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Closing the EU protein gap – drivers, synergies and trade-offs

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Contents

Abstract

The policy and public debate on the EU protein sector requires a comprehensive approach that includes EU plant protein production and supply, while simultaneously addressing the broader challenges and opportunities of protein demand in the food and feed sectors. Taking a food systems perspective, this report assesses synergies and trade-offs between four hypothetical scenarios. These scenarios are considered both individually and in combination, and describe possible futures for EU protein supply and demand: (i) providing specific support for protein crop production; (ii) changing livestock feed practices; (iii) restructuring the livestock herd; and (iv) transitioning towards more plant-based diets. While these scenarios are exploratory and do not prejudge policy decisions, the analysis demonstrates that joint changes on both supply and demand are required to enhance the sustainability and resilience of the EU agro-food system. The modelling results indicate that jointly addressing protein supply and demand can yield substantial environmental benefits and reduce the EU's reliance on imported feed protein. An integrated strategy is also essential to support farmers and the broader food system, realising opportunities and mitigating potential adverse impacts associated with the transition to a more sustainable protein supply and demand.

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1 Introduction

The policy and public debate on the EU protein sector requires a comprehensive approach that includes EU plant protein production and supply and that, simultaneously, addresses the broader challenges and opportunities of protein demand in both the food and the feed sectors. This JRC technical report provides analytical support to this debate through the analysis of four hypothetical yet realistic scenarios, which form the core of this document.

In this introductory section, we establish the context for the analysis of a sustainable and resilient EU protein transition. We outline the key aspects of EU protein demand for both feed and food, highlighting the critical issues associated with achieving sustainable EU protein supply and demand within the broader framework of a more sustainable EU food system. Chapter 2 details the methodological framework, comprising the agro-economic partial equilibrium model CAPRI and the farm-level model IFM-CAP, along with the outlines of the scenario settings. Chapter 3 provides a comprehensive analysis of the scenario results, while chapter 4 draws conclusions based on the assessed scenarios, evaluating their implications for a sustainable and resilient protein transition within EU agriculture.

1.1 EU protein demand for feed and food

A central challenge is the EU's substantial reliance on imported high-protein animal feed. Out of the 71 million tonnes of crude protein used for feed in the EU livestock sector, 24% is imported. Roughage (grass, silage maize, fodder legumes, and dried fodder) provides the bulk of feed protein, contributing approximately 41% to the total. Characterised by low to medium-protein content and high self-sufficiency within the EU, roughage is primarily suited as feed for ruminants and is less applicable for pigs and poultry. High-protein feed (above 30% protein content), such as most oilseed meals and certain crop co-products, plays a crucial role in optimising growth and overall productivity in animal production, accounting for 30% (21.4 million tonnes) of total EU feed protein use. However, the EU has a low self-sufficiency in high-protein crops, relying on imports for 66% of its high-protein feed requirements. Soya bean meals are the primary high-protein feed source, accounting for 17% (11.8 million tonnes) of total EU feed protein use, of which 96% is imported (DG AGRI 2024, Table 1). This import dependency is particularly pronounced in the EU poultry and pig sectors, which collectively account for approximately 67% of the total use of high-protein feed (CAPRI model database).

Table 1. Protein feed sources and EU self-sufficiency rates.

Protein source	Protein content	EU total feed use 2023/2024			
		Million tonnes	Crude protein		
			Million tonnes	% of total feed use	EU self-sufficiency
Roughage		943.0	29.0	41%	100%
– Grass	2.6%	632	16.0	23%	100%
– Silage maize	2.9%	237	7.0	10%	100%
– Fodder legumes	7.2%	73	5.0	7%	100%
– Dried fodder	17.0%	1	0.2	0%	100%
Cereals		156.9	15.2	21%	86%
– Maize	8.0%	58.9	4.7	7%	73%
– Common wheat	11.0%	45.8	5.0	6%	83%
– Barley	10.0%	31.5	3.2	4%	100%
– Others	11-12%	20.7	2.3	3%	73-100%
Oilseed meals		49.0	19.4	27%	27%
– Soya bean meal	45.5%	25.8	11.8	17%	4%
– Rapeseed meal	33.0%	13.9	4.6	6%	72%
– Sunflower meal	36.0%	6.9	2.5	3%	53%
– Other oilseed meals	16-37%	2.4	0.5	1%	15%
Others		44.0	7.8	11%	78-100%
– Other crop co-products (starch, distillers dried gains, etc.)	4-73%	30.3	4.5	6%	93%
– Non-plant sources (fish meal, processed animal proteins, etc.)	9-65%	8.3	1.9	3%	93%
– Pulses (peas, beans, lentils, etc.)	22-35%	3.9	1.0	1%	78%
– Oilseeds (without crushing)	15-33%	1.6	0.5	1%	100%
Total			71		76%

Source: Forecast from the EU Feed Protein Balance Sheet (DG AGRI 2024).

