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The impact of the EU's farm-to-fork strategy on member states' economies: which countries will suffer the most?

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Abstract
Studies assessing the economic impact of the F2F strategy estimate significant losses in EU-27 agricultural production and global changes in markets that will affect other regions. We contribute with an estimate of the impact on individual EU Member States, which has not been assessed so far. The results show that the countries most affected are those with lower EU GDP, poorer economies, and more vulnerable to intervention in the agricultural sector. We also review the coherence of the F2F targets in light of progress to date and suggest improvements to meet EU policy objectives.

Keywords: Economic assessment, European policy, Redistribution effects, Agricultural policy

JEL Classification: Q18, D57

Introduction

The European Green Deal is in jeopardy as protests against the EU's agricultural policies have emerged in response to various challenges, including the Covid pandemic, the Russia-Ukraine conflict and adverse weather events. Farmers are demanding compensation for income losses and increased environmental requirements, as well as greater protection from trade agreements that threaten the sustainability of their farms. In a significant move in February 2024, President Von der Leyen has suspended the Project for the Sustainable Use of Plant Protection Products Regulation and relaxed one of the land set-aside requirements. These decisions appear to have stalled Green Deal F2F and biodiversity strategies.[1]

Criticism of European agricultural policy is not new in the scientific and academic fields either. While there is a broad consensus on the need to promote economic growth based on sustainability and the protection of the environment and natural resources (Pe'er et al. 2019), many voices call for measures based on concrete goals that can be measured using specific indicators, adequate funding for these goals (Storm 2020),

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[1] Euronews. https://www.euronews.com/my-europe/2024/02/01/von-der-leyen-sings-ode-to-farmers-promises-action-to-appease-protests

a more effective CAP strongly oriented toward environmental goals (Pe'er et al. 2020; Stoate et al. 2009), and robust economic evaluations to support decisions (Wesseler 2022; Henning et al. 2021). It is particularly striking that the launch of the Green Deal did not include any impact studies on production, welfare, or market prices, and that the first economic impact study was prepared by the USDA and published in 2020. The EU decided in December 2019 to introduce the targets and publish the 2021 economic impact analysis, causing uncertainty among producers.

From the perspective of economic science, the weaknesses and inefficiencies of some past approaches to agricultural policy have been identified in recent years, providing concrete ways to improve and highlighting the existence of "state failure" (Matthews 2017). Pe'er et al. (2019, 2020) and Simoncini et al. (2019) identified specific weaknesses of the CAP in terms of its structure and its concrete relation to the goals of environmental sustainability and fighting climate change (Guyomard et al. 2020). These include the problem of a "green architecture with vague requirements," the lack of indicators to adequately monitor the achievement of objectives and the effectiveness of the instruments used, and finally, the lack of coherence and transparency in policy-making processes (Purnhagen et al. 2021; Henning et al. 2021; Pe'er 2019).

The new rules introduced for the agricultural sector by the F2F strategy and the new CAP have exacerbated some of the classic problems of the EU's agricultural policy. On the one hand, the weaknesses associated with setting science-based targets and indicators (Henning et al. 2021), the lack of monitoring of the achievement of these targets, and the mismatch between projections and adequate funding persist, while bureaucracy grows (Wesseler 2022).

Given the withdrawal of some of the most ambitious measures announced in the F2F and Biodiversity strategies, this article aims to assess the progress made so far in achieving the targets set out in these plans and to discuss whether the targets are consistent and/or reasonable. In addition, we present our economic assessment of the impacts of F2F and biodiversity measures, focusing on the economies of EU member states (MS), an issue that, to our knowledge, has not been addressed in previous studies. Our multi-sector model captures the complex interactions between economic sectors, institutions, and households on a country-by-country basis. We aim to contribute to the debate on the EU's agricultural policy and to suggest areas for improvement to achieve a better fit between the Green Deal and the CAP.

Several previous studies have already assessed the potential impacts of the Green Deal. The most relevant are those conducted by the USDA (Beckman et al. 2020), the report promoted by the EU through the JRC by Barreiro et al. (2021), and those commissioned by various private entities by Henning et al. (2021), Noleppa and Cartsburg (2021) and Bremmer et al. (2021). Although the methodology and focus vary, they all estimate significant reductions in food production, increases in prices, and food expenditure. Regarding farm income, Barreiro et al. (2021) and Henning et al. (2021), who use the CAPRI model as a methodological basis, estimate increases in this variable, although Barreiro et al. (2021) include the effect of CAP support (pre- and post-reform of 2021) in their impact assessments. In contrast, Beckman et al. (2020) and Bremmer et al. (2021) predict a reduction in farm income in their results. In the case of Noleppa and Cartsburg (2021), estimates are given over a longer time horizon than in the rest, finding increases in farm income. Table 1 in the Appendix shows a brief description of the variables studied, the methodology, and the approach used in these previous studies.

Our paper contributes to this literature by assessing the impact of the measures on MS by calculating losses in gross domestic product (GDP), household income (HH) and total output, which allows us to provide new insights into the distribution of impacts within the EU and the possible imbalances that the F2F and Biodiversity strategies could generate (or aggravate) between MS. In this sense, our analysis complements existing studies that focus on the global impact of F2F. In addition, we offer an evaluation of the progress made since the beginning of the F2F strategy, allowing us to evaluate whether the projections are consistent with the progress made or whether, on the contrary, they need to be strengthened and corrected.

To simulate the reduction in the use of some products proposed in the Green Deal, it is appropriate to use a multi-sectoral model, as it allows a more complete approximation to the inter-sectoral flow of relations, thus enabling the quantification of the effects of an economic policy measure on the production, supply or demand of a good or activity, on the rest of the sectors or agents. Our estimates seek to complement the expected direct effects on agricultural production with the indirect and induced effects on the sector, as well as those that ultimately occur in the whole economy due to interrelationships between sectors and agents. In this sense, the use of Input–output frameworks proves to be the most useful and intuitive, especially with the use of social accounting matrices (SAMs) instead of the typical Input–output tables, as they extend the traditional Input–output model by incorporating (and thus allowing to make them endogenous) the accounts of the institutional sectors, as well as of final consumption, investment, or international exchange (Mainar-Causapé et al. 2018).

The rest of the document is organized as follows: in the next section, we describe the methodology used to assess the economic impacts of the measures on the EU-27 and the MS. Then, an evaluation of the consistency of the forecasts is made in light of the progress achieved so far in each of the measures promoted, using the latest official data available. Next, the impacts by country of the measures promoted by the F2F strategy are presented. Finally, some points for improvement to meet the policy objectives are proposed.

Methods and data

Farm-to-fork and biodiversity strategies: scenarios for analysis

Our analysis covers the 4 most important objectives set in the F2F and Biodiversity strategies. The achievement of these goals will have an impact on the final production that is not quantified in these strategies, so it is necessary an estimation to incorporate into our model. For this purpose, we will consider four scenarios, describing their basis and foundation, adopting anyway the production losses estimated by Barreiro et al. (2021), which are those calculated by the European Commission's JRC. This allows us to provide an impact assessment that complements the JRC study.

