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Sustainable agricultural sector: A key component of EU economic prosperity and security

An economic modellers' perspective

A joint paper by the Horizon Europe projects

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Sustainable agricultural sector: A key component of EU economic prosperity and security

An economic modellers' perspective

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Executive summary

New context. The European Union is facing unprecedented security and economic challenges. While the strategic importance of domestically produced food for security has been recognized in the Niinistö report, as well as in the 2025 European Commission's Vision for Agriculture and Food, which positions agriculture as a key strategic sector, the economic relevance of the sector seems to be neglected in the pivotal Draghi report on strengthening the EU's competitiveness. The primary agricultural sector alone indeed plays only a minor role in EU economic output, but this view ignores its crucial role for the development of important upstream industries and downstream food and bio-based value chains. Simultaneously, agriculture's environmental footprint, impact on natural resources, and climate-related challenges require sustained policy attention.

Background. Economic modelling has been providing robust quantitative science-based underpinning for Common Agricultural Policy development for decades. The models used by the European Commission have been continuously updated to represent evolving societal goals, socio-economic and political contexts, and environmental changes. Three Horizon Europe projects – ACT4CAP27, BrightSpace, and LAMASUS, which together sponsor this paper – are the most recent examples in this tradition. These projects were initialized three to five years ago in a markedly different (geo)political context. As they approach their final phase, including scenario-based policy impact assessments, this paper presents reflections by the project coordinators, senior scientists, and scientific advisors on new priority areas for analysis within these three projects linked to policy action that may fit the current context.

Aim of this paper. Given the urgent need to respond swiftly and strategically to multiple concurrent EU crises, this paper – drawing on the authors' extensive experience in economic modelling and policy analysis – reflects on the agrifood sector's potential to contribute meaningfully to EU competitiveness and economic growth. It identifies key leverage points to unlock these potentials, while fostering food security and environmental sustainability, providing guidance to the analytical work in the above-mentioned projects. The paper concludes by highlighting needed upgrades in the economic modelling capacities to ensure their continued ability to support policy makers in a rapidly changing environment.

Performance. The EU is more than self-sufficient in food, largely due to its internationally **competitive agrifood** sector. This competitiveness is driven by favourable climatic conditions, the use of advanced knowledge, innovation and management practices, integration into strong value chains, and access to global markets. The vast majority of the EU population is **food secure**. Nevertheless, around one in twelve EU residents cannot afford a protein-rich meal. Food production relies on numerous inputs, many of which - like animal feed and fertilizers - are imported. Food security is therefore partly **dependent on imports** and comes with a **significant environmental footprint**. In addition, farmers' incomes, which vary and fluctuate over time, remain under constant pressure due to rising input costs and their relatively weak position within the agrifood supply chain.

Economic opportunities exist throughout the **agrifood supply chain**, not only in the production of high-quality, safe and healthy food, but also in emerging sectors of the **(non-food) bioeconomy**, such as construction materials, biochemicals, and bioenergy, where reducing import dependency is also possible. Although the EU is lagging behind global competitors in the **digital transition of the economy**, multiple applications of digital technologies in agriculture and related sectors could contribute to the necessary push, boosting innovation and strengthening EU competitiveness.

Enabling this progress requires both **innovations** and **policies that foster synergies between public and private sectors and different policy objectives**. **Five priority action areas (PAAs)** have been identified for their high potential for simultaneously boosting EU competitiveness, reinforcing EU and global food security, and reducing the environmental footprint of the agricultural sector. The three Horizon Europe projects mentioned above are well-positioned to assess the economic, social, and environmental impacts of policy measures within these PAAs:

PAA1. Fostering income and resilience through result-based policies that integrate economic and environmental performance. Newly available environmental observation systems may enable a shift from practice-based to result-based policies, providing farmers with the flexibility to develop strategies tailored to their specific situation. This approach helps maximizing synergies between economic and environmental performance, opens new markets for ecosystem services like nature farming, facilitates access to private funding, like carbon credits, and reduces administrative burden.

PAA2. Integrated nutrient management to enhance strategic autonomy. Reducing fertilizer use by mainstreaming precision farming technologies, promoting the production of alternative green fertilizers, and enhancing manure recycling, together with supporting domestic protein crop cultivation, has the potential to reduce both the need for fertilizers as well as feed imports, two critical dependencies in the agrifood sector. These measures can also create new income opportunities for farmers and their suppliers. At the same time, environmental pressures are alleviated.

PAA3. Enhancing the agrifood sector competitiveness and food security through level-playing field trade agreements. Strategically advancing bilateral and multilateral free trade agreements should be further pursued to create new opportunities for the competitive EU agrifood sector and contribute to global food security. At the same time measures need to be taken to prevent unfair competition that may undermine EU food security and social or environmental standards.

PAA4. Strengthening innovation leadership in the new bioeconomy. Enhanced support for research and development as well as technology diffusion at both the farm level and in downstream sectors will enable these sectors to benefit from new (non-food) markets emerging from the transition to a regenerative, fossil-free, circular economy. The bioeconomy is about balancing food and non-food applications of biomass on the one hand and the various needs within a society on the other, with sustainability and circularity as core principles. A robust carbon credits system can play a key role in the process of incentivizing sustainable practices and innovation.

PAA5. Democratizing digitalization to ensure agricultural sector attractiveness and technological innovation. The Common Agricultural Policy should evolve into a digitally enabled policy framework that promotes digitalization in both farming practices and administration, driving and facilitating sustainable productivity growth and simplification.

Capacity building, knowledge transfer, and targeted support, especially for small and medium-sized farms and enterprises, are essential to ensure that no one is left behind. Domestic digital solutions should be promoted to foster EU-led innovation and economic growth while helping to prevent the emergence of new critical dependencies.

Need for new economic modelling developments. The scientific economic modelling community stands ready to support the transition to a competitive, sustainable, circular, and resilient food system by providing tools that analyse the impact of policies and strategies and identify synergies and trade-offs between policy objectives, thus enhancing both effectiveness and efficiency of policy design. However, in light of the evolving geopolitical and economic context, further model developments are essential. Key areas for advancement include:

- Strengthening the connection between agroeconomic and environmental modelling by enhancing the **integration and mutual processing of spatial input and output data** (Model-Data fusion).
- Elements of **Integrated Nutrient Management**, have to be enhanced in the modelling toolbox by enhancing **livestock** representation and including the production and adoption of green fertilisers, the use of precision agricultural technologies and (manure) **circularity practices**.
- Bilateral **trade** agreements modelling, including **sustainability provisions** and regulatory asymmetries in (bi- and multilateral) trade agreements.
- Full integration of the agrifood sector into the broader **bioeconomy** and enhanced representation of the **multiplier effects in both upstream and downstream sectors**.
- **Endogenizing knowledge and innovation processes,** including the role of **digitalization**. Identifying enablers of and barriers to **innovation adoption**, to add model parameters that better represent impacts of investments in technology on yields and other economic, social, and environmental indicators.
- Extending the modelling of shifting **consumer behaviour** by endogenizing changes in consumer preferences (e.g. protein transition) based on nudging behavioural change to better represent the potential impact of demand-side transformations.
- Representing **climate change impacts and adaptation**, including extreme weather events and dedicated adaptation options.

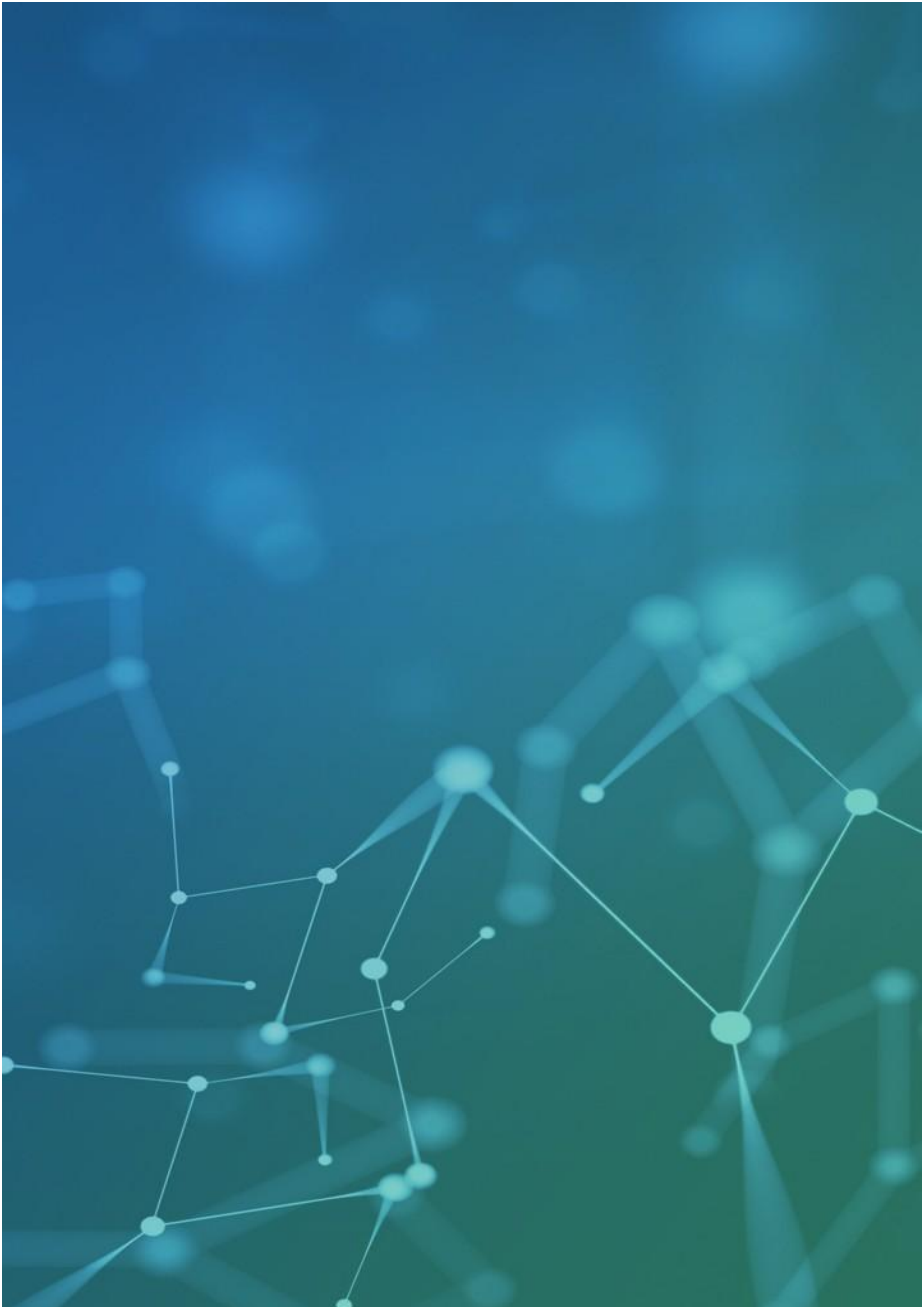

Table of Contents

1 Introduction

The European Union's (EU) agri-food sector holds significant potential and has a unique opportunity to contribute to the EU's strategic objectives and to counter current trajectories of decline within Europe. Realising this potential requires ambitious, coherent, and well-coordinated action across all levels of governance. This perspective paper aims to synthesize and align efforts from several large-scale collaborative research projects to effectively inform policy developments that unlock the sector's potential, thereby ensuring its equitable contribution to the EU's future prosperity and security.