Regarding EU protein demand for human consumption, the main source of protein for human consumption currently is animal products. Between 2010 and 2021 there was a 6% increase in average animal protein consumption across EU Member States, while plant-based protein consumption decreased by 2%. These developments are noteworthy considering that dietary protein intake in the EU is generally above recommended levels. Several socio-economic factors have contributed to shape current consumption patterns, including established cultural preferences, rising disposable income enabling greater access to meat products, convenience factors influenced by marketing strategies, established supply chain structures, and the relative consumer prices of animal and plant-based protein sources. However, the EU medium-term outlook for agricultural markets up to 2035 (DG AGRI 2023) identifies several factors that may contribute to a reversal of the past patterns, with a decreasing trend in EU meat consumption, especially for beef and pigmeat, such as high prices, changing consumer preferences, health awareness, and concerns about sustainability and animal welfare.

Currently, dairy products account for the largest share of human protein intake within the EU at 24%, followed by pigmeat (14%), poultry meat (9%), cattle meat (5%), and eggs (4%). Conversely, cereals (24% of protein intake) and vegetables (5%) represent the primary sources of plant-based protein

(FAOSTAT 2024). Pulses, although accounting for only 2% of current EU human protein intake, are recognised as a crucial component of a healthy diet (EC 2024).

Animal products generally offer a comprehensive profile of essential micronutrients, including when compared to unfortified plant sources. However, the current high consumption levels of red and processed meat within the EU have demonstrably adverse impacts on human health. Meat consumption levels in many countries exceed the healthy recommendations (Clark et al. 2018, Willet et al. 2019). Red and processed meats are associated with an increased risk of various non-communicable diseases, including cardiovascular disease, type 2 diabetes, and certain cancers. Given the widespread prevalence of animal product consumption exceeding recommended levels, a strategic transition towards incorporating a greater share of plant-based protein sources appears imperative to mitigate health risks and promote overall well-being. This dietary transition should emphasise more balanced diets that encompass a greater diversity and healthier food groups, such as pulses, nuts, fruits and vegetables (Willet et al. 2019).

1.2 Challenges and opportunities related to EU protein supply and demand

The protein supply and demand dynamics within the EU are affected by numerous interconnected challenges, but they also present opportunities and avenues for fostering a sustainable protein transition in EU agriculture. In this section, we offer a brief, non-exhaustive overview of the most important issues.

The import dependency on high-protein feed exposes EU producers and consumers to global price fluctuations and supply chain vulnerabilities, as evidenced by recent geopolitical events. Furthermore, the environmental footprint of imported protein raises sustainability concerns. Specifically, soya bean trade is considered an important driver of land-use change, particularly associated with agricultural expansion and deforestation, notably in South America (Gasparri et al. 2013, Fehlenberg et al. 2017). Accordingly, increasing EU protein production and decreasing EU soya bean imports could not only reduce the EU's vulnerabilities related to animal feed import dependency, but also have positive environmental effects in the exporting countries.

A limiting factor for an increase in domestic EU protein crop production is the lower profitability of protein crops compared to other crops, and particularly the competition with established protein imports such as soya beans. Average soya bean yields in the EU are lower than those in major producing regions like the US and Brazil. This is partially attributable to climatic conditions for high-yielding soya beans production in the EU, while also stricter regulations around genetically modified organisms constrain the adoption of potentially higher-yielding varieties in the EU (Wesseler and Kalaitzandonakes 2019). Moreover, the relatively high competitiveness of cereals production in EU agriculture, due to higher and more stable yields, contributes to relatively low production levels of protein rich crops (Watson et al. 2017). In this context, incentivising domestic EU protein crop production could potentially be achieved by providing increased targeted financial support for farmers cultivating protein crops. Such increased coupled support could help to overcome the lower profitability of protein crops compared to other crops established in current mainstream EU crop rotations.

Protein crops are widely recognised as a fundamental strategy for diversifying cropping systems and promoting sustainable agriculture. An enhanced integration of protein crops like soya beans and pulses (peas, beans, lupins, etc.) in crop rotations promotes synergies between ecosystem processes, enhances the yields of subsequent crops in the rotation, and mitigates negative environmental impacts related to crop production (Lötjönen et al. 2017, Rodriguez et al. 2021, Zhao et al. 2022).