Scenario S1: Reduction of chemical pesticide use by 50%: Barreiro et al. (2021) assume an average annual production loss of 10% as a result of this measure based on Sánchez et al. (2019) estimations. Given that other works indicate losses close to 20% (Noleppa and Cartsburg 2021; Sánchez et al. 2019), we simulate two sub-scenarios: 10% loss (S1.1) and 18.6% loss (S1.2).

Scenario S2: Increase in the area under organic farming to 25%: the current percentage of land under organic crops in the EU is 8.1%, but there are countries above and below this average. The EU forecast is that the percentage in 2030 will be 12% without modifying the existing measures, so the objective would be to promote this type of production with additional measures to reach 25%. Production losses are also expected in this scenario since production in organic systems is significantly lower than under other production systems that use chemical fertilizers and pesticides. Barreiro et al. (2021) apply production reductions depending on crop type and production area based on data from the Farm Accountability Data Network, which we use in this scenario.

Scenario S3: Set-aside of agricultural area up to 10%: Currently the set-aside area is 4.7%, so an additional set-aside of 5.3% is considered in this scenario based on the current country distribution taken from Barreiro et al. (2021).

Scenario S4: 50% reduction in gross nitrogen surplus (20% reduction in fertilizer use): The EU assumes that a more rational use of fertilizers (using precision technologies or simply adjusting application to actual needs) would reduce excess nitrogen losses without causing additional yield losses. Therefore, according to this hypothesis, the measure will only have an impact on the sales of chemical fertilizers, the effects of which are evaluated in this scenario.[2]

Data

The database used in this analysis is a set of specific social accounting matrices (SAM), called BioSAMs based on the 2015 year. A SAM could be described as a comprehensive and economy-wide database recording data on transactions between all the economic agents within an economy in a period. SAM is a square matrix with accurate representation, by accounts in rows and columns, of economic activities, commodities (goods and services), factors (capital, labor, etc.), and institutional sectors (household, government, etc.). Each cell of a SAM collects the payment by the account in the column to the account in the row, so the income of accounts is reflected in its corresponding row and the expenditures are described in the corresponding column. The typical structure of a standard SAM is shown in Table 2 of the Appendix.

SAMs improve on traditional supply-and-sse and input–output tables (SUIOTs), incorporating the relationships between incomes and expenditures of institutional agents, not referring only to the productive part of the economy. Social Accounting Matrices increase the explanatory capacity of I-O models, by directly introducing income and its distribution (primary and secondary), and the final consumption of institutional agents (households and government). Here, SAMs are employed for the European Union Member States for 2015, derived from previously used and presented in Mainar-Causapé et al. (2021a), but with specific disaggregation and re-allocation of some accounts for the research purpose of this paper, based on the inherent structure

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[2] Although in this scenario we assume the JRC hypothesis, Noleppa and Cartsburg assume a reduction of 2.75% and Beckman et al. uses an elasticity of substitution of inputs in the production < 1, so that yield losses would also occurred.

of the tables and on additional information mainly based on called BioSAMs (Mainar-Causapé and Philippidis 2021b; Mainar-Causapé et al. 2021a).[3]

To isolate the effect of the restrictions imposed by the Green Deal, the BioSAMs used to disaggregate the fertilizers component from the chemical products account, while the rest of that account is split creating a chemical products account used as inputs in agriculture and another one of those used as inputs in livestock, remaining in the original one all other uses of chemical products (both in production processes and in final demand). In this way, there are already specific accounts to simulate the shock of the reduction in the use of fertilizers and chemical products for crops and livestock. Similarly, to capture the effect of the reduction in the use of arable land, the capital account is separated by estimating an account that only includes the uses of this account for crops, maintaining the rest of the uses in the original capital account. Table 3 in the Appendix shows the SAM accounts related to the research objectives, also containing a broad disaggregation of the agricultural and livestock sectors, which allows a better approximation of the effects on primary output.

The way to simulate the restrictions imposed by the Green Deal will be to suppose an analogous and immediate reduction in the output or the availability of those commodities –scenario S3- (regardless of its origin, which can be approximated by an equivalent reduction in its supply). Excel (VBA) and GAMS software have been used in the estimates. The complete model is described in the Appendix.

Green deal compliance: a review of actual progress

This section is an overview of progress toward the targets set, from the announcement of the Green Deal in 2019 to the present.

The Directive on the Sustainable Use of Pesticides (Directive 2009/128/EC), adopted in 2009, aims to reduce the risks and impacts of pesticide use on human health and the environment. This Directive includes key measures to introduce integrated pest management, such as crop rotation, pest monitoring, and the use of non-chemical pest control techniques and less hazardous pesticides. However, analysis of pesticide use since the Regulation's implementation shows no clear decrease in either terms or amount per hectare, as shown in Fig. 1. The use of these products has remained around 5% above and below 350,000 tons per year and around 3.2 kg/ha in the EU-27 since 2009. In 2022, it reached 358,000 tons (Eurostat 2024a). Spain, France, Germany, Italy, and Belgium are the top consumers in absolute terms, with no significant reductions. In relative terms, the highest consumption is in the Netherlands (10.84 kg/ha), Malta (10.52 kg/ha), Cyprus (9.58 kg/ha), Belgium (6.57 kg/ha), and Ireland (6.54 kg/ha).

In Spain and the Netherlands, pesticide consumption has shown a slightly increasing trend since 2009 (see Fig. 1). Over the last three years, starting from the Green Deal, there has not been a significant change in this trend. In the Netherlands, around 20% of substances measured in surface water have exceeded legal limits since 2014. From 2014 to 2018, the percentage of gage points exceeding these limits decreased from 68 to 51% but rose again to 62% in 2019. Most recently (2022) 53% of the points exceed the limits, and 34% surpass the most severe toxicity limits (Deltares 2023).

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[3] BioSAMs show a very high disaggregation, in agricultural and livestock activities and products, as well as biochemical and biofuels. More details about sources and estimations can be found in Mainar-Causapé & Philippidis (2021).

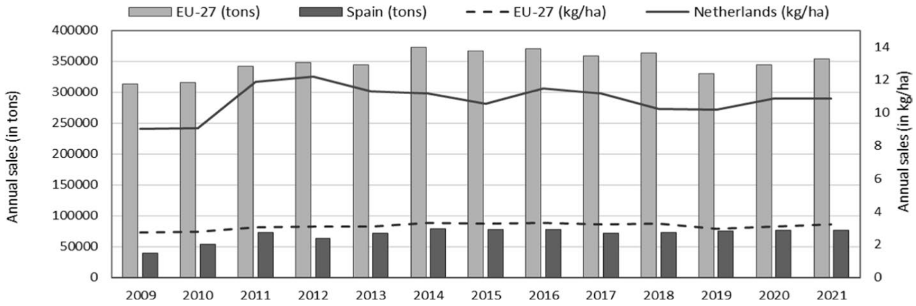

Fig. 1 Evolution of sales of phytosanitary products (pesticides, herbicides, and others) in the EU-27, Spain, and the Netherlands (2009–2021). Source: Faostat (2024), Mapa (2024)

What diagnosis should we make about the effectiveness of past regulations and the monitoring of their enforcement? Why should the new regulations succeed where the old ones did not? In this respect, some of the measures promoted by the new CAP 2023–2027, such as eco-schemes, can be achieved through the adoption of conservation agriculture systems (direct seeding for arable crops, no-tillage and ground-cover for tree crops). Most of these systems replace soil tillage with the use of herbicides to control weeds and may therefore favor the use of more instead of fewer chemicals. The F2F and biodiversity strategies do not estimate the potential impacts of this change, so the environmental impacts may be overestimated.

