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From agriculture to agroindustry: the European Union Farm to Fork policy

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Abstract

The European Union's ambitious "Farm to Fork" strategy, a cornerstone of the Green Deal, aims to transform the European agricultural sector into a more sustainable model. However, the effectiveness of this strategy in addressing the pressing sustainability challenges of the Ag-Food industry remains under scrutiny. This contribution seeks to critically analyse the Farm to Fork strategy and identify areas where further improvement is needed. A systematic literature review of recent scientific contributions on European policies aimed at Ag-Food industries from a cross-disciplinary, holistic, and systemic perspective, was conducted. The study identified best practices and gaps across various areas of the Ag-Food industry, providing insights into the systemic implications of the Farm to Fork strategy. Key findings from the analysis revealed that while the Farm to Fork strategy sets a positive direction for sustainable agriculture, it faces limitations in addressing critical aspects. The assessments point towards a quantitative reduction in production throughout the European Union, increased dependence on imports and a reduction in exports, as well as a reduction in consumer purchasing power. The legislator appear to perceive the strategy as having a net positive impact overall. Yet, the literature seems to show the opposite, highlighting that this may not hold true without significant technological progress such as the adoption of best practices and measures to assist those negatively impacted by the transition.

Keywords Best practice · Sustainability · Agriculture · Ag-food industry · Farm to fork · Green deal · European policies

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1 Introduction

In the context of anthropogenic climate change and demographic dynamics, immutable forces set to shape future horizons, the European productivist agricultural model of the Common Agricultural Policy conceived in the aftermath of the Second World War by the countries of the former European Economic Community (EEC), the now European Union (EU), is undoubtedly obsolete. The European agricultural sector is solely responsible for an annual loss of 700 million tonnes of Ag-Food (Erdiaw-Kwasie et al., 2024), amidst a projected 70% increase in global agricultural production by 2050 to satiate demand (Aznar-Sánchez et al., 2020; Velasco-Muñoz et al., 2021). Worldwide, it represents a third of global GHG emissions coming from food systems (Crippa et al., 2021). The food and beverage sector stands as the most prominent industrial manufacturing sector across the European Union, with an annual turnover exceeding €1.109 billion and employing approximately 4.57 million individuals (European Commission, 2016). The question of the sustainability of our production model reverberates with amplified urgency. To achieve this, all areas of society will be involved, so that together, they can reach the set objective. As global economic systems evolve, the intersection of industrial policies and environmental sustainability becomes increasingly important. For instance, recent studies emphasize the critical need for policies that integrate environmental considerations with industrial growth to address the ongoing climate challenges effectively (Mariotti, 2023). The transition to sustainable business models within the European agricultural sector aligns with broader industrial economic strategies that seek to balance environmental imperatives with economic growth. The significance of comprehensive policy frameworks that promote sustainable development across several sectors is highlighted by this approach (Antoci et al., 2022). To meet these challenges, the EU has opted for the "European Green Deal" (EGD), endorsed by the European Commission (EC) in 2019 and voted by European Parliament (EP) in 2020 (EP, 2020). The main target of this array of policies is to make Europe the first carbon-neutral continent by 2050. The focus on the present study will be on measures concerning the Ag-Food industry, through the "Farm to Fork" strategy (F2F).

The F2F stands at the core of the EGD, it is presented as an opportunity to improve lifestyles, health, and the environment and to reconcile our food system with the needs of the planet. Its primary goal is to allow the reduction of GHG emissions by 55% compared with 1990 levels and is the food system component of the EGD. The F2F aims to create a healthier food environment that would benefit consumers health and reduce health-related costs. And a sustainable system, by reducing our dependency on pesticides and antimicrobials, reduce excess fertilization, increase organic farming, improve animal welfare and reverse loss of biodiversity. The main points of the strategy are ensuring sustainable food production and food security, stimulating sustainable food processing, wholesale, retail, hospitality and food services practices, promoting sustainable food consumption and facilitating the shift to healthy sustainable diets, reducing food loss and waste, and combating food fraud along the food supply chain (EC, 2020).

These are the EC objectives, but a number of quantitative and qualitative studies seem to raise concerns about the feasibility and benefits of this agenda, converging on the conclusion that the negative effects outweigh the positive ones. To assess the implications of the F2F strategy, a systematic literature review was conducted to identify best practices and gaps in areas of the Ag-Food industry that can be the catalyst for change toward a system based on sustainable business models and the systemic implications. This following analysis was conducted to review the literature and to investigate the most recent scientific contributions covering European policies aimed at Ag-Food industries, emphasizing studies that have critically and analytically assessed these policies employing a cross-disciplinary, holistic, and systemic perspective, to provide a reference point on prospective analysis of these policies for further improvement.

The study's key findings reveal that while the Farm to Fork strategy sets an ambitious direction for sustainable agriculture in the EU, it faces significant challenges and potential unintended consequences. Quantitative assessments indicate a substantial reduction in agricultural production across the European Union, increased reliance on imports, and decreased exports, all of which could have far-reaching economic implications. The strategy's environmental goals, while laudable, may not be achievable without significant technological advancements and supportive measures. The analysis suggests that the negative impacts of the strategy may outweigh its intended benefits, particularly in terms of reduced consumer purchasing power and potential food security issues. These findings highlight the need for a more nuanced approach to implementing the Farm to Fork strategy, one that balances environmental objectives with economic realities and technological capabilities.

The article is structured in the following way: after the Introduction, a focus on the EU Policies and Strategies has been conducted, therefore, the methodology applied is presented in the Methodology section, followed by the Results. Then, Discussion section comments on the results obtained and, finally, the Conclusions.

2 EU policies and strategies

After introducing the topic, it is important to outline EU policies and strategies to contextualise the research framework. The EGD stands as the overarching framework under which the F2F strategy and other EU sustainability initiatives operate.

The EGD consists essentially of a cross-sectoral approach that aims to alleviate the consequences of climate change and becoming the first carbon neutral continent by 2050, setting the EU on the path of a green transition, while maintaining economic prosperity and competitivity. The EGD represents a novel growth strategy designed to reshape the EU into an equitable and thriving society, characterized by a modern, resource-optimized, and competitive economy. The objective is to achieve net-zero greenhouse gas (GHG) emissions by 2050, while simultaneously decoupling economic growth from resource consumption. The Green Deal constitutes a fundamental component of the Commission's approach to realizing the United Nations 2030

Agenda and advancing the Sustainable Development Goals. The main initiatives covered by the Green Deal and of particular interest to the Ag-Food sector are the "Fit for 55" package, that aims to translate the climate ambitions of the Green Deal, especially reducing GHG emissions by at least 55% by 2030 compared to 1990, into law.