1.1 Agriculture - an overlooked sector in a changing context

The EU stands at a critical juncture. The choices made in the coming years will determine whether the EU can maintain its global influence and its role as a leading world power or be marginalized with all the risks this entails. The EU faces a stark choice between business-as-usual policies that risk stagnation or even decline, and unprecedented, focused action on a scale not seen before. The window of opportunity is narrow, and the next Multiannual Financial Framework (2028-2034) may be one of the last chances to steer the EU towards a future of democracy, security, and prosperity.

The Draghi report underscores the urgency of this moment, emphasizing that only fast, focused, and large-scale action can effectively address the challenges facing the EU. Unfortunately, the report surprisingly does not explicitly mention the agri-food sector, thus missing the opportunity to draw lessons from the pivotal role that agriculture and food systems have played, as well as the shifts in their orientation to respond to the above challenges. The agri-food sector is not only central to the EU's economy and rural livelihoods but also to its food security, environmental sustainability, and geopolitical resilience. The sector's potential to contribute to the EU's strategic goals — ranging from economic competitiveness to security — must be recognized.

In this context, the EU's Strategic Agenda for 2024-2029 provides a framework for action, emphasizing the need for a prosperous, competitive, and sustainable Europe. The agenda highlights the resilience of the agricultural sector as a cornerstone of economic stability and environmental protection, alongside the green and digital transitions, and the need to reduce harmful dependencies while diversifying and securing strategic supply chains. These priorities align with the outcomes of the Strategic Dialogue on the Future of EU Agriculture, which brought together stakeholders from the agri-food sector, civil society, and academia to address the sector's interconnected social, economic, and environmental challenges. The dialogue emphasized the need to improve farmers' economic prospects, while respecting planetary boundaries, and the role of knowledge and education in driving innovation and competitiveness. The Commission incorporated these insights into its Vision for Agriculture and Food, which conveys a roadmap for establishing an attractive, competitive, resilient, and future-oriented agricultural system. However, for this vision to become a reality, concrete steps must now be taken. This includes translating broad objectives into actionable policies, investment strategies, and regulatory frameworks that provide the necessary support and incentives to drive real change.

The increased competitiveness of the EU's agrifood system during the past three decades has not been the result of some accident; rather, it has been the concrete outcome of a well-thought policy design. EU support prices were significantly reduced to gradually converge with world market prices, leading to the impressive growth in the EU's agri-food trade surplus. While past competitiveness could be measured mainly in terms of comparing the price gap and measuring the agrifood trade balance, competitiveness in the future will have to account for the uncertainties surrounding this price path and increased competition from foreign competitors, and greater uncertainty regarding the rules of international trade. Unless productivity grows, and does so by simultaneously reducing agriculture's environmental footprint, EU competitiveness could seriously suffer.

Climate change, biodiversity loss, demographic changes, and the competition for land and resources further complicate the picture. At the same time, the sector must adapt to changing consumer demands and climate, as well as technological innovations in alternative foods. Amidst these challenges, the EU must also contend with growing geopolitical rivalries, particularly in trade and leadership in key technologies. The rise of new global powers, the war in Ukraine, and the increasing fragmentation of international trade rules pose significant risks to the EU's economic stability and strategic autonomy. The erosion of the multilateral rules-based order — a system that has underpinned global economic growth and relative peace since World War II — adds another layer of uncertainty. The EU must therefore strengthen its resilience and reduce its vulnerabilities, not only in terms of trade but also in critical sectors such as agriculture, where dependencies on third countries for key inputs like fertilizers, feed, energy, and digital technology, as well as the risk of cyber-attacks on critical infrastructures, could undermine food security. These challenges require a holistic approach that integrates economic, environmental, and social sustainability.

1.2 Economic modelling in support of EU policies development

Analytically connecting the dots of the very complex interrelationships that characterise food systems and their interactions with the broader economy and natural environment often suffers from excess complexity. While this is the inherent reflection of the complexity characterising the real world, it undeniably complicates the analytical tasks.

Thus, it becomes imperative to prioritise the main drivers explaining the interrelationships among the various food system components and to identify causal linkages between the various factors that impact its performance. This analytical clarity is essential for designing effective policy options that address identified weaknesses and bottlenecks, thereby enhancing the food system's desired performance.

While developing theoretical frameworks that would facilitate this process is a necessary step, it is far from sufficient. Quantification of the manner in which at least the main elements of such systems interact is important for understanding inherent tensions among them, and for discerning the potential trade-offs and synergies that various policy options could generate. This quantification requires modelling approaches that integrate the various facets of food systems.

Models integrating the socio-economic dimensions of food systems exist, both at the level of primary production (partial equilibrium models) as well as at the level of linking the primary sector with the overall economy (general equilibrium models). Models that translate knowledge from natural sciences into frameworks analysing the interrelationships of broader environmental factors also exist. And, increasingly in recent years, approaches that try to link the socio-economic and the environmental dimension of models have received increased attention.

The success of this endeavour heavily relies on the close interaction among the stakeholders involved – the scientific community, policy actors, and the broader public. Within this interaction, the scientific community's main contribution involves the challenging task of updating the model frameworks to reflect the changing broader environment and improving the capacity of different models to "communicate" with each other. Policy actors have a central role in guiding the research community towards correctly identifying policy scenarios that are both realistic in their implementation and ambitious in their targets. The broader stakeholder community is crucial in identifying concerns, emerging trends, and achievements that often escape the notice of scientists and policymakers, thus acting as a vital reality check for the analytical approaches employed.

1.3 Aim of the paper

The authors of this paper are involved in three different European Commission-funded Horizon Europe projects (ACT4CAP27, BrightSpace, and LAMASUS). These projects collectively focus on enhancing the economic models employed by the Commission to support the development of the Common Agricultural Policy (CAP), specifically by also bridging the knowledge gap that arises when the economy and the environment are analysed in separation from each other.

Our aim is to design relevant policy packages which could be assessed in our projects, and which would respond to the new challenges by reflecting on the best role for the sector in enhancing Europe's prosperity. Our deliberations are informed by key reports, including the Draghi report, the Letta report on the Future of the Single Market, and the Niinistö report on EU preparedness, which explicitly mentions food security as a critical issue.

This perspective paper puts the focus on the potential of the agrifood sector to contribute to EU competitiveness, prosperity, and food security, while enhancing environmental sustainability. The subsequent sections of the paper are structured as presented in Figure 1. First, the **current performance** of the agriculture-related sectors is reviewed in terms of competitiveness, contribution to food security, and environmental sustainability. Second, we discuss **economic opportunities** in five interconnected sectors – primary agriculture, input suppliers, food supply chain, non-food bioeconomy, and digital economy. Then, five **priority action areas**, each focusing on one of the aforementioned economic sectors, are identified to serve as input for scenario development across our projects. Finally, we conclude with an overview of relevant **economic modelling** developments taking place in the three projects, and an outlook on future model development needs to further strengthen their relevance in the new context.