Regarding the goal of reducing the gross nitrogen surplus by 50%, the Nitrates Directive (Directive 91/676/EEC) and the Water Framework Directive (Directive 2000/60/EC) are key European legislations, which are 33 and 24 years old, respectively. Figure 2 shows the evolution of total and per-hectare consumption of fertilizers in the EU-27 area in combination with data on nitrate pollution of rivers and groundwater. Since 1995, total nitrogen fertilizer use decreased by 9%, with notable fluctuations: a downward trend until 2010, an increase to 10.5 million tons from 2011 to 2018, followed by a reduction to 9.4 million tons in 2022. Despite these changes, nitrate concentrations in groundwater have not significantly decreased since 1995, while rivers have seen only a modest reduction (Fig. 2). Per-hectare consumption increased from 70.4 kg/ha in 1995 to 83.18 kg/ha in 2018, then decreased to 75.1 kg/ha in 2022, reflecting a 6.6% increase over the period despite decreases in total consumption and agricultural area.

France, Germany, and Spain lead in total fertilizer consumption with 2 million, 1.2 million, and 1 million tons per year, respectively. The countries with the highest consumption per unit of agricultural area are Ireland (210 kg/ha), Belgium (175.21 kg/ha), Czech Republic (129 kg/ha), Hungary (104 kg/ha), and the Netherlands (100 kg/ha). In France and Germany, there is a slightly decreasing trend in fertilizer consumption per hectare, from 107 kg/ha and 117 kg/ha in 1995 to 87 kg/ha and 74 kg/ha in 2022, respectively. In Spain, consumption per hectare has remained stable at 60 kg/ha.

In countries with high current consumption per hectare, the trend is either increasing or constant, similar to the pattern in leaching values (Fig. 2). Bulgaria, Lithuania, and Romania have notably increased both consumption per hectare and nitrogen leaching and volatilization (Faostat 2024b). Therefore, data from the European Environment Agency indicate an unpromising evolution of nitrate pollution objectives, particularly

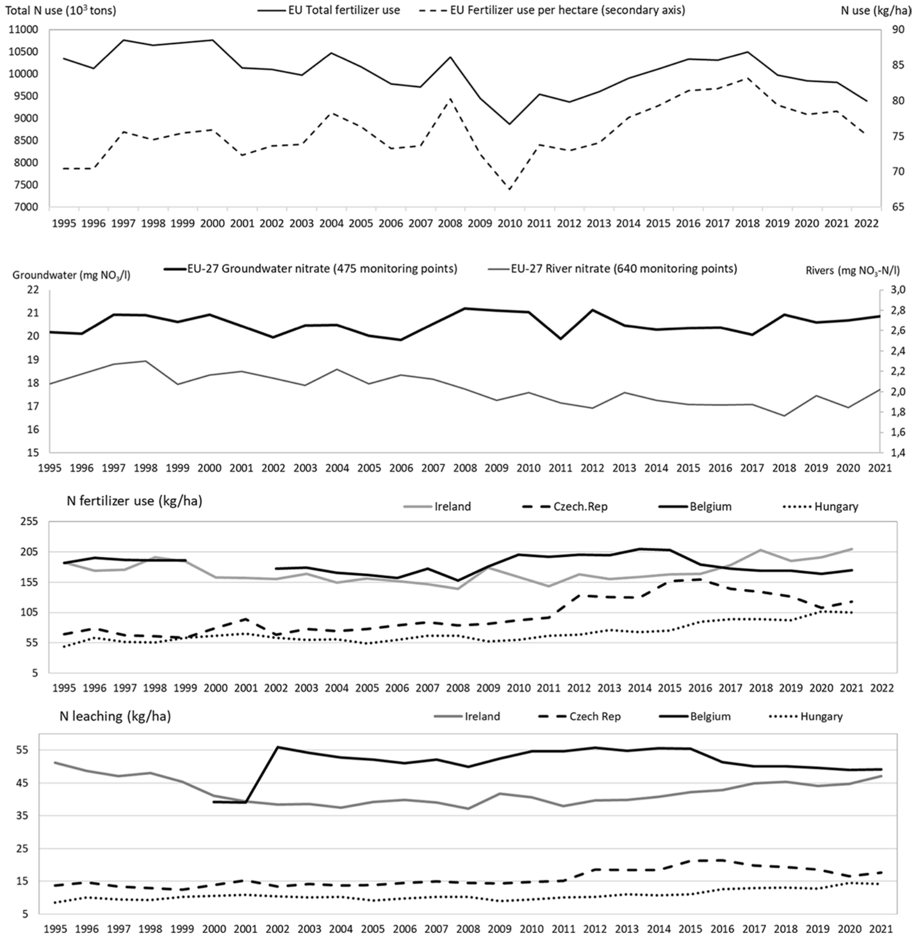

Fig. 2 Evolution of fertilizer consumption, nitrate concentration in EU-27 and N fertilizer and leaching in Ireland, Czech Republic, Belgium* and Hungary. *Only the data that are available for Belgium are shown. *Source* EEA Datahub available at: https://www.eea.europa.eu/en/datahub. *Only the data that are available for Belgium are shown

concerning groundwater quality, which is adversely affected by the lack of rainfall in many southern European areas.

All this suggests that the results of existing regulations have been quite limited and disappointing, highlighting the need for a thorough review of their effectiveness and the monitoring of their implementation. Since the Green Deal was introduced, progress toward the targets set has been insufficient. The rationale behind the 50% reduction target and its connection to pollution targets and instruments lacks solid justification. Therefore, a coherent regulation should justify both the targets and the tools used to achieve them.

As regards the objective of the organic production system, in 2019, 8.6% (14.1 million hectares) of the EU's land was dedicated to organic production. Again, variations between MS are significant. Spain (2.8 million hectares), France (2.7 million), Italy (2.1 million), and Germany (1.6 million) have the largest areas for organic farming, well above the rest of the MS. Green markets in these countries account for significant sales, while Denmark, Luxembourg, Austria, and Sweden have some of the highest per capita spending on organic products (FiBL 2023).

The latest data for 2022 show that 10.4% (16.9 million hectares) of the EU's territory is dedicated to organic production, marking a 1.8% increase in three years (Eurostat 2024b). With the target set for 2030 being 25%, approximately 23.73 million hectares must be converted in eight years. Given the current growth rate, it is unlikely that the 2030 target will be met, with projections showing a 15% surface area share by 2030 if demand growth and current policy support are maintained (Eurostat 2024c). How this will be achieved is not fully specified in the strategies but significant changes will be needed to grow this production system.

