suggests that an increase in capital contributes to the growth of agricultural productivity. Nevertheless, it appears that the increase in agricultural output is also associated with an increase in variable production costs ( $\rho = 0.447$ ,  $p = 0.003$ ) and a decrease in the number of individuals employed in the agricultural sector ( $\rho$

$= -0.432$ ,  $p = 0.005$ ). The negative correlation between capital and labor ( $\rho = -0.663$ ,  $p < 0.001$ ) confirms the inversion of the capital-labor ratio. The results suggest that technological development and automation of the production process, bring about a steady increase in production. Moreover, improvements in equipment and know-how allow labor to be more productive, regardless of the number of workers, with production costs increasing given increased investment in equipment ( $\rho = 0.653$ ,  $p < 0.001$ ). Simultaneously, as the number of people employed in the agricultural sector decreases, production costs increase ( $\rho = -0.783$ ,  $p < 0.001$ ), as a result of changes in the production process, with the integration of more industrialized but also costly practices driving part of the rural population to abandon the agricultural sector.

Stationarity must be established as a prerequisite in time-series analysis to avoid spurious regression relationships (Granger & Newbold, 1974; Phillips, 1986) and ensure consistent parameter estimates (Phillips & Perron, 1988). Thus, ADF and Phillips-Perron unit root tests are applied, using the MacKinnon critical values of -3.441 and -2.866 for a 1% and 5% significance level with a constant term, and -3.974 and -3.417 for a 1% and 5% significance level with both a constant term and trend (MacKinnon, 1996). As observed at Table 2, for all the variables, the assumption of stationarity is accepted at levels.

The confirmed stationarity of all variables ensures that the modified Cobb-Douglas elasticities can be interpreted without the risk of invalidating standard inference procedures due to stochastic trends. The estimation results (Table 3) show that the coefficient  $\beta_1$  is statistically significant with a value of 0.105 ( $p = 0.025$ ), indicating a positive combined effect of capital and labor on agricultural output. Additionally, the interaction between fixed and variable cost signifies a positive impact on agricultural output ( $\beta_2=0.103$ ,  $p = 0.038$ ). Based on the estimated coefficients, output elasticity to labor equals 0.105 and the elasticity of output with respect to variable inputs equals to 0.103, with the output elasticity to capi-

**Table 1.** Spearman correlation matrix.

	Output	Capital	Labor	Cost
Output	1			
Capital	0.338 (0.031)	1		
Labor	-0.432 (0.005)	-0.663 (<0.001)	1	
Cost	0.447 (0.003)	0.653 (<0.001)	-0.783 (<0.001)	1

Numbers in parentheses denote p-values.

**Table 2.** Unit root tests.

	ADF		Phillips-Perron	
	Constant without trend	Constant with trend	Constant without trend	Constant with trend
lnY	-2.897*	-2.928*	-2.958*	-3.421*
lnL+lnK	-4.514*	-4.652**	-3.724**	-3.962*
lnC+lnK	-3.358*	-3.639*	-4.787**	-5.105**

\* Denotes stationarity at 5%.

\*\* Denotes stationarity at =1%.

**Table 3.** OLS estimation results.

Dependent Variable: lnY				
	b	s.e	t	p
Constant	6.972	3.121	2.234	0.031 *
lnL+lnK	0.105	0.046	2.333	0.025 *
lnC+lnK	0.103	0.048	2.142	0.038 *
R <sup>2</sup>	0.282			
F (p)	7.673 (0.002)			

\* Significant at 5%.

tal being equal to 0.208. Consequently, a 1% increase in fixed capital raises agricultural output by 0.208%, while equivalent increases in labor and variable inputs lead to 0.105% and 0.103% increases in agricultural production, respectively, underscoring the relatively greater importance of fixed capital., the production function exhibits decreasing returns to scale.

The modest R<sup>2</sup> of 0.282 reflects that the modified Cobb–Douglas specification – by design – captures only the elasticities of labor, fixed capital, and variable inputs, excluding broader determinants of output such as policy subsidies, climatic shocks, or technological change. Consequently, while the estimated coefficients are informative about input-output relationships, the low goodness-of-fit underscores the need to interpret the results within the context of an inherently multifaceted agricultural system in which many important drivers lie outside the production-function framework.

In Table 4, structural breaks testing is presented. The initial test examines the hypothesis of no structural breaks against the alternative of up to 5 separate breaks in the relationship between production inputs and agricultural output. The corresponding sup F<sub>T</sub>s signal the presence of structural changes, as the null hypothesis of

no structural breaks is in any case rejected. The Wald-Wolfowitz Test, using the WD max criterion, also rejects the null hypothesis, supporting the presence of up to five structural breaks.

Having established the presence of structural breaks in the relationship between production inputs and agricultural output, the determination of their exact number follows by testing the null hypothesis of  $l$  versus the alternative of  $l + 1$  breaks. This procedure identified one significant break based on the supF<sub>T</sub>( $l|0$ ) statistic, while all other supF( $l+1|l$ ) were insignificant. The presence of a structural break is confirmed by the BIC and LWZ information criteria, which identify one break occurring in 2006.

Given the presence of a structural break dated in 2006, the regression model is re-estimated using standard regression techniques, after dividing the sample of observations into two sub-periods with the first covering the 1981 to 2005 and the second 2006 to 2021. The results presented in Table 5, show the existence of significant dissimilarities in the relationship between production inputs and agricultural output for the two sub-periods.

Regarding the 1981-2005 period, the coefficient of capital and labor is statistically significant ( $p = 0.044$ ), equal to 0.161. For the combination of capital and variable inputs, the corresponding coefficient is 0.304 ( $p < 0.001$ ). Therefore, it is indicated that the combined increase of fixed capital and labor and fixed capital and variable inputs of production by 1% implies an increase in agricultural output by approximately 0.161% and 0.304% respectively, expressing the contribution of combined efficiency to productivity. The presence of decreasing returns to scale, with scale is evident, as the elasticities the labor and variable cost are equal to 0.161 and 0.304, respectively, while the capital elasticity attributed to the sum of the aforementioned elements is 0.465.

**Table 4.** Estimated structural breaks.

0 vs unknown number of breaks	0 vs fixed number of breaks		$l$ versus the alternative of $l + 1$		Information criteria			Estimated break dates	
	WDmax	Number of Breaks	sup F <sub>T</sub>	Number of Breaks	Sup F <sub>T</sub> ( $l+1 l$ )	Number of Breaks	BIC Criterion		LWZ Criterion
134.226* (15.590)		1	44.741* (13.980)	$l 0$	44.741* (13.980)	1	-6.479*	-6.123*	2006
		2	30.056* (11.990)	$2 1$	3.972 (15.720)	2	-6.433	-5.856	1990, 2006
		3	26.732* (10.390)	$3 2$	2.882 (16.830)	3	-6.408	-5.591	1987, 1994, 2006
		4	20.230* (9.050)	$4 3$	0.970 (17.610)	4	-6.152	-5.072	1987, 1994, 2006, 2015
		5	14.800* (7.460)	$5 4$	0.219 (18.140)	5	-5.820	-4.442	1987, 1993, 1999, 2006, 2015

\* Significant at 5%.

Numbers in parentheses denote Bai-Perron critical values.

**Table 5.** OLS estimation results under structural breaks.

Dependent Variable: lnY				
	b	s.e	t	p
1981–2005				
Constant	1.225	0.450	2.722	0.011 *
lnL+lnK	0.161	0.077	2.090	0.044 *
lnC+lnK	0.304	0.024	12.461	0.000 **
2006–2021				
Constant	10.161	0.931	10.903	0.000 **
lnL+lnK	-0.411	0.059	-6.996	0.000 **
lnC+lnK	0.304	0.056	5.429	0.000 **
R <sup>2</sup>	0.852			
F (p)	40.514 (<0.001)			

\* Significant at 5%.

\*\* Significant at 1%.

As for the 2006-2021 period, results are strongly differentiated compared to those of the 1981-2005 and even compared to those of the entire 1981-2021 period. The most significant result is the negative sign of the coefficient of capital and labor, which equals -0.411 ( $p < 0.001$ ), indicating that their combined increase leads to a decrease in agricultural output. In contrast, the coefficient for the combination of capital and variable inputs remains at 0.304 and is significant ( $p < 0.001$ ), indicating an increasing effect on agricultural production. The negative elasticity of labor indicates its detrimental effect on production, while capital also shows inelastic behavior with an elasticity of -0.107. In contrast, the positive elasticity of variable production inputs confirms their beneficial effect on agricultural output.

## 5. DISCUSSION

Analyzing agricultural production in Greece and examining its relationship with production factors opens new perspectives for understanding the driving forces that shape the agricultural economy of the country. The period after Greece's accession to the European Union in 1981 and the implementation of the Common Agricultural Policy marked an era of change in the agricultural sector, coinciding with an increase in productivity following the general European trend. However, this trajectory was not stable, as the present study clearly established certain distinct features, providing insight into the evolution of agricultural production and revealing consequent changes in output, employment, fixed capital, and variable inputs.

More specifically, the results highlight a pronounced shift in how labor, fixed capital, and intermediate inputs

drive output, with a clear structural break around the mid-2000s. In the 1981–2005 sub-period, the log-linear estimates under the modified Cobb-Douglas production function, reveal that labor services and variable inputs both made positive contributions to real output, alongside a robust role for fixed capital. The aggregate of the elasticities remained below unity, indicating decreasing returns to scale. This pattern is often seen in agrarian settings with small, family-run plots, where increasing inputs leads to coordination costs and underutilization rather than proportional production increases (Cornia 1985; Rizov et al. 2013). As Latruffe (2010) emphasizes, when scale elasticities lie below unity further productivity improvements must come from gains in technical efficiency, that is, from using the existing technology and resources more effectively.

The structural break in 2006, marks a radical reversal in factor contributions. Negative labor and capital elasticities are highly atypical, but may occur in cases of severe misallocation of production factors. For example, Zorya et al. (2003) and Bezlepikina & Oude Lansink (2003), document negative land and capital elasticities under transition-era credit schemes in post-Soviet republics, attributing these to mismanaged inputs. Additionally, rapid mechanization can lead to a labor surplus, which may depress output and cause marginal labor products to approach zero or become slightly negative (Echevarría, 1998). Moreover, when physical networks and advisory capacities do not expand in tandem with inputs, it can lead to coordination breakdowns and idle resources, further compounding misallocation and reversing marginal productivity (Yuan, 2011).

According to the above the Greek case can be considered an outlier. Two main mechanisms may explain this anomaly. First, CAP's area-based payments eased credit constraints for many smallholders, who often lacked the scale to justify such investments. This prompted them to acquire tractors and other machinery they could not fully employ, resulting in under-utilized capital assets as idle equipment failed to contribute to output (O'Toole & Hennessy, 2015; Di Corato & Zormpas, 2022). Second, labor quality may have deteriorated as younger, more productive workers migrated to urban sectors due to the 2007 crisis (Cavounidis, 2013), leaving a workforce skewed toward older, part-time farmers. As Li & Sicular (2013) demonstrate, such demographic shifts can sharply erode the marginal productivity of those who remain, as older farmers tend to adopt new technologies and practices more slowly, which is relevant to the Greek case.

By contrast, variable inputs retain positive output elasticities throughout the full period. This pattern

aligns with evidence from the Green Revolution, where greater use of fertilizers, irrigation water, and high-yielding seeds underpinned most of the dramatic yield increases of the late twentieth century (Tilman et al., 2002). For instance, adoption of modern agrochemicals and high-yield varieties can serve as a proxy for rapid productivity growth even as land and labor contributions flatten (Fan et al., 2012). Likewise, extension-supported fertilizer programs in Sub-Saharan Africa, have repeatedly demonstrated that well-targeted variable inputs can deliver positive returns despite systemic constraints on scale (Ricker-Gilbert & Jayne, (2012).

The 2006 structural break in Greek agriculture closely corresponds with the implementation effects of the 2003 CAP ‘Fischler’ reform, which Greece opted to apply in fully decoupled form immediately after its adoption. By converting subsidies into area-based entitlements, decoupling dismantled the incentive to deploy labor and capital efficiently, allowing farms—many of which were small, fragmented, and operated by aging farmers—to receive support irrespective of production (Konstantinidis, 2016). Consequently, agricultural output gains remained modest, as traditional inputs delivered diminishing returns within a structurally constrained production environment. EU evidence suggests that decoupling can enhance farm productivity in certain contexts (Rizov et al., 2013). However, Greece’s structural limitations seem to have hindered effective resource reallocation when market signals replaced production-linked support. As a result, productivity gains failed to materialize, and after 2006, total factor productivity growth in Greece remained weak, reflecting the limited responsiveness of both labor and capital inputs.

Beyond decoupling, other CAP instruments likely reinforced the structural shift. The introduction of cross-compliance in 2005, obliged farmers to adhere to environmental and land-management standards, such as soil conservation, crop rotations, and buffer zones, to qualify for payments. While these measures aim to safeguard long-term productivity, they diverted labor toward non-productive compliance tasks, raising costs and constraining intensive practices (Barnes et al., 2013). Similarly, agri-environment schemes launched in 1992 and broadened in 2003, along with compulsory and later voluntary, set-aside payments, compensate for land withdrawal and low-input management, which have been shown to lower total-factor productivity (Mary, 2013) while sometimes prompting costly input re-allocation (Chakir & Thomas, 2022). In Greece, farm-level evidence shows that higher per-hectare organic-farming subsidies, granted without tying support to output, are associated with lower technical efficiency, implying that

such payments can depress factor productivity rather than expand production (Nastis et al., 2012).

The 2013 CAP reform added a “greening” layer, implemented from 2015, that ties part of each farm’s direct payment to compliance with crop-diversification rules, the establishment of ecological-focus areas, and the preservation of permanent grassland. Ciaian et al. (2018) show that these obligations can reduce land profitability and curb intensive cultivation, although the predicted output and productivity losses are limited and vary by region. In Greece, where most holdings cultivate fewer than five hectares (European Commission, 2024), the compliance with greening obligations leads to a shift from cash crops to set-aside and low-input uses, resulting in reduced farm income and a reallocation of labor and capital toward compliance measures rather than productivity-focused activities (Mantziaris et al., 2017).

Finally, the 2007-2013 and 2014-2020 Rural Development programmes channeled CAP Pillar II funds into on-farm modernization, training, advisory services, and agri-environmental measures. Dudu and Smeets Kristkova (2017) show that across EU regions, spending on physical-capital investments, human-capital support, and environmental actions raises total-factor productivity. However, in Greece, the absorption of the 2007-2013 Pillar II budget was only 41%, severely restricting opportunities to upgrade irrigation networks, acquire precision machinery, and expand extension services (Reziti & Zangelidis, 2019). Moreover, recurrent administrative fragmentation and ministerial turnover undermined strategic continuity (Karantininis, 2017). As a result, despite Pillar II’s potential to restore labor and capital productivity, under-utilization of these funds left Greek agriculture trapped in an input-intensive, subsidy-driven equilibrium, reinforcing the negative elasticity observed after 2006.

Policy implications from our findings are clear. To address the decline in labor and capital productivity, Greece’s agriculture policy must shift from general calls for technology uptake to specific actions for efficient use of Common Agricultural Policy (CAP) funds and strengthening national institutions. It is essential to allocate a substantial share of Rural Development (Pillar II) resources to productivity-enhancing activities, such as precision planting technology, drip-irrigated systems, cold-chain storage, and rural infrastructure upgrades, while adjusting co-financing rates based on farm size and business case viability.

Along with financial support for investment in capital, establishing an Agricultural Knowledge and Innovation System (AKIS) is essential for efficiently turning innovations into sustainable productivity improvements.

Plans are underway to set up regional AKIS centers to bring universities, research institutes, extension networks, and producers' associations together into an organized system to provide field-relevant skills pertaining to precision agriculture methods, integrated management methods, and digital farm management materials. Through the creation of specific lines for AKIS budgeting within Pillar I and Pillar II, Greece is seeking to ensure continuity for advisory services despite ministerial leadership instability and to improve support for experienced producers in embracing intricate innovations.

Also, realigning Pillar I direct payments to include performance components is expected to enhance the link between subsidies and efficiency improvements. Linking a portion of basic payments to measurable improvement, for example, per labor unit yield increases or and rising return on invested capital, while ensuring compliance with environmental standards, will create a culture of continuous improvement without undermining income certainty. Finally, ongoing monitoring of input elasticities and returns to scale at the regional level can serve as an early-warning system for inefficiency, allowing policymakers to adapt support measures dynamically.

## 6. CONCLUSIONS

The present study was conducted to evaluate the joint contributions of fixed capital, labor and variable inputs to Greek agricultural output. A log-linear Cobb-Douglas production function, augmented with interaction terms for capital and labor and capital and variable inputs, was estimated through Ordinary Least Squares, and the Bai-Perron multiple-break procedure was employed to detect structural shifts in the input-output relationships. The results of the study demonstrate that the increase in capital and labor, and their interaction, contribute to the increase in agricultural production, aligning with classical production theory. The study also finds a two-way positive relationship between investments in fixed capital and the quality and quantity of production materials, enhancing the productivity of agricultural holdings. However, decreasing returns to scale indicate potential under-utilization of inputs or over-investment in productive factors. This result shows significant changes over time, particularly after 2006, when the efficiency of labor and capital decreased, possibly influenced by the economic crisis, signifying shifts in production patterns.

The negative elasticity of labor is intriguing and complex to explain, potentially attributed to factors such as technological progress and automation. As agricultur-

al technology advances, less labor may be required, yet productivity can still increase. Conversely, the inelasticity of capital suggests diminished returns on investments in fixed equipment, poor management, or inadequate agricultural infrastructure. In contrast, the positive elasticity of variable production factors highlights their crucial role in agricultural output, especially when effectively combined with capital.

Given that Greek agriculture operates within the framework of the CAP, which emphasizes support for agriculture while enforcing compliance with environmental and quality standards, there is an opportunity for Greek agriculture to transition towards higher quality and environmentally friendly production methods. Achieving increased and sustainable agricultural production will require extensive research and innovation efforts across all levels, ensuring that significant innovations are implemented at the necessary scale.

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## The social and economic determinants of farm succession in Ireland

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**Abstract.** This study explores the multifaceted factors influencing farm succession in Ireland, emphasising the interaction among economic, social, and environmental aspects. With an ageing farm population, the need for effective succession strategies is critical to ensuring sustainable agricultural practices. We analyse the impact of drivers and barriers to succession, highlighting the importance of considering social factors along with economic factors using a probit model to examine these relationships. Our findings reveal that while farm size and dairy farming status show complex relationships with the likelihood of presence of a successor, social factors such as excessive workload impact decision-making. Our findings confirm expected relationships while offering new insights into farm succession and the farmer's life cycle. Beyond profitability, social factors – such as workload and its perception by the next generation – play a crucial role in successor identification. Highlighting these dynamics, our study underscores the importance of social sustainability in securing farming's future.

**Keywords:** farm succession, social factors, farmer ageing, probit model, endogenous succession cycle.

### 1. INTRODUCTION

Improving the sustainability of agriculture, across economic, environmental, and social dimensions, is recognised as central to delivering the key objectives of the Common Agricultural Policy (CAP). One such objective is to support generational renewal. An ageing of the farm population is evident in Ireland (Meredith and Crowley, 2018) and across Europe (Bertolozzi-Caredio et al., 2020; May et al., 2019). The share of farm holders aged 65 or over is now almost one-third in Ireland compared to one-fifth in 1991 (CSO, 2021), underlining the extent of the challenge in the Irish context. Farm succession, the transfer of managerial control of the farm, is critical to continued farm sustainability (Leonard et al., 2017a,b; Russell, et al., 2020) with

previous literature highlighting its importance from both the farm household and rural community perspectives. Farm succession is significant for the uptake of innovation, efficient and effective farm management (Nuthall and Old, 2017). Most farms in Ireland are family-owned, and entry into farming sector is primarily through inheritance (Hennessy and Rehman 2006; Deming et al 2019).

The complex nature of farmer decision making around succession and inheritance is multifaceted, with a broad range of economic, personal and social factors at play (Conway et al., 2016, 2021, 2022; Leonard, et al., 2017a, b; Góngora et al., 2019). These factors can be classified as drivers and barriers to succession. Previous research has highlighted the significance of individual farm circumstances (Conway et al., 2016; Eistrup et al., 2019; Schlessner 2021; Rech et al., 2021). Conway et al. (2021, 2022) also highlight the limited capacity of financial incentives alone in facilitating generational renewal and land mobility and contend that policy also needs to address the emotional and social wellbeing of older farmers, as well as their sense of purpose in later life. An improved understanding of these influential factors is vital for the design of effective policy to support generational renewal in the context of the new CAP.

To secure the farm for the next generation, it is also important to consider the environmental performance, which is increasingly recognised as being integral to the sustainability of agriculture (Barral and Detang-Desseudre 2023). Much recent research points that younger farmers in Europe are more aware of environmental issues, quicker to adopt eco-friendly technologies, and more adaptable to policy changes (Perez et al., 2020; Läßle and Kelley, 2015). Despite the significant role of younger farmers in sustainability, studies indicate that there remain barriers to new entrants taking over a farm (Hartarska et al., 2021; Schlessner et al., 2021; Zagata et al., 2017).

Regarding the relationship between succession and sustainability, Potter and Loblely (1996) coined the term ‘*succession, successor and retirement effects*’ to describe the processes whereby an identified successor or lack thereof, can significantly influence the farm holder’s level of interest and investment in the farm when approaching what should be their own retirement from farming. Thus, the sustainability of the farm business is influenced by the presence of successors. Furthermore, Leonard et al. (2017) emphasises economic concerns, whether a farm can generate enough income to support both the farmer and their successor, as well as the farmer’s residual income if they transfer the farm prior to death. Transfer decisions and procedures are often difficult and

stressful and may relate to the valuation of the farm as retiring farmers seek to sell farmland at the highest possible price (Jeanneaux et al 2022).

Despite widespread recognition of the connection between socio-economic factors and farm succession, there is considerable space in the academic literature for further exploration of the potential association between social aspects and farm succession. Previous research acknowledges the limited capacity of financial incentives alone in facilitating generational renewal. Through this study, we expect to make recommendations to policy makers on how social aspects should be considered in the design of future generational renewal policies. This paper identifies the endogenous nature of farm succession and examines the relationship between farm-level economic and social factors and the identification of a successor. The factors are intricately intertwined, making it challenging to consider these intertwined factors and the presence of a successor. This paper is innovative in that it conceptualises farm succession within the framework of the farm life cycle, elucidating the endogenous factors. The significance lies not in listing barriers and drivers, but in analysing the relationship between these factors within the farm life cycle and the presence or absence of a successor. The objective of our study is to explore some of the drivers and barriers to farm succession in the Irish context, with a particular emphasis on relevant social and economic factors.

The next section discusses potential drivers and barriers to farm succession based on the literature. Section 3 provides an overview of the data and methods used in this paper. Section 4 contains the results of the data analysis, section 5 provides some discussion and conclusions.

## 2. LITERATURE REVIEW

The general process of farm inter-generational transfer is well described in the existing literature, which distinguishes between three distinct but inter-related concepts. *Inheritance*, the legal transfer of ownership of farm business assets including land; *retirement*, the withdrawal of the existing manager from active managerial control and/or involvement in manual work on the farm and; *succession*, the transfer of managerial control over the use of these assets (Errington, 2002).

There exists particular policy instruments and financial incentives to encourage early-stage inter-generational farm transfer, however, delayed succession remains a concern throughout the world (Loblely et al 2010). The literature identifies barriers to land transfer to non-family members relating to the value that farmers

place on identity, occupation, control, and status in the community (Duesberg et al. 2017). Schlessner et al. (2021) investigate social and economic factors affecting farm succession using focus groups, highlighting the complex challenges for both the older generation and successors. Understanding these obstacles is crucial for our study to improve insights into the issue.

### 2.1. Economic factors

Farm succession may be anticipated by current farmers' behaviour in making additional investment to expand their farm business (Calus et al., 2008). Farmers with identified successors are more likely to invest or expand in anticipation of a takeover of the farm by a son or daughter than those who do not have a successor, which is known as the succession effect. The prospect of a successor often leads incumbent farmers to make management decisions they might not otherwise make, resulting in substantial improvements to the farm's productivity and sustainability (Leonard et al., 2017; Lobley et al., 2010; Uchiyama et al., 2008). On the other hand, they describe the '*retirement effect*', which generally has a negative impact on farms such that the farmer who has not identified a successor attempts no additional investment and scales down the farm business. Similarly, Carreira and Teixeira (2011) investigate that firms that exit the market appear to exhibit a noticeable productivity disadvantage compared to those that survive, not only in the year preceding exit but also for a significant number of years leading up to the exit. This means that farmers who do not secure a successor will not engage in investment activities for several years before the actual retirement. Much economic research has dealt with the question of farm succession and non-succession by highlighting important explanatory factors at the farm level such as farm holder's age, off-farm employment, farm size, economic viability, farmer's education and household composition (Kimhi and López, 1999; Stiglbauer and Weiss, 2000; Glauben et al., 2006).

The economic viability of the farm is well documented as playing a central role in the succession process (Glauben et al., 2009; Hennessy and Rehman 2007; Zagata and Sutherland, 2015). Farm size is found to have a positive stable effect on farm succession in the case of farming in Italy (Bertoni and Cavicchioli, 2016; Cavicchioli et al., 2018). Successors on larger family farm (both in physical (area) and economic size) are more likely to enter the farm as full-time.

Farmland ownership is also discussed as influencing the farm succession process. Ireland has low land mobility as older farmers accumulate capital to secure their

future financial situation and are unwilling to transfer their farm assets (Leonard et al. 2017). The major farm transfers occur with non-market arrangements, usually inheritance. Irish farmers influence agricultural land markets as most farm transfers occur within the family and this is attributed to the strong emotional attachment to land in Ireland (Bradfield et al., 2023). Rented land (both conacre, the short-term, 11-month land leasing and long-term leasing) accounts for only 18% of Utilised Agricultural Area (UAA) in Ireland, that is the second lowest in EU (European Commission 2021). Policy measures to facilitate land transfer to younger generations have had limited success (Bika, 2007; Geoghegan and O'Donoghue, 2018; Geoghegan et al., 2021).