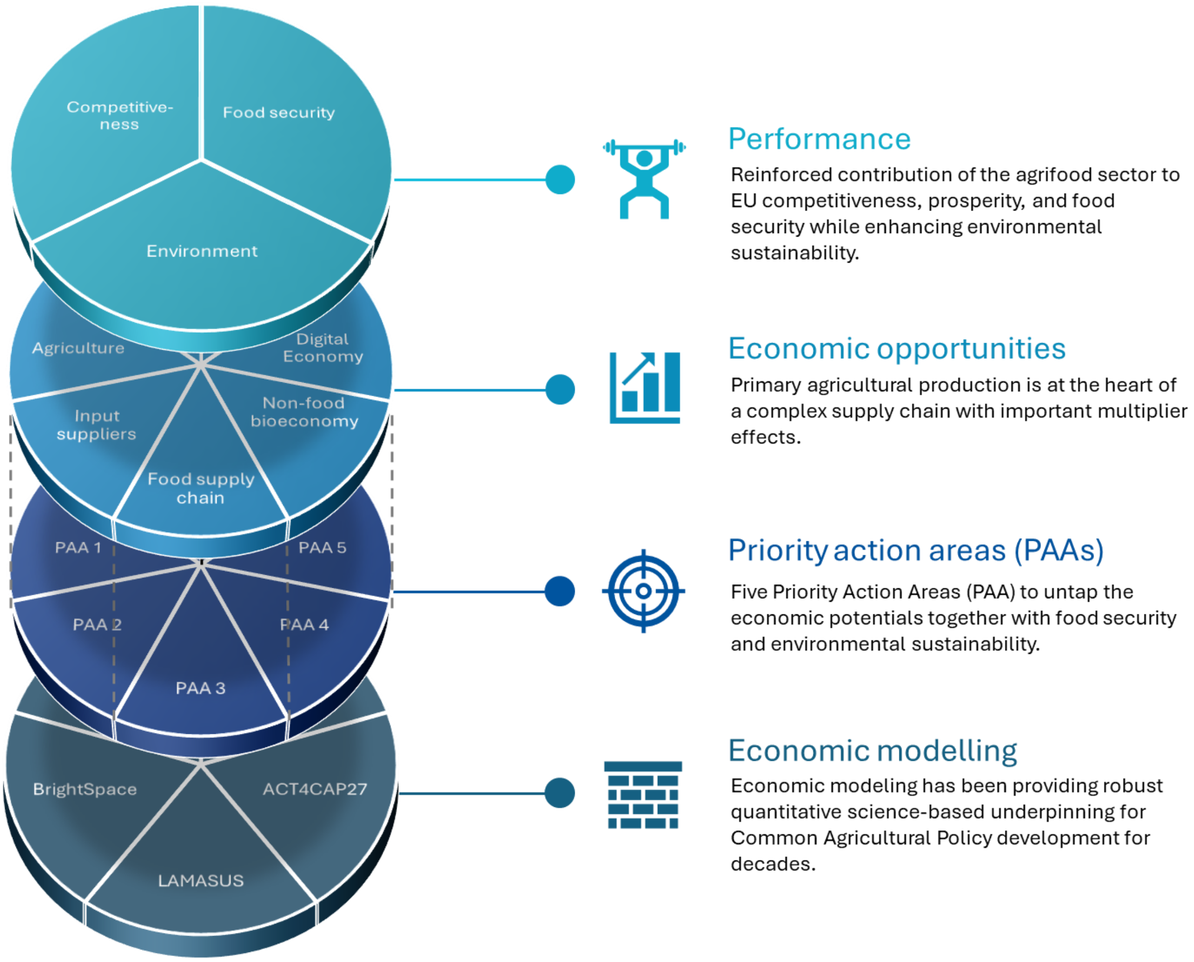

Figure 1. Structure and logic of the paper

2 Current performance

2.1 Competitiveness of the agrifood supply chain

The European Commission, in its recent Communication on "An EU Compass to Regain Competitiveness and Secure Sustainable Prosperity," identifies three transformation imperatives: closing the innovation gap, advancing decarbonisation while reducing excessive dependencies, and enhancing security. These imperatives are supported by measures such as regulatory simplification, investment financing, fostering skills and quality jobs, and improving coordination across governance levels. While the Communication makes only minimal reference to agriculture and food, the EC Vision for agriculture and food calls for placing competitiveness at the core of the EU agrifood sector's strategy for 2040.

The EU agricultural sector represents ~1.3% of the EU's GDP, occupies 38% of its land and ensures the EU is self-sufficient in most (basic) food products. This shows its strategic importance beyond its GDP share, highlighting its central role in food security, environmental stewardship, and rural employment. In addition, the primary agricultural sector, with 9.1 million farmers, is a vital component of the broader agrifood processing and food service providing industry that contributes around 7% to EU's GDP though similar multipliers apply in sectors like chemicals and metals.

The **agrifood supply chain** includes farmers, farm input suppliers, food and drink manufacturing, wholesaling, retailing, logistics, packaging, and related services. The food and drink industry, the EU's largest manufacturing sector, directly employs 4.7 million people across 300,000 mostly SMEs. This industrial ecosystem not only supports upstream agricultural activities but also drives downstream market dynamics within the single market and beyond. The upstream segment, while small with only 10,000 enterprises, provides essential inputs like seeds, fertilisers, feed, and machinery, supporting €55.2 billion in value added and 500,000 jobs. Taken together, the entire agrifood value chain generates more than €1 trillion in gross value added to the EU economy, surpassing the economic footprint of the EU automotive industry. This underlines its strategic importance for food security, innovation, and regional employment.

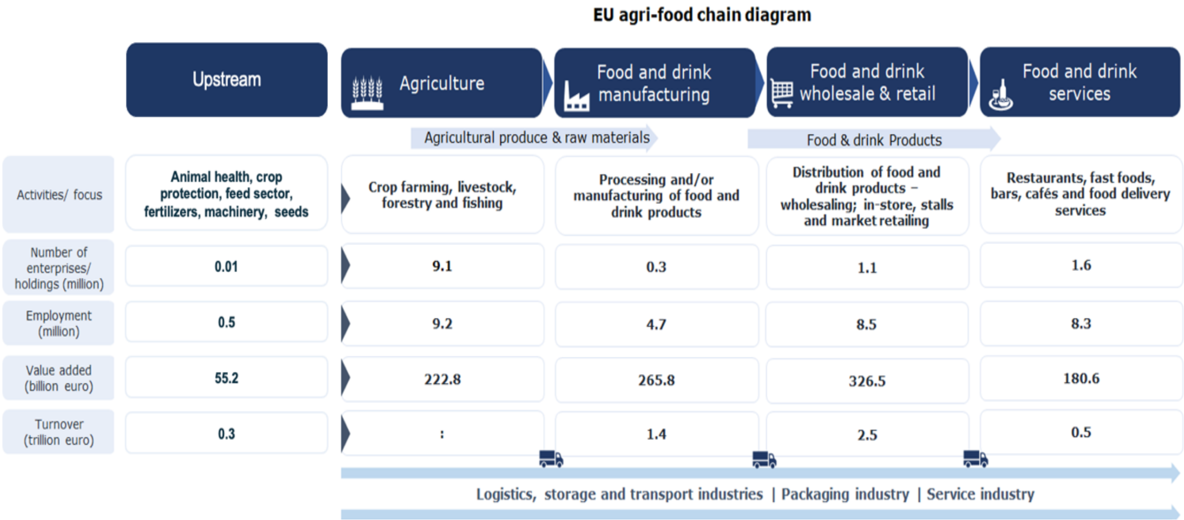

Figure 2. The EU Agrifood Supply Chain. Source: Tidjani et al., 2025 (based on Eurostat data)

This aggregate view conceals significant structural weaknesses. Many farms are too small to be economically viable, characterized by low productivity and very limited income, making innovation uptake difficult. The ageing workforce makes this even more difficult: the share of farmers over 65 rose from 29.7% to 33.2% EU-wide between 2010 and 2020. Moreover, in a shrinking sector where over 90% of successors take over their parents' farm (and many do not), structural change can become irreversible. This raises questions about generational renewal strategies and the risk that explicit policies to retain young people may have unintended social or economic costs.
Restoring competitiveness is a key EU policy priority, particularly in the context of the next Multiannual Financial Framework (MFF). This presents an opportunity to reposition the agrifood sector as an economic asset rather than as a policy liability. Its contributions to innovation, decarbonization, and security align well with the EU's broader economic and sustainability goals.

Innovation has been integral to the EU agrifood system, encompassing primary agriculture and extending throughout the supply chain. The sector has been an early adopter of remote sensing and earth observation technologies, leveraging Europe's global leadership in these areas. EU food and drink enterprises are globally recognized for their innovations in product quality, safety, and value addition. Additionally, bottom-up initiatives and collaborative networks have facilitated the widespread or emerging adoption of innovative practices such as integrated pest management, agroforestry, precision farming or urban agriculture. Nonetheless, concerns remain regarding the slowing pace of innovation diffusion among smaller farms and the risk of a widening gap between frontrunners and laggards in the sector.

EU priorities in the CAP and Horizon Europe research programs have played a role in promoting innovation throughout the agri-food sector that enhances productivity while reducing environmental impacts. EU agricultural productivity has grown steadily, though at a slower pace compared to competitors, with labour productivity surging due to mechanization and the replacement of non-salaried farm labour: labour productivity increased by 32% from 2010 to 2023. From 2010 to 2019-2021, Total Factor Productivity (TFP) of EU agriculture grew faster than that of other high-income countries, but more slowly than that of emerging countries such as Brazil, China or India (European Commission, 2024a). The yields of many crops are stagnating in a majority of Member States (European Commission, 2024a), including wheat (5.5–6.0 tons/ha) and maize (6.5–7.5 tons/ha), with recent declines reported in countries like France and Germany. These trends, linked to climate stress and regulatory limits on inputs (Vidal, 2023), highlight the urgent need for adaptation to safeguard competitiveness. Moreover, the positive development of domestic availability has been achieved at the expense of negative impacts on the climate and the environment.

The EU agrifood sector, characterized by a structural trade surplus of ~€70 billion in 2023[1], demonstrates its competitiveness through exports of high-value, processed goods. Intra-EU trade also underscores its resilience, with 27 integrated markets serving ~450 million consumers. However, internal trade barriers within the EU remain substantial: IMF estimates suggest tariff equivalents of ~44% for goods — which may similarly affect agri-food trade. The sector processes 70% of EU farm output, ensuring a steady supply of trusted, safe, high-quality

[1] https://agriculture.ec.europa.eu/media/news/eu-agri-food-trade-achieved-record-surplus-2023-2024-04-05_en

food. However, this trade strength stems mainly from food processing, while primary agricultural output has grown only ~0.4% annually since 2005, indicating that competitiveness relies more on value-added than output expansion.

The EU's strong food safety standards, harmonized under the General Food Law Regulation (EC No 178/2002), have built global consumer trust and supported export growth. Emerging markets in Asia and Africa present new opportunities for high-quality, value-added products.

The upstream segment of the agrifood supply chain, covering inputs like energy, fertilisers, pesticides, labour, and seeds, has faced steep cost increases over the past decade. Energy costs rose over 40%, fertilisers by 35%, and feed and seeds rose 12% since 2010. While rising input costs can be offset by productivity gains and innovation, these may not suffice if growth stagnates and farms remain constrained in investing in new technologies. Between 2010 and 2023, the sector increased its R&D investments by 35%, with growth in digital tools for precision farming, alternative proteins, and climate-smart practices. SMEs, supported by national and EU-level funding schemes, have driven much of this innovation. Future policies should continue to align CAP instruments, innovation funding, and market incentives to sustain this trajectory.