In this sense, the targets for the growth of the organic system in the EU should align with the growth projections of the EU organic markets, which require objective and properly managed data. For example, annual expenditure on organic products in Spain has grown continuously for 10 years, with a peak in 2015 and a decrease since 2017. The Spanish Ministry of Agriculture's growth forecasts for domestic consumption of organic products are based on the sector's growth from 2015 to 2021, which had an average annual growth of 11.9%. They project an annual increase of 7.81% for 2030. However, growth rates have been declining since 2017, and last year's growth was only 2.65% (MAPA 2023).

Does this mean that the forecasts are wrong? Of course not, if we use the period 2015–2021 as a reference and assume that the data follow a linear trend, which seems reasonable given the fit of the data ($R^2=0.9779$). However, statistical analysis shows a better fit with polynomial ($R^2=0.9932$), logarithmic ($R^2=0.9881$), or potential trends ($R^2=0.9935$). Therefore, the 2030 trend projections are unrealistic, and the rationale for choosing a linear trend should be explained. This illustrates why policy initiatives need to be underpinned by consistent forecasting and why they need to be supported by well-founded impact studies.

A controversial aspect of this issue is the absolute and unambiguous commitment to the organic production system in the EU, to the clear detriment of other systems included in conservation agriculture (no-tillage, minimum tillage). These systems have scientifically proven environmental advantages over the conventional system, without causing high production losses, which would be an advantage over the organic system. These systems, based on soil conservation techniques and efficient use of water and inputs, can significantly reduce gas emissions (Cooper et al. 2021) and improve soil productivity, although they require effective herbicides to replace intensive tillage. There is also evidence that intensive tillage, often used in organic farming for weed control, can lead to the loss of soil organic matter, reduced biodiversity, and increased erosion (Melero et al. 2011; Cornell et al. 2022; Hashimi et al. 2023).

In terms of productivity, organic farming generally produces lower yields per unit area compared with conventional farming (de la Cruz et al. 2023). This means that more land may be required to produce the same amount of food, potentially leading to greater forest clearing and biodiversity loss, which undermines the environmental benefits usually associated with organic practices (Balmford et al. 2018; Seufert and Ramankutty 2017). This is important when assessing the environmental impacts of different production systems. While organic farming may have a low environmental impact per hectare, it can have a high environmental impact per ton of crop, thus it is important to consider multiple indicators (environmental, economic, and social).

Considering the ongoing scientific debate, it seems prudent for the EU to adopt a more cautious approach. The current strategies should include the promotion of alternative production systems, enabling a smoother transition from conventional farming to methods with lower environmental impact in many regions.

For the 10% land reduction target, the latest data from 2021 show 162.91 million hectares of utilized agricultural area, a 0.2% reduction from 2020. Over the last nine years, the area has decreased by 2.7%, averaging 0.3% per year. The 10% reduction by 2030 target seems unattainable at the current rate. In this case, the CAP plays a key role, as set-aside requirements are linked to subsidies. Efforts will also be uneven, with some countries such as Spain, Latvia, and Finland already exceeding 10% withdrawal, while Luxembourg, Czech Republic, Slovenia, and Ireland are below 1% withdrawal.

Results

Figure 3 shows the potential losses in GDP, HH income, and output of the MS economies caused by scenarios S1.1 and S1.2, which considers reductions of 10% and 18.6% in agricultural production, respectively. Annual GDP losses range from 0.76% for Romania to 0.02% for Luxembourg in S1.1 and from 1.36% for Romania and 0.04% for Luxembourg for S1.2. The overall loss in the EU-27 would be 0.25% and 0.45% of GDP for the two scenarios considered, respectively.[4]

The most affected by the measure are not the countries with the highest use of Plant Protection Products in tons (Germany, France, Italy) or tons per hectare (Netherlands, Malta, Cyprus), but those whose agricultural sector has the highest weight in their total GDP. These countries are Romania (4.13%), Bulgaria 4.34%), Greece (4.28%), Lithuania (4.36%) and Hungary (3.80%) (Eurostat 2024a, b). These countries' economies account for a small share of EU GDP, ranging from 1.9% in the case of Romania, to 1.2% in the cases of Hungary and Greece, 0.5% in Bulgaria, and 0.4% in Lithuania (Faostat 2024a). The GDP per capita of these countries is also well below the EU average.

On the other hand, countries with the highest pesticide use (France, Italy, and Netherlands) would suffer losses similar to the EU-27 average, or far below those of the EU-27, as in the case of Germany (10%), Malta, and Cyprus. Spain, despite being the fourth-highest user of pesticides, ranks seventh in losses (0.37%) because its agricultural sector represents 2.5% of its GDP and employs 3.9% of its population (Eurostat 2024a).

The effects on HH income are more severe in countries where the agricultural sector has a higher relative weight in the national GDP. In scenario S1.1. the losses would be around 0.60% for the countries with the highest losses (Romania, Greece, and Bulgaria) and less than 0.08% for the least affected countries (Luxembourg, Sweden, and Belgium). Croatia (0.31%) and Poland (0.28%) are particularly affected due to the significant share of agriculture in their GDP (3.61% in Croatia and 3.3% in Poland), and their small share of the EU-27 economy (0.41% and 4.35%, respectively). In scenario S1.2. the losses rise

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[4] Although the results have been obtained for all the MS individually, for a better and clearer interpretation, in some simulations and for certain shocks, aggregate results or country results that best reflect the impact of the shocks analysed have been selected. Comparative results are presented in Tables 4, 5 and 6.