The EU Biodiversity strategy (BDS) aims to both protect and recover Europe's biodiversity by 2030. Its objective is to make Europe more resilient to possible future threats including climate change, forest fires, food insecurity and disease outbreaks (e.g. zoonosis) by protecting environment and fighting illegal wildlife trade. The EC's ambition is to make this strategy operational by taking a series of measures, including extending the size and number of protected areas of high ecological and climatical value both on land and at sea. Launching a large restoration plan of degraded ecosystems by reducing the use and harmfulness of pesticides.

F2F is a strategy endorsed by the EU to address the upcoming challenges in regard of both food security and the sustainability of the food value chain, from production to consumption. The strategy's main goals are ensuring sufficient, affordable, and nutritious food within planetary limits, support sustainable food production, and promote more sustainable food consumption and healthy diets. The impetus for this reform came from the following observations, a third of the world GHG emissions comes from food systems (Crippa et al., 2021), and the alarming fact that over 50% of European adults are overweight (Marques et al., 2017). There comes the necessity of remodelling our food system in order to make it sustainable, resilient and by ensuring healthy and affordable food for citizens. To achieve this, EU plans to halve the use of pesticides and fertilizers, loss in nutrient, and sales of antimicrobials, increase the amount of land devoted to organic farming, reduce food loss and waste, combat food fraud in the supply chain and improve animal welfare. The organic action plan, presented by the EC in March 2021 (EC, 2021) as part as the F2F strategy, outlines a set of actions to increase the organic farming in EU. Its goal is to allow one quarter of the total arable lands to organic farming by 2030, considering that organic farming is important to ensure sustainability of European agriculture and that it helps secure incomes and create jobs. Lastly, the EU intends to remove 10% of farmland from production: according to the EU BDS "*to provide space for wild animals, plants, pollinators and natural pest regulators, 10% of agricultural area should be brought back under high-diversity landscape features, including, inter alia, buffer strips, rotational or non-rotational fallow land, hedges, non-productive trees, terrace walls, and ponds*" (EP, 2020). By 2030, the European Commission aims to increase the land dedicated to organic farming to 25%, reduce fertilizer use by 20%, cut pesticide use by 50%, lower antimicrobial use by 50%, decrease nutrient losses (N&P) by 50%, and reduce farmland by 10%, according to F2F Targets.

In this context, to fully understand and study the matter, a structured approach to conduct the literature review has been adopted as follows.

3 Methodology

In conducting a literature review, various methodologies may be applied based on the review's intended purpose. These approaches can be qualitative, quantitative, or a combination of both. Three primary types of methods commonly used include systematic reviews, semi-systematic reviews, and integrative reviews. The literature review process typically encompasses four phases: conceptualizing the review, executing it, analysing findings, and documenting the outcomes (Snyder, 2019). Alongside this, the literature review should involve assembling, organizing, and evaluating existing works within a specific domain to shape the research agenda and suggest future directions. There are alternative approaches to constructing a literature review, such as domain-based, theory-driven, methodological, meta-analytical, and meta-systematic reviews. For this research, a mixed-methods approach is employed, following the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol (Paul et al., 2021), adapted to suit the objectives of this article.

The literature presents several examples of adoption of the same methodology in scientific papers related to the topic of sustainability (Alizadeh et al., 2024; Bhattacharyya, 2022; De Ponte et al., 2023; Tuyon et al., 2022).

The method applied study relies on the SPAR-4-SLR three step process: Assembling, Arranging, Assessing (Table 1).

Table 1 SPAR-4-SLR protocol applied to the present research. Own elaboration

Assembling	Identification Domain: Farm to Fork strategy Research Questions: stated below Source quality: Scopus Acquisition Search mechanism and material acquisition: Scopus Search period: 2020–2023 Search keywords: Boolean and wildcard search using a combination of words in Title, Keywords, and Abstracts Number of articles obtained: 658
Arranging	Organization Organizing codes: Language, Document Type, Source Type, Subject Area Purification Language: English Document Type: Research articles Source Type: Journals Subject areas included and excluded: refer to Table 2 Number of articles obtained: 460
Assessing	Evaluation Analysis method: Content analysis of representative results Agenda proposal method: Transdisciplinary or holistic approach and gaps identification Reporting Reporting convention: Figures, tables, words Limitation: Related to data type and subject areas considered

In the initial phase, two distinct sub-phases emerge: the Identification sub-phase and the Acquisition sub-phase. During the Identification sub-phase, the documents slated for review are pinpointed. Concurrently, the Acquisition sub-phase involves initiating the search for these identified documents across chosen databases. Within the context of the Identification sub-phase, the Reference Domain encompasses F2F in the Ag-Food industry. This domain encompasses various facets such as products, processes, technologies, methodologies, and organizations associated with it. These elements have been extensively examined in scholarly literature, addressing the Research Questions that steer the investigation as follow:.

- RQ1—Understanding the F2F strategy and its objectives.
- RQ2—How many papers in the scientific literature have tackled the F2F strategy from a critical or analytical point of view?
- RQ3—To what extent does the F2F strategy serve or not the interests of the Ag-Food industry and consumers?
- RQ4—What are the best practices that could improve the strategy?

In selecting the sources for this study, the focus was narrowed down to Articles and Reviews, as they typically offer more targeted insights into best practices pertaining to the subject matter. Conversely, books, which often provide a broader and more explanatory view of the topic, were excluded from consideration. For assessing the quality of the sources, the Scopus database was chosen due to its extensive coverage and meticulous indexing capabilities, aligning with the recommendations from (Paul et al., 2021). During the Acquisition sub-phase, Scopus served as both the search platform and the source for obtaining materials, given its comprehensive suite of integrated tools. Initially, several prominent online libraries were considered for the search. However, the advanced search functionalities available on Scopus made it the preferred choice. Google Scholar was also considered in order to conduct this study but given the wide number of results (20,300) the choice has been made in favour of Scopus due to its higher level of reliability on scientific and peer reviewed contents.

The time range of the review was established from 2020—since the approval of the European Green Deal by the Parliament, and the expression "Farm to Fork" was consecrated as the name of a European policy—to 2023 considering that this review was carried out at the beginning of 2024, it will therefore cover all last year's work.

Search keywords were looked for in the Title, Abstract and author Keywords to cover the topic of F2F related to Ag-Food industry with emphasis on sustainability using Boolean operators and wildcards in search of the terms:

- In Title: "Farm to Fork" OR {F2F}.
- In Abstract: "sustainab*" OR "agr*" OR "food" OR {F2F} AND "Farm to Fork".
- In Keywords: "sustainab*" OR "agr*" OR "food" OR {F2F} AND "Farm to Fork".

These different keywords and wildcards were chosen with the dual aim of covering both the subject of the F2F specifically, but also of opening the field of research to also bring together the results of researchers who have worked on sustainability and

Ag-Food industry more deeply. At the end of the Assembling phase, the number of results was 658.