2.2 Food security

Food security encompasses the four dimensions of food availability, access to food, food utilization, and stability of these first three dimensions over time (FAO, 1996). The food supply in the EU is currently not at risk (European Commission, 2022). Over the past decade, EU agri-food exports have grown faster than imports, leading to a substantial trade surplus of €63.6 billion in 2024, after reaching a record of €69.4 billion in 2023 (European Commission, 2025a). However, this positive trade balance in value terms masks a structural deficit in nutritional terms, largely due to imports of plant-based proteins used to feed European livestock. As a result, a decrease in the EU's dependence on imported plant proteins would serve a dual purpose — strengthening the protein autonomy of European livestock production and supporting global food availability. Furthermore, a significant share of EU agricultural exports consists of beverages that contribute little to increasing world food availability.

Several factors have put food availability back on the EU's political agenda. Even if the 2020 Covid-19 crisis did not lead to food shortages in the EU, it exposed fragilities within the food supply chain, mainly related to the containment measures taken to deal with the crisis (closure of private and public out-of-home catering during the quarantine period, restrictions on the movement of agricultural workers within Member States and from third countries). It is in a changing geopolitical and environmental context that the future of EU agriculture is taking shape. This raises critical questions whether the EU agri-food sector will be as resilient to other, and potentially compounding, shocks in the future.

Both the Covid-19 crisis and the war in Ukraine have led to a sharp rise in agricultural and food prices worldwide, including in the EU. They put the issue of food inflation back on the agenda. These events highlighted the dependence of EU agriculture on key inputs (fertilizers, energy, animal protein feed) supplied by a limited number of exporting countries, including Russia and Ukraine (Loi et al., 2024). Global geopolitical tensions – not limited to the war in Ukraine – are leading to a strategic re-evaluation of the way we trade, with increased attention to reshoring (the reverse process of offshoring) and friendshoring, which refers to the redirection of supply chains to countries perceived as economically and politically safe or low risk (Goldberg and Reed, 2023). At the same time, trade remains an indispensable mechanism to mitigate domestic production shocks, as shown most recently in the US where egg supplies have been devastated by avian flu containment measures and the US had to appeal for imports to stabilize escalating egg prices.

The development of the EU agri-food system in recent decades has contributed to a downward trend in food prices in real terms (Hennessy and Merlo, 2024), thereby improving access to and affordability of food. However, the percentage of European consumers unable "to afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day" – the definition of household food insecurity used by Eurostat – varies considerably across Member States (from 1.3% in Cyprus and 1.6% in Ireland to 19.9% in Bulgaria and 23.3% in Romania in 2023[2]). This proportion is higher among women, the elderly, renters, single-person and lone-parent households, people with lower education, disabilities, or unemployment status, and tends to increase during periods of food inflation. This raises the issue of unequal access to food. Research indicates that this inequality is not necessarily the highest in the poorest European countries, but in Member States with high proportions of disadvantaged social groups and a less comprehensive welfare regime (Davis and Baumberg-Geiger, 2017). Moreover, many food-insecure households suffer from the "double burden of malnutrition", a condition characterized by the coexistence of undernutrition alongside overweight, obesity, and diet-related non-communicable diseases (WHO, 2017). More generally, the EU today confronts a significant public health challenge related to diet. In 2019, 36% of the adult population was classified as overweight and 17% as obese[3]. These proportions have increased over the last few decades. While recent pharmacological advances, such as GLP-1 agonists, may help to reverse this trend, they do not address the underlying structural issues of dietary imbalances. Diets are unbalanced because they are (too) high in fat, sugar, salt, meat and ultra-processed products and (too) low in fibre, fruits, and vegetables. To date, food policies at EU and Member State level have proven insufficient to induce the significant behavioural changes required to improve nutritional outcomes (Détang-Dessendre et al. 2022).

2.3 Environment

As outlined in the previous sections, agriculture is essential for ensuring food security and remains a cornerstone of rural economies across the EU. However, while providing these vital benefits, the sector exerts significant pressure on the climate and the environment. As climate change accelerates, bringing more extreme weather events such as droughts and floods, farmers will be increasingly required to adapt their practices to new and challenging conditions. EU action – through long-standing policies like the CAP or regulations like the Water Framework Directive and the Nature Restoration Regulation, and policy strategies related to the EU Green Deal – addresses these environmental issues. While some progress is visible - for example, reductions in ammonia (NH_3) and nitrate (NO_3^-) pollution in certain regions - critical challenges remain. The European Court of Auditors (ECA, 2024) emphasizes that EU policies have not yet

[2] https://ec.europa.eu/eurostat/databrowser/view/ilc_mdes03__custom_12893403/default/table?lang=en

[3] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210721-2

achieved the environmental improvements necessary for long-term sustainability and warns that persistent gaps in implementation risk undermining the EU's green ambitions.

Agriculture accounts for 13% of total EU greenhouse gas (GHG) emissions (ECA, 2024). More than half of these emissions are methane (CH_4) from ruminant livestock, 31% nitrous oxide (N_2O) from fertilizers and manure applications, and 11% carbon dioxide (CO_2) from land use and land use changes, including drainage of organic soils. Between 1990 and 1995, GHG emissions fell by 15.3%, but in the following 26 years declined by only a further 15.9%. Reducing emissions further — particularly in light of the EU's 2050 climate targets — will require systemic changes, especially with respect to ruminant livestock, which are both economically vital and environmentally intensive (EEA, 2023a) while ensuring the maintenance of extensive grasslands and biodiversity-friendly landscape management strategies. Agriculture can play a pivotal role in the EU's decarbonisation strategy, simultaneously contributing to emission reductions and carbon sequestration. Numerous projects across the Member States showcase best practices, emphasizing locally adapted solutions within a common policy framework. These efforts provide a foundation for refining policy mechanisms to further incentivize low-emission practices.

While agriculture contributes to GHG emissions, climate change also directly threatens agricultural productivity. Recent estimates indicate that adverse weather events already cause average losses exceeding 28 billion EUR in the EU agricultural sector (fi-compass, 2025). This EU-wide average, however, masks substantial regional disparities. With the projected intensification of extreme weather events due to climate change, crop annual average losses and related livestock losses could reach 40 billion EUR by 2050 (fi-compass, 2025). Droughts are expected to become one of the most important drivers of agricultural risk, particularly in southern, south-eastern, and central regions of the EU, while increasingly affecting northern and western areas as well. Consequently, water availability and resilience emerge as critical priorities for future adaptation strategies.

Water overuse remains a persistent issue, particularly in Mediterranean countries. According to the European Environment Agency (EEA) and the European Court of Auditors (ECA), agriculture accounts for about 25% of total water abstraction in Europe, rising to over 80% in some southern regions. Over-abstraction for irrigation depletes aquifers, dries wetlands, and reduces river flows, jeopardising both ecosystems and future water supply. Despite the Water Framework Directive, many Member States are not on track to meet their 2027 water quality targets. Furthermore, the CAP has often funded infrastructure that leads to greater water use rather than efficiency (EEA, 2023b; ECA, 2021). The EU Water Resilience Strategy aims to restore and protect the water cycle, adopting water-smart practices and green infrastructure, and build a water-smart economy, also specifically addressing the challenges related to agriculture water use, for example by promoting climate-smart irrigation, adaptive cropping systems, and stronger water governance (European Commission, 2025b).

Soil degradation is another critical threat. The JRC's 2024 State of Soils in Europe report highlights widespread issues: soil erosion on over 13% of EU farmland, declining organic matter in intensively cultivated soils, and the ongoing exploitation of peatlands, which — when drained for agriculture — emit high levels of CO_2. Northern countries like Finland, Germany, and the

Netherlands are particularly affected by carbon losses from organic soils, undermining both soil health and climate targets (JRC, 2024).

Nutrient pollution also continues to harm Europe's ecosystems. Excess nitrogen (N) and phosphorus (P) from fertilisers and manure runoff cause eutrophication, especially in livestock-dense regions. Nutrient surpluses and groundwater nitrate concentrations remain significantly above safe limits in many areas, despite some regional progress (EEA, 2023c; EEA, 2018). The EU has several pieces of legislation, notably the Nitrates Directive from 1991, which has contributed to improvements, though its impact has been slower than environmentally desirable due to derogations and insufficient monitoring. The overall nitrogen surplus is known to be the source of several problems, including eutrophication of inland and marine waters, disturbance of oligotrophic ecosystems, PM2.5 formation, GHG emissions, and drinking water problems (Leip et al., 2015; EEA, 2022). As in other world regions, the concentration of livestock and intensive crop production contributes to prominent "hot spot" regions, which have included since many years the Netherlands, Belgium, Denmark, parts of northwest Germany, Britany, and the Po valley. While some regions have seen improvements over time, "catching up" developments have meant that many EU countries now also have their hot spot regions.

The decline of biodiversity is one of the most visible symptoms of unsustainable agricultural intensification. The EEA's 2020 State of the Environment report and ECA Special Report 13/2020 confirm that unsustainable intensification — characterised by monocultures, hedgerow removal, pesticide use, and mechanisation — has turned formerly diverse landscapes into ecologically simplified terrain. This has contributed to the collapse of pollinator, farmland birds, and beneficial insect populations, undermining both ecosystem services and food production (EEA, 2020; ECA, 2020). Again, while the most severe impacts have been slowed, much remains to be done.

To transition to a more sustainable and resilient food system, the EU must reconcile the dual objectives of economic prosperity and ecological sustainability while continuing to ensure food and nutrition security, and the vitality of rural areas.

3 Economic opportunities

While the economic weight of the primary agricultural sector is moderate, its performance is critical for both traditional upstream (farm input suppliers) and downstream (food processing and retail) sectors, as well as the more novel sectors of the non-food bioeconomy and digital economy, Figure 3. It is also vital for the EU's role in global trade and food security, as well as creating a role model for standards on food safety and quality. Untapping the economic potential across these sectors can provide a critical contribution to EU prosperity and security.