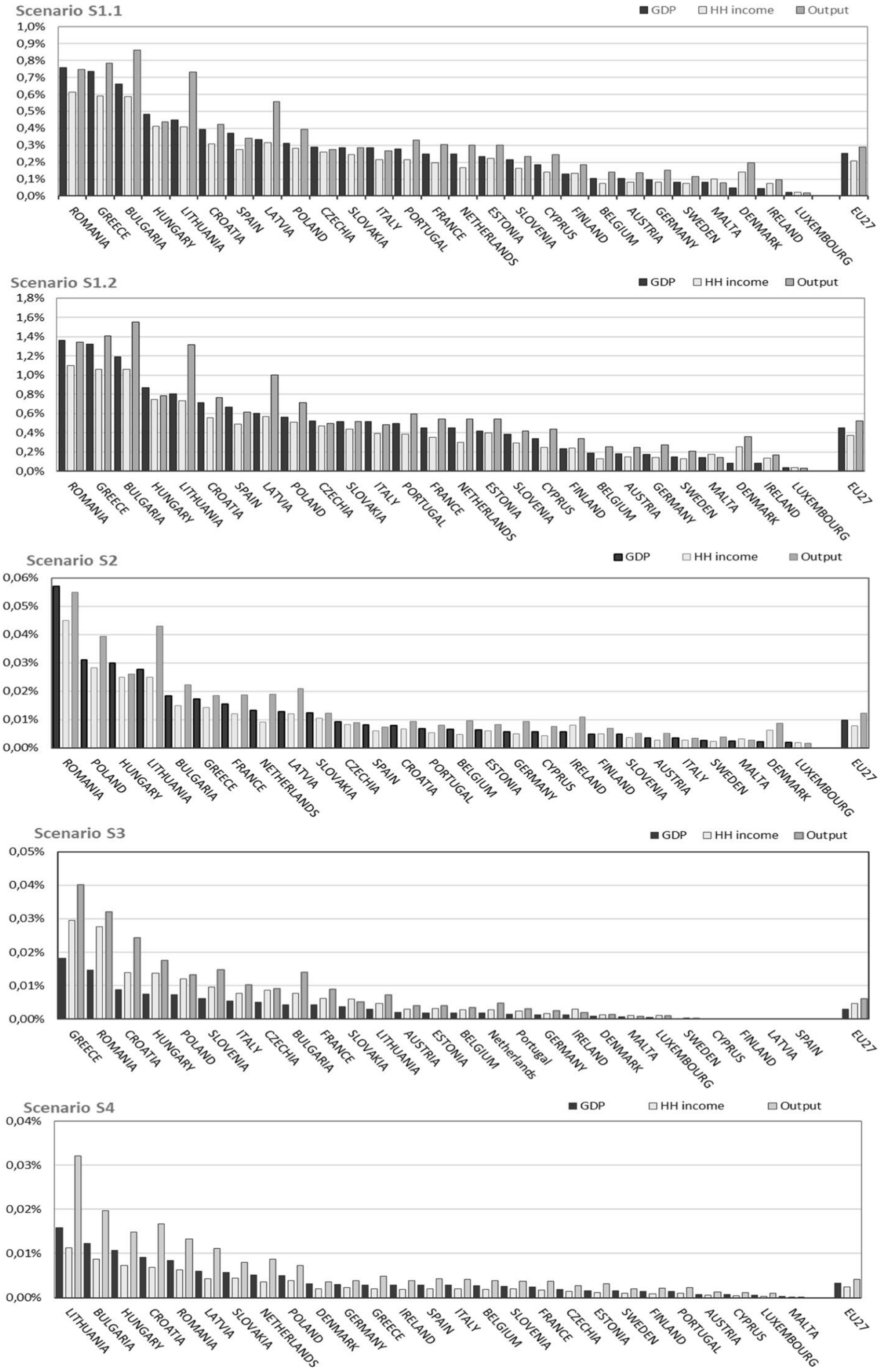

Fig. 3 Estimated annual losses (in %) in GDP, HH income, and Total Output for scenarios

to a maximum of 1.10% and a minimum of 0.04%. The impacts on the EU-27 would be 0.21% and 0.37%, respectively.

In terms of the impact on countries' total output, the reductions range from 0.02% for Luxembourg to 0.86% for Bulgaria, with an annual reduction of 0.29% for the EU-27 for

S1.1. For S1.2, the highest losses would be 1.55%. Bulgaria, Greece, Romania and Lithuania have the largest reductions.

The estimates show that the negative impacts of the scenario would be greatest in countries whose relative weight in the EU is small (0.2% to 2% in almost all cases) in terms of total GDP and GDP per capita. This means the S1 scenario would have a clear negative impact on equity and redistribution. The agricultural sector in these most affected countries accounts for a larger share of their GDP (between 3.5 and 5.8%) compared to the EU-27 average (1.87%). Coincidentally, these countries have the highest rates of material and social poverty according to the latest EU data, making them highly vulnerable to economic and environmental shocks. Thus, measures should be anticipated to mitigate undesirable effects in these least developed EU countries.

In scenario S.2, the GDP losses of the MS are below 0.06%, resulting in an annual loss of 0.01% for the EU-27. The five most affected countries are Romania, Poland, Hungary, Lithuania and Bulgaria. These countries have some of the lowest percentages of their total area dedicated to organic agriculture, with values of 4.42% and 3.78% in the case of Romania and Poland, respectively, or 1.71% in the case of Bulgaria. These countries are also the most affected by scenario S.1.

It is worth noting that the countries with the largest total organic areas (France, Spain, Italy, and Germany) would experience minimal annual losses -below 0.01% of their GDP, below 0.02% of their total output, and 0.01% in HH income. The EU-27 would suffer similar levels of losses. Therefore, the negative consequences of the measure follow the same pattern as in scenario S.1 regarding the redistribution of wealth: the less developed EU-27 countries suffer higher losses.

Under scenario S.3, output losses would be below 0.05% in all countries, with reductions in annual GDP below 0.02%, and HH income losses lower than 0.03%. Again, the most affected member states include Romania, Hungary, Poland, Greece and Croatia. Meanwhile, countries such as Spain, Finland, or Sweden would not experience any impact, as they already meet the requirements of non-productive areas.

Finally, under scenario S.4, output losses in the MS are estimated to be below 0.033%, with reductions in annual GDP less than 0.016% and HH income losses less than 0.012%. The main affected countries would be Lithuania, Bulgaria, Hungary, Croatia and Romania. Surprisingly, Germany, France, and Spain, leading consumers of fertilizers in the EU, are not among the top 10 most affected countries. It should be noted that in this scenario it is assumed that there is no loss of agricultural production, but simply a reduction in sales of chemical fertilizers.[5] Therefore, the highest impacts occur in countries with a fairly significant position in the fertilizer market. For example, Lithuania has a few companies producing fertilizers and nitrogen compounds, but with the highest number of people employed per company in the EU-27, and generating high production value (800 million euros). Bulgaria and Romania, have the highest number of fertilizer-producing companies in the EU-27 (28 and 34, respectively), with a high number of workers per company in the EU (73 and 69, respectively). Hungary and Croatia have similar situations. Therefore, fertilizer production and sales are economically relevant in these countries, explaining their higher losses in the examined variables.

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[5] If we assume a 2.75% reduction in production, as Noleppa and Cartsburg do, our estimates show that the largest reductions will occur in Romania (-0.21%), Greece (-0.20%), Bulgaria (-0.18%), Hungary (-0.13%) and Lithuania (-0.12%).

In summary, all assessed measures negatively affect GDP, HH income, and Total Output across all EU member states, with the most affected consistently being Romania, Greece, Bulgaria, Hungary, Lithuania, Croatia and Poland. These countries would experience greater GDP losses than the EU-27 average. Additionally, their higher share of employment in agriculture means the labor market in these countries would be significantly impacted compared to the rest of the EU-27. Thus, the agriculture employment share in the EU economy is 4.2%, while it is almost 20% in Romania, 11.4% in Greece, 8.4% in Poland, and 6.5% in Bulgaria and Croatia (Faostat 2024a). This makes these countries more vulnerable to any agricultural policy measure that negatively shocks production.

In this sense, the EU's explanatory memorandum to the F2F strategy mentions plans to mitigate potential effects through various instruments, with the CAP playing a central role in supporting *"a socially just transition"* and ensuring that *"no people or places are left behind"* (EC 2020). However, data show that the CAP funds allocated to the seven countries most affected by Green Deal measures account for 28.31%, which is the same share as France and Germany combined (EC 2022). Although it is not the purpose of this paper to analyze the reasons and convenience of the distribution of CAP funds, this indicates a need to analyze whether the resources allocated to the most vulnerable EU countries (from the CAP and other instruments like the Just Transition Mechanism) are sufficient to offset losses and support the *"socially just transition"* in their agricultural sectors, whatever meaning that the EU gives to the term *"just."*

This issue is fundamentally related to the establishment of equal quantifiable targets for all MS, although the agricultural sector within the EU is far from homogeneous. The importance of agriculture in the economies of the MS varies greatly in terms of total production, productivity per hectare or worker, use of technology, etc. The differences are also evident in climatic conditions and potential yields from one region to another, even among the highest-producing countries such as France, Romania, Italy, Bulgaria, Spain, and Poland. Therefore, there might be a technical basis for setting different targets for different countries or regions, a discussion that has not yet taken place.