### 2.2. Social factors

In addition to economic factors, the absence of successors is associated with older farmers' unwillingness to retire, which stems from emotional attachment to the farm (Conway et al. 2022). Farming is a way of life for many older farmers throughout the world and retirement from their daily routines and social circles in the farming community may affect their emotion negatively. Studies show that existing retirement incentives bring limited success in encouraging farmers to retire at or before pension age and seem not to change the traditional family farm transfer (Gilmore 1999; Contzen et al., 2017). Bika (2007) writes that in addition to financial reasons, Irish farmers' reticence in using the early retirement scheme<sup>1</sup> could have been due to 'sentimental bonds with the land'. Indeed, policy around generational renewal can often involve strategies to encourage older farmers to 'step aside' to facilitate new entrants while farmers often wish to remain 'rooted in place' on the farm (Conway et al., 2022) and work for as long as possible (Uchiyama et al. 2008). This farmers' 'never retire' attitude is associated with reduced likelihood of a successor being identified in several countries (Lobley et al., 2010). Thus, retirement in farming is not only influenced by economic factors, but also emotional and social status.

One such consideration is the desire for social inclusion and the avoidance of isolation. Social inclusion, driven by the concept of social capital, plays a crucial

<sup>1</sup> The Early Farm Retirement Scheme (EFRS) was introduced to encourage older farmers to retire and to attract younger farmers into the industry. In Ireland, there have been three rounds to the EFRS scheme, in 1993, 2000 and 2007 but it ceased in 2009. These schemes enabled farmers to retire early (from age 55) and provided them with a pension (up to €15,000 a year for a maximum of 10 years) provided they retired from farming completely by transferring, selling or leasing their farm to a young trained farmer (Hayden et al 2021).

role in farmers' decision-making processes (Shortall 2008). This social capital is composed of resources from networks of relationships based on social structure and acknowledged as important component in farmers' decision-making (Arnott et al. 2021; Cofré-Bravo et al. 2019). This facilitates discussions and the designation of a successor on the farm (Abdala et al. 2022)<sup>2</sup>. By maintaining these positive relationships, older farmers can navigate the complexities of succession planning more effectively, ensuring the continuity of their agricultural operations.

Social factors such as stress or anxiety, and excessive workload are also among the factors that can be considered as barriers to farm succession. Due to the rapid expansion of the dairy sector following the removal of EU milk quotas in 2015, dairy farmers experience an increase in labour intensity in Ireland. Brennan et al. (2021) state that workload related stress was the second highest source of stress among farmers in Ireland, next to poor weather. This stress not only affects the mental well-being of older farmers but also influences the perspectives of potential successors, deterring them from considering a future on the family farm (Brennan et al. 2022). Conversely, strategies such as increasing human capital through workload and information sharing among family members and neighbours can help alleviate this problem, incentivizing potential successors to remain in the agricultural sector (Bertoni and Cavicchioli, 2016).

Human capital here is considered according to the OECD definition as the productive wealth embodied in labour, skills and knowledge (Tan, 2014) or any stock of knowledge or the innate/acquired characteristics a person has that contributes to his or her economic productivity (Garibaldi, 2006). Given the increasing focus on quality of life issues (Contzen and Häberli, 2021), there is a strong case for more emphasis on collaborations that enable a more sustainable farm workload.

Although a wider range of social factors have emerged in the discussion of generational renewal (Brennan et al., 2021; 2022), there are very few recent studies explicitly accounting for social capital and farm succession, except for Abdala et al. (2022), which identifies some relationships between farm succession and social factors in the case of Brazil. Abdala et al. (2022) found that farmers with social capital, such as access to information or networks with customers and suppliers, are more likely to identify a successor. Such social capital includes agricultural education, which can enhance

farmers' ability to manage a farm more effectively (Läpple et al., 2015).

Engaging with farm advisory services through formal advisory contracts is another form of social capital, as it involves leveraging networks to acquire knowledge and information (Cofré-Bravo et al., 2019). However, despite recognition of the importance of social aspects, studies addressing these factors remain insufficient.

The pursuit of better agricultural knowledge can be an indicator of a higher possibility of farm succession as it may indicate willingness to improve and continue the farm business.

Agri-environmental scheme (AES) participation is recognised as one of the strategies for pursuing sustainable agriculture and these types of strategies may be translated into a more sustainable agricultural business for future generations. Farmers with a sustainable strategy tend to participate in AES. Various factors contribute to the decision to participate in AES, including economic concerns, the educational level of farmers, and the environmental features on farms. According to Cullen et al. (2020), farmers who are having a "forward-looking" self-identity are more likely to participate in AES. This type of identity influences AES participation, aligning with research that AES participation is favoured as one possible survival strategy when foreseeing the sustainability of agriculture (Ingram et al., 2013; Cullen et al., 2021). In this sense, motivations to join AES are shaped by the desire to continue the farm, which may be associated with the presence of a successor. In other words, the lack of a successor can be a reason not to enter AES due to a winding down and poor availability of labour with an inability to meet the AES management requirements (Riley, 2006).

### 2.3. Life cycle

The above mentioned drivers and barriers to succession are intertwined and emerge under different conditions at the farm level. Understanding this complexity can be facilitated by conceptualizing farm succession within a farm life cycle approach. Succession processes in family farming must be appreciated for their long duration (Fischer and Burton, 2014). In Ireland, where most new entrants inherit farms, the identity of successors fostered during the life cycle shapes the structure of farming. Potential successors develop their farm business skills by gradually getting involved in farming, influencing the current farm manager's behavior towards succession, such as making additional investments. This life-cycle approach shows that succession is an endogenous process, where practical involvement on the farm

<sup>2</sup> Abdala et al (2022) refer to social capital as the willingness of individuals and groups to obtain information, influence, and nurture solidarity with other social actors through the structure and content of existing relationships (Adler and Kwon, 2002)

increases successor identification and vice versa (Fischer and Burton, 2014). Negative experiences can deter potential successors even if the farm is viable.

Socio-economic studies suggest that factors such as the presence of a male heir and the number of children influence farm transfer decisions (O'Gráda, 1980; Banovic et al., 2015; Kennedy, 1991). In Northern Ireland, Jack et al. (2019) found that succession decisions are shaped by the gender of children, with a preference for male farm employees. Econometric studies from various countries further indicate that a larger number of children increases the likelihood of farm transfer while also delaying farm closure (Väre, 2006; Banovic et al., 2015). Additionally, having more family members present on the farm enhances the probability of family succession (Stiglbauer and Weiss, 2000). However, regional differences exist, as Cavicchioli et al. (2015; 2018) found both weak positive and negative associations between the number of children and farm succession.

From these studies, we hypothesize that farmers with large land ownership and capital assets are more likely to identify successors; those with less social interaction are less likely; AES participation is associated with a higher likelihood of identifying successors; and farmers with identified successors are more likely to invest in their farm in anticipation of succession.

### 3. DATA AND METHOD

#### 3.1. Data

The main dataset for this research is the Teagasc National Farm Survey (NFS) data from 2018<sup>3</sup>. This dataset contains detailed information about farms in terms of their economic, social and environmental performance in Ireland. The choice of time period is based on data availability as the 2018 data includes information about farm succession and whether or not farm holders have identified a successor. The agricultural sector in 2018 was affected by unusual weather with abnormal rainfall levels in spring and drought in the summer. The drought had a more significant impact on the south and east NUTS<sup>4</sup> region relative to the Border, Midlands and West region (Falzoi et al., 2019). Some of the survey responses may reflect the difficult conditions of this year (particularly regarding incidence of farm related stress).

In the Teagasc NFS, a farm accounts book is recorded for each year for a nationally representative survey of farms throughout Ireland, selected on the basis of a stratified random sample using information provided by the Central Statistics Office. The sample size is approximately 900 farms in recent years. This sample of farms is randomly sampled each year to represent approximately 90,000 farms in Ireland. Each farm is assigned a weighting factor based on the farm system and farm size so that the results of the survey are representative of the national population of farms. The analysis focuses on farms with holders over 50 years old, a critical age for succession decisions. Farmers are actively shaping the future trajectory of their farms. This approach allowed us to examine the factors influencing farm succession decisions while accounting for the gradual and nuanced nature of the succession process. For instance, the decision-making process for farm succession can begin several years before the actual succession event takes place (Calus et al. 2008). Moreover, even at an earlier stage, forward-looking farmers may undertake new investments to keep a fragile business afloat if they pursue farm transfer to a known successor, while others may prefer to sell the business. Such farmer's behaviour is observed and influenced by various factors even before retirement age (Paroissien et al. 2021). Examining this age group allows for a larger and more representative sample for robust econometric analysis. This provides a sample of 538 farmers representing approximately 58,000 farms nationally.

Succession decisions are made with factors influencing over a long-time frame (Lobley et al., 2010). Teagasc NFS data from 2013 is used in our model to provide a lagged value for the presence of young people in farm households. This variable is included to examine the importance of family networks, which affect the number of farmers who choose successors as of 2018. Young adults (aged 20 to 44 years) in the farm household may move out of the farm household to enter third-level education or employment elsewhere, but they may still be part of a family network and interested in contributing to the farm. Thus, the presence of young adults in 2013 might be related to the status of successor identification in 2018. Attrition is present in the Teagasc NFS data but most farms participating in the 2018 survey provided data as part of the 2013 survey. The year 2013 is chosen as important changes in household composition can take place in a five-year period and the choice of this year limits the amount of attrition. In the 2018 dataset, 538 farms were available for analysis. To construct the lagged variable for the presence of a young adult in the household, we used data from 2013. Among these, 371 farms

<sup>3</sup> The Teagasc NFS is part of the EU Farm Accountancy Data Network (FADN), this data was collected in addition to the core FADN dataset.

<sup>4</sup> The Nomenclature of Territorial Units for Statistics (NUTS) 3 corresponds to Border, West, Mid-west, South East, South-west, Dublin, Mid-east, and Midlands of Ireland.

could be matched across both years and had relevant information on young adults. In addition, due to missing values – particularly arising from the creation of interaction variables – the final sample size for Model 2 was reduced to 349. For Model 1, which does not include the lagged variable but includes interaction terms, the sample size was reduced to 501. This reduction is likely due to listwise deletion in cases with missing values introduced by the interaction variables.

### 3.2. Methods

In order to analyse the drivers and barriers of farm succession, we use a probit model with the dependent variable being the presence of a chosen successor as a binary variable where successor =1, otherwise=0.

#### *i) Econometric model*

The probit model is used to test the potential relationship between a number of farm, farmer and farm household characteristics (economic and social) with the presence of a chosen successor. Note that due to the absence of adequate long-term survey data to conclusively verify whether the farmer in NFS has indeed undergone farm succession, the identification a successor is employed as a dependent variable for the analysis. The choice of explanatory variables is based on the need to account for particular farm, family and social factors. Farmer age, land quality, and an interaction between the presence of a dairy enterprise and the size of land ownership are included because much research indicates a positive relationship between farm size and farm succession (Uchiyama et al., 2008; Glauben et al., 2009; Wheeler et al., 2012). Average dairy farm income is higher than the income of other systems in Ireland (Donnellan et al., 2020). We therefore expect that higher farm income attracts more successors and thus we use the presence of a specialist dairy farm as an independent variable in this model.

A variable representing investment is included among the independent variables since investment indicates a willingness of the farm holder to further develop the farm. At the same time, investment is another factor that increases a potential successor's willingness to take over the farm business (Calus et al., 2008). The investment variable is based on Net New Investment, which is defined as all capital expenditure during the year less capital sales and grants. The cost of major repairs to farm buildings, plant and machinery as well as land improvements is also included. It does not include investments in land purchases (Dillon et al., 2021, p.89).

Many of the independent variables tend not to vary much in value over time and this reduces the likelihood of

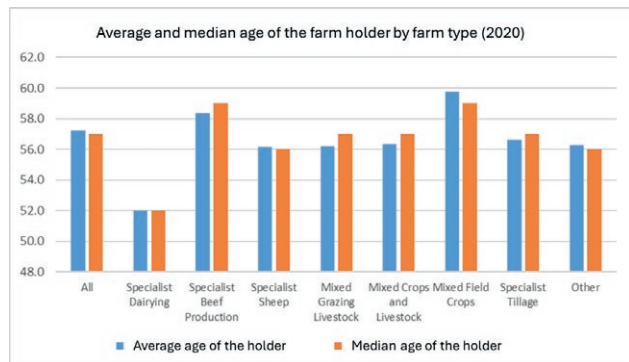
reverse causality. We attempt to account for the influence of past household composition by the inclusion of a lagged independent variable using data from the 2013 Teagasc NFS survey. We create a lagged variable indicating the presence of young adults aged 20 to 44 years old in the household in 2013. The NFS 2018 data provides information about social factors including isolation (defined as those farmers living alone) and the presence of workload stress/pressure<sup>5</sup>. These variables were ascertained as part of an additional special survey of Teagasc NFS farms in autumn 2018. These social variables are likely to be endogenous but are an important consideration given that they are likely to be closely linked to the construction of successor availability and identification. However, to avoid unnecessary sample loss and preserve statistical power, we presented Model 1, which focuses on the full 2018 dataset.

Farm income and farm viability (defined as the farm receiving at least the minimum wage for family labour and a 5% return on non-land assets) are likely to be associated with farm succession (Leonard et al., 2017). Both income and viability variables are likely to be highly endogenous in terms of their relationship with farm succession. Potential successors may play a very important role in influencing the current farm income and viability due to the labour provided on the farm. At the same time, higher farm income and farm viability may incentivise potential successors to seek to take over the farm business at some point in the future. Farm income has a number of components that are exogenous or weakly endogenous including soil quality, land ownership and agricultural training. In the econometric analysis, we therefore include these variables rather than the farm income or farm viability variables individually.

A binary variable representing whether farmers have formal advisory (extension) service contract is included since it could be an indicator of the willingness to improve farming practices, thus, continuation of the farm business.

Participation in an Agri-Environment Scheme (AES) is included since the motivations for participating in AES could be tied to the presence of a potential successor. Conversely, the absence of a successor can be associated with less likelihood of AES participation, as it may indicate a winding-down of the farm business operations, limited availability of labour, and an inability to meet the management requirements set by AES.

<sup>5</sup> Farmers are asked if they have experienced stress/anxiety from any aspect of their farm business in the last 5 years. Ten possible sources of stress/anxiety are listed in the questionnaire and farmers are requested to list the top three sources. Those who chose "Workload e.g. work life balance, seasonal demands (calving, lambing)" as one of the three sources are included in this variable.



**Figure 1.** Average and median age of the farm holder by farm type in 2020. Source: CSO Census of Agriculture 2020.

Figure 1 shows the average and median age of the farm holder by farm type in Ireland. It indicates that certain farm system faces more severe aging problem than others.

### 3.3. Summary Statistics

We describe the summary statistics for the variables used in the econometric analysis. Using the Teagasc NFS 2018 sample of farmers of at least 50 years old, the statistics show that 57 per cent of farmers have identified a successor at that point in time (Table 1). Among them, 34% were dairy farmers. The proportion with a successor varies between farming systems with 53.8 per cent in the case of sheep farms and 58.6 per cent for dairy farms. For the purposes of the econometric modelling and due to the limited sample size, we concentrate the succession analysis on farm holders aged over 50 years.

The descriptive statistics are provided in Table A1 in Supplementary materials. For this particular sample, the average age is 63 years old. The average age of farm holders with a chosen successor is 65 years old and without a successor is 60.4 years old. Dairy farms are similarly represented in both succession and non-succession groups. Dairy farms account for 16 per cent of the farms with a successor and 17 per cent of the farms without a successor. As expected, the proportion of farms in the best soil quality category is higher for those with a successor (32 per cent) relative to those without a successor (26 per cent).

The average Net New Investment is higher on farms with a chosen successor relative to those farms without a successor (€8,085 per annum versus €5,777 per annum). This suggests that investment is associated with the probability of farm succession although the direction of causality may not be clear. The presence of an excessive workload or evidence of farm related stress (as reported

**Table 1.** Farmers who identified successor (over 50 years old).

Farm System	Share of successor farms in each system (%)
Dairy	58.6
Cattle rearing	55.7
Cattle other	57.2
Sheep	53.8
Tillage	54.3
Total	56.7

Source: Teagasc National Farm Survey 2018.

by the farm holder) is more common on farms without a successor (35 per cent) relative to farms with a successor (24 per cent). There is a notable difference between the two groups in terms of the share of farm holders living alone. Table A1 in Supplementary materials shows that 32 per cent of farm holdings without a chosen successor are living alone. This is much lower at 15 per cent for holdings where a successor is chosen.

## 4. RESULT

In this section, we show the results of the probit model in Table 2 and Table A2 in Supplementary materials. The lagged variable representing the presence of a young adult within the household is available only for 371 observations. This is because the creation of the lagged variable relied on 2013 data, and the number of farms that existed in both 2013 and 2018 was smaller than those present only in 2018, leading to a reduced sample size in Model 2 compared to the full sample. However, this remains an important variable for examining the potential role of household composition in influencing succession. We therefore present the results of the probit model both excluding and including the lagged variable (shown as Model 1 and Model 2, respectively). This way allows us for greater statistical power in estimating the core relationships. Marginal effects are calculated to show the change in the probability of succession due to a change in the value of the independent variables.

Farm income has components that are exogenous or weakly endogenous including soil quality, land ownership and agricultural training. In addition, land ownership is included since Irish farm succession mostly occurs via inheritance. The area of owned land could be associated positively with identification of a successor. In this model, we use these variables rather than the reported farm income.

We analyse whether the presence of a dairy farm or the farm size influences the likelihood of succession.

**Table 2.** Probit Model Results: Determinants of Farm Succession in 2018.

Variables	Model 1			Model 2		
	Coef.	sig	Marginal effect	Coef.	sig	Marginal effect
Interaction of Dairy Farm and Land Ownership	0.0095	**		0.0092	*	
Farmer Age	0.0535	***	0.02	0.0585	***	0.02
Best Soil Category	0.2139	*	0.08	0.198		0.07
Excessive Workload	-0.262	**	-0.09	-0.160		-0.06
Isolation of Living Alone	-0.13		- 0.05	-0.109		-0.04
Net New Investment (€)	0.004		0.001	0.002		0.0009
Formal Advisory Contract	0.0170		0.006	0.025		0.009
Participation in AES	0.317	**	0.11	0.226		0.08
Number of Household Members Age 20 to 44 in 2013**	-		-	0.0003		0.0001
Constant	-3.318	***		-3.645	***	
Observations	501			349		

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

We expected that the presence of a dairy farm would increase the likelihood of succession due to the relatively higher farm income on dairy farms relative to non-dairy farms (Donnellan et al., 2020). However, our model finds land ownership (as opposed to rent) is not statistically significant as shown in Table A2 in Supplementary materials, even though these factors are considered positive indicators for identifying a successor. This is not consistent with previous studies showing a positive relationship between farm size and the probability of farm succession (Kimhi and Bollman, 1999; Breustedt and Glauben, 2007; Morais et al., 2018).

The absence of a significant relationship between land ownership size and succession and between dairy farming and succession motivated us to explore the possible interaction of dairy farming and (owned) farm size. We therefore add an interaction variable for the presence of a dairy farm with land ownership (hectares). As a result of this interaction, farm size is not significant for non-dairy but is significant for dairy farms. This indicates that only larger dairy farms are associated with a higher probability of farm succession. These results are presented in Table 2, which we regard as our main results because the model better captures system-specific succession dynamics and reveals patterns that were not evident in the initial specification shown in Table 4. The results from the 2020 CSO Census of Agriculture point to an increase in the average size of dairy farms with a reduction in the number of farms classified as specialist dairy. This indicates a rising concentration within dairy farming. The inclusion of the interaction term in Table 2 provides greater explanatory power and offers a more nuanced understanding of the conditions under which

farm size matters. For this reason, we present Table 2 as our main model.

The age of the farm holder is positive and statistically significant. This is expected given that older farmers are more likely to have reached the point of identifying a successor (May et al., 2019). The marginal effect indicates that the probability of having a successor increases by approximately 2 per cent per year. Stiglbauer and Weiss (2000) also found a positive relation between the age of the farm holder and farm succession.

The soil quality variable is positive and statistically significant in the farm succession decision. It indicates that better soil quality brings higher productivity, that provide sufficient income to support two generations during succession process.

The results in Table 2 point to the importance of social factors, including excessive workload. Farmers who report excessive workload and related stress are less likely to have identified a successor. While this may seem intuitive, its importance lies in the broader context of succession as a long-term, endogenous process. May et al. (2019) found that farmers experiencing hardship may be reluctant to encourage their children to pursue farming, reinforcing the idea that such stress has cumulative intergenerational effects. Succession is a gradual process shaped by accumulated experiences, evolving identities, and intergenerational interactions (Fischer and Burton, 2014). Continuous exposure to workload stress as observed by the next generation, can alter perceptions of farming as a viable or desirable career. Such social aspects therefore warrant consideration alongside economic drivers to inform more holistic policy and advisory strategies.

Isolation is not statistically significant in both model (with/without lagged variable) and has a negative coefficient as expected. It is noteworthy that a substantial proportion of the sampled farmers, approximately 23%, live alone, and these farmers tend to be less likely to identify successors. The marginal effect of isolation is relatively substantial at -5%, compared to other binary variables. While this finding does not reach statistical significance, it aligns with previous research by Dudek (2016), which emphasises the importance of household composition in farm succession based on panel data from Poland. One possible reason for the lack of significance in our case could be sample size limitations. Nonetheless, the results suggest that social factors, particularly household structure, may play an important role in farm succession decisions. Therefore, incorporating social dynamics into succession models remains a relevant avenue for further research.

Investment was expected to have a strong association with the probability of succession as reported in a previous study in Belgium (Calus et al., 2008). Here it is found to be positive and not significant. Investment could be potentially endogenous given that the presence of a successor could motivate the current holder to invest more. However, we include investment in our model considering its importance, and the fact that farm succession itself has been verified as an endogenous cycle (Fischer and Burton, 2014). Although the investment was not statistically significant in our results, previous research has established it as a key indicator of farm succession. For instance, Calus et al. (2008) found that succession intentions begin influencing farm investment decisions up to ten years before the actual transfer. This suggests that even if this variable does not appear significant in our model, it remains a crucial factor in succession planning, reinforcing the need for early successor identification to ensure farm continuity. The lack of statistical significance in our findings may be partly attributed to sample size limitations. Further research with larger datasets would be beneficial to fully capture the role of investment in farm succession dynamics.

We expected that formal advisory (extension) contract could be an indicator of a higher possibility of farm succession since it may indicate openness or willingness to improve farming activities. While it is not statistically significant, it showed a positive coefficient. Including this variable is valuable, as research on farm succession has often placed less emphasis on social factors. Access to advisory services can be seen as a form of social capital, potentially influencing farm succession decisions by providing guidance and strategic planning support as Abdala et al., (2022) investigated. The lack of statistical

significance in our model could be due to heterogeneity in how advisory services are utilised, such as the timing of advisory service use may vary, with some farmers engaging with advisors too early or too late in the succession process for measurable effects to be captured within our dataset.

Farmer participation in an AES is found to be positive and statistically significant in model 1. This supports the conclusion of Cullen et al. (2020) that participation in such schemes has a positive association with the willingness to continue farming. Participation in environmental schemes can also provide economic incentives to younger farmers.

Finally, the lagged independent variable for the presence of young adults in the farm household is positive and not significant, which is only included in model 2. Although this lagged variable is not statistically significant, it is retained in Model 2 due to its conceptual importance in succession literature and to test robustness. While this result does not provide strong evidence in our model, the presence of young adults is often considered a key factor in succession decisions. The use of this lagged variable allows us to capture long-term household dynamics that may influence successor availability. The lack of significance in our results could be due to sample size, timing differences in succession planning, or unobserved factors influencing young adults' career choices around the age categories. Nevertheless, as previous research of Fischer and Burton (2014) suggests, early exposure to farm life and involvement in decision-making processes play a crucial role in the eventual transfer of farm management.

## 5. DISCUSSION AND CONCLUSION

In this study, we use econometric methods to explore the drivers and barriers to farm succession, incorporating both social and economic factors. While profitability and land ownership are often key drivers of succession decisions (Pitson et al., 2020), our findings indicate that social factors, such as workload stress and participation in agri-environmental schemes (AES), also play a significant role in shaping succession outcomes. These insights suggest the importance of considering social sustainability alongside economic factors in the farm succession process.

Our results reveal that economic characteristics, particularly land ownership size and soil quality, are key determinants in identifying successors associated with greater successor potential. However, social factors also influence succession decisions by shaping both the cur-

rent farmer's management practices and the potential successors' perceptions of the farm's long-term viability. For example, workload stress can affect how farmers operate day-to-day, while participation in AES may reflect a more future-oriented outlook, which may appeal to younger generations.

Succession should not be viewed as a one-time decision but as a continuous process, influenced by ongoing actions and experiences. The decisions of the current farm manager, such as improving soil quality or expanding land, directly affect how potential successors view the farm's future and their potential role. These accumulated experiences contribute to the successor's identity formation and long-term engagement with the farm.

In line with Calus (2009), our findings challenge the traditional view that succession is driven solely by economic incentives. Instead, we show that succession unfolds gradually, shaped by evolving social and familial dynamics. Social and economic elements interact over time, making succession a dynamic process rather than a fixed event. Supporting this view, findings from a cluster analysis of Irish farm types further confirm that succession decisions are nuanced and shaped by farm-specific economic viability and household or workload-related social conditions (Loughrey et al., 2025).