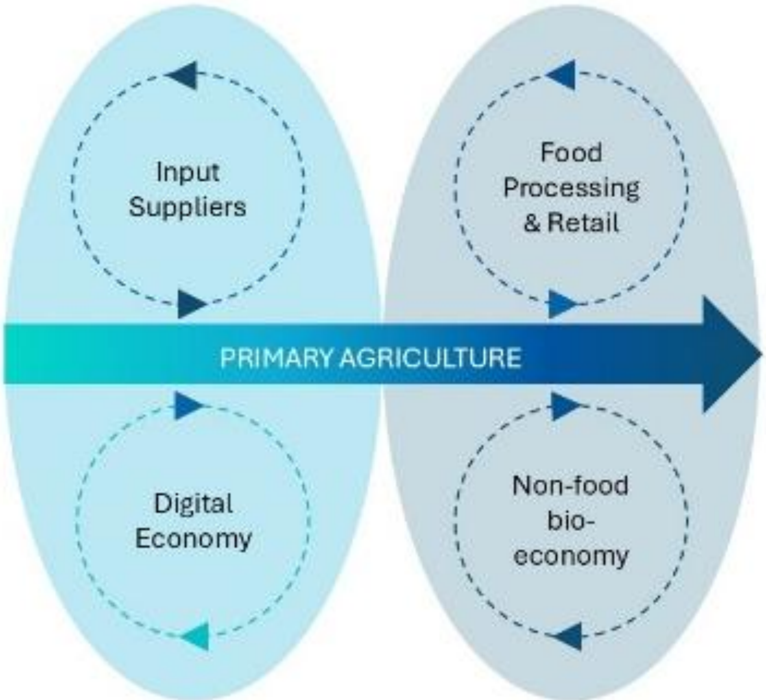

Figure 3. Primary agriculture at the core of an important economic segment

3.1 Primary agriculture, farm input suppliers, food processing and retail

Global food demand will continue to increase in the coming decades due to population, economic growth and urbanization. Projections from the OECD/FAO (2024) indicate an annual growth in total food consumption of 1.1% over the next decade, with 94% of the additional consumption expected to occur in middle- and low-income countries. Within this global context, the EU's role as an exporter of bulk agricultural commodities is projected to remain relatively constant. Both the OECD/FAO and the DG AGRI medium-term Agricultural Outlook (European Commission, 2024b.) project stable export volumes for the EU's primary commodities, indicating that the EU will not be a principal actor in meeting this growing global demand for raw agricultural goods.

The strategic strength of the EU agrifood sector is the processing of commodities into high-quality food products that are safe and healthy. Increasing prosperity in emerging economies present significant opportunities to expand the EU's export position in the future, while maintaining established positions in important markets such as the US, UK, China, and Japan. Realizing this potential, however, is contingent upon the maintenance of an open international trade environment, a condition challenged by recent trends towards national protectionism.

Opportunities for the EU agrifood sector are also present within its internal market, where consumer preferences undergo a gradual but significant transformation. Meat consumption, particularly of beef and pork, is steadily declining, while demand for plant-based alternatives, such as pulses, is increasing (European Commission, 2024b). This shift reflects a broader trend towards flexitarianism (SmartProtein, 2023; AHFES, 2021), signalling a declining importance of livestock products within European diets. The transition is motivated by increased consumer awareness of health and ethical considerations, including animal welfare, and the environmental footprint associated with livestock production (Perez-Cueto et al. 2021; Ammann et al., 2024). Structural factors, such as the growing availability of plant-based alternatives and EU-level policy initiatives (e.g. sustainability labels; EIT Food, 2024) further reinforce this transition. While consumer preferences for sustainable and ethically produced food are evident across the EU, significant heterogeneity exists (de Boer and Aiking, 2022), often linked to cultural, geographical, and historical factors. Beyond sustainability, there is growing demand for high-quality, nutritious, functional, and fortified food products, further diversifying the internal market landscape.

The EU's dependency on imported protein-rich crops creates vulnerability to global price volatility and supply chain disruptions. A recent JRC analysis suggests that a food systems approach is required. An accelerated shift towards more plant-based diets would effectively complement supply-side adjustments, generating positive outcomes for global sustainability by reshaping production patterns within and beyond the EU (Hristov et al., 2024). New genomic techniques (NGTs) could offer a pathway to enhance the scalability, resilience, and productivity of EU protein and other crop production. However, realizing this potential requires the adoption of a science-based regulatory framework for NGT's, along with improved information dissemination to address safety concerns of consumers and stakeholders (Purnhagen and Wesseler, 2021; Purnhagen et al., 2023).

Irrespective of the protein source, food affordability and access remain critical concerns, strongly influenced by price volatility in other sectors, notably energy. Food chain bottlenecks stemming from the asymmetric exit from COVID-19 pandemic, coupled with pre-existing tensions in energy markets and the subsequent war in Ukraine, have led to the combination of high energy and food prices that put food affordability and access in Europe under pressure for low-income households. This is exacerbated by underlying trends of increasing income inequality within the EU. Poor(er) households suffer the most from rising food and energy prices. Addressing their food insecurity requires dedicated social policies aimed directly at alleviating poverty and ensuring access for low-income households., which in turn would increase the demand for agrifood products.

3.2 Non-food bioeconomy

There are many biomass uses outside food that could raise employment and income in rural areas, contribute to soil and water quality through more diverse crop rotations, reduced fertiliser runoff, and the use of perennial and cover crops, reduce dependency on fossil fuels and enhance human health by replacing harmful synthetic chemicals and reducing pollution exposure.

Traditional non-food uses include biomass for energy (e.g. wood), construction (e.g. insulation materials, panels and boards), textiles (e.g. cotton) and cosmetics and personal care (oils, waxes, extracts). Next to this there are bioplastics, (platform) chemicals and biobased materials where biomass can replace fossil inputs. Attention is also needed for biochar (soil enhancement, water purification, and pharmaceuticals (active compounds, extraction from plants for medicines, supplements, or herbal remedies). However, as highlighted in the EEA's Biomass Puzzle report (EEA, 2023d), there is not enough sustainably available biomass in the EU to meet projected demand across all sectors without trade-offs. This underscores the need to prioritise high-value uses, improve circularity, and reduce waste to alleviate demand pressures.

The EU is one of the technological leaders in the bioeconomy, and the sector represents new income opportunities for agriculture and the economy as a whole. The economic potential of biomass supply from agriculture and forestry needs to be carefully assessed, taking into account the potential conflict with food security and environmental sustainability. The EEA (2023d) notes that while progress is being made towards bioeconomy goals, environmental challenges (such as overexploitation and land-use competition) persist.

The agricultural and forestry sector currently supplies 2% of EU energy use and thus contributes to EU energy security. However, the energy demand of human society is large compared to other demands, and this demand can only be marginally provided by biomass as feedstock; this counts not only for electricity (power) generation but also for transport fuels (Bos and Broeze, 2020).

As climate change mitigation efforts intensify, the demand for biomass as a substitute for fossil fuels is also expanding into areas such as chemicals and materials (mostly plastics). The volume of biomass needed to phase out oil in these applications is much smaller than for power generation or transport fuels (Bos et al., 2024). Moreover, in these applications, the carbon atom is used as a building block and is thus embedded in the product, therefore providing a carbon sink during the lifetime of the product.

A study by the Renewable Carbon Initiative (RCI) and the Bio-based Industries Consortium (BIC) indicates that by 2050, sustainably sourced agricultural and forestry biomass could supply at least 20% of the carbon feedstock required by Europe's chemicals and materials industry without compromising food security (Carus et al. 2025). Advanced agricultural technologies, including artificial intelligence, precision farming, drones, and genetically modified organisms, have the potential to increase this contribution up to 40%.

In the Berkhout et al. (2024) approach, non-food (materials and chemicals) are considered as direct human consumption (based on the assumption that it is also primary human demand or basic human needs), even if you do not eat it, and these can be produced both from unused side streams of food production processes and from direct cultivation. By-products of cultivation for non-food production can still go to livestock farming. Since for materials and chemicals it is especially carbohydrates that are a suitable feedstock, these by-products are mainly proteins and thus suitable for livestock feed. So, there can also be synergy effects as, for example, a split between protein and carbohydrate by the production of plant-based protein leads to higher availability of carbohydrates.

The EU's commitment to the bioeconomy is evident in its research and innovation initiatives, which promote the development and deployment of bio-based products and processes. These efforts are integral to achieving zero pollution and climate neutrality by 2050, in alignment with the European Green Deal objectives. However, it is crucial to carefully assess the economic potential of biomass supply from agriculture and forestry, considering potential conflicts with food security and environmental sustainability.

According to the IEA (2021), clean energy technologies vary widely in mineral intensity, and bioenergy generally has lower critical mineral demands than solar PV or electric vehicles. The European Commission's Critical Raw Materials Act aims to ensure a secure and sustainable supply of critical raw materials, supporting the EU's climate and digital objectives.

3.3 Digital economy

Digitalization and its associated technologies in agriculture promise a profound transformation in food production and supply chain management. Converging technologies, including AI, the Internet of Things (IoT), robotics, blockchain, and big data analytics, are reshaping farming practices and offering novel solutions to persistent challenges in the sector by enhancing efficiency, sustainability, and transparency.

The digital transformation of the agrifood sector, when properly harnessed, enhances resource efficiency, e.g. through the precise application of water, fertilizers, pesticides, and antibiotics. This targeted approach can reduce input costs and environmental impacts while also enhancing resilience and agricultural productivity. Resilience is strengthened through early detection of nutrient deficiencies, water stress, pests, and extreme weather risks, allowing for timely corrective actions. It also reduces dependency on scarce or volatile inputs like water, fertilisers or antibiotics, increasing farms' ability to cope with shocks such as droughts or disease outbreaks.

Digitalization in agriculture also holds substantial potential for streamlining administrative processes, particularly those related to governmental reporting, subsidy allocations, and payment procedures. Using integrated digital systems, the agricultural sector can further transition from paper-based, manual processes to automated, data-driven workflows, thereby reducing administrative burdens for both farmers and regulatory bodies.