In its strategies, the EU has chosen to set the same percentage targets for all MS due to the simplicity and straightforwardness of this approach. However, no other target selection criteria have been explored (at least not publicly available), nor have the reasons behind choosing specific instruments for decision-making been presented. This is in contrast to the impact studies on public policies (such as cost–benefit, cost-effectiveness, and cost-efficiency analyses) that are typically conducted.

In contrast, the new CAP 2023–2027, introduces flexibility by allowing part of the funding to be dependent on criteria set by the member states (MS) in their territories. This addresses a longstanding claim made by academic studies (Pe'er et al. 2019). The main question is whether this flexibility will help achieve common goals across all regions or, on the contrary, if it is better to set goals adapted to the characteristics of each region based on common criteria. In any case, decisions on objectives, instruments, and financing, as well as the forecasts on which they are based, should be supported by a preliminary and rigorous technical–economic analysis based on scientific evidence, with compliance assessed through measurable and transparent indicators. In this regard, it is unreasonable to conduct impact assessment studies after setting the targets and not before, as this may force them to be retired.[6]

Conclusions and policy recommendations

First, before conclusions can be presented, it is necessary to recognize the limitations of the model used. Thereby, an approach based on the use of linear multipliers applied in SAMS has been used, which is a limitation compared to other methods such as Computable General Equilibrium Models, which allow for flexible use of inputs or the inclusion of variations in prices. However, this limitation is compensated by the ease of understanding and replicability of the linear models. In addition, the results obtained from these models can be taken as a first approximation to the effects of the simulated shocks.

Regarding the main conclusions, under the assumptions of agricultural production losses used in this study, the most severe impacts on GDP, HH income, and total output correspond to scenario S.1., with total losses for the EU-27 territory ranging from 0.25 to 0.45%. However, the variation between member states (MS) is significant, and the countries most affected are those with lower EU GDP, poorer economies, and greater vulnerability to agricultural sector interventions. These results show that a rigorous study of the potential impact on the EU-27 economy and MS economies should have accompanied the EU's proposed agricultural measures. It is crucial to consider the potential impact on the most vulnerable countries within the context of cohesion policy, especially when designing common agricultural policy (CAP) income support policies for agricultural producers. The withdrawal of the legislative proposal to reduce the use of chemical pesticides by 50% highlights internal inconsistencies in designing and implementing agricultural policy and should serve as a lesson for the future.

Based on the previous analysis, several suggestions for improvements in future legislative proposals are as follows. Firstly, the objectives set need to be justified, clearly linking them to the instruments chosen to achieve these objectives. Objectives should be based on realistic forecasts, considering the historical evolution of the indicators, the available technical and economic resources, and ensuring a fair distribution of effort among different stakeholders according to their starting points.

Secondly, proposals should include a comprehensive impact assessment for the EU-27 region, as well as on a country-by-country basis. This helps avoid potential equity impacts and allows for adapting measures to specific in vulnerable countries. Setting different targets could ensure a balance in efforts made by countries, considering factors like impacts per hectare or kilogram produced, given the agricultural sector's heterogeneity and the EU regions' climatic characteristics.

Thirdly, regarding impact assessments, the selection of possible alternative policies should be based on criteria of efficiency and effectiveness. There should be regular monitoring of compliance, based on clearly defined indicators and a system for correcting deviations from compliance. Finally, the measures should be accompanied by an estimate of the costs and a detailed explanation of the accompanying policies (such as the Common Agricultural Policy).

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[6] In January 2022, the Commission received the Regulatory Scrutiny Board's opinion on Directive 2009/128/EC as an essential part of achieving the objectives of the F2F strategy. The conclusions indicate the lack of a robust data-driven analysis of the objectives, as well as significant gaps in the impact assessment and compliance monitoring tools (EC, 2021).

The possibilities for future research based on this work are broad. Based on the database and the model used, the analysis can be extended to issues such as impacts on employment, income distribution or even the real impacts on GHG emissions or the environment in general. Also, extensions to CGE models can be considered.

Appendix

Description of the model

Starting with the first approximation (reduction in the final output of activities producing now "constrained" goods), we start from the classical Leontief multiplier model, applied to a SAM. Thus, the starting point for the analysis is the following equilibrium equation:

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{y} \iff \boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{y} = \boldsymbol{M}\boldsymbol{y} \tag{1}$$

where **x** is the vector of total gross output of endogenous accounts (N), with **y** being the vector of values of exogenous variables (usually final demand) for these accounts. **A** is the usual matrix of technical coefficients (its elements $\boldsymbol{a_{ij}}$ show the share of sector ***i*** in each unit produced by sector ***j***). ***M*** is the matrix of linear (accounting) multipliers, and its elements, m_{ij}, capture the effect of a shock to the final demand of account *j* on the output of account *i*.[7] The column sum yields the total output multipliers, which show the increase in output in the economy generated by an exogenous shock in final demand values (e.g., exports) for a given product. This is the classical Input–output model, applied here to a SAM instead of a conventional *I-O* table. However, it should be noted that what is needed here is the effect, on the output of all economic activities, of shocks also on the output of the restricted activities (and not on their final demand), so it is necessary to make a small transformation in the multipliers estimated in Eq. (1). Thus, following Miller & Blair (2009), a new multiplier matrix, *M**, can be obtained with elements $m_{ij}{}^{*}$ resulting from dividing the elements of ***M*** in each column by the element of the diagonal eb in that column:

$$m^{*}_{ij} = m_{ij}/m_{jj} \tag{2}$$

Hence, the elements of ***M****, $m_{ij}{}^{*}$, show the increase (decrease) in the industry *i*'s output caused by the unit increase (decrease) in *j*'s output.

For the second approach (reduction in the availability of some final goods/inputs, which will become "restricted"), the I-O model (here SAM type model) should be supply-driven. Applied to a SAM, the well-known supply-driven Ghosh model[8] (Ghosh 1958) is described by the expression

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[7] When using SAMs based on Supply-Use Tables (SUT), care must be taken with the sub-matrix of M that is considered to analyze effects and impacts. However, in order to facilitate the interpretation of the results, the BioSAMs in this work have been transformed from their original SUT format to a symmetric activity-by-activity transaction matrix format (as discussed above), thus overcoming this problem.

[8] Some authors (as, for example Oosterhaven 1988, 1989), claim for the 'implausibility' of Ghosh model because it allocates output responding to shocks in value added in selected sectors while no further changes in this value-added, Guerra and Sancho (2011) and Manresa and Sancho (2020), show how the endogenization of value added (or at least part of it: following Leontief (1986), no static economic model can be completely closed, so it is necessary that some exogenous accounts act as driving force.), makes this model plausible.