Among the main challenges facing EU protein supply and demand is that protein supply through livestock production is often linked to major anthropogenic impacts such as greenhouse gas (GHG) emissions, biodiversity loss, and nitrogen cycle acceleration (Hoekstra and Wiedmann 2014, Leip et al. 2015, Clark et al. 2019, Poore and Nemecek 2019, Willet et al. 2019). Thus, apart from being healthier than most current Western diets that predominantly rely on animal-based protein intake, a shift towards more plant-based protein diets is also associated with considerable reductions of adverse environmental impacts of the food system (Springmann et al. 2018, Poore and Nemecek 2019). For example, reducing the over-consumption of animal-based food to the maximum recommended levels would lead to considerable reductions in agricultural GHG emissions (Frank et al. 2019). In addition to being more environmentally sustainable and healthier than current dietary habits (Tilman and Clark 2014, Springmann et al. 2018, Murray et al. 2020), an increased uptake of plant-based diets is associated with enhanced air quality and reduced premature mortality, as shown by Himics et al. (2022) for the EU.

However, it is important to maintain a differentiated view when looking at the impacts of animal production, as the livestock sector, in addition to its economic and social importance (Dumont et al. 2019, Guyomard et al. 2021), can also provide environmental benefits. For example, ruminants raised in mixed and less intensive systems rely more on crop residues, by-products, or grass from land unsuitable for crop cultivation (Mottet et al. 2015, Herrero et al. 2013), thus converting these low-opportunity-cost feed resources into valuable food and manure, contributing significantly to human food supply (van Zanten et al. 2018, 2019). Such ruminant production systems also promote nutrient recycling, as the animals convert these materials into manure, which can enrich soil fertility for subsequent crops. Moreover, well-managed livestock farming can provide ecosystem services, contributing, for example, to biodiversity conservation in grasslands and maintaining diversified and open landscapes (Rodríguez-Ortega et al. 2014, Dumont et al. 2019, Guyomard et al. 2021).

The various positive services that livestock farming systems can provide have to be weighed against their negative environmental impacts and against other land uses that provide other types of benefits, such a reforestation, rewilding, or renewable energy production. Here, again, a differentiated analysis is required, considering not only one indicator in the assessment (Garnett 2016). For example, comparing poultry to beef production reveals lower GHG emissions in the former (e.g., per kilogramme of meat produced). However, poultry production relies significantly on feeding cereals that could potentially serve as direct human food sources, and thus competes for the available arable land for cereals production, while for grassland-based beef production this competition is lower.

The potential environmental services provided by livestock production are closely related to the underlying production system. While environmental benefits are often associated with less intensive livestock systems, certain intensive systems, particularly those where animal production is geographically separated from feed production, can contribute significantly more to adverse environmental impacts, including nitrogen pollution. While nitrogen is an essential building block of the entire food system, if nitrogen cycles become unbalanced with significant nitrogen surpluses, then they cause air and water pollution, degradation of soil quality, and contribute to climate change and biodiversity loss (Leip et al. 2015, 2021, Chang et al. 2021). The spatial distribution of livestock in the EU demonstrates a link between high livestock density (measured in livestock units (LSU) per hectare of utilised agricultural area (UAA)), intensified manure production, and high nitrogen pollution levels. To regulate the local environmental impacts of imbalanced nitrogen cycles, the EU has implemented policies such as the Nitrates Directive. Moreover, limiting livestock densities in agriculture is one of the strategies that could further contribute to comply with regional nitrogen surplus boundaries and reduce the environmental impacts related to intensive livestock systems (Dumont et al. 2019, Guyomard et al. 2021, van Selm 2023).

Production systems aiming to improve feeding practices, such as precision feeding and the use of feed additives tailored to the specific needs of animals, can optimise protein consumption and reduce overfeeding. In these production systems, the need for protein feed and the GHG emissions related to livestock production are generally lower (see, e.g., Pomar et al. 2019, Fellmann et al. 2021, Agrosynergie et al. 2024).

Alternative protein sources for animal feed, such as insects and algae, also show potential to reduce the EU's reliance on protein imports and emissions related to livestock production. However, especially the costs associated with their production, as well as food safety considerations, seem to require further assessments (Jensen et al. 2021, Elleby et al. 2022). Similarly, alternative protein sources for human consumption, beyond plant-based proteins, such as cell-based meat, insects, single-cell and fermented protein, need further evaluation regarding production costs, food safety, consumer acceptance, and environmental sustainability to determine their true potential as an alternative protein source and their ability to reduce the associated environmental footprint (Parodi 2018, Post et al. 2020, Rubio et al. 2020, Lähteenmäki-Uutela et al. 2021).