Two key aspects link digitalization and public monitoring: (1) Public authorities may promote adoption by rendering the use of a digital farm book mandatory for farms above a certain size, thereby accelerating both uptake and technical progress. (2) At the same time, digital technologies can be used to measure environmental outcomes more precisely, supporting the transition towards result- or impact-based payments. This dual potential increases the legitimacy and transparency of CAP expenditures.

Digital platforms can automatically collect data from multiple sources to generate comprehensive reports, minimising human error and reducing the time farmers spend on compiling and submitting documentation. Advanced digital systems can, for example, integrate financial management with regulatory compliance. Cloud-based platforms further enable the consolidation of administrative tasks, such as tax filings, subsidy claims, and payment tracking, within a single interface. This integration reduces duplication and improves data consistency. Furthermore, it could also enable a shift from retrospective reporting to real-time compliance monitoring, potentially accelerating payment cycles and reducing administrative delays. By automating routine tasks, digital tools can reduce the labour and resources required for data collection, reporting, and validation. This reduction benefits individual farmers by lowering operational costs and allows state agencies to reallocate resources towards more strategic functions rather than routine data processing.

A recent report presented by the World Economic Forum (2025) highlighted the gap in private investment in the EU compared to the US in R&D for modern technologies, such as AI, earth observation, cloud computing, and next generation software development. This gap amounted to EUR 451 billion annually in 2022. This broader investment gap in digital innovation may appear to contrast with observed growth in EU agri-food R&D, particularly in areas like precision agriculture. However, these trends are not contradictory: targeted investments in agricultural innovation have occurred, but overall private investment in the underlying digital technologies remains insufficient. The agricultural sector has led innovation in related areas also in the past, including earth observation, precision farming, and drones. If redirected to incentivize the adoption of modern technologies, the annual CAP budget of EUR 50 billion alone could provide substantial resources for R&D. These resources could be complemented by public procurement of digital systems for monitoring and reporting, and together with additional direct R&D funding would substantially contribute to closing the R&D investment gap. Innovations from the agricultural sector would spill over into other sectors of the economy and could thus provide non-negligible contributions to enhanced economic growth.

However, substantial challenges to realise the digital transformation of the EU agrifood chain and maximize its benefits remain. Advanced digital tools require substantial upfront investments, which creates a significant financial barrier, particularly for smallholder farms and regions with limited access to credit. Centralised data collection raises concerns about ownership, privacy, and ethical use, which requires new governance frameworks that balance innovation with farmers' rights. One significant obstacle is the prevalence of heterogeneous data formats and systems, where the integration of data from various sensors, legacy equipment, and modern IoT devices is hindered by specific and uncoordinated data formats and structures. The rapid evolution of digital tools outpaces the current skill sets of many farmers, leading to underutilization or misapplication of available technologies. Major obstacles prevail also for the administrative simplification, particularly concerning privacy, data ownership, and security.

4 Priority action areas

In this section, we propose five Priority action areas (PAA) to untap the economic potentials together with food security and environmental sustainability. Each of them broadly corresponds to one of the five agriculture-related economic sectors discussed in Section 3 – namely (primary agriculture, farm input suppliers, food processing and retail, non-food bioeconomy, and digital economy. For each PAA, a coherent set of measures involving policy interventions and innovations is presented with focus on measures for which our research projects can provide relevant impact assessments. Priority is given to the measures expected to contribute to multiple areas simultaneously.

The proposed PAAs are put forward in the following sections.

4.1 Fostering income and resilience through result-based policies

Reducing the ecological footprint of EU agriculture requires that the measures adopted do not undermine farm viability and resilience, while also minimalizing administrative burdens. The EU must leverage all available sources of productivity, including precision agriculture, advanced breeding technologies, and digital technologies, provided that they are sustainable on climate and environmental criteria. Result-based approaches may allow for more flexible, performance-driven compensation systems, which, if properly designed, can enhance farm income while rewarding the provision of public goods.

The increasing maturity of environmental monitoring solutions has the potential to shift environmental policies from a focus on commitments to means (practices), compliance with standards, and compensation for income losses, to a focus on commitments to results (impacts), incentives, and payments proportional to services provided. However, result-based schemes should be applied selectively and pragmatically. For some areas, such as carbon sequestration or biodiversity outcomes, reliable measurement systems already exist or are emerging. In other areas, such as nitrous oxide emissions or livestock methane mitigation, technical and economic monitoring limitations may require continued reliance on well-calibrated practice-based proxies or hybrid approaches. Policymakers should prioritize cost-effective instruments tailored to the environmental objective in question, rather than adopting a one-size-fits-all model.

Result-based payments introduce also an element of uncertainty, as environmental results can be influenced by weather conditions and other elements beyond farmers' control. Risk mitigation measures or smoothing mechanisms could encourage farmers to use result-based payments. Such schemes also open avenues for payments not only from public funds but also from private actors, like food companies or energy providers, who have a stake in reducing climate and biodiversity impacts along the value chain.

To promote a more sustainable and resilient agricultural sector, several potentially conductive policy measures should be considered. One foundational approach involves the use of sustainable benchmarking at the farm level to identify priority action areas and guide targeted improvements. While benchmarks are not a substitute for direct measurement, they can complement monitoring efforts by providing performance thresholds and reference levels for comparison once reliable data are available.

Additionally, policies should support a broad range of technologies, including Artificial Intelligence (AI), that facilitate automated monitoring systems. These technologies can enhance data collection and analysis, enabling more effective result-based remuneration systems that directly reward environmental performance or support multi-tiered practice-based estimations (e.g., Tier 1, 2, 3 approaches), which approximate environmental effects with increasing precision. Finally, developing markets for environmental services—such as nature farming—or integrating agriculture into existing markets like carbon farming, can provide additional income streams for farmers while incentivizing the delivery of ecosystem services.

Improved competitiveness and resilience can be achieved through targeted policies and diversification of income sources within the primary agricultural sector. This includes that payments are directed into areas with minimal trade-offs between environmental outcomes and agricultural production, or possibly with co-benefits for agricultural production. While identifying areas with low trade-offs or high co-benefits between production and environment is context-specific and often challenging, even partial win-wins (such as more efficient nutrient use or better water retention) can increase system resilience. The goal should be to direct payments where environmental improvements can be achieved cost-effectively without severely compromising productive potential.

4.2 Integrated nutrient management to enhance strategic autonomy

Nitrogen and phosphorus pollution represent central environmental challenges confronting the EU. Overuse of nutrients in agriculture damages ecosystems and contributes to contamination of drinking water. At the same time, reliance on synthetic fertilizer imports is one of the most critical dependencies of the EU agricultural sector, while its productivity and competitiveness rely on affordable nutrient inputs. Addressing these complex and interconnected challenges requires a set of coherent measures regarding technologies, legislation, management practices, and policies. As a central strategy, integrated nutrient management (INM) practices and technologies offer a range of complementary measures with multiple co-benefits. Key components of INM include: (i) reduction of fertilizer needs by increasing the share of biological nitrogen-fixing crops in crop systems (legumes such as lentils, peas, soyabeans, etc.), (ii) enhancing fertilizer use efficiency through the use of decision-support tools and precision agriculture technologies, (iii) substituting synthetic fertilizers with organic alternatives from agricultural and non-agricultural sources, including through methanisation, (iv) developing novel approaches to manure recycling, including systems enabling their transport, or that of their processed products, over long distances, and (v) expanding the European supply of mineral fertilizers, including green fertilizers produced using alternative energy sources, such as hydrogen-derived energy, instead of relying on natural gas.

To support a transition towards INM and reduced dependence on imported nutrients in agriculture, several enabling policy measures can be considered. One approach is the taxation of mineral nitrogen fertilizer use, as an incentive to reduce excess nitrogen use, though this would hit both efficient and inefficient users alike. Promoting protein crops is also a measure which is relatively easy in terms of monitoring. More challenging monitoring is needed for a taxation of nutrient losses at the farm level. In both cases, revenues could be redistributed to farmers in a decoupled way. Another key area is the adoption of decision-support tools and precision fertilization technologies, which help optimize fertilizer use, reduce environmental impact, and increase efficiency. While stronger economic incentives or obligations may spur resistance by farmers, a balanced approach, incorporating both incentives and regulations, is necessary. The development of a European supply of green fertilizers should be prioritized as part of the EU's broader reindustrialization strategy, helping to reduce reliance on imports and lower emissions. Finally, policies should support the shift to non-fossil energy sources for fertilizer production, aligning agricultural inputs with the EU's climate and energy goals.

This PAA will contribute to EU food security by decreasing synthetic fertilizer needs and imports. It will have a positive impact on the climate and environmental footprint of EU agriculture and will create economic opportunities by optimizing fertilizer use. Manure recycling can also be an opportunity of additional income for livestock producers, contingent on advancements in processing technologies to facilitate cost-effective manure transport between farms. The development of a European supply of fertilizers close to farms would also generate employment opportunities in rural areas.

4.3 Enhancing the agrifood sector competitiveness and food security through level-playing field trade agreements

The EU agrifood sector strongly benefits from export opportunities, thereby also strengthening the EU's geopolitical role. Consequently, the EU should engage in the further development of bilateral and multilateral trade agreements. At the same time, ensuring fair competition on international markets requires vigilance regarding regulatory asymmetries. While the EU already applies its food safety and certain animal welfare standards both to domestic production and imports, there remains ongoing debate around the legal and practical feasibility of extending such requirements to production processes more broadly. Characterising competition from goods produced under different regulatory frameworks merely as illicit oversimplifies this multifaceted problem. Thus, attention needs to be directed at mechanisms – consistent with WTO rules and international obligations – that allow the EU to preserve its regulatory autonomy without undermining the principles of open trade.