Notably, our study contributes to the growing body of literature by quantitatively examining social factors (Abdala et al., 2022; Špička and Berg, 2022) and providing unique insights into their role in farm succession dynamics. High work intensity, especially in demanding systems like dairy farming, can contribute to farm exits (Ferjani et al., 2015), further influencing succession dynamics. In addition, succession decisions evolve gradually, shaped by long-term experiences rather than isolated events (Lobley, 2010). The long-term impact of witnessing parental stress from farming can influence the decisions of potential successors, underlining the importance of resilience across both social and material dimensions (Darnhofer, 2020).

Further supporting this perspective, Bertolozzi-Caredio (2024) confirms that the presence of a successor influences the behaviour of incumbent farmers, reinforcing the idea that farm succession is a dynamic and mutual process. To facilitate smoother transitions, targeted strategies are needed to support both successors and incumbents. One such approach includes fostering farmer partnership agreements or hiring additional labour that have proven beneficial but remain underutilized (Conway et al., 2017; Garcia et al., 2023; Shin et al., 2023). These measures not only alleviate excessive workloads but also enhance the attractiveness of farming as a viable career path for the next generation.

Farms with lower incomes can seek to improve farm viability through participation in AES schemes for example as an economic incentive, particularly on less intensive farms, to stabilise farms. Cullen et al. (2020) notes that a forward-looking self-identity is linked to greater AES participation, ensuring farm continuity for future generations. Furthermore, innovative environmental practices, such as organic farming, may attract younger farmers with new financial incentives through the CAP (Farrell et al., 2022).

Policy should broaden its focus to enable succession not only within families but also through hired labour or non-relatives. Our findings imply that policies should address the pathways for both new entrants and incumbents, potentially facilitating partnerships to share workload, knowledge, and profits, thereby ensuring the sustainable continuation of farming enterprises.

A limitation of this study is that it relies on farmers' self-reports about whether they have identified a successor, rather than tracking actual succession events. In addition, capturing farm succession over a longer period would be beneficial. The endogenous cycle of farm succession highlights the link between farmers' identity development and the farm business ladder, which could be better understood using a panel data framework, as in Dudek and Pawłowska (2022). This would help establish the cause-and-effect relationship over time and provide more evidence on the impact of succession on farm continuity, productivity, and sustainability.

This study provides valuable insights into farm succession by utilizing a nationally representative dataset. While the dataset used is from 2018, making it one of the most recent sources available for analyzing long-term succession trends, it does not capture the potential impacts of recent economic and social changes, such as the COVID-19 pandemic or the ongoing inflationary crisis. These events may have influenced succession decisions by altering economic stability, labour availability, and generational attitudes toward farming. Future research should incorporate more recent data to assess these effects.

The statistical significance of some results is limited, partly due to the sample size constraints. Expanding the dataset or complementing quantitative findings with qualitative approaches, such as interviews with farmers and advisors, could provide deeper insights into the role of social capital in succession planning.

Despite these limitations, this study highlights the importance of understanding both economic and social factors in farm succession. Future research should continue exploring these aspects, particularly in the context of evolving economic conditions and policy changes that shape generational renewal in agriculture.

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# Towards sustainable business models in the circular bioeconomy: The case of bio-based fertilizers

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**Abstract.** Bio-based fertilizers (BBFs) offer a sustainable solution to the environmental and economic challenges of conventional fertilizers by enhancing nutrient recycling and soil health, aligning with EU strategies. Despite the availability of frameworks like the Business Model Canvas (BMC), these models have not been comprehensively applied in the context of BBFs. This paper addresses this gap by using the BMC framework to provide a holistic overview of BBF business models, integrating economic, environmental, and social dimensions. A comprehensive literature review was conducted, focusing on studies examining specific aspects of BBF business models, including value proposition, value creation and delivery, and value capture. The analysis highlights key insights, such as BBFs' potential to recycle waste, and enhance soil health, alongside challenges like nutrient variability and market adoption barriers. These findings support strategies for advancing sustainable circular bioeconomy practices, offering valuable guidance to stakeholders in the fertilizer and agricultural sectors.

**Keywords:** circular bioeconomy, bio-based fertilizers, sustainable business model, Business Model Canvas.

## 1. INTRODUCTION

### 1.1. Towards sustainable agriculture: From bio-waste to bio-based fertilizers

Agricultural production growth has relied heavily on chemical fertilizers and synthetic pesticides (European Commission, 2019). However, excessive application of essential nutrients like nitrogen (N) and phosphorus (P), combined with inefficient plant absorption, has caused air, soil, and water pollution and has significantly reduced biodiversity in aquatic ecosystems (Juncal et al., 2023; Yang et al., 2008). Similar to healthcare principles that warn against overuse, agronomy advocates for limited fertilizer application to maintain ecological balance (Pandian et al., 2024). Moreover, fertilizer production relies on finite fossil-based resources, such as natural gas, phosphate rock, and potassium salts, which are depleting (Anlauf, 2023; Cordell et al.,

2009). The European agricultural sector, heavily dependent on imports of these essential raw materials, is vulnerable to supply chain disruptions, threatening food security (Smol, 2021; de Ridder et al., 2012). This dependency highlights the fertilizer industry's critical challenge: efficient nutrient recycling (Barquero et al., 2024).

Despite these issues, global chemical fertilizer use increased from 12 million tons in 1961 to over 110 million tons by 2018 (Rodríguez-Espinosa et al., 2023). The European Commission (EC) has targeted a 50% reduction in nutrient losses while maintaining soil fertility (Heyl et al., 2023; European Commission, 2020). The Common Agricultural Policy promotes precision agriculture to improve nutrient efficiency (Álvarez Salas et al., 2024). Additionally, the EU's Farm to Fork (F2F) Strategy, part of the Green Deal, aims to reduce fertilizer use by 20% by 2030, promoting a shift to circular bio-based production processes (European Commission, 2020). Supporting this goal, the 2019 EU Fertilizing Product Regulation (Regulation (EU) 2019/2009), effective since May 2022, mandates circular and sustainable fertilizer systems by integrating organic and waste-derived fertilizers into the market.

The bioeconomy, encompassing sectors reliant on biological resources (Bröring and Vanacker, 2022), along with bio-based fertilizers (BBFs) as sustainable alternatives to synthetic fertilizers, plays a crucial role in advancing a circular economy. A prominent initiative is the Circular Bio-based Europe Joint Undertaking (CBE JU), a public-private partnership between the EU and the Bio-based Europe Joint Undertaking, with a €2 billion budget for 2021-2031 (Donner and De Vries, 2023). In addition to CBE JU, initiatives such as Horizon Europe, the European Circular Bioeconomy Fund (ECBF), the European Investment Bank (EIB), and national research and innovation programs provide critical financial and strategic support for advancing BBFs development and commercialization. BBFs offer sustainable alternatives by recycling bio-waste, improving nutrient use efficiency, and reducing environmental impacts compared to traditional fertilizers (Álvarez Salas et al., 2024). Although no standardized definition exists, efforts at European level aim to establish one. BBFs are generally described as materials or products sourced from biomaterials (such as plant, animal, or microbial sources, often including waste, residues or by-products from agriculture, industry or society) containing bioavailable nutrients fit for use as crop fertilizers (Arzeni et al., 2024). Examples of BBFs include compost-based fertilizers, manure-derived fertilizers, biochar, and nutrient-rich products from anaerobic digestion, such as digestate or struvite (Kurniawati et al., 2023; Chojnacka et al., 2020).

## 1.2. The sustainable business model for bio-based fertilizers

Academic research on business models, stemming from foundational theories like Drucker's (1985), defines a business model as a structure detailing how a company creates, delivers, and captures value (Teece, 2018; Osterwalder et al., 2005). The Business Model Canvas (BMC), developed by Osterwalder and Pigneur (2010), remains the most widely adopted template, comprising nine elements. Central to this model is the value proposition, which captures the unique benefits a company offers to its customers. The market component (customer segments, channels, and customer relationships) addresses external elements critical for reaching customers and determining product desirability. The infrastructure component, which includes key activities, resources, and partnerships, defines operational feasibility, while the financial component (cost structure and revenue streams) ensures economic viability.

The concept of "bioeconomy," introduced by Christian Patemann, emphasizes using renewable biological resources to meet societal needs with reduced environmental impact (Lange, 2022). Transitioning to a bioeconomy requires substantial changes to existing business models (Reim et al., 2019). Although the literature on bioeconomy business models often overlaps with circular economy discussions, there are distinctions (Donner and De Vries, 2023). The bioeconomy emphasizes replacing fossil resources with renewables, while the circular economy focuses on cascading resource use (Bröring and Vanacker, 2022; Venkatesh, 2022).

Sustainable business models communicate value propositions that capture economic value while maintaining or regenerating environmental, social, and economic capital (Schaltegger et al., 2016), as outlined in the Triple Layered Business Model Canvas (TLBMC) by Joyce and Paquin (2016). The TLBMC extends Osterwalder and Pigneur's BMC by adding social and environmental layers, providing a holistic view of value creation. While bioeconomy models have sustainability potential, they are not inherently sustainable (De Keyser and Mathijs, 2023). Challenges such as resource use, environmental impact, and social equity must be addressed for these models to realize their sustainability potential. When sustainability is embedded in bioeconomy goals, it can foster positive social and environmental impacts and stimulate economic growth through innovation, particularly in agriculture and food production sectors (Pfau et al., 2014).

Research on sustainable business models, particularly within the agrifood sector, is still sparse (Mili and Loukil, 2023; Bröring and Vanacker, 2022; Donner and

de Vries, 2021; Salvador et al., 2023; Reim et al., 2019). While interest in the BMC has been growing, its application within the agrifood sector is still limited. Only a few studies (e.g., Mili and Loukil, 2023; Basile, 2021; Partalidou et al., 2018) have applied this model within this specific context, and none directly focus on BBFs. The existing literature does touch upon various aspects of BBF business models (e.g., Álvarez Salas et al., 2024; Garmendia-Lemus et al., 2024; Kvakkestad et al., 2023; Moshkin et al., 2023; Cazador et al., 2022; Chojnacka et al., 2020; Egan et al., 2022; Smol, 2021; Tur-Cardona et al., 2018). However, to the best of the authors' knowledge, no study offers a comprehensive BMC incorporating sustainability-oriented value propositions specific to BBFs. This study contributes to the existing literature by applying the BMC framework to BBFs, offering a comprehensive analysis of their commercialization pathways. Although not all elements of the BMC for BBFs are addressed in current literature, broader bioeconomy studies and research on diverse business model components provide valuable insights to guide the development of sustainable BBF business models. Customer-related components, however, remain relatively underexplored (Hatvani et al., 2022). Conventional business model frameworks often underemphasize sustainability (França et al., 2017). This paper seeks to address this by examining key elements for sustainable BBF business models.

## 2. METHODOLOGY

This study employs a literature review for analyzing sustainable business models within the circular bioeconomy. The BMC framework was applied as a conceptual framework for this study to evaluate and categorize key components of sustainable business models, with a literature review serving as the primary method to populate and elaborate on its components. While the TLBMC provides a framework to deepen insights into sustainability-specific dimensions, this study uses the BMC for its clear structure and broad applicability, serving as a practical starting point for analyzing BBF commercialization.

The literature review was conducted using three primary academic databases: Scopus, Web of Science, and Google Scholar. To ensure a comprehensive search, relevant keywords were used, including “circular bioeconomy,” “bio-based fertilizers,” “sustainable business model,” “Business Model Canvas,” “recycling-derived fertilizers (RDFs),” “waste-based fertilizers,” and “bio-based fertilizer products (BFPs).” Boolean operators such as *AND* and *OR* were applied to refine and expand the search results. The search primarily targeted peer-

reviewed articles, book chapters, and reports published in English, with the majority dating from 2013 to 2024 to reflect recent advancements and industry developments. Earlier studies were included when particularly relevant to the research objectives. The selection process followed a systematic three-step approach. First, titles and abstracts were screened to assess relevance to BBF business models and the BMC framework. Next, studies passing the initial screening underwent a full-text review to ensure alignment with the research objectives. Finally, studies providing insights into at least one of the BMC components—value proposition, value creation and delivery, or value capture—were included for analysis. Only high-quality sources, such as peer-reviewed journals and academic publications, were considered to ensure reliability and rigor. To enhance the reliability and robustness of the concepts presented, this study incorporates insights from real-world business models drawn from the B-FERST project, which focuses on integrating bio-waste valorization into fertilizer production, offering practical examples of sustainable business models in the bioeconomy. Data extraction was performed manually, with insights mapped to the nine building blocks of the BMC framework: value proposition, customer segments, channels, customer relationships, key activities, key resources, key partners, revenue streams, and cost structure. These elements were further grouped into three main BMC segments: value proposition, value creation and delivery (market and infrastructure), and value capture (financial aspects) (Vehmas et al., 2024; Schaltegger et al., 2016; Richardson, 2008). The extracted data were synthesized systematically to identify common themes, opportunities, and challenges associated with BBF commercialization. To guarantee the quality of the included studies, criteria such as source credibility, methodological rigor, and relevance to BBF business models were applied during the review process. Studies contributing to BBF commercialization, circular bioeconomy frameworks, and sustainability were prioritized, while those lacking sufficient methodological detail or academic rigor were excluded. The key components of the BMC applied to BBFs are summarized in Table S1.

## 3. RESULTS AND DISCUSSION

### 3.1. Value proposition in sustainable business models for BBFs

A value proposition encompasses the benefits a company offers its customers, including not only product/service features that drive sales but also environmental and social values (Hatvani et al., 2022). Studies indicate

that plant growth and yield potentials achieved with recovered nutrients are comparable to or even surpass those of conventional fertilizers (Barquero et al., 2024). Integrating services into business models is vital for the bioeconomy, enhancing value creation and promoting bio-based solutions. Product-Service Systems (PSS) combine products with complementary services, tailored to meet customer needs (Bröring and Vanacker, 2022). In BBF context, service offerings could include nutrient management consulting, application services, monitoring and analysis, product customization, and logistics solutions.

The environmental value of BBFs lies in their ability to address the ecological challenges posed by conventional fertilizers. This value can be assessed using the Life Cycle Assessment (LCA) approach, which evaluates a product's environmental impact through indicators such as CO<sub>2</sub> emissions, energy use, resource depletion, and water consumption. By recycling bio-waste, BBFs contribute to nutrient recovery, reduce dependence on finite fossil-based resources, and promote circularity in agriculture. Furthermore, BBFs help minimize greenhouse gas (GHG) emissions, reduce nutrient leaching, and enhance soil health and quality. However, BBFs also present environmental challenges that must be addressed to maximize their potential. Nutrient variability in BBFs can impact their agronomic performance, often leading farmers to favor synthetic fertilizers due to their predictability and immediate results (Bonnichsen et al., 2020). BBFs also require mineralization for nutrients to become available to plants (Leytem et al., 2024). This process may not always match crop growth cycles, leading to inefficient uptake, nitrate leaching, eutrophication, and potential acidification. Additionally, BBFs derived from waste (e.g., manure or sewage sludge) may contain pathogens or heavy metals, posing health and ecological risks if not properly treated (Kurniawati et al., 2023). Effective mitigation strategies are essential to manage these risks (Álvarez Salas et al., 2024).

BBFs also create significant social values related to stakeholder management approach, focusing on indicators such as community engagement, labor conditions, health and safety, and fair competition (Vidaurre et al., 2020; Rafiaani et al., 2018; Joyce and Paquin, 2016). By utilizing local bio-waste as feedstock, BBF production supports local job creation and stimulates rural economies (FAO, 2018). The involvement of local stakeholders, including farmers and waste processors, fosters community engagement and strengthens local value chains. In terms of health and safety, hygienization-focused BBFs mitigate health risks related to salt and heavy metal accumulation from synthetic fertilizers, which can be

absorbed by plants (Kurniawati et al., 2023; Smol, 2021). BBFs further promote fair competition by offering sustainable alternatives to synthetic fertilizers, empowering farmers to adopt environmentally friendly practices.

### 3.2. Value creation and delivery in sustainable business models for BBFs

#### 3.2.1. Market

##### *Customers segments*

Market segmentation divides the market into distinct groups with shared needs, enabling targeted marketing strategies. Stimulating demand for BBFs requires a deep understanding of behavior influenced by values, ethics, self-interest, product features, and policies. This complexity demands an interdisciplinary approach involving psychology, economics, and sociology (Nejadrezaei et al., 2024). While farmers are primary BBF users, other groups, like nurserymen, also show interest in adopting waste-based fertilizers, supporting the circular economy (Smol, 2021). Key product attributes influencing BBF adoption among farmers include nutrient content, high organic matter, cost, and ease of application (Kvakkestad et al., 2023; Egan et al., 2022; Tur-Cardona et al., 2018). Generally, BBFs must offer comparable properties to mineral fertilizers at a competitive price.

As sustainable practices gain momentum, BBFs are becoming more desirable, especially among environmentally conscious farmers seeking alternatives to mineral fertilizers (Tur-Cardona et al., 2018). However, a significant barrier is public knowledge and confidence, which can be addressed through effective education and communication on the benefits of bio-economy products (Bröring and Vanacker, 2022; Reim et al., 2019). Convincing consumers of BBF advantages remains challenging, as many farmers prefer synthetic fertilizers for their quick results, despite the availability of eco-friendly alternatives at similar prices (Ruth et al., 2020). Companies struggle to measure and communicate sustainability due to limited data and tools (Bröring and Vanacker, 2022). Field trial data on nitrogen release from BBFs could significantly enhance adoption by providing farmers with evidence of their performance and reliability (Kvakkestad et al., 2023).

Research by Morgan et al. (2015) highlights that anticipated financial gains and self-efficacy—farmers' belief in their ability to achieve desired outcomes—are key drivers for adopting Low-Emission Agricultural Practices (LEAP). This insight is highly relevant for BBFs, as improving farmers' self-efficacy through targeted educational programs, technical support, and demon-

stration trials could encourage their adoption. Morgan et al.'s study identifies four farmer categories—Non-Green Dismissive, Uncommitted, Green Adopters, and Profit-Driven Adopters—each with distinct attitudes towards climate change, environmental values, time orientation, place attachment, and knowledge self-efficacy. Tailored engagement strategies, such as showcasing the economic and environmental benefits of BBFs to Profit-Driven Adopters or emphasizing sustainability to Green Adopters, could help overcome resistance in different farmer groups. Similarly, Gazdecki et al. (2021) categorize consumers by their sustainability approach into Doers, Conscious, and Reluctant groups. These categories can be linked to BBF adoption by targeting Doers and Conscious consumers—who are more inclined to adopt sustainable alternatives—through eco-labeling, certification, and branding strategies that emphasize BBFs' environmental value. Addressing the concerns of Reluctant consumers through education and communication campaigns could further strengthen market adoption.

Targeting “premium” segments willing to pay more for environmentally and socially valuable products is essential (Reim et al., 2019). Studies identify a “green premium” where consumers pay more for bio-based products, and a “certified green premium,” where willingness to pay (WTP) increases for certified bio-based options (Morone et al., 2021). Standards, certifications, and eco-labeling could improve BBF market penetration by verifying sustainability, supporting green purchasing, and reinforcing consumer trust (Reim et al., 2019; Yenipazarli, 2015). Branding also affects BBF acceptance, as terms like “biosolids” over “treated sewage sludge” can positively shape consumer perceptions (Álvarez Salas et al., 2024).

### *Channels*

Market channels describe the pathways through which a company delivers its value proposition to customers, yet they are relatively understudied in the bioeconomy context (Reim et al., 2018; Coughlan, 2006). Channels can be direct, like company websites or stores, or indirect, such as through retailers or distributors, and they comprise five phases: awareness, evaluation, purchase, delivery, and after-sales support (Osterwalder and Pigneur, 2010). The shift from traditional media to digital platforms has redefined how sustainable agricultural practices are promoted. A comprehensive channel strategy for bioeconomy products should incorporate both traditional and digital media to maximize reach. For farmers with limited digital access, traditional methods like print, radio, agricultural fairs, posters, conferences, and field demonstrations remain effective. Demonstrations, in particular, allow farmers to engage firsthand with new

technologies and practices (Sutherland and Marchand, 2021). Digital marketing, meanwhile, can reach a broader audience via social media, influencer partnerships, email campaigns, webinars, and online advertising. Additional tools include agricultural apps and video content, which provide interactive and visual resources ideal for conveying complex information to farmers (Bentley et al., 2019). Digital training programs that build on existing farmer knowledge and practices are crucial for fostering adoption. These programs facilitate collaboration and knowledge co-creation by integrating traditional, indigenous, and scientific expertise, along with the expertise of farmers (Maurel et al., 2022).

Effective channel management also involves ensuring the timely delivery, proper handling, and optimal storage of products to maintain quality (Remondino and Zanin, 2022; Behzadi et al., 2017; Routroy and Behera, 2017). Efficient logistics and storage are necessary to handle the diverse and bulky bio-based materials, facilitating smooth operations (Donner et al., 2021). After-sales support, including technical assistance and application guidance, is essential to build trust and loyalty, encouraging repeat purchases (Rebello et al., 2021). Training for distributors and retailers is also vital, equipping them to effectively promote and sell BBFs, thus supporting wider adoption among farmers.

### *Customer Relationships*

Customer relationships outline how a company establishes and maintains connections with specific segments to drive customer acquisition, retention, and sales growth. Many consumers are willing to pay a premium for environmentally sustainable, organic, chemical-free, and locally sourced products. Companies should identify these “bioeconomy customers” and tailor their offerings accordingly (Hatvani et al., 2022). Consumers play multiple roles in advancing a sustainable circular bioeconomy (Lang et al., 2023). As buyers they influence the market by selecting fertilizers, encouraging BBF producers to adapt products to meet customer demands; as lobbyists and influencers, they shape public perception; as partners they contribute to developing standards for BBF usage; and as co-creators they actively participate in value creation, providing feedback and ideas for product improvements. Farmers are increasingly recognized as vital co-creators in developing sustainable agricultural practices and innovations. Their local knowledge and experience make them essential in designing practical solutions. Researchers can also be involved in the co-creation process, identifying gaps that farmers may not have the resources or expertise to address (Ruth et al., 2020).

Effective customer relationship models require integrating information and communication technology (ICT) to educate farmers on the benefits of BBFs through high-quality content and examples of successful applications. Influencers can also promote sustainable practices by sharing trusted recommendations and educating farmers (Vilkaite-Vaitone, 2024). However, research shows that “peer farmers” are the most influential information source, as farmers often learn from each other through conversations and by observing practices (e.g., roadside farming) (Sutherland and Marchand, 2021). Peer influence, or the impact of social interactions within a group on individual behavior, is significant in shaping farmers’ sustainable behavior (Garmendia-Lemus et al., 2024; Niu et al., 2022; Tran-Nam and Tiet, 2022; Bell et al., 2018). Translating traditional customer relationships into the virtual marketplace by establishing and maintaining online communities allows farmers to connect and share knowledge (Farquhar and Rowley, 2006). These communities, a key form of customer relationship alongside personal assistance, dedicated personal assistance, self-service, automated services, and co-creation, also help companies better understand their customers (Osterwalder and Pigneur, 2010).

### 3.2.2. Infrastructure

#### *Key activities*

Key activities encompass essential tasks a business must execute to create, deliver, and sustain value, generate revenue, and achieve its goals. In BBF production, key activities include raw material collection, nutrient recovery, and fertiliser production (granulation stage, and addition of non-microbial plant biostimulant (NMPB) or microbial plant biostimulant (MPB), with the requirement of a coating stage when the biostimulant is MPB) (Cazador et al., 2022; B-FERST Advanced Technology Brochure, 2024). Biostimulants improve nutrient efficiency, tolerance to abiotic stress, and crop quality traits, independent of their nutrient content (du Jardin, 2015). In the circular bioeconomy, particularly BBF production, core activities center on value recovery from waste (waste valorization), converting organic waste into BBFs while maintaining sustainability and resource efficiency. Production relies on secondary bio-based raw materials obtained through methods like composting, anaerobic digestion, and fermentation. Efficient logistics, storage, and quality control are essential for reusing byproducts and ensuring sufficient biomass supply (Reim et al., 2018). Logistics and supply chain models for bio-based products are complex due to the seasonal variability, dispersed distribution, and qual-

ity inconsistency of biomass sources. Challenges include biomass deterioration, diverse conversion technologies, and interdependencies among logistics operations (Stellingwerf et al., 2022). Resource volumes, particularly feedstocks from agriculture, can vary significantly, posing a challenge for markets like chemicals that are not typically exposed to such fluctuations (Hatvani et al., 2022). Collection across vast regions with varying quantities necessitates logistical adjustments and strategic planning (Bröring and Vanacker, 2022; Donner et al., 2021). Furthermore, nutrient recovery technologies in BBF production must address the inherent variability in product qualities, as BBFs need to meet diverse agronomic requirements and cater to a wide range of application contexts. This variability highlights the importance of technological flexibility and adaptability in production processes to ensure consistency and efficacy across different products. Future fertilizer plants must accommodate multiple biomass feedstocks using either single or a combination of integrated processes. Recycling and waste utilization require careful planning regarding collection, storage, transport, and pretreatment, depending on biomass volume and location (Cazador et al., 2022).

Ongoing R&D is crucial for cost-effective and high-quality production. Optimizing BBF production processes ensures efficiency, adaptability, and minimal environmental impact. In the bioeconomy—a sector characterized by high innovation and intensive research—advancements in new product applications, sidestream uses, and innovations toward bio-based and renewable resources play a critical role (Salvador et al., 2023). Scaling up newly developed technological solutions presents significant challenges. New technologies must be compatible with existing fossil-based infrastructure to ensure value creation. Additionally, navigating complex intellectual property issues, which can be costly and time-consuming, is essential for technology development (Bröring and Vanacker, 2022). Transitioning to a bioeconomy also involves internal transformation, requiring a cultural shift within established companies. Ongoing innovation and business model evaluation are critical for success (Reim et al., 2019).