In the Arranging phase, also subdivided in two sub-phases namely Organization and Purification. They consist in selecting filters to apply to our research to narrow the range of results. Using the Scopus database, we proceeded by Language (i.e. English), Document type (i.e. Research article and Review), Source type (i.e. Journal) and Subject areas presented in (Table 2), this decision was made to get findings closer to the research questions, by leaving out areas that are not directly related, selecting the main topics linked to the results of the first phase. Following the process of Purification, 460 results were acquired.

In the final phase of Assessing, itself composed by two sub-phases: Evaluation and Reporting, we have manually investigated the content of several representatives' results, focusing on studies that highlighted the sustainability of European policies regarding the Ag-Food industry, from an analytical or critical point of view, and with a prospective outlook.

Results prior to 2020 were not considered, giving that the Green Deal was only approved by the Parliament during this year. A linguistic filter was also applied, with English-only results, as the language recognized for scientific exchange. Conclusively, as a framework-based review, we based our assessing on a thematic approach—clustering of concepts and relationships (Kahiya, 2018)—and on content (i.e. number of articles in the journal, organization, number of citations, most popular theories, contexts, methods) (Paul et al., 2021).

Themes and categories were derived manually by analysing the titles, abstracts, and full texts of the selected articles. Recurring concepts relevant to the research questions were identified through a systematic coding process. These codes were refined in multiple iterations to ensure consistency and alignment with the study objectives. The derived themes were grouped into broader categories reflecting key patterns and trends in scientific literature. The manual coding approach allowed for a focused analysis tailored to the research questions. To ensure reliability, the coding

Table 2 Subject areas included and excluded after the acquisition phase

Subject areas included	Subject areas excluded
Agricultural and Biological Sciences	Art and Humanities
Biochemistry, Genetics and Molecular Biology	Computer Science
Business, Management and Accounting	Decision Sciences
Chemical Engineering	Earth and Planetary Sciences
Chemistry	Health Professions
Economics, Econometrics and Finance	Materials Science
Energy	Mathematics
Engineering	Medicine
Environmental Science	Nursing
Immunology and Microbiology	Pharmacology, Toxicology, and Pharmaceutics
Multidisciplinary	Physics and Astronomy
Social Sciences	Psychology
	Veterinary

process was reviewed within the research team, resolving ambiguities and verifying the accuracy of theme identification.

The themes, such as sustainability challenges and best practices, were finalized through a collaborative process involving multiple steps to ensure their validity and relevance. After the initial coding phase, where recurring concepts were identified, the research team reviewed the preliminary themes in the context of the research questions and study objectives. During this phase, each theme was evaluated to ensure it adequately represented the data and was not overlapping with or redundant to other themes.

The process involved iterative discussions within the research team to resolve any discrepancies in interpretation and to refine the definitions and scope of each theme. Key criteria for finalizing themes included their frequency in the reviewed literature, their relevance to the study's focus areas, and their ability to contribute to identifying gaps in existing research.

4 Results

The application of the approaches proposed in Methodology provided both the result of the systematic literature review and an overview of the scientific output related to the F2F strategy, since its adoption in 2020, highlighting trends in publication volume, key contributing countries, and leading research organizations.

Figure 1 displays the number of studies produced on our subject since it became public news in 2020 following its adoption by the European Parliament. One year later, we witness a 44% growth in the number of publications, followed by an identical increase in 2022 to reach the maximum number of annual documents produced on F2F to this day (i.e. 151). In 2023, we can observe a slight decline in the interest in the subject by the scientific community (i.e. a 13% decrease in the number of publications) but remaining significant (131 publications this year). This pattern suggests an initial surge of academic attention as researchers sought to understand and analyse the implications of the new policy, followed by a potential shift towards more focused and in-depth studies as the initial wave of descriptive research diminished.

Interestingly, it appears that Italy is the main country regarding contributions to this precise topic, this can be attributed to the fact that the country has been investing heavily in the sector in recent years, with the aim of developing it further, and for its role as a top player in agriculture in the EU. The same logic applies for Germany, which is the third contributor in the research. The same goes for other European countries such as Spain, Netherlands, France, Poland. Those countries whose economies are heavily reliant on agriculture, logically have a proportionally higher level of research in this field. Also worthy of note are the contributions of the United States and India, which are particularly active in the field of research in general and are significantly involved in all stages of the Ag-Food industry (Fig. 2). This concentration of research in EU countries, particularly those with significant agricultural sectors, indicates a regional bias in the literature. While this focus is logical given the EU-centric nature of the F2F strategy, it also suggests a potential gap in understanding the