Establishing a level playing field on international markets requires carefully calibrated policy measures and could be approached by a combination of trade measures and supportive domestic policies. Further bi- and multilateral trade agreements to diversify trade relationships and create new opportunities for EU agricultural products can embed sustainability provisions, improve regulatory cooperation, and foster mutual recognition where feasible. However, the use of non-tariff measures (NTMs) to align import conditions with EU domestic standards is a contentious area. Imposing EU domestic standards broadly on all imports, particularly when potentially motivated by protectionist intentions, risks contravening WTO principles and could exacerbate global trade fragmentation. Such an approach disregards the legitimate diversity in national regulatory priorities, which may come from differing development stages, resource endowments, or societal preferences, analogous to variations in labour costs or other factor endowments. While trade restrictions may be justifiable in specific, narrowly defined circumstances, broad demands for reciprocity in standards, particularly those not yet underpinned by international consensus, warrant considerable caution due to their potential for misuse, disguised protectionism and retaliation.

Addressing the cost disadvantage potentially faced by EU farmers due to stringent regulations on environmental protection, human health, animal welfare, plant health, and food safety requires a nuanced approach. Policy responses designed to mitigate these disadvantages need to prioritize measures with minimal trade distortions. This could include targeted domestic support for sustainability transitions that help maintain competitiveness on domestic markets while upholding the EU's high standards, rather than broad compensatory tariffs or across-the-board mirroring requirements that could trigger retaliatory spirals and undermine the multilateral trading system.

Ultimately, fostering the competitiveness and sustainable growth of the EU agrifood sector, without compromising its established high standards, is integral to ensuring food security both within the EU and globally. However, this needs to be done within a framework that respects international trade law and acknowledges the diversity of global production systems.

4.4 Strengthening innovation leadership in the new bioeconomy

Food demand in the EU is stabilizing and for some products even declining. However, given ambitious climate mitigation targets the demand for biomass for non-food uses, such as materials, chemicals, and bioenergy, will become the dynamic sector, in which the EU has still a technological leadership. The challenge will be to maintain this leadership while ensuring that biomass production is ecologically sustainable and resilient to climate change. As illustrated earlier, the bioeconomy must balance food security and non-food biomass needs. One example of such synergies is the valorisation of carbohydrate-rich by-products from protein extraction for use in materials and chemical sectors.

To create new markets for agricultural products, several policy measures can be put in place. These measures include supporting research and development (R&D) to stimulate innovation and broaden the range of economically viable biomass applications. Encouraging the sustainable collection and use of crop residues (while taking into account potential trade-offs with soil carbon, fertility, and biodiversity) and food waste, can help supply raw materials for emerging sectors like bioplastics and biomaterials. Developing robust systems for carbon credits can also create new income opportunities for farmers who adopt climate-friendly practices. While carbon markets are not exclusive to the bioeconomy, linkages exist when payments are based on biomass production methods or land-based sequestration (e.g. agroforestry or soil carbon retention).

The EU and many Member States already have bioeconomy strategies, but their effectiveness remains uneven. Many fail to prioritise between competing biomass uses or to set clear sustainability safeguards. Strengthening these strategies requires clearer objectives regarding the cascading use of biomass, improved monitoring of biomass flows, and integration with biodiversity, circular economy, and LULUCF policies. Without such cross-sectoral coherence, the bioeconomy risks to undermine its own resource base.

The EEA's 2023 "European Biomass Puzzle" report warns that the EU's policy ambitions may exceed the sustainable supply of biomass available from EU land. If policy incentives increase biomass demand across sectors — e.g. for energy, chemicals, and construction — without coordinating priorities, this could result in land use conflicts, reduced biodiversity, carbon sink degradation, and threats to food security (if prices rise). Climate risks, such as droughts and forest damage, already threaten biomass supply in parts of southern and central Europe.

Policy therefore needs to focus more clearly on enabling innovation within the ecological limits of biomass supply. This includes:

- Scaling up circular and cascading use of biomass, especially for wood materials, where reuse and recycling can reduce primary demand.
- Promoting regionally adapted biomass production systems that account for ecosystem fragility and climate resilience.
- Investing in advanced biorefineries and precision fermentation technologies to increase resource-use efficiency.
- Targeting subsidies and R&D funds to reduce reliance on imports of critical raw materials (e.g. phosphate-based fertilizers) and fossil-based inputs.

The bioeconomy also offers a strategic advantage for EU technology exporters, including machinery, enzymes, digital solutions, and biorefinery equipment. This sector can provide a new source of income for farmers and contribute to reducing critical dependencies on fossil energy-based products.

Finally, innovation leadership in the bioeconomy requires better data and coordination. A significant share of biomass flows (especially unreported wood and crop residues) remains poorly monitored. Strengthening data infrastructures and forward-looking modelling is essential to manage the trade-offs between carbon removals, material substitution, and ecosystem health.

4.5 Democratizing digitalization to ensure agricultural sector attractiveness and technological innovation

Digitalization has a great potential to transform the agricultural sector into a more attractive, profitable, and environmentally sustainable business. By improving competitiveness and environmental performance, and lowering administrative burdens, digital technologies can enhance the overall performance of the agrifood sector. Moreover, agricultural digitalization can also make a substantial contribution to innovation in the digital economy itself. However, the digital transition also bears risks of favouring the already well-off large farms at the expense of smaller farms, thus contributing to homogenization of agrifood products, potentially without respecting the diversity and cultural specificity of the European way of life/eating. Additionally, without the EU-based technology providers catching up, the sector risks developing new dependencies on imported digital solutions. Therefore, a coordinated EU approach to digitalization is required, one that will not only support a thriving agrifood sector but also generates substantial spillover effects across the broader digital economy.

To boost the adoption of digital technologies in farming, several key policy measures need to be put in place. The facilitation of cooperative models, where farmers share investments in digital infrastructure and technology services, alongside government funding programs or subsidised technology adoption, can mitigate the challenges of large upfront investments. Furthermore, modular and scalable digital solutions allow farms to start small, with the option to expand as benefits become evident. Infrastructure investments, such as ensuring broadband access in rural areas, remain necessary. EU must provide regulatory frameworks with clear guidelines on data ownership, privacy, and security. The EU also needs to provide a supportive regulatory framework that incentivises open standards and penalizes fragmentation and overly restrictive proprietary practices, establishing regulations that promote data portability, uniform communication protocols, and modular system design. Capacity-building programmes need to be implemented to provide targeted training and extension services to improve digital literacy among farmers. Furthermore, digital advisory services offering real-time guidance and troubleshooting are essential to accelerate technology adoption. Pilot projects that integrate financial management, compliance, and reporting functions could provide valuable proof-of-concept, demonstrating the feasibility and benefits of broader adoption.

4.6 Priority areas and policy linkages

The key policy measures outlined in the priority areas above represent only a selection from a broader spectrum of potential interventions put forward in DG AGRI's Vision for Agriculture and Food (European Commission 2025c). The Vision's policy interventions cover a wide area of political objectives, including making agriculture an attractive sector, ensuring a fair standard of living, and leveraging new income opportunities. It also envisions a competitive and resilient agricultural sector in the face of global challenges, future-proof, working hand in hand with nature, valuing food, and fostering fair living and working conditions in vibrant rural areas. Specific interventions include, for instance, the more effective targeting of direct, area-based payments, introducing nature credits, promoting carbon farming, reducing nitrogen surpluses, or supporting the cultivation of strategic crops. The Vision also underscores the importance of the bioeconomy, particularly the use of non-food biomass.

Most policy interventions are related to more than one of the PAAs proposed above. For instance, carbon farming can both create alternative income streams for farmers (PAA1) and enhance the sector's international competitiveness on internation markets (PAA3), when supported by measures like the Carbon Border Adjustment Mechanism (CBAM). Similarly, carbon farming can play an important role in the development of the bioeconomy by incentivising the production of biomass input materials. **Table 1** presents a non-exhaustive list of policy interventions discussed above and in the DG AGRI Vision (European Commission, 2025c) and how they relate to our research projects. An 'x' indicates alignment between each policy intervention and the relevant PAA.

Beyond their cross-cutting nature, certain measures may also yield synergistic benefits, simultaneously advancing multiple policy objectives. Others, however, may involve inherent trade-offs. A prominent example is the support for non-food uses of agricultural outputs in the bioeconomy, which can conflict with goals related to food and nutrition security.

Furthermore, beyond the synergies and trade-offs associated with individual policy measures along the agri-food supply chain, careful consideration must be given to the cost-effectiveness and efficiency of these measures in achieving their intended outcomes. A nuanced understanding of implementation costs and systemic impacts is essential to establish appropriate and enduring incentives for farmers and other actors within the agri-food system.

Table 1. Contribution of the research projects to policy interventions impact assessment

Policies	Priority Action Areas (PAAs)					Projects
	PAA1	PAA2	PAA3	PAA4	PAA5	
Carbon and nature farming	x		x	x	x	B,L,A
Sustainable benchmarking	x	x			x	B,L,A
Support for strategic crops	x	x	x	x		B,L,A
Innovative agro-environmental practices	x				x	B,L,A
Support AI solutions for environmental monitoring	x				x	B,L,A
Farm-level nitrogen surplus taxation		x				B,A
Support for adoption of precision farming		x			x	B,A
Per area payments for nitrogen fixing crops		x				B,A
Energy price subsidies for fertilizer producers		x				B,A
Bilateral trade agreements, NTM			x			B,A
Support for R&D				x	x	L, B
Support for collection of crop residues and food waste				x		L, B
Carbon credits	x			x		L, B
Capacity building and support for adoption for small and medium size farms/enterprises					x	B
Support to R&D					x	B

Legend:

A: ACT4CAP27, B: BrightSpace, L: LAMASUS, x: connection between policy and enabler strategy

Research activities that assess the effects of both existing and novel policy instruments, management practices, and technological innovations should explicitly account for interactions and cross-effects. A strong example of such integrated research is provided by three ongoing Horizon Europe projects: LAMASUS, BrightSpace, and ACT4CAP27.

BrightSpace explores the synergies and trade-offs between socio-economic and environmental outcomes of agricultural policies and technologies, framed within the concept of a Safe and Just Operating Space (SJOS).

ACT4CAP27 takes a comprehensive food systems approach, aiming to strengthen analytical capacity for assessing the impacts of forthcoming agri-food policies within the CAP after 2027 regarding socio-economic and environmental sustainability.