#### *Key resources*

The key resources block identifies essential assets for a business model’s success, encompassing tangible (e.g., financial, physical), intangible (e.g., technology, reputation), and human resources (e.g., skills, expertise) (Näyhä, 2020). The European Union relies heavily on externally sourced, non-renewable raw materials for fertilizer production, with natural gas as the primary energy source (B-Ferst Advanced Technology Brochure,

2024). Fertilizer production is highly energy-intensive, relying on fossil fuels (such as the Haber–Bosch process for nitrogen fertilizers) or fossil ore deposits (such as phosphate rock) (Chojnacka et al., 2020). Phosphate rock needed for production of phosphorus-based fertilizers is a finite and irreplaceable resource, concentrated in a few countries worldwide. Inefficient phosphorus use has pushed it beyond the planet's safe limits, and continued reliance on primary phosphorus resources threatens agricultural sustainability (Magaya et al., 2024). This underscores the urgent need for nutrient recovery from alternative sources.

Wastes, especially biomass, offer a large reservoir of materials that can be converted into fertilizers through various technologies. High-potential bio-wastes for BBF production include agricultural waste, food waste, sewage sludge, and plant residues (Chojnacka et al., 2019; 2020). Agricultural by-products like crop residues, plant trimmings and compost provide sources of essential nutrients. Animal by-products, such as manure and offal, and agri-food industry waste (e.g., fruit and vegetable peels, pulp, seeds) also serve as valuable inputs. Wastewater treatment plant (WWTP) sewage sludge, or the organic material left after wastewater treatment processes, such as ashes and struvite as a source of P and K, is another nutrient source. Factors such as quality, regulation, processing feasibility, logistics, product stability, economic feasibility and carbon footprint influence the viability of these biowastes (Cazador et al., 2022).

Bioeconomy business models encounter challenges with biomass quality and availability. The unsuitability or seasonality of raw materials, along with inadequate infrastructure and capacity, can make biomass supply unreliable, disrupting the value generation process. Furthermore, various industries compete for the same biomass resources. The heterogeneity of these raw materials, particularly when using harvest residues, affects the consistency and quality of the final product (Bröring and Vanacker, 2022). Biostimulants, which enhance plant growth and soil health, are key resources in BBF production (Soltaniband et al., 2022). These include both microbial and non-microbial biostimulants. Biodegradable biopolymer coatings can be used to guarantee the performance of certain biostimulants and enhance the performance of BBFs, ensuring controlled nutrient release and increased agronomic efficiency (Cazador et al., 2022; B-FERST Advanced Technology Brochure, 2024).

Intangible and human resources play a vital role in the shift toward a circular bioeconomy. An innovative, adaptable, motivating organizational culture driven by “power people” and non-hierarchical leadership is essential. Communication, marketing skills, and team-

driven innovations supported by diverse expertise are also critical (Näyhä, 2020). Many organizations struggle with implementing new business models due to the dominance of established frameworks and a lack of absorptive capacity to acquire new knowledge and skills that may relate to distant sectors. Additionally, business models requiring new skills face obstacles such as skilled workforce shortages or limited research facility access (Bröring and Vanacker, 2022). Advanced bio-based, product-oriented technologies are frequently required to facilitate new and complex conversion processes (Donner et al., 2021). Laboratories are also considered as a key resource or a key partnership, since bioeconomy is a highly innovative and research-intensive sector. Laboratories and pilot facilities, essential in the highly innovative and research-intensive bioeconomy sector, are key resources or partnerships for evaluating and scaling diverse nutrient recovery methods to produce high-quality BBFs tailored to varied market demands (Hatvani et al., 2022).

#### *Key partners*

The key partnerships block details the network of suppliers and collaborators essential for effective business operations. Partnerships allow companies to optimize operations, reduce risks, and access external resources and capabilities (Osterwalder and Pigneur, 2010). Unlike traditional models focused on shareholders and suppliers, sustainable business models broaden the partnership scope to include stakeholders who add economic, environmental, and social value. The bioeconomy demands high levels of collaboration, with value chains requiring alignment and proactive coordination among diverse stakeholders (Bröring and Vanacker, 2022). The Quintuple Helix Approach provides a framework for understanding this collaboration by incorporating five key sectors: economic actors, educational and research institutions, policymakers, civil society, and the natural environment (Hatvani et al., 2022). Key stakeholders in the BBF market include livestock and crop farmers, waste management firms, recycling fertilizer companies, garden owners, horticultural producers, governments, NGOs, investors, and scientists, all of whom contribute to raw material supply, technological development, and BBF commercialization (Álvarez Salas et al., 2024; De Keyser and Mathijs, 2023).

Securing a reliable biomass supply and managing logistics are vital for bio-based companies, often requiring partnerships across previously unconnected sectors, such as chemical companies and small-scale farmers. Primary producers are central to bioeconomy value chains, making collaboration between the agricultural

and fertilizer sectors essential for developing sustainable management practices (Cazador et al., 2022). Strong relationships with farmers, supported by secure payments, timely transport, and financial support for infrastructure, are crucial for success (Hatvani et al., 2022). Engaging and benefiting biomass producers not only supports the supply chain but is also key to achieving social sustainability in the bioeconomy (Lange et al., 2021). Farmers' influence on BBF supply and demand varies; livestock farmers are incentivized to use excess manure, while crop farmers hold more power, selectively accepting or rejecting recycled products based on their preferences (Álvarez Salas et al., 2024).

Transportation and logistics partners maintain a smooth supply chain, ensuring the delivery of raw materials to production facilities and fertilizers to distributors and retailers. Research institutions play a crucial role by collaborating on scientific studies and field research to foster trust and promote new solutions (Moshkin et al., 2023). Agricultural extension services are vital for supporting farmers in adopting BBFs and ensuring proper application, maximizing their value (Kvakkestad et al., 2023). Policymakers establish regulatory frameworks for BBF production and marketing, ensuring safety and environmental standards compliance (Ruth et al., 2020). Media and NGOs play a significant role in shaping consumer perceptions. Although farmers may be open to using recycled nutrients, skepticism from consumers and the food industry can hinder broader adoption. Educating consumers on the environmental benefits of BBFs is therefore essential to increase acceptance (Álvarez Salas et al., 2024).

### 3.3. Value capture in sustainable business models for BBFs

#### 3.3.1. Finance

##### *Revenue Streams*

The revenue stream block defines cash flows from each customer segment, essential for profitability (Osterwalder and Pigneur, 2010). Primary revenue streams in the fertilizer industry include fertilizer sales, soil testing, agricultural consulting, distribution, specialty fertilizers, and licensing. For BBFs, revenue relies on pricing strategies and competitive positioning compared to mineral fertilizers, shaped by market demand, product availability, logistics, regulatory conditions, and regional fertilization practices (Álvarez Salas et al., 2024). Price reflects product quality and brand positioning, and must match customer expectations and willingness to pay. To facilitate market adoption and maximize market share, BBFs must be competitively priced. Research suggests pricing

BBFs below mineral fertilizers to attract farmers; Tur-Cardona et al. (2018) recommend pricing BBFs at approximately 65% of the cost of mineral fertilizers. Similarly, Bonnichsen et al. (2020) found that farmers would prefer a price reduction of up to 50% compared to current mineral fertilizers. Moshkin et al. (2023), however, found that significant price reductions might primarily be needed for rapid market uptake rather than overall revenue maximization. Alternatively, pricing BBFs at levels similar to mineral fertilizers could maximize revenue even if initial market penetration is slower, provided marketing strategies effectively address customers' willingness to pay. Premium pricing can be an effective approach for bio-based products, especially when highlighting their environmental value, such as reducing reliance on fossil fuels. By positioning waste recovery as a value-added service and reducing production costs through waste inputs, BBFs can justify premium pricing due to their environmental benefits (Salvador et al., 2023). Market data indicate that while BBFs currently contribute a smaller share of global fertilizer revenue compared to mineral fertilizers, their market share is expected to grow steadily as demand for sustainable agricultural practices increases (Joshi and Gauraha, 2022). In 2023, the global biofertilizers market was valued at approximately USD 2.31 billion and is projected to reach USD 4.77 billion by 2032, reflecting a compound annual growth rate (CAGR) of 8.5% (Global Market Insights, 2024). In contrast, the overall global fertilizer market, valued at USD 202.20 billion in 2023, is projected to reach around USD 276.92 billion by 2034, with a CAGR of 2.9% from 2024 to 2034 (Precedence Research, 2024). Additionally, environmentally conscious consumers are willing to pay a higher but competitive price if the products not only deliver similar functionality but also address their unique demands and preferences (Hatvani et al., 2022).

Beyond fertilizer sales, additional revenue streams can be derived from value-added services, such as customer support, loyalty programs, and product optimization services. Subsidies can support revenue, but they should underscore long-term benefits, proving bioeconomy products' profitability beyond public funding reliance (Reim et al., 2018). Effective use of subsidies and taxes should reflect the socio-economic and environmental advantages not captured in market pricing. Larger companies often integrate bio-based products into their broader product range, enabling them to leverage internal financing from other profitable business areas. These firms also benefit from EU funds during the early development stages, supporting essential R&D efforts needed for future industrial-scale investments (COWI, Bio-Based World News and Ecologic Institute, 2019).

### *Cost Structure*

To maximize growth and profitability, it is essential to understand cost structures, including both fixed and variable costs. Companies may adopt cost-driven models focused on efficiency or value-driven models that prioritize value creation and high-quality products, even at higher costs. In the bioeconomy, production costs and market feasibility are influenced by several factors, primarily the cost of biomass or feedstock, which must be procured competitively amid competition from other industries. Maintaining quality control and regulatory compliance also challenges BBFs' cost competitiveness with conventional fertilizers, highlighting the need for industry standardization. A major challenge for new bioeconomy business models is the high opportunity cost of substantial initial investments in technology development, with operations often remaining costly due to low production volumes and competition for limited resources (Reim et al., 2019). Many bio-based products lack economies of scale, limiting their competitiveness with fossil-based alternatives and slowing return on investment (Bröring and Vanacker, 2022).

The cost structure of BBFs varies significantly based on the technologies employed, such as composting, thermal processing, nutrient recovery, and advanced coating technologies. Each technology presents unique cost drivers, including energy use, material requirements, and regulatory compliance. Sourcing large quantities of bio-based materials from diverse locations introduces logistical challenges, complicating supply chains and driving up costs, particularly when production rates at specific sites are limited (e.g., struvite) (Bröring and Vanacker, 2022). Additionally, navigating varied European safety and logistics regulations increases operational expenses, impacting overall economic feasibility. The commercialization of BBFs entails a lengthy approval process, requiring extensive scientific data collection that adds to operational costs (Giuliani, 2023). Technology development must be complemented by strategic marketing, public relations, and specialized sales to emphasize product benefits, with marketing costs often exceeding development expenses but frequently overlooked in cost analyses (Hatvani et al., 2022). Packaging costs are also significant, especially when designing premium packaging to differentiate BBFs from conventional fertilizers. On a positive note, efficient production strategies can create economies of scale, reducing per-unit costs and boosting profitability. Using high-quality, concentrated biobased materials can streamline production processes, potentially minimizing costs associated with quality control and material waste (Cazador et al., 2022). Currently, phosphorus recovery is expensive and energy-intensive,

involving high-temperature processes and costly reagents (Giuliani, 2023). Technological innovation, especially in developing cost-effective nutrient recovery methods, such as for phosphorus, can also optimize costs. By optimizing production and logistics, companies can reduce costs, enhance profitability, and support competitive pricing.

## 4. CONCLUSIONS

This paper addresses the research gap on sustainable business models for BBFs by applying the BMC framework to provide a comprehensive overview of key elements and considerations related to BBF business models, integrating economic, environmental, and social dimensions. It highlights the significant environmental impact of conventional chemical fertilizers and the need for sustainable alternatives, as underscored by EU strategies like Farm to Fork and the EU Fertilizing Product Regulation. BBFs offer potential solutions through nutrient recycling and soil health improvement, but a transition to bioeconomy requires substantial business model transformation, with sustainability as a core objective.

This paper contributes to the literature by presenting the BMC as a comprehensive tool to examine the status of all key aspects and considerations related to commercialization of BBFs, integrating a holistic perspective on value proposition, value creation and delivery, and value capture with sustainability as a central objective. It has potential for providing valuable insights for stakeholders in the fertilizer and agricultural sectors, policymakers, and the research community, providing a foundation for developing strategies to transition towards sustainable circular bioeconomy. Future studies should explore the entire TLBMC in the context of BBFs to integrate sustainability principles. Since the market-related segments of the BMC are less explored in bioeconomy literature, further research could focus on these areas, leveraging behavioral economics to provide deeper insights into farmer adoption behavior. Finally, developing effective education and training programs that build upon farmers' existing knowledge and practices to improve BBF adoption, remains a vital avenue for future exploration. An effective educational approach is necessary not only for farmers but also for the broader public, including policymakers, businesses, and citizens. As Christian Paternmann, widely recognized as the "father of the bioeconomy," highlights, the greatest challenge in advancing the bioeconomy is its inherent complexity and the need to translate this complexity into accessible understanding (Giuliani, 2022).

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## Weathering the storm: A systematic review of climate change adaptation in agriculture. Methods, metrics, and impacts

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**Abstract.** Much attention has been paid to the impact of the agriculture sector on the environment and its contribution to climate change. However, the sector is also vulnerable to the impacts of climate extremes. Thus, a growing number of studies have focused on adapting to these changes. We conducted a systematic literature review and assessment of the evidence gathered from 124 studies on the impacts of and adaptation to climate change in the agriculture sector in OECD member countries. Results highlight a significant knowledge gap in understanding the full economic effects of climate change as the impacts of climate change on input costs is not extensively studied in the way that impacts on farm output is. Additionally, there is a need to understand the indicators used to assess climate impacts in agriculture for easier comparison across studies. We recommend targeted research and funding to close this knowledge gap including conducting long term analyses to evaluate the costs and benefits of adaptation strategies as well as capacity building and knowledge exchange.

**Keywords:** systematic review, climate change, adaptation, agriculture, impacts.

### 1. INTRODUCTION

Agricultural production is sensitive to weather and therefore directly affected by climate change (Nelson et al., 2014; Malhi et al., 2021). With rising temperatures, shifting rainfall patterns, and the increasing prevalence of extreme weather events such as floods and droughts, not to mention the growing scale of potential climate impacts, it is critical to assess the risks posed to the sector and evaluate the effectiveness of adaptive practices (World Bank, 2010) to aid decision-makers in resource allocation. Given that budgets are often constrained (Mysiak et al., 2018), understanding the risks and potential adaptation strategies within the agriculture sector can allow policymakers to understand where funds and resources are most needed and can be most effective. Challenges for effective adaptation policy for agriculture include financial constraints, lack of coordination and knowledge

gaps. These factors often lead to maladaptation whereby the sector becomes more vulnerable to climate change (OECD, 2023). To minimise the risk of maladaptation, adaptation policies that are flexible and suitably robust across a range of climate scenario outcomes should be prioritised (Ignaciuk, 2015). To aid policymakers in avoiding maladaptation in this way, this review aims to present a range of climate risks faced by farmers and the effectiveness of adapting to these risks with specific adaptation strategies. Furthermore, understanding the impacts of climate change on agriculture and how detrimental effects can be mitigated by investing in appropriate adaptation strategies is crucial not only for the sector itself but also for the wider economy (Gallic & Vermandel, 2020), and for global food security.

Historically, much attention has been paid to the agriculture sector's impact on the environment and its contribution to climate change. However, there is now a growing body of literature on the impacts of climate change on agriculture and how adapting to climate change affects farm businesses (Burke & Emerick, 2016; Cogato et al., 2019; Chatzopoulos et al., 2020). Where previously the economic literature has rarely included weather or climate extremes in analysis, there is now development of literature on the effect of climate extremes on agriculture. This shift in focus reflects the increasing awareness and acknowledgment of agriculture being severely impacted by climate change and not just a driver of climate change. As farmers attempt to cope with the growing impacts of climate change on their enterprises, it has become more pertinent to explore the impacts of this in the literature. While numerous empirical analyses exist in the literature, the methods, metrics, and case studies are highly heterogeneous, making it challenging to compare findings across studies and formulate consistent recommendations for decision-makers.

Therefore, one of the aims of this review paper is to identify and summarize the methods and metrics used, highlighting gaps and the latest advancements in the literature. We scrutinize a large number of studies that meet our inclusion criteria, synthesizing and discussing the diversity in metrics used to capture climate change, the variety of adaptation strategies, and the range of outcome variables included in models to assess impacts. This approach allows us to identify less-studied areas, observe methodological trends in the literature driven, among other factors, by the availability of new and more sophisticated data, and recommend directions for future research. Finally, we outline the economic costs and benefits associated with climate change adaptation strategies, as well as comparing the impacts of climate change on agriculture with and without such adaptation.

Unlike previous reviews, our study examines both climate change impacts and adaptation, with a focus on OECD member countries. This broader scope enables a more comprehensive assessment of agriculture in relatively comparable socio-economic contexts, improving the potential for cross-study and cross-country comparisons. Such an approach supports policymakers in making decisions based on the capacity and resilience of agricultural systems, rather than prescribing specific adaptation strategies – a best-practice approach given the challenges of determining which strategies are most effective at the local level (OECD, 2023). In addition, easier comparison between studies strengthens the findings surrounding the effectiveness of adaptation strategies. By focusing on both impacts and adaptation, we add value to previous analyses, as it is well known that the impact of climate change heavily depends on the effectiveness of adaptation strategies employed. Furthermore, a key aspect in formulating policy recommendations is the need for a deeper understanding of the costs and benefits of adaptation strategies.

Ultimately, our work aims to explore the following areas; a) the methods and metrics used in the literature to assess the impact of climate change on agriculture and the effectiveness of climate change adaptation measures; b) the effects of changes in the climate system; c) the adaptation strategies employed to reduce the effects of climate change; and d) the effectiveness of these strategies in reducing different types of detrimental socio-economic losses. By assessing the effectiveness of these measures, we provide an indication of the potential economic savings of adaptation to boost farm resilience. The findings and recommendations of this review are addressed to the scientific community to inform future research and efforts to identify the adaptation strategies that are the most appropriate under different conditions. This is perceived as useful also for stakeholders and policymakers who can design, and finance measures aimed at encouraging the use of the most promising strategies.

The review continues as follows. In section 2, we outline the methodology employed to identify, process and extract relevant studies conducted. In section 3, we present the results of the review including a bibliometric analysis and outline of the effectiveness of adapting to climate change in the agriculture sector. Finally, in section 4 we conclude with a summary of the main findings and their implications for policy and future research.

## 2. METHODOLOGY

In order to gain a better understanding of the climate impacts affecting agriculture and how farmers are

adapting to these changes, we conducted a systematic review of the literature according to PRISMA guidelines (Page et al., 2021). The framework facilitated transparent and complete reporting of the findings (Fig. 1). Inclusion criteria for the review was designed to identify studies that analyse the impacts of climate change and adaptation in the agriculture sector. The population of interest was the agri-food sector in OECD countries. As mentioned in section 1, We focus on OECD countries to enable a broader examination of agriculture in settings with more comparable socio-economic conditions, environments, and policy frameworks, making cross-country and cross-study comparisons easier. The outcomes considered in the review were determinants (i.e. weather and climate shocks such as drought and flood events, changes in precipitation patterns and increases in temperature), impacts (i.e. impact on profit/farm income, yield, land value), model estimation of impacts (e.g. long difference approach, fixed effects panel approach, Ricardian approach), adaptation strategies employed (e.g. drought resistant crops, irrigation), and the effectiveness of these adaptation strategies. Full details of the inclusion criteria can be found in the supplementary materials. We included empirical research published worldwide in English up to November 2024. Paper retrieval was conducted from April 2024 to June 2024 and again in October 2024 to check for further relevant papers published after this time. Only empirical research papers were considered for inclusion in the review, i.e. not letters to editors, commentaries, responses and so forth. The Web of Science and Scopus electronic databases were searched to identify relevant literature. Details of the full search strategy can be found in the supplementary materials including the search queries and keywords employed.

Identified studies were screened in two steps according to best practice guidelines: firstly, by titles and abstracts, and secondly by the full text. Potential biases were addressed by using more than one reviewer during the screening process as recommended by PRISMA guidelines. Publication information, study characteristics, and findings from included studies were recorded in a standardised data extraction form using Covidence™ (Veritas Health Innovation, 2016), a software programme used to organise and manage systematic and scoping literature reviews. Extracted data gathered information on three main areas: impacts, adaptation, study characteristics. Data on impacts included the type of weather or climate shock analysed, the impact type analysed, timing of the impact, and quantification of the impact. Data on adaptation included the tool or strategy implemented, timing of the strategy, and effectiveness of the strategy. In terms of study characteristics, we gathered information

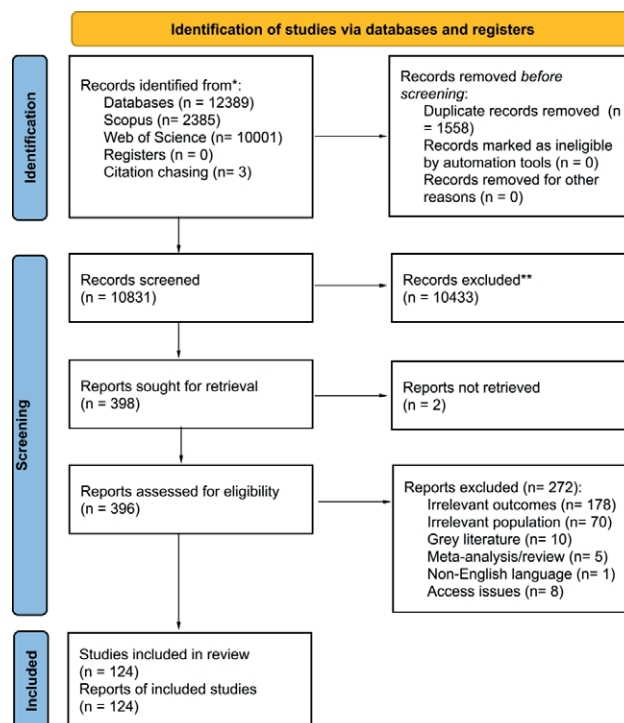


Figure 1. PRISMA flow diagram.

on publication year, country of origin, study objectives, currency units, farm type, level of analysis, and model employed for analysis. We employ a narrative synthesis approach as this is better suited to reviews where the subject area is broad (El Chami et al., 2022).

The database searches yielded 12,389 records. After removing duplicates this was reduced to 10,831 records which were screened according to the methods outlined above. Robust screening of the records resulted in 124 studies being included in the review. This process was carefully and transparently documented and has been schematically summarised for simplification according to the diagram above (Fig. 1).

The reasons for excluding studies from the final review as outlined in Fig 1 can be defined as follows. ‘Irrelevant outcome’ refers to studies that do not indicate an impact of either climate change or adaptation practices. ‘Access issues’ refers to studies that we were unable to gain access to within the timeframe of the review process. ‘Irrelevant population’ refers to studies that focused on other aspects of the agri-food sector such as trade or did not focus on an area within the scope of OECD countries. ‘Grey literature’ refers to working papers, commentaries, conference abstracts or other non-empirical papers. ‘Non-English studies’ refers to studies conducted and published in a language other than English.

### 3. RESULTS: THE STATE OF EVIDENCE ON IMPACTS AND STRATEGIES

In this section we begin with a bibliometric analysis to outline the temporal and spatial trends in the literature. We then examine the climate parameters explored in the literature and the impacts of these changes in the climate system. We follow this with an examination of how these impacts can be adapted to and indicate the effectiveness of these strategies.

#### 3.1. Bibliometric analysis

The first relevant study which captures the research questions of this review was published in the mid-nineties. The number of studies by publication year (Fig. 2) shows that interest in both climate impacts and adaptation has fluctuated over the years, however adaptation studies are lagging behind climate impact studies despite a more recent increase in interest. It is most likely that

adaptation studies are simply fewer in number rather than there being slower in development or impact. Given that the impacts of climate change need to be understood before adaptation measures can be planned or implemented, it is not surprising that there are more studies on impacts than adaptation.