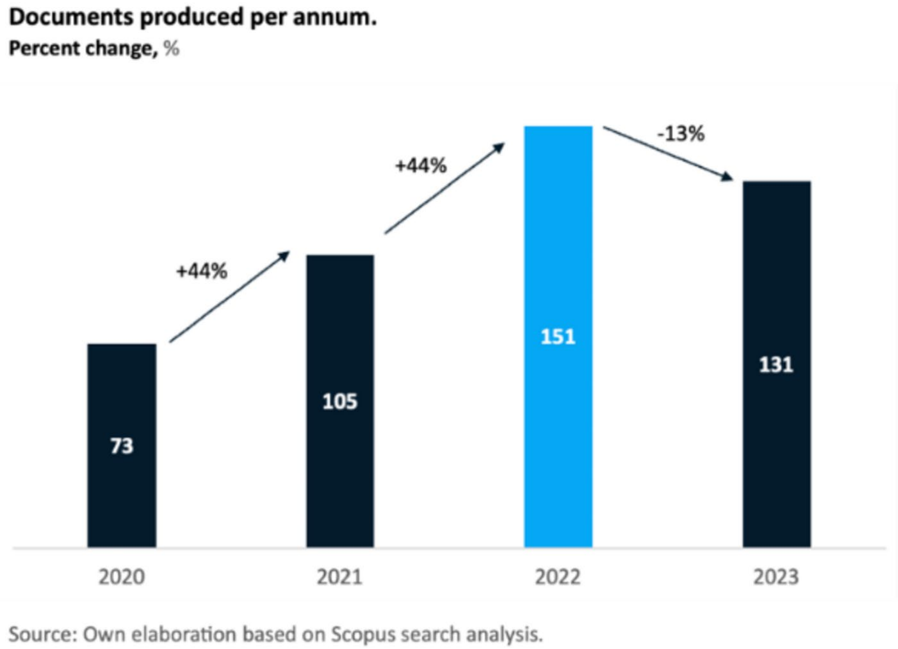

Fig. 1 Documents per year. Own elaboration based on Scopus results

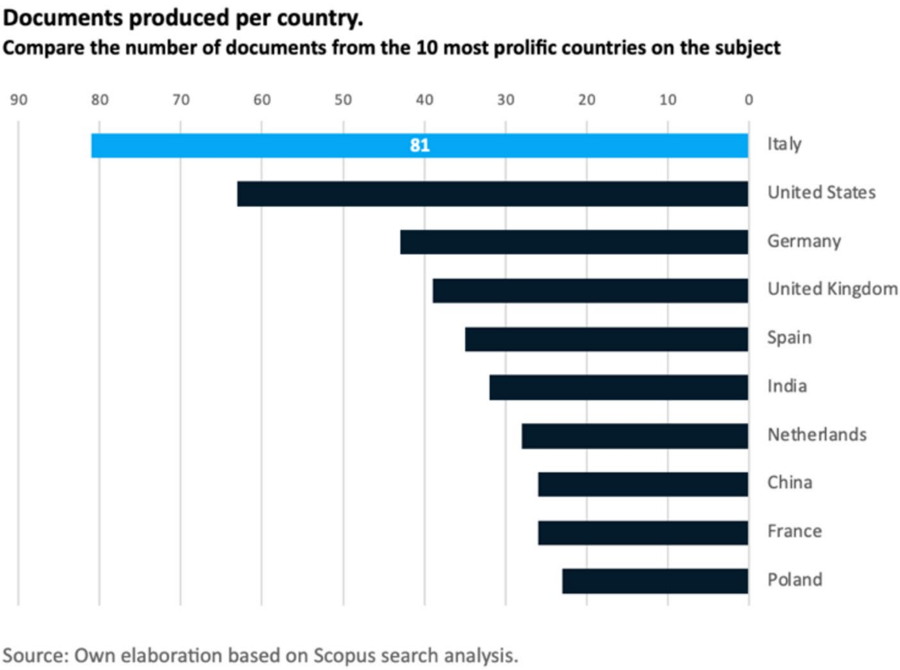

Fig. 2 Documents per country. Own elaboration based on Scopus results

global implications of the policy, particularly its effects on non-EU trading partners and developing nations.

It seems important to note that the most prolific providers in term of organizations are, quite logically the European Commission itself with 6 studies produced in intern, to which should be added 18 studies produced by the European Joint Research Centre which depends on the EU Commission. This institutional landscape reflects a close alignment between policy-makers and researchers, which could facilitate evidence-based policy refinement.

Moreover, 17 studies were written by the United States Department of Agriculture. And then 16 papers by Wageningen University which is well known as a major contributor to agricultural and agronomic research in general. Various other Universities and Research centres such as University of KwaZulu-Natal, the College of Health Sciences and the University College of Dublin are involved in the field. Finally, the French organisms are reasonably involved too, with the INRAE and CNRS, both being public organisms depending on the government, the first being specialized in agronomy and environment and the latter in all type of research (Fig. 3).

For keywords analysis, "sustainability" related keywords have the larger number of studies, similar to the number of results around "gaps" related keywords while "best practices" is almost three times less represented and "impact assessment" 20 times less represented. The prevalence of sustainability-related keywords, alongside a high frequency of "gaps" related terms, suggests that while sustainability is a central focus, researchers are identifying numerous areas where the F2F strategy may

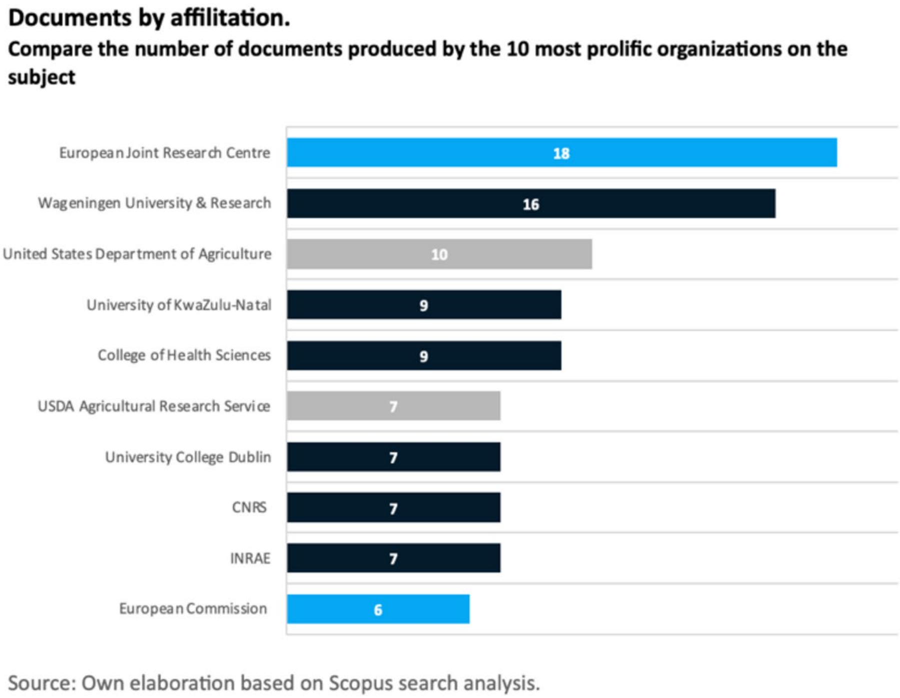

Fig. 3 Documents by affiliation. Own elaboration based on Scopus results

fall short or require further development. This pattern aligns with our research questions about the potential challenges and unintended consequences of the strategy. The relatively lower representation of "best practices" and "impact assessment" in the keyword analysis indicates potential gaps in the literature. These areas warrant further examination in the Discussion section, as they are crucial for understanding how to effectively implement the F2F strategy and evaluate its outcomes. Drawing connections between these results, we can observe that the initial surge in publications coincides with a focus on broad sustainability issues and identifying gaps. As the research field matures, there may be a need for more targeted studies on best practices and rigorous impact assessments to address the identified gaps and challenges.

As outlined in the methodology, the authors selected representative findings for each aspect of the topic by reviewing titles and abstracts. This approach was employed to facilitate a more in-depth discussion, presenting noteworthy practices and indicators aimed at guiding the industry in adopting Sustainable Business Models (SBMs). The literature reveals conflicting perspectives, with EU legislators perceiving the strategy as having a net positive impact, while many studies suggest the opposite. This divergence sets up a critical point of debate regarding the strategy's effectiveness that will be explored in the following Discussion part. The analysis also highlights a significant gap in the current research: the lack of comprehensive studies on technological advancements and supportive measures that could alleviate the negative impacts of the F2F strategy. Additionally, there appears to be a need for more research on the long-term implications of the strategy on food security, biodiversity, and the economic viability of the EU's agricultural sector. These findings directly address our research questions by providing an overview of the current state of F2F research, identifying key areas of concern, and highlighting potential biases and limitations in the existing literature. The results set the stage for a critical discussion of the strategy's potential impacts and the need for a more comprehensive, global perspective in future research.