LAMASUS focusses on land use, developing an innovative modelling system to anticipate potential effects of agricultural and forestry policies. While thematically related, each project maintains a distinct focus.

Their ongoing collaboration facilitates mutual learning and cross-fertilization of insights. In particular, their joint efforts on baseline projections and the development of workflows for exchanging spatial and statistical data — as well as research findings — have proven mutually beneficial.

5 New model development needs

The three research projects — ACT4CAP27, BrightSpace, and LAMASUS — share a model toolbox that forms the analytical core of their work. This common foundation enables a coherent and synergistic approach to policy assessment, enhancing overall capacity to address complex and interrelated challenges in agricultural, environmental, and social systems.

Each project has introduced new developments that significantly expand the analytical capabilities of the shared toolbox. ACT4CAP27 (launched in 2024) aims, among others, to provide deeper insights into upcoming agri-food policies and their sustainability impacts, including the social (including health) outcomes of CAP measures, along with more detailed analysis of interactions between primary agriculture and other segments of the food value chain. BrightSpace aims to cover the safe and just operating space of EU agriculture and has improved the alignment between biodiversity-friendly practices and biodiversity indicators, enhanced the integration of remote sensing data, refined crop-yield responses to nitrogen application, and incorporated new indicators for animal welfare. It also devotes significant resources to improving modelling of adoption and impacts of digital technologies, including precision farming. LAMASUS has advanced the modelling of land management dynamics, their drivers, and their environmental and economic impacts supporting more integrated assessment across different land use sectors at various spatial scales.

The developments in the shared model toolbox have significantly expanded the scope of policy analysis, enabling assessments that were previously unattainable. The models can now illustrate not only economic trade-offs — such as those between producer and consumer prices — but also the complex interactions between economic, societal, and environmental objectives. This is especially relevant given the high diversity in environmental, social, and economic conditions and objectives across Europe. However, adequately reflecting this heterogeneity requires a high level of model detail, which is usually constrained by inherent structural rigidities and limitations of the existing models. For example, while global CGE models like MAGNET are valuable as they include the links between agrifood and the rest of the economy, including a full loop between (production factor) income and expenditures, they lack the commodity-specific detail of sector models like CAPRI or AGMEMOD, or the production and environmental granularity of farm-level models like FarmDyn, and the comprehensiveness and detail of environmental performance assessment like GLOBIOM. Expanding the level of detail across all models is neither feasible nor conceptually desirable. A more effective approach lies in focusing on the comparative advantages of each model within coordinated frameworks, fostering coherence through cross-model harmonization and parameterization, allowing each model to benefit from the results of other modelling teams. This approach preserves model diversity while improving interoperability and the robustness of policy insights.

Notwithstanding the synergies and advancements achieved, important gaps remain. Key areas, such as trade competitiveness and the diversification of the emerging bioeconomy sector, are not sufficiently covered. This underscores the need for further methodological innovation, comprehensive data development, and enhanced interdisciplinary integration to meet the demands arising from the next generation of policy challenges. This is especially important to further provide comprehensive assessments of policy actions taken in the context of the PAAs presented in the previous chapter. We identified six model improvement areas, which would allow to comprehensively assess the PAAs in the new geopolitical context. The identified model improvement areas are interconnected and can relate to several PAAs simultaneously.

First, on the supply side, **strengthening the connection between agroeconomic and environmental modelling** by enhancing the integration and mutual processing of spatial input and output data. There is a need to better represent the jointness that exists between economic and environmental outcomes at the farm level. While economic parameters, for example expressed in the form of output and input prices or yields, are well represented as they form the basis of agri-economic models, other factors that are central to the interaction between production output and environmental footprint are less well captured. These factors reach from the valuation of ecosystem or environmental services (e.g. carbon\nature farming), the impact of practices on soil health to the nuanced influence of changing climate on agricultural systems. The wealth of information, facilitated by automated (AI-driven) monitoring systems, that is available on **spatial data**, primarily for soil, but also where accessible for water or biodiversity metrics, offers a promising basis for model improvements in this regard. The almost real-time model-data fusion would also improve **accountability** within agricultural policies.

Second, elements of **Integrated Nutrient Management** have to be enhanced in the modelling toolbox. This includes the production and adaptation of green fertilisers, the use of precision agricultural technologies, and the adoption of (manure) **circularity** practices. These measures, by effectively reducing nutrient losses also through recycling, can largely reduce environmental impacts. It is striking how rudimentary the representation of the **livestock** sector remains in current large-scale economic models. An enhanced representation of the livestock sector and proper integration with the crop sector is also key for integrated nutrient management assessment. Beyond farm-level cycles, the broader nutrient cycles, including food waste and human excreta, require also explicit modelling and closure.

Third, at the global level, the interaction between supply and demand through **trade** forms one of the most essential elements of market clearing. Traditionally, the impact from subsidies and tariffs was sufficient to analyse the impact of changes in the trade regime. However, the increasing interaction between economic, environmental, and social dimensions of agri-food activities generates policy recommendations that are not easily represented in current models. How to incorporate not only the set of **emerging non-tariff measures**, but also the use of tariffs as **"reciprocal" or retaliatory means to impose domestic policy priorities** on international trade, constitutes a modelling challenge that, while difficult to analyse, needs to be identified and addressed.

Fourth, at a systems approach level, a further improved modelling of food systems is required, including the **full integration of the agrifood sector into the broader bioeconomy**, incorporating a more explicit and systemic representation of upstream- and downstream- linkages and their associated multiplier effects. This entails enhanced modelling of the dynamic interactions between agricultural production and the evolving food and non-food demand for bio-based materials, bioenergy, biobased-chemicals, and biobased-pharmaceuticals. Attention must also be given to the enhanced options offered by advancements in biotechnology to balance crop production in relation to diverse societal needs, alongside a robust analysis of imperfect competition and price transmission and employment effects across the entire value chain.

Fifth, also on the supply side, there is a compelling need to **further endogenise knowledge and innovation processes,** including the role of **digitalisation.** Technological change has a critical role as an essential engine of supply-side transformation. A more comprehensive analytical framework requires detailing the entire process, from R&D to innovation and adoption, critically including national and international knowledge spillovers. Such an enhanced understanding would not only render the modelling frameworks more robust in assessing long-term competitiveness but also enable better analysis of the systemic impacts of potentially transformative technologies, such as digitalization and biotechnology, the latter being particularly relevant also to the emerging bioeconomy.

Finally, two cross-cutting issues need attention. On the demand side, the potential impact from **changes in consumer behaviour** is often identified as essential in the path towards sustainability (in terms of safe and healthy diets but also including the environmental dimension). Yet also too often, the impact of such changes rests upon broad assumptions, with price and income factors expected to play a major role in shifting consumer behaviour. However, food consumption patterns are to a considerable extent also rooted in culturally influenced tastes and preferences, rendering them prone to resistance to change. The rich literature on nudging behavioural change, as well as broader research on consumer behaviour, including demographic patterns, could shed some light on whether and to which extent the present models could be adapted to better represent the potential impact of demand-side transformations on food markets and agricultural production.

On the supply side, **climate change adaptation** needs to be integrated into the economic models used for policy impact assessments. European farmers are already strongly affected by climate change, particularly by extreme weather events, and these impacts will further deteriorate in the coming years. At the same time, the standard policy impact assessments and outlook exercises (OECD/FAO 2024, European Commission 2024d) ignore climate change entirely, or at best consider only the gradual shifts in average climatic variables. New methodologies need to be developed to mainstream climate change impacts, including extreme weather events, into these assessments. Similarly, while substantial efforts have been dedicated to the analysis of various climate change mitigation efforts, including their associated economic cost, climate change adaptation strategies typically default to standard mechanisms, such as international trade. Explicit modelling of dedicated adaptation options is needed to capture their potential role in shaping supply-side responses.

In conclusion, the integrated modelling approach developed across ACT4CAP, BrightSpace, and LAMASUS represents a major advancement in policy-relevant analysis. The three Horizon Europe projects are well-positioned to assess the economic, social, and environmental impacts of policy measures within the five priority action areas outlined in this perspective paper. Nonetheless, further conceptual refinement, empirical integration, and cross-model alignment are essential to further enhance the toolbox's capacity to inform policy decisions in an increasingly complex and dynamic agri-food system.

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Sustainable agricultural sector: A key component of EU economic prosperity and security

An economic modellers' perspective

This joint paper, authored by leading economic modellers from the Horizon Europe projects ACT4CAP27, BrightSpace, and LAMASUS, presents a compelling case for placing a sustainable agricultural sector at the heart of the European Union's future prosperity and strategic autonomy. Arguing that "business as usual" is no longer an option, the paper outlines how agriculture, while only a small portion of the EU's GDP, underpins a vast and complex agri-food and bioeconomy network with significant multiplier effects. The authors stress, in line with the Draghi report that renewed political and investment efforts are needed to boost innovation, competitiveness, food security, and environmental resilience across the sector.

The paper introduces five Priority Action Areas (PAAs): fostering farm resilience through result-based policies, integrated nutrient management, boosting agri-food competitiveness through fair trade, leading innovation in the bioeconomy, and democratising digitalisation to ensure sector-wide inclusion. Each area is grounded in the premise that sustainable practices and technological advancements can drive both economic and ecological gains. The authors also underscore the urgency of maintaining the EU's global leadership in high-value food production while reducing critical dependencies on imported inputs like fertilisers and digital technologies.

Drawing on decades of experience in model-based policy assessment, the paper calls for a new generation of economic modelling tools to support the Common Agricultural Policy (CAP) and broader EU strategic goals post-2027. These include better integration of environmental and economic data, representation of nutrient cycles, full bioeconomy integration, modelling of innovation dynamics, and deeper analysis of shifting consumer behaviours and climate change adaptation. The collaboration among ACT4CAP27, BrightSpace, and LAMASUS exemplifies how research can offer rigorous, science-based insights to support policy design in an increasingly complex agri-food landscape.

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