Relevant studies did not cover all OECD member countries with 13 countries not represented in this review (Austria, Costa Rica, Denmark, Estonia, Iceland, Ireland, Israel, Latvia, Lithuania, Luxembourg, Norway, Slovak Republic and Slovenia). This does not indicate that studies are not available in these regions, but rather that they did not meet our robust inclusion criteria specific to this review. For example, some studies in these countries have focused less on observed impacts in the climate system and therefore were excluded from this review. The United States offers the most publications (n=36). Many studies are also conducted across Europe without focus on one specific country (n=12). Germany offers 9 studies, Australia and Spain offer 7 studies each and Türkiye offers

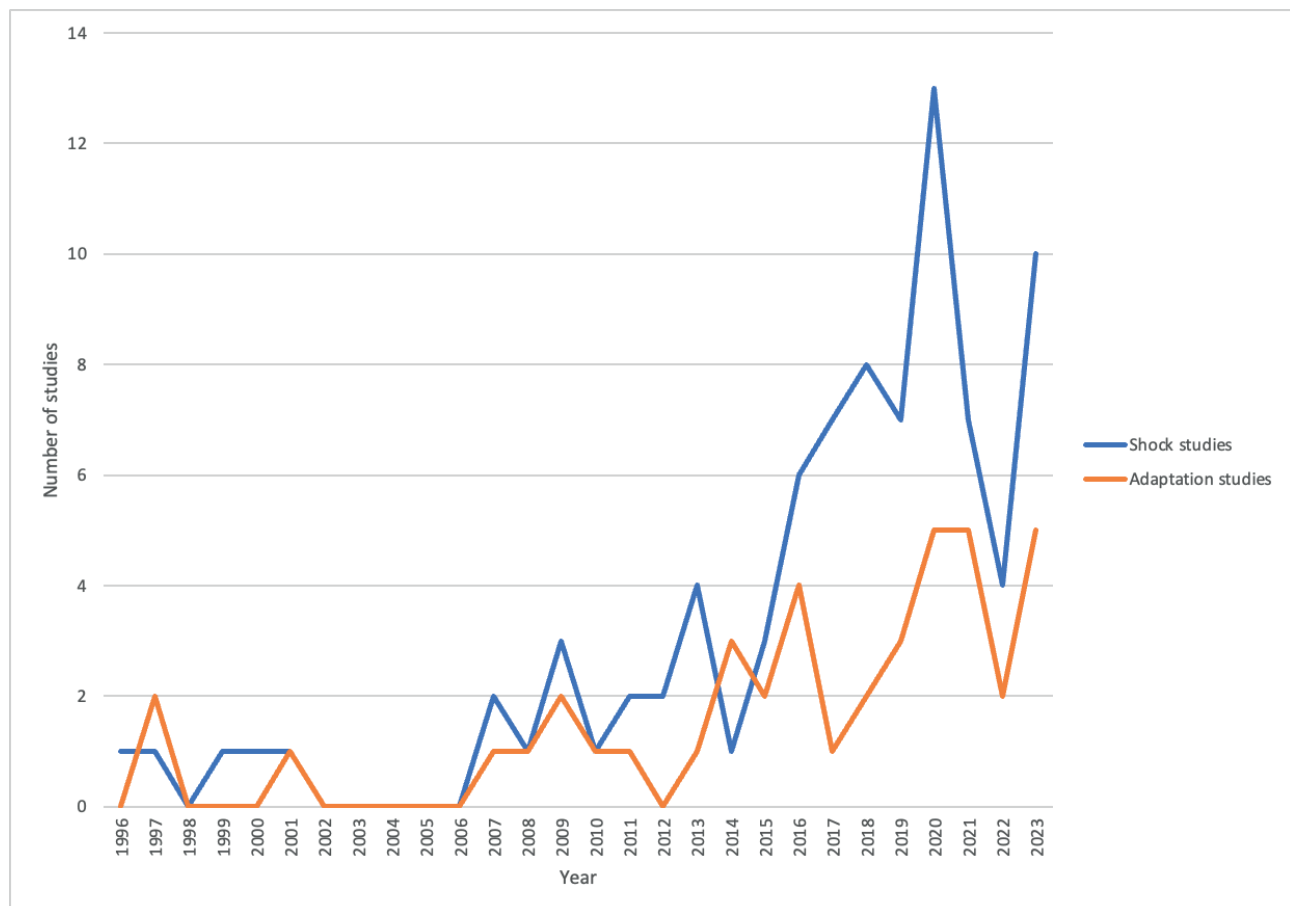
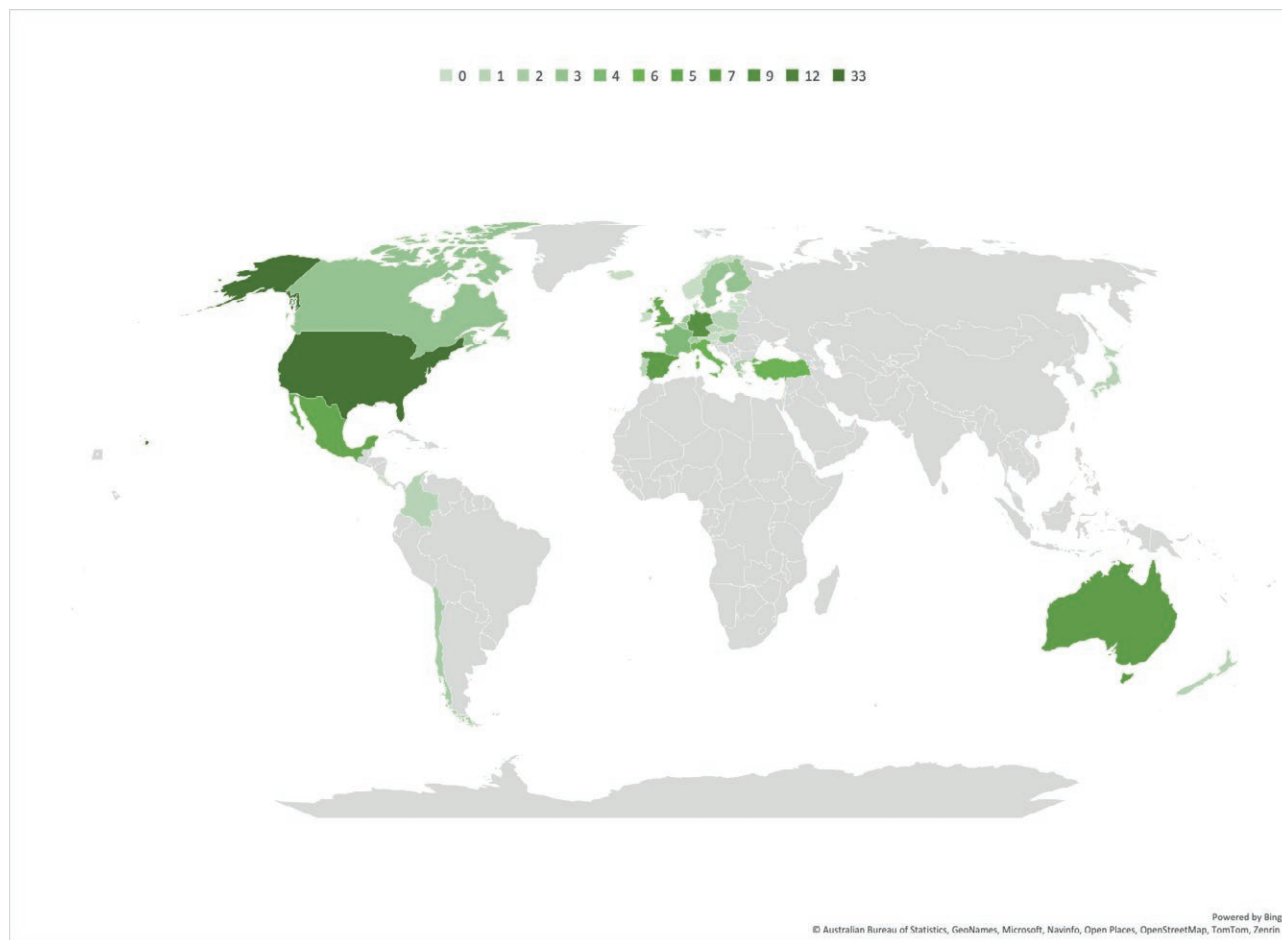


Figure 2. Number of studies by publication year.



**Figure 3.** Number of studies by OECD country.

6 studies. The countries which are covered the least with only one study each are Colombia, Czechia, Japan, New Zealand, Poland and Portugal (Fig 3).

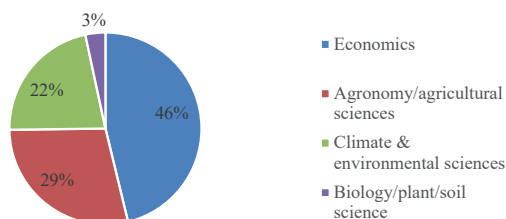
The publications can be divided into four subject areas (Fig. 4). The most common is economics ( $n=62$ ), followed by agronomy and agricultural sciences ( $n=34$ ) and climate and environmental sciences ( $n=26$ ). The remainder are classified as biology/plant/soil sciences ( $n=4$ ). It is unsurprising that the majority of studies have been conducted within the economics field as the financial impacts of climate change and adapting to climate change are crucial for farmers and their farm enterprises and thus this aligns with perceived needs.

### 3.2. Impacts of climate change

A total of 89 studies explored climate change impacts on agriculture. In terms of the farm types that are explored, arable farms tend to dominate ( $n=64$ ).

Nine studies examine dairy farms, and four studies examine other types of livestock farms. Three studies are based on mixed crop/livestock farms and the remaining nine studies either cover all farm types or do not specify. The studies also analyse impacts across a range of levels (Table S1). Most studies were conducted at the region or county level ( $n=42$ ). Many studies were also conducted at the farm level ( $n=17$ ) and at the national level ( $n=15$ ). The remaining studies were conducted at the individual plot or crop level ( $n=9$ ) or other levels, namely the European level ( $n=7$ ).

We build on the work by Ortiz-Bobea (2021) to classify the methods used in the existing literature to analyse climate impacts. They are categorised as follows: biophysical approaches ( $n=2$ ), Ricardian approach ( $n=8$ ) (e.g., Mendelsohn et al., 1996; Van Passel et al., 2017; Massetti et al., 2018; Fabri et al., 2022), standard panel approaches ( $n=57$ ) (e.g., Powell et al., 2015; Zipper et al., 2016; Ortiz-Bobea et al., 2019; Pourzand et al., 2020;



**Figure 4.** Number of studies by subject area.

Gulino et al., 2023; Karahasan et al., 2023; Demirdogen et al., 2024), time series approaches ( $n = 2$ ) (Hamed et al., 2021; Vanongeval et al., 2023), joint estimation of short and long run responses ( $n = 5$ ) (e.g., Chandio et al., 2020; Çakan et al., 2024), mixed statistical and biophysical approaches ( $n = 1$ ), machine learning approaches ( $n = 4$ ) (e.g., Feng et al., 2018; Beillouin et al., 2020) and other econometric approaches ( $n = 10$ ) (e.g., Durant et al., 2018; Ray et al., 2018; Wang et al., 2021). While these categories are not an exhaustive list of all empirical approaches, they are useful for classifying the methods identified in this review. For a more in-depth discussion of some of these approaches, see Ortiz-Bobea (2021).

Standard panel approaches are the most commonly used method when analysing the impacts of climate change on agriculture. This result is unsurprising given that there is a long tradition of using longitudinal data to analyse weather conditions in agricultural economics, with a surge in interest within the scope of climate change following Deschênes & Greenstone's (2007) seminal work on the impacts of climate change in the agricultural sector. Jiang et al (2020) use a multiple linear regression model to quantify the relationships between corn yield and meteorological factors in the USA. They find that on average, extreme heat (KDD) is estimated to be the most stressful meteorological factor in most districts. Corn yield reduces by 0.011, 0.020, 0.022, and 0.008 Mg/ha for one unit of KDD increase in four growth phases, respectively. Increasing precipitation reduces yield by 0.002 Mg/ha per mm at the early vegetative stage, yet additional precipitation promotes yield by 0.006 and 0.005 Mg/ha per mm at the grain filling stage and 0.001 Mg/ha per mm at the late dry-down stage. Using a standard panel approach has allowed for the examination of climate impacts on corn yields over the course of the growing season. In a similar vein, Demirdogen et al (2024) estimate the impact of climate change on wheat production (yield and land) in Türkiye over the past 25 years using a panel data model with fixed effects. Results indicate that a 1°C increase in temperature is associated with a yield loss of approximately

6% and the observed 1.5°C temperature increase over the past 25 years has led to a yield loss of nearly 9%. They also find that temperature changes and drought events during May have a particularly significant impact on wheat yields. An increase of 1°C in May temperatures results in a reduction of approximately 4% in wheat yields and contribute to a decrease in the size of the harvested area, exceeding 6%.

In most of the models in environmental economics, weather and climate measurements are solely based on temperature records. In agricultural economics these measurements are often supplemented by rainfall observations in order to characterise agricultural returns patterns (Gallic & Vermandel, 2020). The climate changes analysed in the literature can be categorized as changes in weather patterns (i.e. fluctuations in temperature and precipitation), and extreme weather events (e.g. drought, heatwaves, floods etc) (Lucas et al., 2021). It is important to note that some studies consider more than one metric for instance, many examine both temperature and precipitation changes, or precipitation changes and drought. Both temperature and precipitation are widely explored in the literature ( $n = 50$  and  $53$  respectively). Given that agriculture is dependent on weather conditions it is unsurprising that marginal changes in temperature and precipitation have been extensively studied. We observe a pattern among studies examining these changes that increases in precipitation in the short term tend to bring positive impacts for crop yields (although not in the long term), whereas crop yields tend to be negatively impacted by increases in temperature (Burke & Emerick, 2016; Çakan et al., 2024; Chandio et al., 2020; Dogan et al., 2018).

Among extreme weather events, drought is the most widely studied ( $n=14$ ) (e.g., Zipper, 2016; Sheng, 2019; Schaub, 2020; Nguyen, 2023) followed by heatwaves and heat stress ( $n = 10$ ) (e.g., Mukherjee, 2013; Finger, 2018; Schaubberger, 2021; Fabri, 2022), storms/hurricanes ( $n = 5$ ) (e.g., Durant, 2018; Huitu, 2020; Klatt, 2021), flooding ( $n = 3$ ) (e.g., Klatt, 2020; Wang, 2021; Pérez-Uribe, 2024) and frost events ( $n = 1$ ) (e.g., Dalhaus, 2020). These studies suggest that drought has an overwhelming negative impact on agriculture in terms of yield and economic output (Benito-Verduga et al., 2023; Nguyen et al., 2023; Quiroga et al., 2009; Pérez-Uribe et al., 2024; Schaub et al., 2020; Sheng et al., 2019). Where drought may have the opposite effect on yield, other factors such as crop type (Ray et al., 2018) or location (Zipper et al., 2016) are at play. Far less attention has been paid to extreme weather events such as flooding, storms and hurricanes, and frost events. This lack of information on the potential impacts of these shocks represents a gap in knowledge and impedes preparation for adaptation.

The majority of studies assessed the impact of climate change on production (yield change, variability, or loss, including milk yields on dairy farms) (n= 81). A considerable proportion also assessed the impact of climate change on economic output (farm profitability, income, crop prices) (n= 27). Only one study examines the impact of climate change on input costs, for example fertiliser costs, which is also important for understanding the full financial impact of climate change and are also affected by changes in weather patterns and climate change (Schaub et al., 2020). Additional outcome variables include changes in farmland value (n= 10), herd size on livestock farms (n= 3), damage payments or subsidies (n= 2), and changes in product quality (n= 5). These results are summarised in Fig 5. As the main focus in the literature is on arable farming, there is also a gap in information on the livestock sector, in which understanding climate impacts and the need for adaptation is pivotal. Livestock systems face distinct climate risks—including heat stress, altered disease dynamics, and feed shortages—that require tailored adaptation strategies (Rojas-Downing et al., 2017). Neglecting this sector undermines food security, especially for smallholders and pastoralists who depend heavily on animal produc-

tion and often have limited adaptive capacity. Moreover, livestock and crop systems are interdependent in many mixed farming contexts, meaning insufficient attention to livestock resilience can compromise whole-farm adaptation. In addition, a wide range of output variables have been used to convey the impacts of climate change on agriculture. Nevertheless, there is no standardised set of indicators to compare and contrast these impacts, or the climate metrics involved, making it difficult to quantify the exact economic consequences of changes in weather and climate conditions.

We also classify the climate impacts by timing—short, medium and long term. We define these as seasonal impacts (short term) (n= 48), annual impacts (medium term) (n= 28), and multi-annual impacts (long term) (n= 24). Some studies, especially those which employ long difference methods and joint estimation approaches, can be classified in more than one category. Long term impacts are the least studied within the literature and tend to focus on climate impacts on outcomes such as land value (Mendelsohn et al., 1996; González et al., 2008; Bozzola et al., 2018), which require analysis over a longer time period and/or use methodologies which lend themselves to analysing longer term

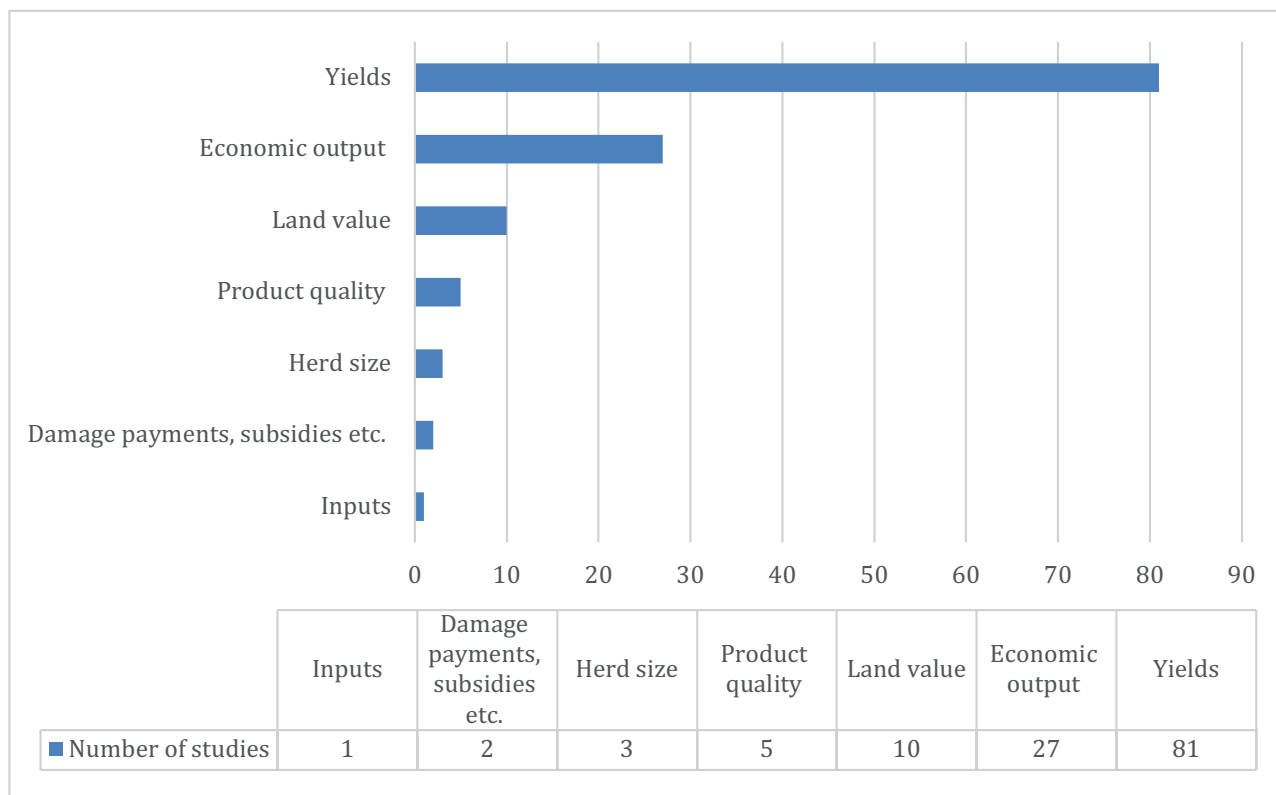


Figure 5. Types of impacts explored. \*Some studies examine more than one impact.

impacts such as the Ricardian approach (Chatzopoulos et al., 2015; Massetti et al., 2018; Fabri et al., 2022). On the other hand, short term impact studies tend to focus on changes in yields as would be expected with seasonal impacts (Wu et al., 2017; Beillouin et al., 2020; Benito-Verdugo et al., 2023).

### 3.3. *Adaptation strategies*

A total of 47 studies explored adaptation in the agriculture sector. As is the case for climate impact studies, the majority of adaptation studies focus on arable farms (n=36) while dairy and livestock farms are less studied (5 studies respectively). The remaining studies explore mixed crop/livestock farms (n=1) or cover all farm types (n=5). In terms of the level of analysis conducted in these studies (Table S2), the largest proportion was conducted at the region or county level (n= 20), followed by at the farm level (n= 12), and the individual crop or plot level (n= 8). Fewer studies were conducted at the national level (n= 3) or European level (n= 4).

In terms of the methods used in the studies examining the effectiveness of adaptation, a range of approaches have been implemented. The studies employed the Ricardian approach (n= 2) (Polsky et al., 2001; Vanschoenwinkel et al., 2018), standard panel approaches (n= 29) (e.g., Reidsma et al., 2010; DiFalco et al., 2014; Wang et al., 2016; Karapinar et al., 2020; Wittwer et al., 2023), time series approaches (n= 1) (Matsushita et al., 2016), joint estimation of short and long run responses (n= 4) (e.g., Di Falco et al., 2008; Foudi et al., 2011), machine learning approaches (n= 1) (Akbar et al., 2020), and other econometric approaches such as sensitivity analysis and principal-agent models (n= 12) (e.g., Zhang et al., 2018; Pexas et al., 2021). As is the case for impact studies, standard panel data approaches have been the most used methods throughout the included literature. Joint estimation of short and long run responses as introduced by Moore & Lobell (2014) combine elements of panel approaches and cross-sectional methods to jointly estimate the short- and long-term impacts of climate change and adaptation (Ortiz-Bobea, 2021). Di Falco et al (2008) investigate the effects of rainfall shocks on agroecosystems productivity and how increasing the level of spatial crop diversity can mitigate negative impacts in Italy using the joint estimation approach. They find that crop biodiversity ensures that the agroecosystem remains productive when facing low or scarce rainfall both over the short and long term. These findings indicate crop diversification can be a long-term adaptation strategy that can continue to bring benefits to farmers beyond a seasonal timeframe. This can encourage

investment in this strategy and increase adoption. While several of the included studies employ this method there is scope for this approach to be utilised further to conduct longer term experiments and better understand the costs and benefits of adapting to climate change.

An array of adaptation tools and strategies have been adopted to cope with the impact of climate change. In response to droughts, irrigation (e.g. Auci et al., 2023; Jordan et al., 2021; Lu et al., 2020), water storage (e.g. Smith et al., 2021; Wheeler et al., 2014) and crop diversification (e.g. Di Falco et al., 2008; Bowles et al., 2020) have been studied. In response to more frequent heat waves, some economic agents have installed cooling systems (e.g. Li et al., 2020; Mukherjee et al., 2013; Pexas et al., 2021). Additionally, certain strategies are policy-driven rather than driven by the autonomous decisions of farmers, such as participation in agri-environment schemes and other government strategies (e.g. Won et al., 2024; Aláyon-Gamboa et al., 2011). On livestock farms, steps have been taken to reduce herd sizes (which also allows for meeting climate change mitigation goals) or change to breeds that are more resilient and better suited to new weather conditions (e.g. Akbar et al., 2020; Skidmore et al., 2022). Other strategies include changing cropping patterns and tillage systems (Whitebread et al., 2015; Ruiz et al., 2019; Peltonen-Sainio et al., 2014), participating in insurance schemes (e.g. Kath et al., 2018; Wang et al., 2021), leasing additional acreage (e.g. Zhang et al., 2018), adopting or changing fertilization techniques and/or quantities (e.g. Pérez-Urbe et al., 2024; Reidsma et al., 2009a; Reidsma et al., 2009b), and converting to organic farming (e.g. Bouttes et al., 2019; Reidsma et al., 2007). See Fig 6 for a complete overview of the adaptation strategies identified in the literature.

Although adaptation may seem like a simple concept of adjusting behaviours, actions, and decisions within biological, social, and built systems in response to climatic changes (Smit & Pilifosova, 2001), it has proven difficult to reach consensus within the literature on a definition. Robert et al (2016) classify adaptation strategies through timing, temporal and spatial scopes. Timing refers to whether adaptation is proactive (anticipatory) or reactive (a response after a shock). Temporal refers to whether adaptation is strategic (long term adjustments) or tactical (short term adjustments). Spatial refers to whether adaptation is localised (e.g. a single crop) or widespread (e.g. farm system). Adaptation can also be autonomous (a decision made solely by the farmer at the farm level) or dependent (based upon changes in policies or subsidies) (Forsyth & Evans, 2013). The most used classification in the literature is reactive versus proactive adaptation (Engler et al., 2021). However, despite

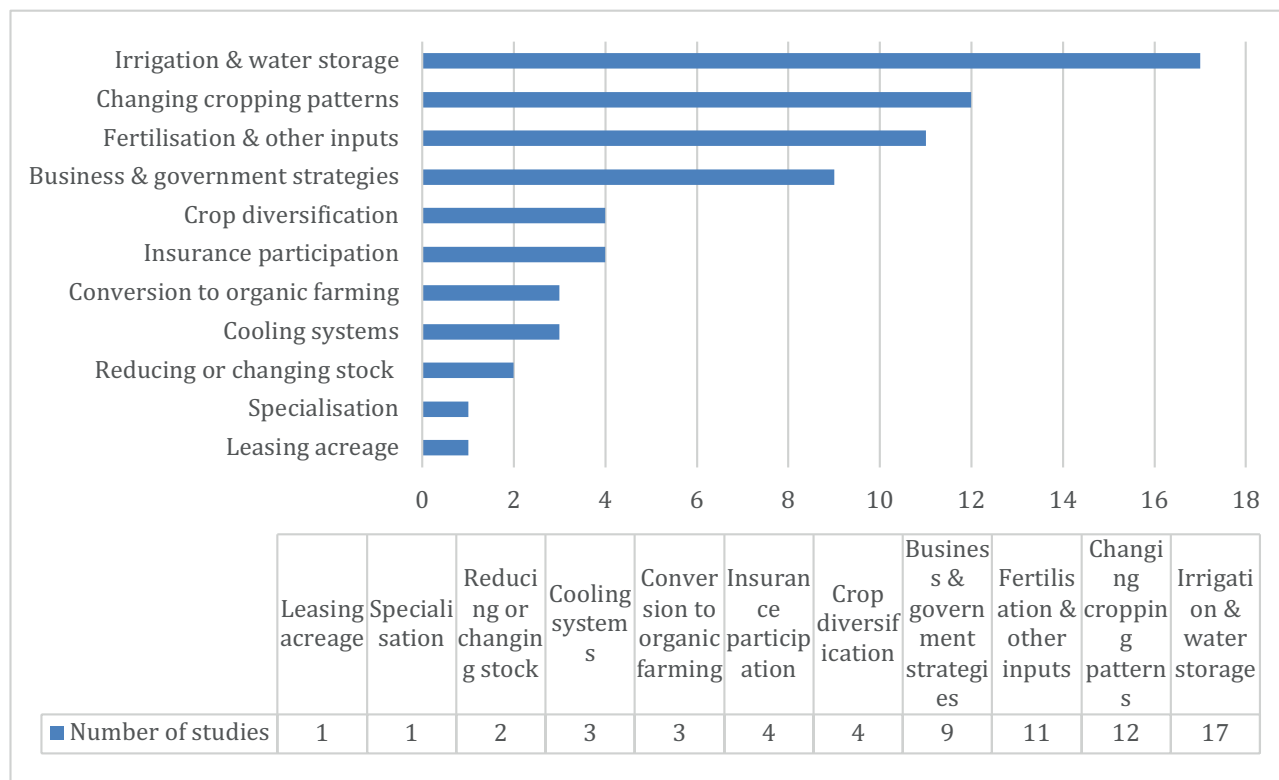


Figure 6. Adaptation strategies explored in the literature.

the agreement on the definition of reactive and proactive adaptation, the strategies that can be included in each category can vary depending on the case study. For example, the widely used practice of changing the timing of sowing and harvesting has been classified as both proactive and reactive by different scholars. Therefore, an adaptation strategy could be both depending on if it is a response (reactive) or a coping mechanism (proactive) (Carman & Zint, 2020).