5 Discussion

Building on the results emerged, some considerations arise. The European agricultural sector stands at a crossroads, where ambitious restructuring efforts must balance sustainability goals with the economic realities of food security, profitability, and global trade dynamics. However, our analysis reveals significant challenges and potential unintended consequences that warrant careful consideration. The quantitative studies examined point to a substantial reduction in agricultural production across the European Union, increased reliance on imports, and decreased exports, all of which could have far-reaching economic implications. While the strategy sets ambitious environmental goals, the literature suggests that without significant technological advancements and supportive measures, the negative impacts may outweigh the intended benefits. This section will critically examine these findings and explore potential pathways to enhance the strategy's effectiveness in achieving its sustainability objectives while mitigating adverse economic effects.

There is the need for a paradigm shift, abandoning the productivist approach to agriculture, defined by Tony Fitzpatrick as “the ideological fetishisation of productivity growth where the latter takes on the quality of an end rather than a means” (Fitzpatrick, 2004), which is no longer appropriate due to the increasing scarcity of resources and the plethora of deleterious environmental and health impacts. It is worth to take time addressing the different issues with rationality and consider all the aspects of the transition. Several studies conducted by United States Department of Agriculture (Beckman et al., 2020), Wageningen University and Research (Bremmer et al., 2021) as well as the European Joint Research Centre (Barreiro-Hurle et al., 2021), have highlighted the negative consequences of the Farm to Fork (F2F) strategy, causing concerns for both the EU and the world in relation to vital aspects such as food security, food sovereignty, farmers’ incomes, and consumer prices. These studies visibly show the inevitability of trade-offs considering the consequences of F2F, BDS and EGD. In the following sections, we will look at the various consequences of these policies on different sectors of society, as well as explore potential boundaries of the F2F strategy via the range of sustainability and best practices that could be implemented for transitioning to Sustainable Business Models (SBMs).

Given the highly ambitious objectives of the F2F strategy, significant consequences for European agricultural production are to be expected. To fully grasp the extent of these impacts, the following section examines key findings from studies conducted by the United States Department of Agriculture (USDA) and Wageningen University. These analyses provide valuable insights into how the strategy may influence production, yields, arable land use and imports/exports within the EU and beyond.

The study conducted by USDA was done with the Computable General Equilibrium (CGE) model, which evaluate the economy-wide and sector-specific impacts of policies by considering inter-industry linkages and land use changes. They specifically used the GTAP-AEZ model, which divides the world into 18 agroecological zones and allows competition between cropland and other land uses. This model estimates medium-term (8–10 years) impacts of policies like regulations, taxes, and subsidies on markets, land use, and food prices. To assess food security implications, the study combined CGE model outputs, such as GDP and food price changes, with the USDA’s IFSA model, which estimates food consumption in developing countries. USDA has considered three different scenarios. In scenario one, EU independently implements the Strategies without trade restrictions—EU-only scenario. The second scenario, denoted as the “middle scenario,” expands restrictions on agricultural inputs to include the EU’s major food and agricultural trade partners, assuming a 50% import restriction from regions not adopting similar strategies. The third scenario, the “global scenario, considers worldwide adoption of the Strategies, predicting a universal reduction in agricultural production inputs. For the EU-only scenario, the data obtained by the USDA converge on a loss of production of around 12%, an increase in imports of around 2% and a massive decrease in exports of around 20% in the EU in 2030 (Beckman et al., 2020).

It is important to note that these figures are the result of an average, therefore, some sectors might be impacted far more than others. For instance, according to the prospective of the USDA, wheat production may decrease by around 50%, and oil seeds production by around 60%. The Commission’s decision to devote a quarter of

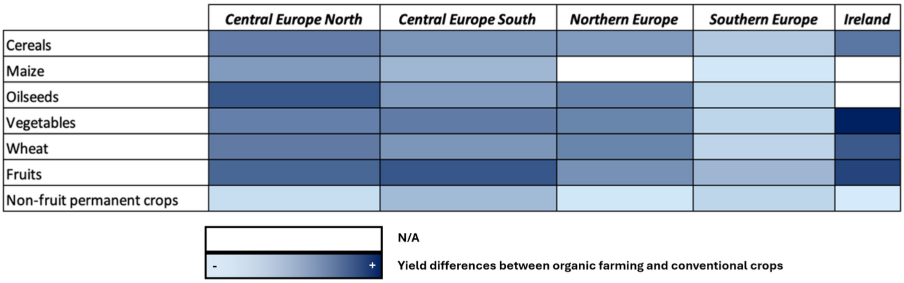

Fig. 4 Heat map of the yield differences between organic farming and conventional crops by agro-ecological region. Own elaboration based on Beckman et al. (2020) and Barreiro-Hurle et al. (2021) data

arable lands to organic farming will also have an impact on yield levels, as organic farming is less efficient due to restrictions on pesticides, herbicides, and nitrogenous fertilizers. Prospective data obtained using the Farm Accountancy Data Network (FADN) database highlights the differences of yield between organic farming and what is considered by opposition as conventional farming in different areas of continental Europe. The differences are especially marked in central north Europe with a difference of around 60% in oilseeds yield, 43% in cereals and 50% in fruits. In Ireland, differences reach almost 80% for vegetables, 64% for fruits and 56% for wheat. In 2021, the share of EU's agricultural land under organic farming was 9.9%, an expansion of this proportion of 15% by 2030 will necessarily results to a drop in yields (Fig. 4).

Wageningen University (Bremmer et al., 2021) used *AGricultural MEmber states MODelling model* or AGMEMOD which is a dynamic multi-country model that analyses agricultural markets, focusing on supply, demand, trade, and prices for key commodities in the EU and neighbouring countries. It combines econometric analysis with expert input, tailoring country-specific models to capture unique dynamics, and integrates them into a broader framework for consistent market projections. They have estimated that achieving the EGD objectives may lead to a reduction of livestock and crop production in the order of 10–15% (range coincides with USDA estimate of 12%). They obtained this range with their fourth scenario (i.e. 50% reduction of use and risk pesticides, 50% reduction of use hazardous pesticides, 20% reduction use of fertilizers, 50% reduction in emission of nutrients and a margin of error of 10%).

The European Joint Research Center (JRC) produced an analysis on the impacts of the F2F strategy. In their analysis, Barreiro-Hurle et al. (2021) used the CAPRI model in order to analyse the F2F strategy. It is a quantitative tool, used for ex-ante impact assessment of agricultural, environmental and trade policy aspects. It combines two main components: regional supply models, which simulate EU farms' profit-maximizing behaviour under constraints like land, nutrients, and policies, and a global market model, which describes international trade and commodity markets. These components interact iteratively, linking EU farming decisions with global prices and vice versa. The model uses advanced techniques to ensure alignment with real-world data and considers factors like trade policies and environmental impacts. This structure enables CAPRI to assess how policy changes affect markets, trade, and production across the supply chain globally and within EU.