Table 1 Description of the previous studies on the economic impact of F2F strategy

	Beckman et al. (2020)	**Barreiro et al. (2021)**	**Noleppa and Cartsburg (2021)**	**Bremmer et al. (2021)**	**Henning et al. (2021)**
Funded by	United States Department of Agriculture	Joint Research Center of the European Commission	Euroseeds (elaborated by HFFA Research consulting)	CropLife Europe, European Association of Crop Protection (elaborated by the University of Wageningen)	Grain Club (German Agricultural Associations representing green, oilseed, and feed industries)
Methodology	Computable General Equilibrium Model- GTAP-AEZ model (Global Trade Analysis Project-Agro Ecological Zone)	Partial Equilibrium-CAPRI model (Common Agricultural Policy Regionalized Impact)	Multiregional model combined with the Total Factor Productivity (TFP) by crops	Partial equilibrium model AGMEMOD (Agricultural Member State Modeling) -Combine specific farm-level studies in 7 countries for 10 specific crops	Partial Equilibrium CAPRI model
Variables analyzed	-Farm income, food expenditure, GDP	Production, production revenues and costs, prices, net trade Nitrogen surplus, Greenhouse gas emissions	Production, production value, food expenditure Greenhouse gas emissions	Farm costs, farm return, production, prices, imports, exports	Production, consumption, and trade Greenhouse gas emissions, biodiversity indicator

Table 2 Standard structure of a SAM

	Commodities	**Activities**	**Factors**	**Households**	**Enterprise corporations**	**Government**	**Savings-Investments**	**Rest of the world**	**Total**
Commodities (C)		Intermediate (input) consumption		Household consumption		Government expenditure	Investment and stock charges	Exports	Demand
Activities(A)	Domestic production								Gross output / Production (activity income)
Factors (F)		Remuneration of factors/ factor income						Factor income from RoW	Factor income
Households (H)			Factor income distribution to households	(Inter-household transfers)	Distribution of corporations income to households	Government transfers to households		Transfer to households from RoW	Household income
Enterprise / Corporations (E)			Factor income distribution to enterprises			Government transfers to enterprise		Transfer to enterprises from RoW	Enterprise income
Government (G)	Net taxes on products	Net taxes on production	Factor income to Government / Factor taxes	Direct Household taxes/ transfers to Government	Direct enterprise taxes and transfers to Government			Transfer to Government from RoW	Government income
Savings-Investments (S-I)			(Depreciation)	Household savings	Enterprise savings	Government savings	(Capital accounts transfers)	Capital transfer from RoW (Balance of Payment)s	Savings
Rest of the World (RoW)	Imports		Factor income distribution to RoW	Household transfer to RoW	Corporation income to RoW	Government transfers to RoW			Payments to RoW
Total	Supply	Cost of production activities	Expenditure on factors	Household expenditure	Enterprise expenditure	Government expenditure	Investment	Income from RoW	

Table 3 Commodities accounts related to simulation of effects of green deal

Paddy rice	Live plants
Wheat	Fodder crops
Barley	Tobacco
Maize	Other crops
Other cereals	Bovine cattle
Tomatoes	Sheep, goats, horses, asses, mules and hinnies
Other vegetables	Swine
Grapes	Poultry
Fruits and nuts	Other animals and their products
Rapeseed	Raw milk
Sunflower seed	Chemical products for crops
Soya seed	Chemical products for livestock
Olive	Chemical, rubber, plastic products (other uses)
Other seeds for the oil industry	Fertilizers
Sugar beet	Capital for agriculture (crops)
Fiber-plants	Capital (other sectors)
Potatoes	

Table 4 Estimated GDP losses (%) for each simulation and MS

	S.1.1	S.1.2	S.2	S.3	S.4	Total (with S.1.1)	Total (with S.1.2)
Austria	0,1031	0,1855	0,0036	0,0020	0,0008	0,1094	0,1919
Belgium	0,1036	0,1866	0,0066	0,0019	0,0027	0,1148	0,1977
Bulgaria	0,6627	1,1928	0,0185	0,0043	0,0122	0,6978	1,2279
Croatia	0,3954	0,7117	0,0080	0,0088	0,0092	0,4214	0,7377
Cyprus	0,1874	0,3373	0,0058	0,0000	0,0007	0,1938	0,3438
Czechia	0,2904	0,5227	0,0092	0,0050	0,0019	0,3066	0,5389
Denmark	0,0482	0,0867	0,0022	0,0009	0,0031	0,0543	0,0929
Estonia	0,2325	0,4185	0,0064	0,0019	0,0015	0,2424	0,4284
Finland	0,1304	0,2347	0,0048	0,0000	0,0014	0,1366	0,2409
France	0,2505	0,4509	0,0155	0,0043	0,0024	0,2727	0,4731
Germany	0,0973	0,1752	0,0058	0,0012	0,0030	0,1074	0,1853
Greece	0,7348	1,3226	0,0174	0,0183	0,0029	0,7733	1,3611
Hungary	0,4842	0,8716	0,0301	0,0076	0,0107	0,5325	0,9199
Ireland	0,0457	0,0822	0,0057	0,0012	0,0029	0,0555	0,0920
Italy	0,2864	0,5156	0,0036	0,0054	0,0028	0,2982	0,5274
Latvia	0,3346	0,6023	0,0128	0,0000	0,0060	0,3533	0,6210
Lithuania	0,4478	0,8061	0,0277	0,0029	0,0159	0,4943	0,8526
Luxembourg	0,0232	0,0418	0,0019	0,0005	0,0005	0,0261	0,0447
Malta	0,0798	0,1436	0,0023	0,0007	0,0002	0,0830	0,1468
Netherlands	0,2503	0,4506	0,0132	0,0018	0,0052	0,2705	0,4707
Poland	0,3122	0,5620	0,0311	0,0074	0,0051	0,3557	0,6055
Portugal	0,2780	0,5004	0,0069	0,0016	0,0014	0,2879	0,5103
Romania	0,7562	1,3612	0,0571	0,0147	0,0085	0,8365	1,4415
Slovakia	0,2874	0,5173	0,0125	0,0038	0,0058	0,3094	0,5394
Slovenia	0,2146	0,3864	0,0048	0,0062	0,0026	0,2282	0,4000
Spain	0,3723	0,6701	0,0082	0,0000	0,0028	0,3833	0,6811
Sweden	0,0827	0,1489	0,0026	0,0002	0,0015	0,0870	0,1532
EU27_2020	0,2513	0,4524	0,0098	0,0031	0,0033	0,2675	0,4685