Proactive refers to anticipated adjustments, also referred to as anticipatory or ex ante adaptation. Of the included studies, 29 referred to proactive adaptation including crop diversification and insurance participation. Reactive refers to adaptation performed after a shock and is also referred to as responsive or ex-post adaptation. As expected, more studies have focused on reactive adaptation such as changing stock sizes or crop-

ping patterns (n= 34). Localised adaptation is usually conducted at the plot scale whereas widespread adaptation usually concerns the entire farm. Of the studies included in the present review, 32 studies explore localised adaptation. Examples include installing cooling systems in barns or changing cropping patterns. Twenty-eight studies examine widespread adaptation including conversion to organic farming. Strategic adaptation is the capacity to adapt in the long term (years). A total of 24 studies discuss adaptation that can be classified as strategic such as changing livestock breeds or leasing acreage. Tactical adaptation is instantaneous short-term adjustments over a seasonal to daily timescale, for example, changing cropping patterns or fertiliser use. A greater proportion of the studies discuss tactical or short-term adaptation (n= 40) (Table 1).

Given the uncertainty of climate change and its

Table 1. Adaptation dimensions.

	Timing		Temporal		Spatial	
	Proactive	Reactive	Tactical	Strategic	Localised	Widespread
Number of studies	29	34	40	24	32	28

impacts, it is difficult for farmers to anticipate a shock and adapt accordingly in a proactive manner. This is exacerbated by lack of knowledge or insufficient information on climate change (Robert et al., 2016). However, to reduce the impacts of climate change, it is crucial for farmers to take more proactive, anticipatory steps to minimise damages. To encourage farmers to undertake proactive steps to adapt, it is crucial that information on long term climate impacts is distributed. Within the included studies, there is also a pattern of autonomous adaptation dominating over planned, dependent adaptation. Autonomous adaptation has been a controversial topic within the literature, with economists arguing that this type of adaptation is inefficient and likely reduces the urgency surrounding necessary, planned interventions from governments or other key stakeholders (Stern, 2007; Eisenack, 2009; Forsyth & Evans, 2013). Therefore, more evidence is needed to identify how autonomous adaptation might connect with planned adaptation and there is greater need for governments to step up with efficient interventions to reduce the burden on individual farms.

### 3.4. Effectiveness of adaptation practices

In this section, we present the effectiveness of adaptation practices reported in the included studies. The majority of the studies reported negative effects of climate change (n= 60). Only five studies reported positive effects while 23 studies reported both positive and negative effects of climate change. The majority of studies assessing the effectiveness of adaptation strategies report positive impacts (n= 34). Only four studies reported solely negative effects of adapting (Wang et al., 2021; Skidmore, 2022) while the remainder reported both positive and negative effects (n= 12) depending on other conditions such as crop types or timing, and of course how the authors define “positive” or “negative” impacts. In an example of a negative impact of adapting, Wang et al (2021) demonstrate that participation in a crop insurance programme led to more detrimental impacts on crop yields as farmers did not feel the need to implement other adaptation strategies owing to their insurance participation. However, in Australia, Kath et al (2018) found that participating in an excessive rainfall index insurance scheme could make sugar cane farmers better off by 269.85 AUD/ha on average in years with excessive rainfall.

Irrigation was the most commonly studied adaptation measure and has proven to have a largely positive effect by enhancing revenue through increased yields (Polsky et al., 2001). For example, in the USA both Li et al (2020) and Lu et al (2020) find that irrigation leads

to yield increases. Li et al (2020) find that yields are increased by 12.28% per acre while Lu et al (2020) find that crop yields increase by 147%, 139%, 132% and 124% for spring wheat, hay, corn silage and corn grain respectively. Changing cropping patterns is another commonly studied adaptation strategy and has also led to generally positive results. In Hungary, Lång et al (2021) demonstrate how when combining barley and sweet corn yields during double cropping the overall crop yield was 18.5 tonnes/ha compared to single cropping which yields 5.6 tonnes/ha. However, in Switzerland Wittwer et al (2023) find pronounced and consistent yield reductions due to experimental drought events for all cropping systems. In Table S3, we further compare the effects of climate change with the impacts of adaptation in order to demonstrate the effectiveness of adaptation in boosting resilience in the agriculture sector.

Adaptation is only efficient if the cost of making an adjustment is less than the resulting benefits. Results suggest that adaptation will reduce damages caused by climate change. However, while efficient adaptation responses can reduce the overall impacts associated with climate change, inefficient adaptation can increase costs (Mendelsohn, 2006), and as such maladaptation should be avoided. The example outlined in Wang et al (2021) where participating in insurance schemes led to a decrease in planned adaptation demonstrates how adaptation strategies can sometimes not have the desired effect. A similar effect can be observed in the mitigation literature where some strategies such as carbon removal can deter or delay mitigation efforts (McLaren, 2016). Therefore, this mitigation deterrence theory could also be transferred to the adaptation literature as ‘adaptation deterrence’. This is particularly pertinent for insurance schemes, government strategies and subsidy payments which can prevent other adaptation strategies that aid in reducing or preventing further damage. Careful planning and further research into the effectiveness of climate adaptation can prevent maladaptation from increasing the damages associated with climate change in the agriculture sector.

## 4. CONCLUSION

In this systematic review, our aim was to evaluate the impact of climate change on the agriculture sector and examine the effectiveness of adaptation strategies responding to these impacts. Examining 124 studies, we sought insights into the methods and metrics used to assess the impacts of climate change on agriculture, what the effects of changes in the climate system are,

which adaptation strategies are employed, and how effective these strategies are.

In terms of the metrics used within the literature, marginal changes in temperature and precipitation have been studied most frequently. This is unsurprising given that agriculture is highly dependent on weather patterns. Yet it is important to note that climate change will also exacerbate extreme weather events and therefore these should be examined further. Drought has been extensively studied in the literature however other extreme events such as storms and frost events have not. While a range of methods have been identified in this review, standard panel approaches have been employed most often. We find that there is scope for further studies employing joint estimation of short and long run responses to better understand the long-term costs and benefits of adaptation.

In examining climate impacts on agriculture, it is evident that there are overwhelmingly negative effects across the sector, including decreasing yields, reductions in product quality, and loss of income. Given that the majority of studies focused on arable farming, changes in yield were most frequently examined in the literature. The least studied impact was changes in input costs, indicating a gap in knowledge surrounding the full economic costs of climate impacts on agriculture.

A wide range of adaptation strategies have been identified in the literature. Those which have received more attention have been irrigation, changing cropping patterns, and fertilisation and other inputs. Conversely, leasing acreage, specialisation and reducing or changing stock have been identified as the least studied strategies. Overall, adaptation tends to be reactive, short term and localised. Thus, there is a lack of forward planning where climate change is concerned within the sector, leaving farmers vulnerable to future threats from a changing climate. Nonetheless, we find that adaptation has a generally positive role to play in reducing the negative impacts of climate change.

Given these findings, this review highlights several important implications for future research. While there is abundant data on the impact of climate change on farm output, the effects on input costs such as fertilizer, water, and labour, have not been extensively studied. Understanding these cost variations is crucial for a more comprehensive assessment of the economic impacts of climate change, particularly given that fertilisation and other inputs have been identified as a widely used and effective adaptation strategy. In terms of adaptation strategies studied, there is a lack of research into organic farming, diversification, specialisation, leasing acreage and cooling strategies while irrigation, govern-

ment strategies, fertilisation and changing crop patterns have been widely studied in the literature. Additionally, the literature suggests a need for long term experiments to evaluate the costs and benefits of adaptation strategies as current research predominantly focuses on short term investments and impacts therein. Another key recommendation is the need to understand the pros and cons of the various methods and indicators used to assess climate impacts on agriculture, as well as the opportunities and challenges that new data and technologies present to the industry and researchers. This understanding would facilitate easier comparison across studies and help in developing more effective management strategies for both farmers and policymakers. There are also other factors at play in the adoption and effectiveness of adaptation strategies that have not been the focus of this review such as extension services, land tenure security and farmer perceptions. These provide other potential avenues for future interdisciplinary research. While every effort was made to make this review as comprehensive as possible, it is limited by the decision to exclude grey literature and non-English studies, particularly in underrepresented contexts and these would provide further detail in future reviews.

This review also formulates a number of policy implications. For instance, while the majority of studies assess impacts on arable agriculture, there is also considerable evidence that climate change impacts and the need for adaptation is pivotal also in the livestock sector (aside the well-known importance of climate change mitigation). Capacity building and knowledge exchanges through participatory approaches will prove invaluable. The assessment of effectiveness and associated costs and benefits of specific impacts and adaptation strategies can contribute to forward planning both on the part of farmers and policymakers.

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Short Communication

## Public information instead of vertical integration – Exploring “recommended variety lists” in the Swiss maize seed market

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**Abstract.** Institutional economists have suggested vertical integration as a solution in cases of high asset specificity, frequency, and uncertainty. Although asset specificity and uncertainty are major issues in the seed market, vertical integration is not an option because farmers and breeders work by different organizational patterns. This study hypothesises that the public provision of information can be an alternative to vertical integration and illustrates this with the “list of recommended maize varieties” in Switzerland issued in a private-public partnership based on data generated by the public administration. A survey of maize growers and contractors shows that contractors and farmers in regions ideal for maize production rely strongly on these lists. For users who rely less on maize production, past experience is the most important guide for the choice of variety. It can be concluded that this intervention in the market generates value added for farmers and saves transaction costs.

**Keywords:**-institutional economics, information economics, seed, maize, governance.

### 1. INTRODUCTION

In our market economy, private goods are mostly traded between private entities, and government intervention in such cases may easily cause misallocations (Sadeh et al., 2020). However, this may be different if the public intervention consists in information about the traded goods. While the government’s provision of information is sometimes justified as a necessity (eg. Ding, 2014), there is little evidence about the impact that such public engagement may have.

The Swiss seed market offers a case study that may shed some light on this question. Public authorities, in collaboration with partners from the sector, issue lists that recommend certain varieties of cereals, soybeans, potatoes, rapeseed, feed crops and maize, called recommended variety lists (RVLs). As Switzerland follows one of the most protectionist agricultural policies in the world (Nguyen et al., 2021; Huber et al., 2023), it is easy to consider this unusual practice as another case for misallocation (see Salvatore, 1993, for an extensive debate on the relationship between misallocation and protectionism).

As we know from Ciliberti et al. (2024) that farmers do not always find technical assistance helpful, it is the objective of this paper to evaluate whether the RVL meets any demand by its potential users. Do farmers benefit from the work done by public authorities by selecting varieties according to their benefit for agronomical and technical use compared to others (being not recommended)? Is the RVL an important source of information for maize producers? And does this apply to innovative farmers more than to others? These questions are novel, as scholars in the past (Turner and Bishaw, 2016; Mariani, 2021; Yang et al., 2024) have mostly described the procedures how new varieties are released to the market, but not critically evaluated them. We use a survey among maize growers to understand the users' perspective of the maize RVL as an important element of dealing with maize varieties. Section 2 sets the empirical and theoretical frame by describing the role of RVLs and by exploring transaction cost economics as a potential reason for public intervention. Section 3 then introduces the methodology to add empirical evidence of the acceptance of RVLs, and Section 4 presents the results. The conclusions are drawn in Section 5.

## 2. FRAMEWORK

### 2.1. Case study description

Every year, research groups of Switzerland's agriculture research station, Agroscope, in collaboration with national sector organisations and local partners carry out field experiments with new varieties or candidate varieties of Switzerland's main arable crops, based on which they evaluate the value of cultivation (e.g. yield, ripening behaviour, and tolerances/resistances to pests, diseases and lodging) and use (e.g. digestibility of maize, oil quality of rapeseed, rheological properties of wheat) of single varieties and eventually make suggestions on a selection of varieties that offer a sufficient degree of added value for Swiss arable farmers and the rest of the value chain. The sector organisation then invites representatives of farmers and other parts of the value chain to discuss the results, to make suggestions and make adaptations, after which the "recommended variety lists" (RVL) are published prior to the subsequent growing season. This practice distinguishes Switzerland from countries that solely decide whether a new variety is sufficiently distinct from the old ones to qualify as a variety of its own but do not interfere in the market beyond that (e.g. Heidt et al., 2025). Only few other countries like Ireland (Department of Agriculture, Food, and the Marine, 2024) have decided to recommend certain varie-

ties to their farmers, but to the authors' knowledge, these lists were never part of a critical evaluation.

One of the RVL contains varieties for maize, which is the RVL chosen as our case study. Maize is one of the most important arable crops in Switzerland, mostly for the feed market, covering approximately 20% of the arable land (FOAG, 2023) but with a high variability between the different cantons due to climatic differences. There are two main target groups for maize RVL:

- Farmers growing maize (and deciding themselves which variety they want to grow);
- Contractors sowing maize for farmers, who delegate the choice of variety to them.

Additionally, the RVL is also used by extension officers, either from private companies or at agricultural schools.

### 2.2. Theoretical background

The "good" that Switzerland's government (supported by private partners) provides for free is an informational good. Several economists have examined the market for information. This is a market that is complex due to the intangibility and complexity of information, and undoubtedly one of the most difficult issues in economics. Information has been described as a global public good (Stiglitz, 1999), which implies that it should be provided by governments. It has also been described as a fully private good that can easily be marketed and therefore can be fully left to the market (Kastl et al., 2018). If they are taken as "absolute" answers, both stances are oversimplistic. There is no doubt that ignorance, i.e. the absence of information, can entail high costs on societies (McCoy, 1995), so that information has certainly aspects of public goods. Stiglitz and Kosenko (2024) have shown that it can be taken for granted that governments improve welfare if they prevent disinformation through fraud laws and disclosure requirements. On the other hand, the literature on intellectual property rights has shown how legal protection concentrates (Benkler, 2002) and improves (Fang et al., 2017) the production of information. This underlines the aspect of private goods that information undoubtedly has as well.

A key to a better understanding of public intervention is transaction cost economics. In particular, Williamson (1971, 1979) was first to bring asset specificity, the frequency of transactions and uncertainty into the centre of the institutional discourse, arguing that a high degree of asset specificity and uncertainty and a high frequency of transactions would push companies to organise labour rather in a hierarchical way instead of buying it in the marketplace, leading to vertical integra-

tion. It is worthwhile to reflect on whether these conditions apply to the seed market, as presented below.

Asset specificity has been explored in depth by institutional economists (Meirelles des Souza Filho and Varella Miranda 2019; Richman 2019; Cao 2022; Grindal 2022). Is maize seed a specific asset? Dallago (2001), for example, defined asset specificity as the degree to which a good is system-specific. Maize seed, for example, is only useful for the production of maize and is therefore very system-specific, even more so since there are submarkets like maize for biogas or maize for non-food-uses with specific requirements. Developing a somewhat stricter definition, Lonsdale (2001) defined specificity as “the extent to which the investments made to support a particular transaction have a higher value to that transaction than it would have if they were redeployed for any other purpose”. This definition sets limits to the degree of specificity: indeed, maize seed is only of use for farmers willing to grow maize. However, there is a major number of maize growers; therefore, we should refer to a high relative specificity of a seed, not of absolute specificity, as there is a demand for the seed in a small societal niche with several potential buyers.

Regarding frequency, Crook et al. (2013) emphasised that occasional transactions can easily be governed through contracts, whereas contracts for frequent transactions can cause high transaction costs. In this respect, the seed market is unexceptional. Most farmers need seed in spring before sowing, and usually it is part of a crop rotation where this applies every year, so that maize seed is usually traded once per year, except for the few regions where two harvests are possible (McKenzie and Pede 2005). With such a frequency, maize seed is situated between goods like staple food which may be bought daily and a house that is maybe bought once per lifetime.

Uncertainty, however, is a major issue when selecting seeds, aiming for (typically) high yields and a good quality of the crop. The seed market is dynamic. The average life cycle of a specific maize variety in Switzerland, to return to this example again, averages around four years. This does not leave ample room for farmers to collect experiences regarding the variety’s characteristics. However, these characteristics are crucial for farmers. They need to know which variety is adapted to the soils and climate of their region, to which diseases the varieties are less susceptible, and which yields and quality to expect. None of these questions can easily be addressed by looking at the product itself. Thus, it is always necessary to rely on the information provided.

Transaction cost economists would therefore most likely recommend that the market for maize seed be

integrated (Klüppel, 2021; Boykin, 2023); on a first sight, this may seem as a promising pathway. While currently breeders usually sell their seed to a cooperative or a private trader from which it is then bought by farmers, a joint company for breeders and farmers has the potential to save transaction costs. However, there are important geographic and organisational obstacles that prevent such an option, at least under current production technologies. The breeding of arable crops is an oligopolistic market in which large multinational companies select and produce in a few places in the world (Zhang 2018). The process of concentration continues (Bonny 2017). Growers, by contrast, are very decentralised and often small enterprises, technologically usually much more diversified and equipped with entirely different technologies as compared to breeders (e.g. Kiriti-Nganga 2012), and seed is only one of the many inputs they need. This also applies to Switzerland, the country in which the RVLs are issued and one characterised by family farms with an average size of 20 hectares (Lakner et al. 2018). As a company can hardly integrate central structures with such decentral structures, vertical integration is not an option.

The impossibility of vertical integration leads farm managers and contractors who sow maize to choose between very high transaction costs or suboptimal decisions. Hence, farmers can either rely on past experiences (which they often do according to Haden et al., 2012) or word-of-mouth from their social network (another recurrent behavioural pattern according to Ma et al., 2022). This strategy will often lead to a less-than-optimal variety choice. Or they can undergo major efforts gathering information from competing breeders and perhaps colleagues elsewhere who tested the reliability of the company’s information.

This is where public involvement that treats information as a public good can help by lowering transaction costs for approximately 20,000 farm managers who grow arable crops in Switzerland. If the federal research station that issues the RVLs is perceived as a credible source, farmers that consider themselves innovators will particularly benefit from the list as a transaction cost-saving tool; that is, it is reasonable to assume that the usefulness of the RVLs can be measured by the demand for it. This leads to the following two hypotheses:

*H1: RVLs are the most important source of information for the choice of maize varieties among farm managers and contractors.*

*H2: Actors who rely on innovation place a higher value on the RVLs than actors who rely on their previous experience.*

### 3. METHODS

The two hypotheses require the knowledge about the perceptions of farmers and contractors, so that it became necessary to carry out a survey. The information in the RVLs is devoted to a particular crop, and for more concrete analysis and findings, we chose the RVL of maize as a case study.

In spring 2024, we sent a survey to 2000 farm managers growing maize (using addresses provided by the Federal Office of Agriculture) and to 375 contractors (distributed by the Association of Contractors), the majority of whom were also farm managers. Reminders were sent once, and a prize draw with vouchers for Switzerland's main agricultural supplier or the Swiss railroad served as an incentive to participate. 442 questionnaires were returned, i.e. a response rate of 19 per cent was obtained (21 per cent for farm managers, 8 per cent for contractors).

The survey was designed to test the two hypotheses using variables depicted in Table 1. Two variables were used to describe the position of the RVL in the decision-making system of maize producers and contractors:

- One was the degree to which potential users were familiar with the RVL ("knowledge").
- The other ("information") was a ranking in which respondents familiar with the RVL ranked the importance in comparison with other sources of information about seed (information by breeders, information by traders, prior experience, exchange with colleagues, advice from extension officers).

For the test of the first hypothesis, it was sufficient to analyse the results of this ranking, the general knowledge of the RVL, and its use. The first was achieved by

comparing the means of the six options of decision support using the Wilcoxon matched-pairs signed rank test (O'Brien and Fleming, 1987) through a descriptive evaluation of the "knowledge" variable.

It was more complex to operationalise the degree to which users were innovative in order to test the second hypothesis. For this purpose, the rank of "relying on prior experience" in choosing the maize variety was chosen, even though this may neglect important aspects of innovation such as the use of novel technologies. The underlying assumption was that prior experience was less important for innovative farmers and contractors than for farmers and contractors with a conservative orientation.

As a sub-sample of this empirical exercise, only respondents who knew about the existence of the RVL were included. As indicated in Table 1, the "importance" variable was the rank of RVL as compared to other information sources such as neighbours or previous experience. It is therefore technically dependent on the other rankings (as respondents could, for example, use rank 1 only once) and therefore could not be used as the dependent variable. Instead, the "Knowledge" variable was regressed against three information sources for maize varieties, of which one was "Experience", the other two sources used by more innovative actors. Farmers not knowing the RVL were, of course, excluded from the sample, as they would be unable to rank the importance of the RVL as an information source.

Some control variables had to be included to avoid distortions. Researchers have claimed, for example, that public actors in the breeding market have a particular responsibility to deliver and promote varieties that deliver high-quality public good characteristics, such as

**Table 1.** Variables for the regression analysis explaining the degree of using RVL.

Variable	Meaning	Measurement	Mean	Minimum	Maximum
<i>Popularity variables</i>					
Importance	Degree of using Recommended Variety List	<i>From 1 = most important information source to 6 = least important information source</i>	2.66	1	6
<i>Independent variables</i>					
Experience	Degree of using prior experience for choice of variety	<i>From 1 = most important information source to 6 = least important information source</i>	2.09	1	6
Exchange	Degree of using exchange with other farmers/contractors for choice of variety	<i>From 1 = most important information source to 6 = least important information source</i>	3.95	1	6
Extension	Degree of reliance on extension officers for choice of variety	<i>From 1 = most important information source to 6 = least important information source</i>	3.84	1	6
Resistance	Importance of disease resistances	<i>From 1 = unnecessary to 5 = very important</i>	3.92	1	5
Farmer	Respondent's occupation	<i>0 = contractor, 1 = farmer</i>	0.93	0	1
Gender	Respondent's gender	<i>0 = female, 1 = male</i>	0.95	0	1
Age	Respondent's age	<i>No. of years</i>	47.8	23	75
Region	Region's suitability for maize production	<i>1 = excellent to 4 = marginal</i>	2.46	1	4

resistance against diseases (Mann 2013). As one of the control variables, we checked how important the resistances of a variety were for the respondents.

Most contractors specialise in arable farming (Nye 2020); if farmers contract them, they have a high motivation to choose the best and most adapted maize variety for the farmer as part of their service quality. Different to that, most farmers in Switzerland also have animals that receive a lot of attention and time; thus, they are likely to devote a smaller part of their time to maize production which is often used as feed for their own animals. Therefore, it was necessary to distinguish between the two professional groups for the analysis.

Many other analyses of the behaviour of Swiss farmers have noticed that both the age (Karali et al. 2013; Baur et al. 2014; Ferjani et al. 2015) and gender (Mann and van Aken 2021; Junquera et al. 2022) of farm managers are important predictors of variances. This made it necessary to include these sociodemographic variables in the equation. Finally, the heterogeneity of Swiss agriculture in terms of topography has also been shown to be decisive (Rossier 2012; Karali et al. 2014; Herzog et al. 2017); therefore, it had to be integrated as another control variable.

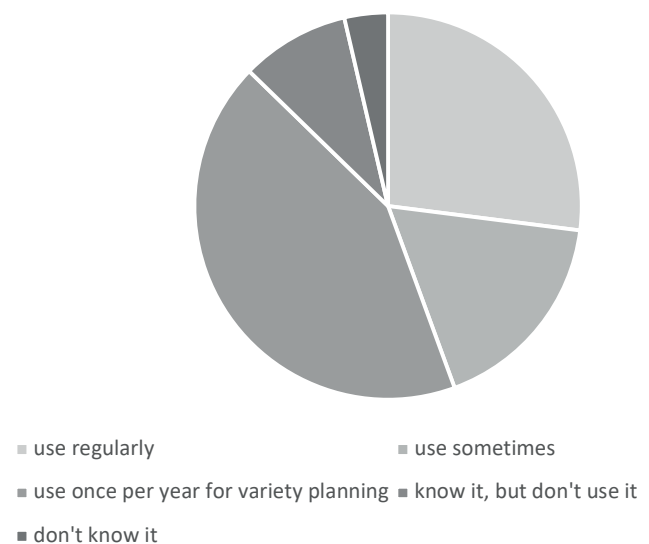
#### 4. RESULTS

Figure 1 and Table 2 display the numbers needed for the test of Hypothesis 1. Figure 1 indicates that the RVLs for maize were well-known and the most popular external information source. However, Table 2 shows that hypothesis 1 still needs to be rejected. Prior to the RVL, past experience guided farm managers in selecting maize varieties as the most important factor. Nevertheless, the RVL ranked second. Importantly, with the exception of the advice of extension officers and other farmers who were similarly unimportant information sources for maize varieties, there was a relatively clear hierarchy in information sources. Farmers unequivocally preferred direct information on single varieties by breeders to indirect information provided by input dealers. However, the public information source was considered more important than the less neutral communication by the breeders themselves.