The data obtained by the JRC shows that the European agricultural sector is indeed able to achieve the F2F and BDS objectives, but at the cost of trade-offs in terms of production. To take a few key figures, their estimates point to a reduction in production of around 15% for cereals, 15% for oilseeds, 12% for fruit, vegetables and permanent crops, as well as a 10% reduction in raw milk supply and 13% in beef meat (Barreiro-Hurle et al., 2021). Building on the anticipated decline in agricultural production within the EU, it is crucial to examine the broader economic consequences that will stem from these changes. As production shrinks, the EU is likely to face constraints in the availability of key agricultural commodities, which will drive up prices across the region. This price escalation, alongside reductions in farm income and shifting trade patterns, will have far-reaching effects not only within the EU but also in global markets. The following analysis delves into these economic implications, highlighting the impacts on production value, food security, income distribution, and GDP both within the EU and globally.

Significant declines in agricultural production within the EU, as seen in the EU-only scenario, will result in a constrained availability of agricultural commodities. This, in turn, will lead to a rise in prices estimated by the USDA to increase by 17% within the EU. Bremmer et al. (2021) projected a reduction in production value for 2030 of about 92 billion euros, alongside a modest rise in food prices not exceeding 20%, and an expansion of land use between two to three million hectares (Wesseler, 2022). The escalation in EU prices affects both imports and exports, creating a ripple effect across global markets and intensifying competition for domestically produced goods.

On the other hand, USDA also assessed the variation in gross farm income by considering the impact of changes in prices and quantities on agricultural returns (Beckman et al., 2020). In the EU-only scenario, gross farm income in the EU experiences a 16% decline due to reduced productivity, preventing farmers from capitalizing on higher prices. Conversely, gross farm income increases across all other regions, with the EFTA region leading with a 26% rise, primarily driven by augmented agricultural exports to the EU. Consequently, farmers worldwide benefit from increased prices and a reduction in EU production, while the burden of these higher prices is endured by food consumers. USDA measure of gross farm income encompasses the overall returns on all factors engaged in agriculture, including rents to landowners, wages to labourers, and dividends to capital owners, both in primary and processing stages. Since the collective ownership of resources may not align with individual farmers' typical ownership (e.g., some farmers may lease land or employ off-farm labour), this measure does not capture changes in total net incomes that producers might undergo with the implementation of the proposed strategies. This is especially relevant for farmers who do not own land, as the return on this resource is expected to increase significantly.

The model presented in Beckman et al. (2020), known as the International Food Security Assessment (IFSA), is used to generate food insecurity estimates. This serves as a foundational benchmark for evaluating how the strategies could potentially impact food insecurity. Food insecurity occurs when the estimated food consumption of 2,100 kcal per day and per capita (FAO, 2009) are not reached. Estimates suggest that the number of food-insecure people will increase by 22 million limited to 76 poorest countries in the world if the strategies are adopted.

The reduction in agricultural production is anticipated to exert pressure on the food supply within the EU, leading to a notable escalation in prices. As a result, European citizens may experience a rise in food costs amounting to approximately 153 US dollars. Similarly, individuals in the United States could see an increase of around 59 US dollars, while globally, the average increase is projected to be around 52 US dollars per person. These projections highlight the potential financial implications across different regions as a result of adopting the proposed strategies.

In the scenario where the Strategies are exclusively adopted within the EU the resulting impact on GDP is mixed, with notable increases observed in only two regions—Argentina and Ukraine. Conversely, the majority of regions, mirroring the EU's experience, witness declines in GDP. The EU itself faces the most substantial contraction in GDP, registering a decline of 0.3%, equivalent to a staggering $71 billion reduction when calculated based on actual GDP.

Examining the EU-only scenario, on a global scale, there is a marginal decrease of 0.1% in worldwide real GDP. However, a pivotal shift occurs when considering the global implementation of these strategies, leading to a substantial worldwide GDP reduction exceeding 1%, equivalent to a staggering $1.1 trillion. This global impact is particularly pronounced in regions heavily reliant on agricultural exports. For instance, Ukraine faces a considerable GDP decrease of nearly 6%, Africa sees a 3% reduction, and Brazil experiences an almost 3% dip. Of significance is the EU's heightened vulnerability to GDP contractions under the global scenario in comparison to its individual implementation of the Strategies. As the leading exporter of pesticides, the EU encounters a pronounced reduction in GDP due to a decline in international demand. This ripple effect underscores the intricate connections between global trade dynamics and the economic outcomes of regions engaged in agricultural exports.

As we have seen, the impacts of the F2F strategy raise important concerns, particularly regarding agricultural production and global trade dynamics. However, these economic consequences are only part of the broader picture. In parallel, there are significant policy and implementation challenges that must be addressed for the strategy to truly align with sustainability goals.

In their study, Pe'er et al. (2020) highlight seven major shortcomings in the implementation of the EGD and F2F, emphasizing the need for more effective policy measures. The first pertains to the perpetuation of subsidies through direct payments without sufficient consideration of environmental criteria. Notably, they critique the "Area Payments Schemes," which are subsidies proportional to the cultivated hectare. According to Pe'er et al. (2020) these are deemed ineffective both in terms of farmers' income—with direct payments often benefiting landowners more than operators (Hennig & Breustedt, 2018; WBAE, 2018)—and from an environmental perspective, acting as market distortions in violation of WTO rules (OECD, 2017). The authors then draw attention to the issue of budget cuts for rural development programs under the second pillar of the Common Agricultural Policy (CAP), suggesting that, adequately funded and rid of administrative complexity, these programs could be among the most effective measures. Thirdly, they address "misleading claims attached to insufficient climate action," akin to a form of greenwashing (de Netto et al., 2020). As the fourth point, within the framework of a 'Green Architecture,' wherein requirements remain vaguely defined, member states and farmers retain the flexibility to opt for less ambitious environmental alternatives. Fifth, there is a lack of clear and precise indicators to guide progress. The penultimate point of interest underscores that broadening the scope of insurance instruments without a direct association with risk mitigation has the potential to incentivize unsustainable and risk-prone conduct. Lastly, there is a deficiency in the circulation of information, transparency, and coherence.