Table 5 Estimated households income losses (%) for each simulation and MS

	S.1.1	**S.1.2**	**S.2**	**S.3**	**S.4**	**Total (with S.1.1)**	**Total (with S.1.2)**
Austria	0,0829	0,1491	0,0028	0,0031	0,0005	0,0893	0,1556
Belgium	0,0740	0,1333	0,0048	0,0028	0,0019	0,0835	0,1427
Bulgaria	0,5882	1,0587	0,0151	0,0077	0,0087	0,6196	1,0902
Croatia	0,3086	0,5554	0,0068	0,0139	0,0068	0,3360	0,5829
Cyprus	0,1394	0,2509	0,0043	0,0000	0,0004	0,1441	0,2556
Czechia	0,2603	0,4685	0,0083	0,0085	0,0014	0,2786	0,4868
Denmark	0,1424	0,2564	0,0062	0,0013	0,0021	0,1521	0,2660
Estonia	0,2219	0,3995	0,0060	0,0032	0,0011	0,2323	0,4098
Finland	0,1338	0,2409	0,0049	0,0000	0,0009	0,1396	0,2467
France	0,1963	0,3533	0,0120	0,0061	0,0017	0,2161	0,3731
Germany	0,0805	0,1450	0,0049	0,0017	0,0022	0,0894	0,1538
Greece	0,5906	1,0631	0,0142	0,0295	0,0021	0,6364	1,1089
Hungary	0,4140	0,7452	0,0251	0,0136	0,0073	0,4600	0,7912
Ireland	0,0754	0,1357	0,0082	0,0029	0,0018	0,0883	0,1486
Italy	0,2167	0,3900	0,0027	0,0077	0,0020	0,2291	0,4024
Latvia	0,3176	0,5716	0,0120	0,0000	0,0043	0,3339	0,5880
Lithuania	0,4082	0,7348	0,0250	0,0046	0,0113	0,4491	0,7757
Luxembourg	0,0208	0,0375	0,0018	0,0012	0,0004	0,0241	0,0408
Malta	0,0998	0,1796	0,0033	0,0011	0,0001	0,1043	0,1842
Netherlands	0,1686	0,3035	0,0092	0,0028	0,0035	0,1842	0,3191
Poland	0,2832	0,5098	0,0284	0,0120	0,0038	0,3274	0,5540
Portugal	0,2153	0,3876	0,0054	0,0023	0,0009	0,2240	0,3963
Romania	0,6118	1,1012	0,0450	0,0276	0,0062	0,6907	1,1801
Slovakia	0,2440	0,4392	0,0106	0,0059	0,0044	0,2648	0,4600
Slovenia	0,1641	0,2953	0,0036	0,0096	0,0020	0,1793	0,3105
Spain	0,2739	0,4931	0,0060	0,0000	0,0020	0,2820	0,5012
Sweden	0,0732	0,1317	0,0024	0,0003	0,0010	0,0769	0,1354
EU27_2020	0,2063	0,3714	0,0078	0,0046	0,0024	0,2211	0,3862

$$\mathbf{x}' = \mathbf{x}'\mathbf{B} + \mathbf{v}' \rightarrow \mathbf{x}' = \mathbf{v}'(\mathbf{I} - \mathbf{B})^{-1} = \mathbf{v}'\mathbf{G} \tag{3}$$

where $\mathbf{x}$ is the vector of outputs of endogenous accounts, $\mathbf{v}$ is the value of expenses of endogenous on exogenous accounts (as "inputs")[9] and $\boldsymbol{B}$ is the distribution coefficients matrix, whose elements are the elements of the SAM divided by the total of their corresponding row. The supply-driven multipliers matrix is derived as $\mathbf{G} = (\boldsymbol{I} – \boldsymbol{B})^{-1}$. The elements of $\boldsymbol{G}$, g_{ij}, indicate the impact on the output of account j of an exogenous shock (through the accounts considered as such, usually including some value-added) on account i.

Given the objective of this model and the use of the supply model described above, in this case (as opposed to the previous model) the transformation of the SAM to a symmetric transaction matrix is not implemented here, keeping the Supply-Use structure, as it is more informative in this context. For this reason, we only need to focus on the

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[9] This implies that in the Ghosh model, vector $\mathbf{v}$ is the sum of payments to exogenous. In this application, it has been considered as exogenous Government, Saving-Investment, Rest of the World and, to be able to analyze the shocks included in scenario S.3 (decrease in land availability), the part of Value Added corresponding to land use (extrapolated as part of agricultural capital).

Table 6 Estimated output losses (%) for each simulation and MS

	S.1.1	S.1.2	S.2	S.3	S.4	Total (with S.1.1)	Total (with S.1.2)
Austria	0,0829	0,1491	0,0028	0,0031	0,0005	0,0893	0,1556
Belgium	0,0740	0,1333	0,0048	0,0028	0,0019	0,0835	0,1427
Bulgaria	0,5882	1,0587	0,0151	0,0077	0,0087	0,6196	1,0902
Croatia	0,3086	0,5554	0,0068	0,0139	0,0068	0,3360	0,5829
Cyprus	0,1394	0,2509	0,0043	0,0000	0,0004	0,1441	0,2556
Czechia	0,2603	0,4685	0,0083	0,0085	0,0014	0,2786	0,4868
Denmark	0,1424	0,2564	0,0062	0,0013	0,0021	0,1521	0,2660
Estonia	0,2219	0,3995	0,0060	0,0032	0,0011	0,2323	0,4098
Finland	0,1338	0,2409	0,0049	0,0000	0,0009	0,1396	0,2467
France	0,1963	0,3533	0,0120	0,0061	0,0017	0,2161	0,3731
Germany	0,0805	0,1450	0,0049	0,0017	0,0022	0,0894	0,1538
Greece	0,5906	1,0631	0,0142	0,0295	0,0021	0,6364	1,1089
Hungary	0,4140	0,7452	0,0251	0,0136	0,0073	0,4600	0,7912
Ireland	0,0754	0,1357	0,0082	0,0029	0,0018	0,0883	0,1486
Italy	0,2167	0,3900	0,0027	0,0077	0,0020	0,2291	0,4024
Latvia	0,3176	0,5716	0,0120	0,0000	0,0043	0,3339	0,5880
Lithuania	0,4082	0,7348	0,0250	0,0046	0,0113	0,4491	0,7757
Luxembourg	0,0208	0,0375	0,0018	0,0012	0,0004	0,0241	0,0408
Malta	0,0998	0,1796	0,0033	0,0011	0,0001	0,1043	0,1842
Netherlands	0,1686	0,3035	0,0092	0,0028	0,0035	0,1842	0,3191
Poland	0,2832	0,5098	0,0284	0,0120	0,0038	0,3274	0,5540
Portugal	0,2153	0,3876	0,0054	0,0023	0,0009	0,2240	0,3963
Romania	0,6118	1,1012	0,0450	0,0276	0,0062	0,6907	1,1801
Slovakia	0,2440	0,4392	0,0106	0,0059	0,0044	0,2648	0,4600
Slovenia	0,1641	0,2953	0,0036	0,0096	0,0020	0,1793	0,3105
Spain	0,2739	0,4931	0,0060	0,0000	0,0020	0,2820	0,5012
Sweden	0,0732	0,1317	0,0024	0,0003	0,0010	0,0769	0,1354
EU27_2020	0,2063	0,3714	0,0078	0,0046	0,0024	0,2211	0,3862

submatrix of ***G*** formed by commodities accounts as rows and activities accounts as columns, ***G(c, a)***. An element $g_{\mathrm{c,a}}$ of ***G(c,a)*** shows the impact of a unitary increase (decrease) of the supply of commodity c on the output of activity a.

Abbreviations

CAP	Common agricultural policy
CAPRI	Common agricultural policy regional impact analysis
EC	European commission
EU	European uniom
F2F	Farm-to-fork
GDP	Gross domestic product
HH	Households
MS	Member state
SAM	Social accounting matrix
SUIOTs	Supply and use and input–output tables
USDA	United States department of agriculture

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

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