Table 3 indicates that hypothesis 2 cannot be rejected. The more farmers relied on their past experience, the less they valorised the RVL. The significance makes it clear that innovative farmers benefit more from the RVL than less innovative farm managers, if innovation can be described negatively through not orienting on last year’s variety. However, the exchange with colleagues

was, unexpectedly, an even stronger substitute for the RVL, measured by both the coefficient and the significance (even though, as indicated by Table 2, colleagues are, in general, not an important source of information). The substitution effect between the RVL and extension services was much weaker, suggesting beyond the line between innovative farmers (using the RVL) and traditional ones (preferring to relying on their experience), there was a clear distinction between farm managers who preferred horizontal information (such as exchange with their colleagues) and those who preferred sources of information that could be considered superior (such as extension officers and the RVL).

Partly based on their insignificance, the control variables showed that there was no background distortion. This included the lack of significant effects of gender, age, and the perceived importance of resistant varieties. Other control variables, however, showed a more signifi-



**Figure 1.** Distribution of answers to the variable “Knowledge”.

**Table 2.** Ranking of information sources for maize seed varieties with 1= most important and 5= least important.

Answer	Average Rank
Experience	2.08
RVL	2.66
Breeders	3.46
Extension	3.84
Colleagues	3.95
Input Dealers	4.62

Brackets between variables denote insignificant differences at the 95% level. No brackets between adjacent figures next to the table denote statistical differences at the 95 % level.

**Table 3.** Results of the ordered logit analysis explaining “Importance”.

Variable	Coefficient	z-value
Experience	-0.351***	-3.60
Exchange	-0.396***	-5.20
Extension	-0.189*	-2.40
Resistance	-0.797	-1.17
Farmer	0.992**	2.86
Gender	-0.531	-0.77
Age	-0.014	-1.39
Region	0.335**	2.80

\*\*\*p < 0.001; \*\*p < 0.01; \*p < 0.05; n = 305, pseudo R2 = 0.06.

cant impact. Contractors, for example, relied much more on the RVL than farm managers. The same applies to maize growers in arable regions well adapted to maize production. They also used the RVL more often than farmers in peripheral maize regions.

## 5. DISCUSSION

The fact that Hypothesis 1 had to be rejected insofar as prior personal experience prove to be the most important information source for variety selection points to the tremendous importance of personal knowledge. In fact, this importance has also been repeatedly emphasized by transaction costs economists like Czarniewski (2014) or Williams and Balasz (2021) and is also prominent in the literature on the behaviour of farmers in general (Gebrehivot and van der Veen, 2021; Duden et al., 2023; Ricart et al., 2023). Still, the RVL has proven to be the most important external source of information. If one takes the two findings together, it is likely that farmers combine their prior experience and the RVL, checking how happy they are with last year’s choice and whether there is a more promising option on the RVL.

It must be admitted that, with an R2 of six per cent, our analysis can only explain a minor share of the differences in importance of the RVL among farmers and contractors. There are certainly soft factors that could not be measured but are of high importance, and maybe some “hard facts” have been overlooked as well. While this is a major limitation of our study, the significant variables still warrant attention. This starts with the role of existing knowledge among farmers, reflected by the “Experience” variable. Research has demonstrated the strong influence of both explicit and tacit knowledge for farm management (for a review, see Tumwebaze et al., 2024). Therefore, the diminishing role of prior experience in determining the importance of the RVL should not come as a sur-

prise. Similarly, the “Exchange” variable reflects the role of social networks. While research clearly highlights the importance of social capital for information generation (Raudiliduniene et al., 2021), including in agriculture (Yu and Gambrah, 2024), our analysis shows how social capital reduces the need for public information. While there is also substitution between extension as a source for variety information and the importance of the RVL, as indicated by the “Extension” variable, this effect is only half as strong as for the previous two. This aligns with the views of economists who emphasize the limited impact of extension services under many circumstances (Cerdan-Infantes et al., 2008; Aker, 2011; Kasser and Alemu, 2017). Today, farmers have access to much more information sources than they used to, including social media, which may limit the added value of extension services.

The high significance of the “Farmer” variable underscores the important role of contractors in agriculture as multipliers. These individuals inform themselves using the RVL and pass their knowledge on to their customers. This aspect has been neglected in the limited body of literature on contracting in agriculture (Nye, 2020; Bachev, 2024).

As the final significant variable, it is no surprise that the RVL plays a larger role in traditional maize-growing regions, compared to, for example, the hilly region. Buzzi et al. (2021) show the vast importance of climatic factors like temperature for the productivity of maize. Again, the significance of this variable confirms that the RVL is used if maize production is of great importance for the user. From there, the knowledge trickles down to areas where maize is of less importance.

The non-significant variables do not require much further elaboration. The preference for the RVL does not depend on the importance placed on resistant varieties, nor on age or gender.

## 6. CONCLUSIONS

Although the maize RVLs seem to be less important for the selection of maize varieties than the farmer’s prior experience, it is still a crucial tool. The results of our survey suggest that there is what Widen and Steinerova (2019) called a hierarchy of information flows. Contractors and farmers in areas highly suitable for maize consult the RVL and are, therefore, likely to transfer their knowledge to other farmers. Similar models of information diffusion in other realms of agriculture have been described by Rebaudo and Dangles (2011) and Shaijumon (2018). Invariably, we show that the maize RVL plays a more prominent role in this information flow than the

information provided by the seed companies themselves. It is likely that two perceptions - that public sources have greater credibility and that they have all the information collected - control this prominent role of the RVL.

The results can also be considered as a justification for the public involvement in providing information on the seed market. On the base of our results, it is likely that using tax money for the RVL may save transaction costs on a societal level as many farmers do not have to collect the information by themselves. Therefore, the policy implications of our study are that money invested into the support of farmers in their selection of appropriate varieties is probably well-invested.

#### DATA STATEMENT

The data is confidential as it contains single-farm-data not ready for publication.

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Policy Paper

## Rural policy in the 2028-2034 EU budget: Reform or Retreat? A rural-proofing analysis

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**Abstract.** The proposed EU Multiannual Financial Framework (2028–2034) reshapes rural development by consolidating instruments into a Single Fund and recentralising strategic decisions at national level. Although presented as simplification, the reform risks reinforcing existing biases toward urban, high-productivity regions. Drawing on rural proofing concepts, EU comparative analyses, and fine-grained Italian municipal data, the article shows that 2014–2020 Cohesion Policy allocated only a limited share of resources to rural areas, while the EAFRD remained the main—though uneven—source of support. The reform also gives rise to concerns about resources and institutional responsibilities for broader rural measures, including diversification, infrastructure, services, and funding for LEADER and cooperation initiatives. Key recommendations include: (i) a mandatory rural chapter in NRPPs; (ii) explicit rural safeguards in Single Fund rules; (iii) clearer rural typologies and better data systems; (iv) stronger multi-level governance with real local participation; and (v) dedicated resources for capacity-building and co-design.

**Keywords:** EU budget, CAP Reform, rural development, rural proofing, cohesion policy.

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### 1. INTRODUCTION: THE MULTI-ANNUAL FINANCIAL FRAMEWORK (MFF) FOR 2028-2034. THE EUROPEAN COMMISSION'S PROPOSAL

The European Commission's Communication<sup>1</sup> on the MFF 2028–2034 (EC, 2025a) was presented in July 2025 and immediately sparked a controversial debate. The main components of the proposal are as follows:

- a) The new budget architecture shifts from separate budgets for each fund to a system where only a few interventions are ring-fenced. The total budget is €1,985 billion, with the largest share allocated to “Economic, Social and Territorial Cohesion, Agriculture, Rural and Maritime Prosperity and Security” (€1,062 billion, 53%). The MFF removes the cur-

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<sup>1</sup> The Communication and related documents can be downloaded from the following site: [https://commission.europa.eu/publications/multiannual-financial-framework\\_en](https://commission.europa.eu/publications/multiannual-financial-framework_en)

rent two-pillar structure: most agricultural interventions will be financed through a ring-fenced €294 billion, while only some measures – such as LEADER, territorial and local cooperation initiatives, and support for knowledge sharing and innovation – will be funded as mandatory measures from the non-ring-fenced amount. This means most CAP interventions will be ring-fenced.

- b) The MFF proposal introduces a 25% flexibility margin within each NRP plan to enable Member States to address crises during the programming period, revise priorities at the time of the mid-term review, or provide additional resources to existing measures. In the context of the recent EU-Mercosur agreement, the Commission has proposed that Member States can allocate, as early as 2028, part of this flexibility margin (approximately €45 billion) within their NRP plans to provide additional resources – beyond the €294 billion already ring-fenced – for either CAP income support measures or investment in rural areas.
- c) Another important share of the EU budget is allocated to a broad “economic, territorial and social cohesion, including rural communities and tourism” envelope, which also covers the aforementioned rural development measures (LEADER, etc.) outside the CAP ring-fenced envelope. This broad set of interventions can be programmed by Member States with more flexibility than in the past, subject to a minimum earmarking for less developed regions and minimum targets for social (14%) and environmental and climate objectives (43%).
- d) All measures will be financed through a single multi-purpose fund: the European Fund for Economic, Social and Territorial Cohesion, Agriculture and Rural, Fisheries and Maritime Prosperity and Security. This Single Fund merges previous instruments and will be distributed via nationally pre-allocated envelopes under shared management between the Commission and Member States. According to the proposed common Regulation, the fund will pursue multiple objectives, from reducing regional imbalances and supporting employment to implementing CAP and fisheries policy, as well as strengthening EU defence and security.
- e) Resources will be disbursed following the approval of a National and Regional Partnership Plan (NRPP) prepared by each Member State. The NRPP will define priorities, investments, and interventions based on national and regional challenges. The single-fund structure aims to provide “a simpler and more flexible policy framework that enhances syn-

ergies and complementarities across sectors” (EC, 2025).

- f) Another relevant innovation concerns the new financing model, largely inspired by the Recovery and Resilience Facility (RRF), under which most EU payments to Member States will depend on the fulfilment of predefined milestones and targets for reforms and investments, rather than on the current reimbursement of eligible expenditure incurred.
- g) Among management rules, it is worth mentioning that the proposal introduces an n+1 decommitment rule, which could represent a tightening compared to the current rules in cohesion policy, home affairs and rural development, where n+2 or n+3 rules apply and allow implementation for two or three years after the EU funds are committed, without the Member State losing those funds.
- h) The MFF proposal has been accompanied by draft regulations<sup>2</sup> for the NRPF, ERDF, Cohesion Fund, CAP, and ESF. The regulation establishing the Single Fund significantly narrows the scope of CAP-eligible measures, removing support for rural diversification into non-agricultural activities as well as for infrastructure and essential services for rural populations. The underlying assumption is that these types of interventions will be addressed by non-CAP instruments, managed by non-agricultural administrations, within a broader framework of policy integration and coordination.

The initial proposal faced strong opposition from the European Parliament and the Committee of the Regions over rural priorities and limited regional involvement, prompting revisions reflected in the EU Presidency’s draft Negotiating Box for Heading 1 (European Council, 2025). Several elements of criticism have been raised in recent documents of the European Court of Auditors (ECA, 2026). European Commission President Ursula von der Leyen has sent a letter to European Parliament and European Council’s president outlining adjustments to the proposed MFF, proposing that at least 10% of national allocations (after deducting the minimum ring-fenced amount for the CAP) be earmarked for rural objectives<sup>3</sup> and ensuring mechanisms for a stronger regional role in multi-level governance. However, implications for rural areas still require detailed analysis, particularly regarding policy effectiveness and institutional efficiency.

<sup>2</sup> The whole set of draft Regulations can be downloaded from the following site: [https://commission.europa.eu/strategy-and-policy/eu-budget/long-term-eu-budget/eu-budget-2028-2034\\_en](https://commission.europa.eu/strategy-and-policy/eu-budget/long-term-eu-budget/eu-budget-2028-2034_en)

<sup>3</sup> This target should be monitored, by summing expenditure taking place in regions coded 02 as rural regions.

**Table 1.** Granularity matters: comparison of results from two cross-European studies on territorial distribution of EU funds.

Study	Reference period	Share of Cohesion Policy allocated in rural areas		Ratio urban/rural allocated funds	% of non-allocated funds	Definition of “rural”
		billion €	(% of total)			
Kah et al., 2020 (EP-REGI Committee Study)	2014-2019	45,6	9.7%	3.74	54.5%	DEGURBA classification (cities; towns and suburbs; rural areas).
Münch et al., 2024 (EC-DG-AGRI study)	2014-2021	35,7	Between 19.5% (ERDF) and 23.7% (Cohesion Fund)	2.90	18.0%	NUTS3 regions classified as “rural” according to EUROSTAT typologies

Source: authors' elaboration.

Key concepts underpinning Rural Proofing (RP) methodologies can support our analysis. RP approaches stress that policy design must rely on existing data on rural dynamics, including socioeconomic indicators, service provision levels, territorial disparities, and past public investment patterns. OECD (2024) highlights that RP requires evidence-based decision-making grounded in available data. EU RP frameworks link the process to Territorial Impact Assessment tools (CoR, 2022), which use quantitative territorial data – often including historical indicators and past funding where relevant. Some national guidelines explicitly require assessing funding allocations. UK guidance (DEFRA, 2022) states that RP must examine financial allocations and past fund distribution to ensure that “funding formulae reflect needs in rural areas.” This necessarily involves reviewing how funds were previously distributed across territories<sup>4</sup>.

Based on these concepts, this article aims to address the following questions:

1. To what extent have the past ERDF and ESF fund allocations prioritized rural areas, compared to EAFRD? Section 2 will analyse EU 2014-21 allocation choices, based on studies across EU countries and a specific study on the Italian case which can offer data availability of the funds' distribution at the granular level.
2. In light of the evidence on past fund allocation between urban and rural areas, and the most recent experience with rural development implementation at the national level, what can be said about rural development prospects after 2027? Section 3 discusses this issue.
3. What policy recommendations can improve the proposed MFF approach? These considerations will be developed in the final section.

<sup>4</sup> One key issue raised by the UK guideline is about “Distribution, equality, devolution and funding”, with a related question to be answered by rural proofers on “Is an equitable proportion of your funding programme going to rural Areas?” (DEFRA, 2022, p. 8).

## 2. ASSESSING THE RURAL FOCUS OF ERDF, ESF AND EAFRD: EVIDENCE AND ANALYSIS

### 2.1. The territorial allocation of funds in Europe

Assessing how much Cohesion Policy funding reaches rural areas is essential for evaluating territorial priorities and is a core element of rural-proofing. At EU level, only two cross-country studies provide sufficient evidence: Kah, Georgieva and Fonseca (EP-REGI, 2020) and Münch et al. (DG AGRI, 2024). Results differ because “rural” is defined in different ways. The EP study uses DEGURBA and examines programme-level allocations, reflecting planned rather than actual spending. The EC study classifies NUTS3 regions as rural, but this masks internal heterogeneity. These methodological differences explain divergent estimates: about 10% in the EP study versus 19–24% in the EC study (Table 1).

The choice of analysis unit also affects project location identification, especially for large-scale projects or when territorial codes are missing (Münch et al., 2024). These operational limits lead to high shares of non-allocable funds, which increase with finer granularity. The EP study reports 54% of funds as non-allocable, compared to 18% in the EC study using NUTS3 regions. After adjusting for non-allocable funds, urban areas still receive three to four times more funding than rural territories (Table 1).

Both studies reveal significant differences among EU countries, allowing for three clusters regarding Cohesion policy:

- a) Countries with strong territorial targeting and a substantial share of funds allocated to rural areas (around 20–30%), such as Austria, Finland, Sweden, Czechia, and Slovakia;
- b) Countries predominantly targeting urban areas, including the largest Member States (France, Germany, Italy, Spain) and others like Belgium and the Netherlands;

c) Countries with no clear territorial targeting, such as Slovenia, Estonia, Bulgaria, Croatia, Cyprus, and Denmark.

These findings suggest that only group a) explicitly prioritise rural areas in their Cohesion programmes, while urban areas dominate actual Cohesion Policy allocations.

The EC study also examines Cohesion Policy’s contribution to rural regions facing specific constraints—such as islands, mountain areas, regions with persistent demographic decline, very low population density, or extreme remoteness. In 2014–2020, these areas received an estimated €13.4 billion annually, mainly from CAP Pillar I (60%) and, to a lesser extent, Pillar II (24%), with only a marginal share from Cohesion funds. Moreover, some authors note that Cohesion Policy’s contribution has fluctuated over time. For example, ERDF support for rural areas increased between 1993–99 and 2007–13, but it was significantly reduced in 2014–20 (Soldi, 2016).

2.2. Territorial distribution of EU expenditures in Italy: A more granular analysis

Few studies have examined territorial allocation in Italy. Recent research has analysed financial distribution at the municipal level (LAU), focusing first on EAFRD (Mantino et al., 2024) and later comparing ERDF, ESF, and EAFRD allocations (Mantino et al., 2025). The objectives were twofold: to assess whether Cohesion policies effectively reach rural areas and to explore whether varying intensities of demographic change affect the uptake of Cohesion and rural development policies. Demographic dynamics can influence the performance of rural and urban territories, including their ability to respond proactively to economic and environmental transitions—a relationship widely documented over the past decade.

These studies applied the DEGURBA classification of rural and urban areas using LAU-level information. As highlighted in the EP analysis, a substantial share of expenditure appeared in the databases as non-allocable, due to many projects lacking a unique municipal location (e.g. large interventions covering multiple LAUs or crossing regional boundaries). This issue was particularly significant for ERDF and ESF projects, but much less relevant for EAFRD. Non-allocable projects generally concern large-scale infrastructures and services, which only marginally affect rural areas. Even after accounting for these funds, the share of ERDF and ESF absorbed by rural areas in Italy remains lower than the 10% estimated by the EP study for the EU overall (Figure 1): it ranges from 2% for ESF to 8% for ERDF, well

below the rural population share (around 17%). By contrast, EAFRD funding allocated to rural areas is substantial and increases when managed locally by LAGs under LEADER.

It is worth noting that around 42% of EAFRD resources go to urban areas, mainly small towns and peri-urban municipalities near agricultural zones. By contrast, ERDF and ESF funding is concentrated in the largest urban centres, which act as key hubs for economic development, innovation and services, including in less developed regions such as the Mezzogiorno. This pattern reinforces the asymmetry whereby major cities attract disproportionate investment due to higher institutional capacity, greater visibility and denser beneficiary networks.

Figure 2 illustrates the biased distribution of policies whose stated objective is to reduce intra-territorial disparities: more than half of ERDF funding and nearly

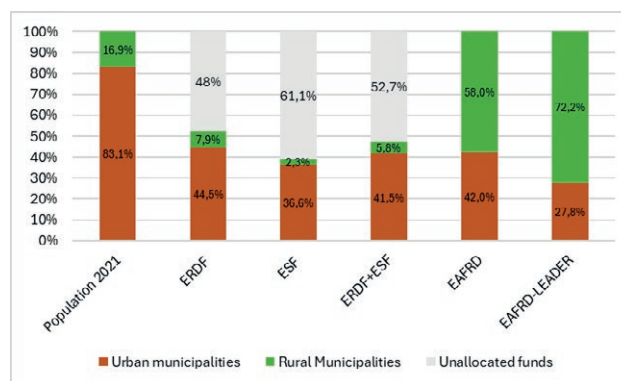


Figure 1. Comparison of EU Funds’ commitments in terms of territorial allocation (Italy, 2014-2021). Source: Authors’ owns elaboration from OpenCoesione and regional ranking lists of approved projects.

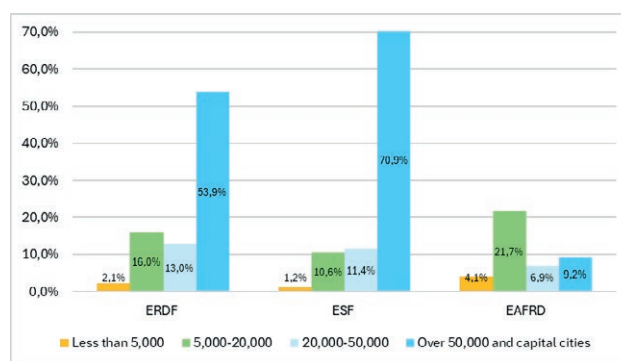
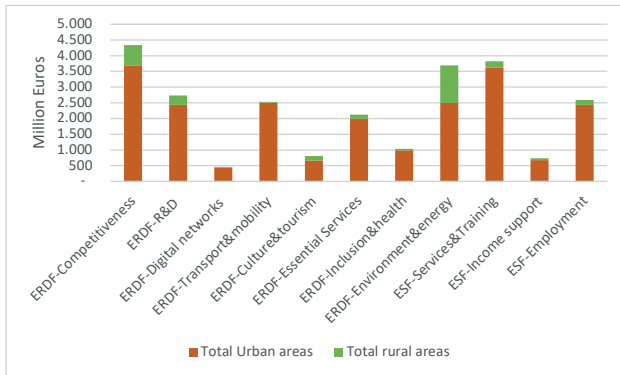


Figure 2. Distribution of Funds commitments in urban areas by municipal size (Italy, 2014-2021). Source: Authors’ owns elaboration from OpenCoesione and regional ranking lists of approved projects.



**Figure 3.** Distribution of Cohesion commitments by category of investment and type of areas (Italy, 2014-2021). Source: Authors’ owns elaboration from OpenCoesione and regional ranking lists of approved projects.

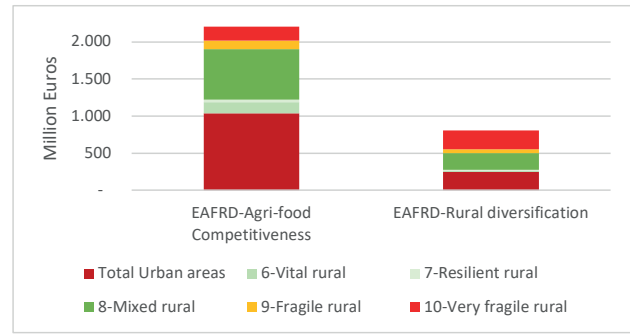
three quarters of ESF funding are allocated to cities with more than 50,000 inhabitants, as well as to regional and provincial capitals. By contrast, the EAFRD mainly supports small urban centres.

Cohesion Policy plays only a marginal role in supporting rural areas in Italy, with the main exceptions being interventions related to the environment and energy (Figure 3) and, to a lesser extent, measures aimed at enhancing the competitiveness of small and medium-sized enterprises. This result partly confirms the pattern observed at the European level (Kah et al., 2020). Nevertheless, it is noteworthy how little priority Italian authorities assign to rural areas in key policy fields for addressing population decline, such as transport and mobility (ERDF), essential services for residents (ERDF), and employment opportunities (ESF).

An analysis across urban and rural typologies clearly shows that Cohesion Policy pays little or no attention to demographically fragile rural areas, whereas the EAFRD allocates 22% of rural development funding to these areas, with LEADER interventions accounting for around 37% of the total.

Nevertheless, the EAFRD’s capacity to target the most fragile areas varies by intervention type (Figure 4): participation by beneficiaries in fragile areas is substantial in non-sectoral schemes, covering a wide range of measures linked to rural diversification (e.g. non-agricultural activities, small-scale services and infrastructure, non-productive investments, forestry). By contrast, competitiveness-oriented measures are concentrated in urban areas and in resilient or dynamic rural regions. This dichotomy is particularly problematic given the limited role of Cohesion Policy in strengthening rural contexts, as shown above.

In conclusion, many needs in rural areas remain



**Figure 4.** Distribution of EAFRD commitments by category of investment and type of areas (Italy, 2014-2021). Source: Authors’ owns elaboration from OpenCoesione and regional ranking lists of approved projects.

unmet by both the EAFRD and Cohesion Policy investments<sup>5</sup>. This is due, first, to the continued focus of Rural Development Programmes on traditional agricultural support instruments; and second, to the weaker capacity of the most fragile rural areas to absorb funding compared with urban areas and with resilient or dynamic rural regions – both for the EAFRD and for the ERDF/ESF. This raises a key question: is the limited territorial focus on rural areas the result of shortcomings in the EU-level policy design, or of weak programme implementation at national and regional levels? Evidence suggests that both levels play a role, although in different ways. Under shared management, the European Commission is responsible for ensuring coherence between national/regional actions and the EU’s agreed priorities (EC, 2025b), meaning that responsibility for the quality and orientation of Cohesion programmes is jointly shared with national administrations.

Current EU regulations for the ERDF and ESF prioritise thematic objectives – such as innovation, digitalisation, SME competitiveness, employment and social inclusion – rather than specific territorial types. Although the regulations allow rural targeting, they do not require dedicated allocations for rural areas. Evaluations (Munch et al., 2024; Dwyer et al., 2021) show that Structural Fund priorities are not well aligned with rural needs, reflecting structural territorial neutrality in fund design. Alternative policy options therefore need to be explored, given the controversial implications of the new MFF institutional architecture.

<sup>5</sup> Similar considerations can be raised regarding the CAP first-pillar instruments, given their distortive effects at the territorial level (Baldi et al., 2025).

### 3. DISCUSSION: RURAL DEVELOPMENT PROSPECTS AFTER 2027

This section discusses the most significant implications for the future allocation of funds for rural development. Two main types of implications emerge: those concerning the overall volume of resources, and those more generally related to the governance system for NRP plans.

Concerns about future resources relate both to the territorial dimension of rural development measures—such as LEADER, local cooperation initiatives, diversification into non-agricultural activities, and rural infrastructure and essential services—and to the potential rural share of the Single Fund outside CAP interventions. For the former, the mandatory inclusion of LEADER and cooperation initiatives within the CAP ensures their presence in future NRPs. However, the volume of resources will depend on how strongly national and regional rural/agricultural authorities favour a sectoral approach. Additional factors may further reduce funding for these measures: pressures from agricultural lobbies supporting direct income payments, and the new n+1 decommitment rule, which shortens implementation timeframes and tends to reward faster, simpler measures over more complex interventions with higher transformative potential (ECA, 2026). This particularly affects LEADER/CLLD and cooperation initiatives, which require longer implementation periods and specific capacity-building support.