In this study, Pe'er et al. point out, with 3600 signatures from the scientific community to back it up (Pe'er et al., 2020), that sustainability would emerge as a paramount societal concern and an imminent challenge, enshrined as a goal in the Treaty of the European Union. Given the documented inadequacies of the Common Agricultural Policy (CAP) concerning sustainability, continuing with business as usual would cease to be a viable option. The EC, Council, and Parliament would be required to undertake ambitious and responsible initiatives. Swift and effective measures would become imperative to ensure environmental and social sustainability, along with securing long-term food security.

This is apparently at odds with the initial analysis conducted by Bremmer et al. (2021), Beckman et al. (2020) and Barreiro-Hurle et al. (2021), which stated, to put it trivially, that the consequences of the EGD on the economy, production and purchasing power of Europeans in particular, but also of the world market to a lesser extent. Here, the authors declare that the Green Deal would not go far enough and should be rethought to bring it into line with environmental issues. A head-on confrontation between the "business as usual" model and a "sustainable" model that is more ecological and perennial.

Adding to the discussion, (Sikora, 2020) the author points out EGD's legal and financial limitations, notably its ambitious goal of mobilizing €1 trillion in sustainable investments over the next decade. This initiative presents challenges in defining and incorporating the complex concept of 'environment' into legal and regulatory frameworks. Environmental protection extends beyond a narrow regulatory focus, encompassing a wide range of issues that will have significant financial implications for all sectors of the EU economy.

Current EU law prohibits the use of genetically modified organisms (GMOs) in organic farming, while achieving the Sustainable Development Goals (SDGs) may benefit from including biotechnology innovations in organic farming. The authors argue that the current EU legal framework creates a conflict between organic farming and the use of biotechnology innovations, even though the two could complement each other well. They present evidence that organic farming often leads to reduced yields, studies suggest that it is in a magnitude of 20–25% under experimental conditions and up to 50% under practical farming conditions (Purnhagen et al., 2021). Despite having just, a small percentage of its land dedicated to organic farming, Europe relies heavily on imports of vegetable oil and feed protein, such as palm oil and soy, which contribute to deforestation in Southeast Asia and South America.

Barreiro-Hurle et al. (2021) and Henning et al. (2021) evaluated the impact of the Farm to Fork (F2F) strategy on reducing greenhouse gas (GHG) emissions within the

EU's agricultural sector, noting a reduction of 20–35% primarily due to changes in using fertilizer. However, despite this reduction, they pointed out a significant leakage, where more than half of the reduced emissions in the EU are offset by increases elsewhere globally, according to Barreiro-Hurle et al. (2021). Conversely, Henning et al. (2021) in his research observed minimal impact from leakage, mainly affecting Africa, Asia, and South America. To address these issues, the EU plans to implement border taxes related to the GHG emissions of imported goods through the Carbon Border Adjustment Mechanism (CBAM). Under the CBAM, EU importers are required to buy carbon certificates that match the cost of carbon that would apply if the imported goods had been manufactured under the EU's carbon pricing regulations[1]. Economically, this could be problematic because it might diminish the advantages of locating production in areas that have more efficiency in terms of emission (Wesseler, 2022).

Besides critically analysing the limitations of EGD and F2F, we also wanted to demonstrate the need to include more virtuous practices, given the abundance of examples of this in the literature. Although not exhaustive, three studies have been selected as representative of best practices that can be implemented to pave the way for improving existing policies, but also to demonstrate concrete ways for all stakeholders to move in the direction of sustainability and resilience. Following examples demonstrate how sustainability is becoming increasingly important as a competitive advantage rather than just an environmental responsibility. One might also observe that some businesses are founded and structured entirely around sustainable technologies and procedures, further emphasizing the growing significance of sustainability in the entire Ag-Food value chain.

In their study Riccaboni et al. (2021) emphasized the need for Research and Innovation (R&I) in the entirety of the value chain and implying all the stakeholders in the process. Namely, the providers (i.e. farmers) which would benefit from symbiotic and multi-layered agricultural practices remarkably concerning soil-health issues, as we know that soil erosion is a major concern regarding the sustainability of our agricultural system (Borrelli et al., 2021). Practices such as purposeful use of beneficial soil microorganisms (e.g. mycorrhiza). But also, livestock-crops combination, demonstrating a significant reduction in environmental detrimental effects of agriculture (Paolotti et al., 2016). Other practices such as multi-layered agroforestry and symbiotic aquaculture 'the process of growing aquatic organisms and plants symbiotically' (Yep & Zheng, 2019) should be mentioned. Today's digital agriculture also plays a role in the transition, with sensor-based monitoring systems to collect data about crop health, soil conditions, and weather patterns. This data is then used to make informed decisions about irrigation, fertilization, and pest control. As a result, precision agriculture can help farmers to increase yields, reduce costs, and protect the environment. 'Out of soil agriculture' then, innovative farming methods that grow crops without soil are becoming increasingly important for optimizing land use in urban areas, particularly where there is limited space. These methods, such as hydroponics, can help to conserve land, reduce soil degradation, and provide fresh produce to local com-

[1] Carbon Border Adjustment Mechanism, European Commission, 2025. https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en

munities. Hydroponics is a proven technique for growing vegetables indoors, and it is less environmentally harmful than traditional agricultural practices if it relies on renewable energy sources. All the food processors, implied in the transformation and supply chain, should also contribute. Besides the aforementioned practices, the importance of new plant breeding technologies (NPBTs) cannot be overlooked, as they notably increase the productivity and adaptability of organic farming practices to climate change (Purnhagen et al., 2021). Purnhagen et al. (2021) also highlighted the benefits of NPBTs not only in organic agriculture but also in general agriculture. However, the accessibility of these practices is greatly hindered by the existing EU approval processes. The challenges faced by NPBTs underline the urgent need for reforming the approval process for planting materials in the EU, essential for the effective implementation of the F2F strategy as outlined by Purnhagen et al. (2021) and Wesseler (2022).

By developing new food products, such as cultured meat, imitation meat, and insects, have the potential to reduce land use and greenhouse gas emissions while providing a source of calories and protein. A study by Alexander et al. (2017) compared the sustainability of these new food products to traditional animal products and found that insects and imitation meat were more sustainable options. Insects are highly efficient at converting feed into edible food, and imitation meat can provide a similar nutritional profile to animal meat without the environmental impact. The authors conclude that a diet that includes a mix of conventional animal products, insects, and imitation meat would be the most sustainable option for the future. A core problem worldwide about food industry and food consumption is undoubtedly food waste, estimated at around one third of production (Gustavsson et al., 2013). Riccaboni et al. (2021) calls for 'integrated measures to avoid food waste'. The circular economy approach offers innovative solutions for converting waste products into valuable resources. Several studies demonstrate the potential of circular economy principles in various sectors, including pig farming, meat processing, food waste management, and food packaging. By adopting circular economy practices, industries can reduce waste, improve efficiency, and mitigate environmental impacts while creating new revenue streams. Retailers can improve efficiency and reduce food waste by using IoT-based logistics systems, traceability, and implementing blockchain technology. They can also differentiate themselves by offering fair trade products and providing clear information about food sustainability and quality. Distributors and wholesalers can improve efficiency by using advanced analytics and supply chain management software. They can also enhance their value proposition by offering tailored solutions to retailers and food services providers. Food advisory services can play a key role in promoting sustainable food practices and helping farmers and other value chain actors to adopt innovative technologies. They can also provide training and education to consumers. The paper also discusses the role of policy makers and researchers. Policy makers can support innovation by providing funding, incentives, and regulatory frameworks. Particularly, the F2F strategy is benefits a substantial financial commitment of 10 billion euros under Horizon Europe (2021–2027), allocated for research related to food, bioeconomy, natural resources, agriculture, and the environment to achieve the F2F targets, ensuring the EU agriculture sector's transition towards sustainability is well-supported (Wesseler, 2022). In turn, this financial support helps researchers can develop new technologies and practices that can be adopted by businesses.