Within a context of budget constraints and rising competition among national lobbies, another critical issue concerns the share of the Single Fund that may be allocated at national level to rural diversification, infrastructure, and services. Two scenarios appear plausible. In the first, non-agricultural administrations would assume greater responsibility for financing collective rural investments, while CAP structural measures would focus more narrowly on agri-food systems and innovation. Alternatively, the current mix of CAP structural and territorial instruments could be retained, continuing to support both agri-food investments and rural diversification—mainly through LEADER/CLLD—while Cohesion Policy instruments would take on a larger role in funding rural services and infrastructure.

Whichever scenario prevails, addressing broader rural needs requires non-agricultural administrations to treat rural areas as territorial priorities, a task for which they are not necessarily inclined or adequately prepared. It also demands the creation of effective coordination mechanisms across interventions and consistent support for LEADER groups as they implement diversified local development strategies. This pathway is demanding, as

it depends on institutional capacity and political commitment that remain uneven across EU Member States (Münch et al., 2024), including Italy.

A growing body of literature (Rodríguez-Pose, 2025) highlights that Cohesion Policy is increasingly oriented towards high-productivity urban centres, often at the expense of marginalised territories such as intermediate cities, peripheral rural areas, and former industrial regions. This trend is likely to intensify in the next programming period, given the strong emphasis on strengthening the EU's competitiveness—an approach that channels investments into a narrow set of strategic sectors while paying limited attention to territorial disparities or the value of place-based approaches.

Regarding governance, the new policy framework reshapes the balance of power within the multilevel system, despite its reassuring rhetoric on the role of regions and local authorities. By placing strong emphasis on simplification and flexibility in defining strategic priorities, it effectively promotes a recentralisation and nationalisation of EU investment programmes. This shift continues a trajectory already evident in the 2021–2027 period with the introduction of National Recovery and Resilience Plans (NRRPs) and CAP Strategic Plans (SPs). Experience with these models has generated substantial criticism, particularly concerning transparency, the lack of a coherent strategic vision (Erjavec et al., 2025), the erosion of regional and local responsibilities in programme design and implementation (Rodríguez-Pose, 2025), and the limited – if not negligible – administrative simplification actually achieved<sup>6</sup>. A “one-size-fits-all” logic has often prevailed more strongly than in earlier regionalised approaches, reducing flexibility during implementation and negatively affecting the quality of rural development strategies at local level.

The experience of 2021–2027 raises a key question: how can genuine simplification be reconciled with the creation of a single national plan covering Cohesion Policy, the CAP, migration and border management, and climate-related interventions, without sacrificing the level of detail traditionally required in EU Operational Programmes? The first major challenge will be transforming these plans from broad catalogues of measures into genuinely strategic instruments capable of articulating clear priorities and demonstrating policy synergies and complementarities.

A second challenge concerns the risk of top-down intervention menus, as occurred with the NRRPs and CAP SPs. Ensuring that regional and local institutions

<sup>6</sup> Matthews A. (2025). Fitting the CAP into the next MFF long-term budget, available at: <https://capreform.eu/fitting-the-cap-into-the-next-mff-long-term-budget/>.

retain adequate flexibility during implementation will depend largely on how meaningfully the partnership principle is applied within Member States. Significant territorial variation persists, shaped by domestic political contexts, raising the ongoing risk of a “patchwork Europe” (Foote, 2025) characterised by uneven participation and fragmented governance practices.

#### 4. CONCLUSIONS AND POLICY RECOMMENDATIONS

Policy recommendations start with redefining rurality. Current undifferentiated notions and categories such as “less-favoured areas” fail to capture rural diversity. More nuanced typologies and granular socio-economic diagnostics are needed to represent the full diversity and complexity of rural spaces across Member States. The issue therefore remains open and calls for greater political attention as well as a more sustained research effort at the national level. The definition based on the DEGUR-BA classification represents a useful starting point, but it requires further refinement to capture the heterogeneity that exists within the broad category of rural areas.

A second set of recommendations concerns the legal provisions governing the design of future NRP plans. The draft regulation establishing the Single Fund specifies that each NRP should be organised into chapters grouping measures, objectives, and associated milestones and targets. A complementary proposal circulated by the European Council (2025) allows NRPs to include national, sectoral-including one dedicated to the CAP- and several regional or territorial chapters. This option is especially relevant for countries with regionalised governance structures.

Introducing a dedicated “rural chapter” would provide an effective framework for shaping an integrated strategy for rural areas and for differentiating interventions within the same NUTS2 region, regardless of its classification as less developed, transition, or more developed. Such a chapter would be particularly important for addressing the needs of peripheral rural areas facing demographic decline, weakened local economies, and shrinking essential services.

Only a limited number of Member States currently have experience with these types of territorial policies. Spain, Italy, and France are experimenting with holistic, intersectoral, and multi-fund approaches (Münch et al., 2024). These initiatives combine dedicated financial resources, strong governance arrangements, and clear delineation of areas exposed to severe demographic challenges-elements that would benefit from a more coherent European-level framework. Some scholars (Rod-

ríguez-Pose, 2025; Hansum, 2025) propose allocating cohesion funds based not only on GDP per capita but also on socio-economic exposure to green and demographic transitions.

Joint work led by DG AGRI and DG REGIO under the Rural Pact may support preparations for the next programming period. However, this should be complemented by stronger efforts to valorise existing national and regional experiences. Establishing a rural chapter would also serve as a safeguard for interventions structurally less compatible with the n+1 decommitment rule, which tends to prioritise rapid expenditure over complex place-based processes.

Another set of recommendations concerns the need for NRP plans to grant local communities sufficient autonomy to define their own development strategies, based on thorough diagnostic assessments and tailored to local needs. To achieve this, national and regional administrations should avoid imposing rigid, top-down lists of eligible measures, which limit flexibility and hinder genuine place-based approaches. This broader room for manoeuvre should be ensured by appropriate EU-level implementing rules. Furthermore, adequate resources must be allocated at the national level to support strategic planning, including granular data collection, the development of intervention logic, the setting of priorities, and strengthened learning and co-design processes. Recent research – such as the Horizon Europe RUSTIK project<sup>7</sup> – shows that multi-actor approaches like living labs can significantly improve data provision, co-creation and local learning capacities. However, these approaches require dedicated capacity-building resources to establish meaningful stakeholder engagement structures. Broader room for manoeuvre also applies to LEADER/CLLD initiatives, which continue to face constraints, including concentration in areas with stronger social capital, procedural rigidity imposed by managing authorities, and challenges in combining funding streams due to inconsistent rules.

Although the proposed reform of EU policies emphasises simplification at higher levels of government, ensuring efficient and effective design and implementation of NRP plans will require a clear division of responsibilities and robust coordination between national and regional authorities, notably in regionalised countries. The timetable for submitting and approving NRP plans by January 2028 may be challenging. This is not only due to the intensive work and coordination required within Member States and with the Commission, but also because it is essential to ensure that the plan’s time-

<sup>7</sup> See the content and deliverable of the project at the site: <https://rustik-he.eu/>.

line allows for meaningful engagement of stakeholders throughout the design process. Robust methodological guidelines have to be developed by the national coordinating authority to guarantee effective stakeholder participation, particularly involving local actors.

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Policy Paper

## What is still common in the Common Agricultural Policy?

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**Abstract.** The European Common Agricultural Policy has a long history, and decisions regarding its reform have been conditioned by this history ever since its inception. Despite recurring changes in appearance, the CAP remains constrained by the limitations of a short-term redistributive policy ill-suited to addressing the current and future challenges of economic, environmental and social sustainability. This article summarises the evolution of the CAP and, in light of this historical overview, sets out to evaluate the proposals for the support mechanism and the budget for the seven-year period 2028-2034.

**Keywords:** Common Agricultural Policy, CAP history, CAP reform, CAP 2028-2034.

### 1. INTRODUCTION

On 4 September 2024, the European Commission published the results of the *Strategic Dialogue on the Future of Agriculture* (European Commission, 2024). This was followed on 19 February 2025 by the Communication *A Vision on Agriculture and Food* (European Commission, 2025), which announced the agricultural policy guidelines of the second Von der Leyen Commission and the new Commissioner for Agriculture, Christophe Hansen. Finally, on 16 July 2025, the proposal for the Multiannual Financial Framework 2028-2034<sup>1</sup> and the legislative proposal for the European Agricultural Policy 2028-2034<sup>2</sup> were published simultaneously.

There are two major changes. The first concerns the budget, in which, as announced, agricultural, cohesion and regional policies are merged and financed (together with other minor policies) with a single allocation, undergoing a significant overall cut. The second is the entrusting of National and Regional Partnership Plans to Member States with the task of ensuring coherence and joint programming between 14 different European Funds,

<sup>1</sup> Proposal for a Regulation laying down the multiannual financial framework for the years 2028 to 2034, COM(2025) 571 final.

<sup>2</sup> Proposal for a Regulation establishing the conditions for the implementation of the Union support to the Common Agriculture Policy for the period from 2028 to 2034, COM(2025) 560 final

while respecting their specificities<sup>3</sup>. Among these funds are the two agricultural ones: the European Agricultural Guarantee Fund (EAGF) for direct payments and market measures and the European Agricultural Fund for Rural Development (EAFRD).

This article summarises the historical evolution of the CAP and, in light of this overview, sets out to evaluate the proposals for the support mechanism and the budget for the seven-year period 2028-2034. For further details on the history of the CAP, please refer to the recently published volume *European Agricultural Policy. History and Analysis* (Sotte & Brunori eds., 2025).

## 2. HISTORIC EVOLUTION OF THE CAP

### 2.1. *The inception of price support*

Originally, in the Sixties, European agricultural policy was a source of revenue for the European Community. Since the latter had a food deficit, food security was pursued through the imposition of particularly high duties on imported agricultural products. Consequently, in just a few years, the Community went from being the world's leading importer of agricultural products to the second largest exporter (after the USA). This was the result of artificially high domestic prices, the introduction of more efficient technologies and the fast recovery of European agriculture in the post-war years. To keep prices high, duties were mainly replaced by export subsidies, euphemistically called “refunds”, paid for out of the common budget.

Expenditure under the “Guarantee section” of the European Agricultural Guidance and Guarantee Fund (EAGGF) thus literally exploded. From 1965-66 to 1969-70, it rose from 239 million units of account to 2,783 million. As early as 1968, Agriculture Commissioner Sicco Mansholt noted in the “Agriculture 80 Programme” that:

Market and price support policies alone cannot solve the fundamental difficulties of farming. These policies are subject to narrow limits; if these are exceeded, markets will be disorganized and the costs to the Community will be intolerable, without any effective improvement for the farming population (European Commission, 1968).

According to its proponents, foremost among them Mansholt himself, the CAP was supposed to be a stra-

tegic policy aimed at transforming agriculture in the medium-long term. It was to focus on structural policies. Market policy was to aim, as set out in the text of the 1957 Treaty of Rome, solely at stabilising prices. Not at supporting them. Other objectives were set in the Treaty of Rome. Some of them were in clear conflict with price support, such as that of “ensuring reasonable prices for consumers”.

The decision to support prices appeared immediately particularly unfair. Instead of helping the farmer most in need of support, 80% of the funds were concentrated on the 20% of beneficiaries. These were farmers with the largest farms, the most affluent and technologically advanced. Small farmers and those lagging in development were left with only scraps. Refunds quickly exhausted the Community budget, making it impossible to finance the structural policy, which in the following decades never exceeded 5% of the entire common agricultural budget.

Despite its inconsistency and exorbitant cost, price support not only remained in place throughout the Seventies and Eighties but was strengthened under pressure from agricultural lobbies and the entire agro-industrial and agri-food chain. So much so that, in 1985, CAP expenditure still accounted for 71% of all EEC payments, producing distorting effects not only within the Community but also worldwide, and forcing all other common policies to contend with the constraints of the residual Community budget.

### 2.2. *From price support to direct payments*

It was not until 1993, under Commissioner Ray MacSharry, that the first reform took place. Under pressure from the GATT negotiations on international trade, price support was gradually reduced. It was replaced by compensatory payments from the Community budget. On that occasion, it was proposed to modulate payments, i.e. to cover only partially the largest beneficiaries of the previous price support. It was also proposed that compensation should be gradually reduced over the years and then abolished at a certain point in time. The savings would have been allocated to so-called “accompanying measures”, a first attempt to introduce measures with agri-environmental and social objectives.

Instead, it was decided that compensation should be full for all beneficiaries, with the result that the first agri-environmental policy was initiated with very few resources. The consequence was a further increase in the cost of the CAP for the Community budget. In the meanwhile, with the Maastricht Treaty, was established the European Union integrating the European Commu-

<sup>3</sup> Proposal for a Regulation establishing the European Fund for economic, social and territorial cohesion, agriculture and rural, fisheries and maritime, prosperity and security for the period 2028-2034 and amending Regulation (EU) 2023/955 and Regulation (EU, Euratom) 2024/2509 COM(2025) 565 final

nity, common foreign and security policy and cooperation in the field of justice and home affairs.

In 1999, the CAP was reorganised around two pillars. The first concerned market policies, which included compensatory payments, renamed “direct payments”. The second pillar focused on rural development was financed from 2005 by the new European Agricultural Fund for Rural Development (EAFRD), with the aim of integrating a territorial approach with the traditionally sectoral approach of the CAP. In the original plans, the two pillars were to be gradually allocated similar funding. However, under pressure from lobbies, the first pillar was allocated around 90% of the entire CAP budget. This percentage has fallen in subsequent years, but never below 75%.

In 2003, on the initiative of Commissioner Franz Fischler, all direct payments received by each farmer were incorporated into a “Single Farm Payment” (SFP). This support was equal to the average of all direct payments received by the farmer in the three-year period 2000-2002. This was combined by the complete decoupling of support from production, in the sense that the right to receive the SFP was completely disconnected from the beneficiary’s production choices. To the extent that he could continue to receive it even if he ceased the activity. Payments were made on condition that a series of European and national norms, mainly of environmental nature, were complied with. This is known as eco-conditionality or cross-compliance.

Once again, it was proposed to gradually reduce the budget for direct payments over the years and to set a maximum limit (capping) on the individual SFP. But the proposals were dashed, and the distribution of expenditure among beneficiaries retained the old imbalance.

Direct payments were maintained, albeit split into several schemes in the CAP 2014-2020 (later extended to 2022). A component of farmer payments known as “greening” was also introduced for agri-environmental purposes, but its effects in terms of sustainability have been decidedly disappointing (Matthews, 2013).

### *2.3 The transition to income support*

With the CAP 2023-2027, inspired by the Green Deal and its two implementation strategies : “From Farm to Fork” and “European Biodiversity Strategy for 2030”, direct payments have been once again split into several types of intervention. The key support intervention has been renamed “Basic income support for sustainability” and consists of a payment per hectare. Currently basic payment remains differentiated as long as the titles remain in force. In perspective it will tend to be uniform across the EU . This has been accompanied by

so-called “eco-schemes”. They are optional measures for the farmer aimed at adopting practices geared towards environmental sustainability and contrasting/adapting to climate change. This was effectively the first attempt to transform, at least in part, direct payments from passive expenditure to active interventions for the care of common goods of European importance. However, leaving it up to Member States to choose which measures to adopt from a pre-set menu, resulted in a patchwork of interventions that were not entirely consistent.

Cross-compliance has been reinforced both by introducing additional requirements (e.g. crop rotation) and by adding social requirements. This was the most ambitious attempt in the history of the CAP to impose stringent (albeit mild) conditions on recipients of direct payments (Brunori, 2023; Coderoni, 2023). It was followed by tractor protests, which led Von der Leyen to effectively restore the previous agricultural policy.

As for the second pillar of the CAP, it has been assigned three distinct tasks: support for agricultural investment, agri-environmental payments and territorial development (rural development in the strict sense). Despite the limitations that have affected its functioning (especially the long implementation times), it has generally been a better targeted and better tailored policy than that of the first pillar. Nevertheless, or perhaps precisely for this reason, the financing of the second pillar has been almost systematically opposed by agricultural lobbies. So much so that the funds allocated to it grew through so-called modulation until 2013 without ever reaching more than 25% of the total CAP funds. It then fell again in subsequent MFFs to absorb more of the cuts in overall CAP funding

In summary, considering its cost and the distribution of funding, the CAP shows a remarkable chameleon-like ability to survive by adapting its features to the times. At the same time, it has remained substantially invariant, in terms of its distribution and effects, throughout its history. This invariance consists of its projection to the short term, support for the rent and large recipients , despite some mechanisms of adjustment toward equity are planned for the period 2023-2027 (Pierangeli et al. 2023). It is a one-size-fits-all, individualistic transfer policy that is not adapted to deal with the profound transformations in agriculture today and lacks a systemic and strategic vision (Sotte, Brunori 2025). Meanwhile, all measures aimed at promoting structural adjustment, technological and organisational renewal, competitiveness, entrepreneurship and the development of rural areas, especially those remote and marginal, in the medium to long term remain in the background and underfunded . We refer here to the second pillar,

which is often overlooked in political debate, but also to European policies outside the CAP that have a marked influence on the future of agriculture and rural areas: research policy, cohesion and regional development policy, education and training policy, etc. At the same time, as evidenced by the recurring assessments of the European Court of Auditors, there is still insufficient commitment to transforming agriculture in terms of sustainability, resilience and combating and adapting to climate change (European Court of Auditors, 2021 and 2024).

At each seven-yearly renewal of the MFF, substantial cuts and a different distribution of funds have been proposed. However, this has been opposed by the strenuous defence of the sector's lobbies, supported in the European Parliament by the Committee for Agriculture (Comagri). This defence has been echoed in the Council, due to the governments' fear of losing consensus.

### 3. THE CAP BUDGET

The CAP's share of the EU budget has fallen over the years, from 74% in 1976 to the aforementioned 71% in 1985, 49% in 2000 and the still substantial 31% today. Meanwhile, to offer a comparison, since the CAP was established, the percentage of farmers in Italy has fallen from 42% to 3%, in France from 28% to 2% and in Germany from 24% to 1%.

Throughout the long history of the CAP, criticism of its weight in the EU budget and its inefficiency, ineffectiveness and unfairness has been constant and increasingly pressing (Zeller, 1971; Andrews, 1973; Galli & Torcasio, 1976; Marsh et al., 1982; Fennell, 1997; Fanfani, 1996; Loyat & Petit, 1999; Oskam et al., 2010; Swinnen, 2015; Sotte & Brunori 2025). The most recent strategic documents on the future of the Union, which should also serve as a reference point for CAP reform proposals, do not even mention it. Other priorities are: security, immigration management, border control, counter-terrorism, defence, combating discrimination, employment and economic recovery, reducing the social and economic gap between regions, structural reforms, macroeconomic stabilisation and the transition to sustainable development models.

The only references to the CAP found in strategic documents mainly criticise its exorbitant cost. This was the case in the preparatory work for the current MFF (2021-2027). The final report of the High Level Group on Own Resources appointed by the Commission and chaired by Mario Monti in 2016 stated:

There is a consistent criticism towards the two major spending posts – agriculture and cohesion – as being essentially redistributive and not providing enough added

value, partly because Member States focus their efforts to “get their money back”, and partly because policies are not optimal (European Commission, 2016).

A similar opinion is found in the Draghi Report:

The EU's annual budget is small [...]. It is also not allocated towards the EU's strategic priorities. Despite attempts at reform, the shares of the 2021-2027 Multiannual Financial Framework (MFF) allocated to cohesion and the common agricultural policy are still 30.5% and 30.9%, respectively (Draghi, 2024).

It comes as no surprise, then, that today, faced with the difficulty of significantly increasing the EU budget with new revenue, debt or higher contributions from Member States, the CAP (and cohesion policy) budget is being tapped to support the European Competitiveness Fund mentioned in the Draghi Report, which is in any case underfunded compared to what is needed.

### 4. THE CAP AND THE PRINCIPLE OF SUBSIDIARITY

The opportunity of the CAP budget review should have been accompanied by a reorganisation of the CAP based on the principle of subsidiarity enshrined in the Treaty. On this basis, policies with greater European added value should have been defined and managed at European level. We refer to combating and adapting to climate change, for technological change, product quality, consumer health, food security, research. Other policies should be designed, managed and financed jointly by the EU, Member States and Regions, as has been the case for rural development to date, with multi-level governance: cooperation, services to agriculture, diversification, and policy for the EU's remote and marginal territories.

As for income support, which is entirely funded by the EU budget, and sectoral subsidies, which currently account for by far the largest share of the CAP budget, their ineffectiveness, inefficiency and unfairness have long been noted. A very recent report by the Bruegel Institute, notes that:

the CAP relies heavily on direct income support and sectoral subsidies, which are not conducive to food security but are rather policy preferences. [...] The CAP continues to reflect national-sectoral support rather than EU-wide public goods provision (Darvas, Dom et al., 2025).

This is not a new position, considering that more than twenty years ago, a study carried out on behalf of the Romano Prodi Commission found that there were no reasons to reserve income support for farmers that

was different from that granted to all other individuals in economic hardship; and that in any case, as a social policy, on the basis of the principle of subsidiarity, it should be the Member States and not the EU that had to deal with it and pay the cost. It stated as follows:

Path dependency seems to be the main argument for the current existence of direct payments and market interventions. [...] The case for centralisation of direct payments is not clear. Both normative and positive analyses argue for decentralisation of such (personal) income support policies. There are no clear economies of scale, nor is there any internalisation of externalities if these activities are conducted at EU level. [...] Because these policies are to a large extent a transformation of previous market and intervention policies, it is understandable that these policies are part of the EU budget. However, economic reasoning suggests that it is sensible to shift these policies to the Member States in the future (Sapir et al., 2003).

Even earlier, in 1987, a working group set up by the European Commission and chaired by Tommaso Padoa Schioppa had expressed a similar view (Padoa Schioppa, 1987).

## 5. A MISSED OPPORTUNITY

In the proposals for the future MFF and CAP 2028-2034, agricultural and regional policies are therefore subject to substantial budget cuts and will be financed, together with other minor policies, from a unified fund of €865 billion. Member States, for their definition and management, will draw up a National and Regional Partnership Plan (NRPP). Part of the funds, €628 billion, are pre-allocated. Of these, €294 billion are ring-fenced for the CAP for income support, agri-environmental actions or climate change mitigation and adaptation, risk management, investments, and the establishment of young farmers and new businesses<sup>4</sup>.

It is easy to predict that, having kept income support at the top of the list of possible destinations for ring-fenced CAP funds, this will take the lion's share. Moreover, it will once again be distributed based on hectares owned. Direct payments are generally linked to cross-compliance commitments (of ecological or, after 2023, even social nature). These typically involve compliance with European regulations (Statutory Management Requirements) or national rules (Good Agricultural and Environmental Conditions). As these are universal legislative standards, they must be complied with by every-

one, even those who do not receive payments.

Some additional commitments were actually introduced with the 2023-2027 CAP. They regarded in particular crop rotation, ecological focus areas, and the limited employment of plant protection products. However, these measures were revoked or their effects mitigated after tractor protests began in Germany in December 2023 and continued in the following months in France and finally in February 2024 in Brussels. Since income support based on hectares is not generally linked to additional commitments other than compliance with the rules that apply to everyone, they generally constitute a blatant gift to rent and a clear attempt to appease the agricultural lobbies, often aimed at defending the path dependency with short term measures, more than operating for a real sustainable entrepreneurial transformation of European agriculture in the face of new technologies, market opportunities, and international scenarios.

All other objectives of agricultural and, especially, rural development policy will compete, at national level in the NRPP, with other policies, which have so far been financed mainly by the European Regional Development Fund and the European Social Fund. It will therefore compete for the €237 billion that has not been pre-allocated or for any additional national funding. Each Member State, albeit within the framework of an overall strategy defined at Community level, will therefore be free to adapt its agricultural policy according to its own needs and budgetary resources. Twenty seven different national agricultural policies will therefore be pursued for objectives that are clearly in the European public goods domain.

As a result of the different agricultural policies of each Member State and their different capacities/willingness to support them financially, the rules of the single market will also be broken. Competition will no longer reward the best farmers but, given equal technical and managerial efficiency, those farmers who operate in the Member States with the greatest financial potential and commitment to supporting their own agriculture.

The common agricultural policy has been a fundamental pillar of European integration. Until the mid-1980s, it was the only policy that was effectively financed and managed jointly. But now the CAP is falling apart due to its inability to keep up with the times and the inadequacy of the institutions and organisations responsible for it.

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<sup>4</sup> It has recently been authorised that another €45 billion may be transferred to agricultural policy, at the expense of other areas.

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### Full Research Articles

- 3 Vineta Tetere, Jack Peerlings, Liesbeth Dries, *The importance of wooden biomass in the transition to a bioeconomy in Latvia*
- 13 Zisis C. Mandanas, Dimitrios P. Petropoulos, Nikolaos Apostolopoulos, *Input interactions and structural dynamics in Greek agriculture productivity*
- 27 Mika Wakamatsu Shin, Jason Loughrey, Emma Dillon, Anne Kinsella, *The social and economic determinants of farm succession in Ireland*
- 43 Viktorija Jankuloska, Blagoja Mukanov, Angela Zhivachka, Jovana Milosavljeva, Mario Petkovski, Tanja Popovska, *Towards sustainable business models in the circular bioeconomy: The case of bio-based fertilizers*
- 57 Tanisha Waring, Luigi Biagini, Martina Bozzola, Simone Severini, *Weathering the storm: A systematic review of climate change adaptation in agriculture. Methods, metrics, and impacts*

### Short Communication

- 77 Stefan Mann, Mauricio Benincore, Jürg Hiltbrunner, *Public information instead of vertical integration – Exploring “recommended variety lists” in the Swiss maize seed market*

### Policy Papers

- 87 Francesco Mantino, Giovanna De Fano, Gianluca Asaro, *Rural policy in the 2028-2034 EU budget: Reform or Retreat? A rural-proofing analysis*
- 95 Franco Sotte, *What is still common in the Common Agricultural Policy?*