Chen et al. (2020) argues that smart packaging technologies have the potential to revolutionize the food supply chain by improving its quality, safety, integrity, and sustainability. These technologies enable real-time monitoring and traceability of products, providing valuable information that can be used to prevent food loss, protect brands, and ensure compliance with regulations. Implementing these technologies requires collaboration among experts from various disciplines, and supply chain management principles can guide this cross-collaboration. By embracing smart packaging, the food industry can enhance its efficiency and contribute to a more sustainable future.

A study conducted by Sovacool et al. (2021) accentuates the necessity of decarbonizing the food and beverages industry. The text focuses on the benefits of decarbonizing the food and beverage industry. The author highlights a variety of positive outcomes, including reduced energy consumption and greenhouse gas emissions, lower energy bills and operating costs, environmental protection, and improved worker health and safety. Overall, decarbonization presents a win-win situation for the food and beverage industry, offering benefits to both the environment and the company's bottom line. This report reviews various technological options to decarbonize the industry, including improved land management, precision agriculture, decentralized food systems, automation, renewable energy adoption, energy efficiency, sustainable packaging, sustainable sourcing, supply chain management, food waste reduction, plant-based alternatives to meat, diet change, food sharing, precision biology, photobioreactors, automated robots, and artificial intelligence in supermarkets, and zero-carbon readymade meals. The report concludes that adopting a combination of these technologies is essential for addressing climate change and ensuring a sustainable future.

Ultimately, serving as the cornerstone economic agent of this entire ecosystem, is arguably none other than the consumer. As outlined also by Riccaboni et al. (2021), F2F aims to foster a supportive food environment that encourages individuals to embrace healthier and more sustainable dietary choices. Implying the empowerment of consumers to make informed decisions regarding their food consumption and encouraging food businesses to recognize this empowerment as both a responsibility and an opportunity. Moreover, the growing demand for fresh, unprocessed, and sustainably sourced food is propelling significant transformations within the food industry. We add the need to rethink the F2F approach, perhaps from another angle, towards an approach based on informed consumer choice, enabling a virtuous, sustainable system to be promoted downstream rather than upstream.

This approach, known as Fork to Farm, involves a reversal of the upstream-downstream vision initially present in the F2F strategy. The aim is to give the consumer back an important role, moving him from spectator to actor in the food system. In their study, Schulze et al. (2024) propose the implementation of a 'consumer information label'. This label is intended as an alternative to the over-simplistic traffic light system, which obscures too many important aspects of the products we buy. This new label would focus on the essential environmental services that promote sustainability. The study cites a few examples, such as biodiversity services, carbon capture and sequestration, and water management systems. A farmer concerned about these dimensions would see his products labelled in accordance. Interestingly, the study points out that, unlike producer labels, this new consumer label would not need any government or institutional support, as labelled products would be self-financed thanks to the visibility offered by the label to consumers who are increasingly concerned about environmental issues.

6 Conclusions

To conclude, this study was conducted with a dual aim, first was to establish a state of the art of the research about the predicted consequences, and the relevance in the light of sustainability of the F2F on the Ag-Food industry with a wide scope. On the other hand, we tried to emphasize here hints of some of the best practices, implying all stakeholders in the Ag-Food value chain, in regard of sustainable business models. Our findings suggest that, drawing upon prospective datasets emanating from the USDA, Wageningen University, and the EU-JRC, the envisioned assimilation of the F2F and BDS by the EU, with a particular emphasis on their realization by the year 2030—directed towards a 50% reduction in the utilization of pesticides and antibiotics, an equal curtailment of nutrient losses (specifically pertaining to nitrogen and phosphorus), a 20% diminution in fertilizer application, the withdrawal of 10% of agricultural acreage from active cultivation, and the elevation of organic farming land to constitute a quarter of the total—is prognosticated to exert profound effects upon the economic and productive landscape of Europe. Other studies also point to the limitations of this policy, raising issues of financing and legal barriers to its application. The scientific literature seems divided on the matter. Some considering that this policy would jeopardize the Union's economy, production, and competitiveness. Another view claiming that, conversely, the European Green Deal does not go far enough in its measures to ensure its main objective of decarbonizing the continent by 2050. However, we advise caution when interpreting the findings presented. Although the study provides a glimpse into potential interactions between targets and a general idea of their possible effects on production and markets, it is important to note that these insights are dependent on the underlying assumptions and the models used and do not encompass the full extent of the F2F and BDS strategies.

The first limitation of this study is that, considering impact assessment or prospective analysis, it is always a difficult task to predict the future. And these scenarios are just some of the possibilities, based on extrapolations from the present, and dependent on the intrinsic robustness of the models used by researchers. Conclusively, even though this study tried to look upon a multidimensional aspect, we only covered a fraction of it whereas the impact of such a far-reaching policy should be considered from a systemic point of view. However, the publications reviewed did not reveal any bias.

As mentioned in the Discussion part, an innovative paradigm in the field could be that of the 'Fork to Farm' approach. Rather than considering the need for sustainability in the Ag-Food industry in a top-bottom way, one could consider thinking the other way round. Through the axiomatic and ideological promotion of virtuous behaviour among enlightened consumers, the latter who would naturally be brought to sustainable business models and who would support them through their purchasing power.

The European Commission dictates the terms of the transition to decarbonization, but without necessarily providing the support frameworks to various stakeholders, enabling them to absorb the impact of this policy, the consequences of which will undoubtedly be disruptive. There will be winners and losers in this transition. The key challenge is to support the 'losers' through public policies. However, the European Union should not be viewed as a mere collateral of the transition but as an engine driving it forward. This implies that despite the potentially detrimental effects on the EU economy, the necessity of a continent being a first mover to initiate the movement is essential.

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Declarations

Conflict of interest No conflict of interests to declare.

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