1.3 Reconciling EU protein supply and demand for a sustainable EU protein transition

The preceding sections have outlined key aspects and critical issues associated with a sustainable EU protein transition. The challenges and potential opportunities for market development encompass both protein supply and demand, highlighting the limitations, which a purely supply-side strategy approach would suffer from. Thus, a coordinated approach is needed to reshape and improve protein production and consumption patterns within the EU.

An integrated strategy is essential to support farmers and the broader food system in navigating this transition, realising opportunities, and mitigating potential adverse impacts associated with a more sustainable protein supply and demand. This approach aligns with the concept of food systems, which extends beyond the traditional linear perspective of agriculture and food production to encompass a broader framework that considers interconnected activities and their impacts (FAO 2018). Food systems involve diverse actors and activities across production, consumption and disposal, operating across various scales from local to global. Sustainable food systems have to align with multiple societal, environmental and economic objectives, and given the complexity of food systems, require balancing trade-offs and leveraging synergies (Ruben et al. 2021).

In this context, a sustainable protein transition in the EU, as part of the broader transition towards more sustainable food systems, requires focusing on both the supply and the demand side. Focusing solely on the supply side risks neglecting the interconnected nature of food systems. A sustainable protein supply cannot be achieved in isolation, it requires a comprehensive transformation of the entire food system, including production and consumption. This broader approach is crucial for realising the multiple objectives of a sustainable EU food system (Hundscheid et al. 2024). Accordingly, efforts to enhance EU protein sustainability can encompass a spectrum of strategies, which may range from incentivising domestic production of protein-rich crops to diversifying protein sources for both food and feed, optimising livestock farming systems, or addressing the current relative neglect of legumes in comparison to main crop types.

Building on the rationale for a sustainable EU protein transition, this report explores potential synergies and trade-offs, within a food systems approach by assessing the combined impacts of four key scenarios. These scenarios represent hypothetical outcomes introduced to the supply and the demand side, and do not reflect actual public policies, which would require their own specific and detailed analysis, thus falling outside the scope of this report. The four scenarios are: (i) increased coupled income support for EU protein crop production (i.e., incentivising domestic production of protein-rich crops); (ii) adoption of low-nitrogen-feeding (LNF) strategies for livestock (i.e., increasing protein feed use efficiency); (iii) implementation of livestock production density limits (to mitigate negative environmental impact associated with intensive livestock production systems); and (iv) transition towards more sustainable human diets (i.e., healthier dietary patterns that better align with dietary recommendations).

2 Modelling framework and scenario setting

This chapter outlines the methodological framework employed to assess a sustainable and resilient protein transition in EU agriculture. For the scenario analysis we primarily use the partial equilibrium model CAPRI, and complement it with results of the farm-level model IFM-CAP. Both models are integral components of the JRC's integrated Modelling Platform for Agro-economic Commodity and Policy Analysis (iMAP), which provides in-house policy support to the European Commission by assessing a wide range of policies and topics related to sustainable food systems (Fellmann et al. 2023, Barreiro et al. 2024). Section 2.1 describes the structure and key features of the two models, and section 2.2 outlines the background assumptions and specific conditions that define the scenarios explored within this report.

2.1 Model description

2.1.1 CAPRI

The agro-economic model CAPRI (Common Agricultural Policy Regional Impact Analysis) is a partial equilibrium, comparative static, global multi-commodity, agricultural sector model (Britz and Witzke, 2014). CAPRI operates through an iterative process, integrating two primary components: (i) highly detailed and disaggregated supply modules specific to the EU agricultural sector, and (ii) a global market model focusing on agricultural commodities.

The EU regional supply models are developed using a positive mathematical programming (PMP) approach, chosen for its capacity to flexibly capture important interactions within production activities and with the environment (Heckelei et al. 2012). Each representative regional farm model is designed to maximise profit within constraints related to land availability, nutrient balances, and policy mandates. This optimisation process lays the foundation for a thorough understanding of agricultural dynamics at regional, Nomenclature of Territorial Units for Statistics (NUTS) 2 level. CAPRI features a dedicated feed module that specifies the input allocation for feed. This allocation specifies the quantity, measured in kilograms, of various feed categories (such as cereals, rich protein, rich energy, feed based on dairy products, and other feed) or individual feeding materials (such as fodder maize, grass, fodder from arable land, straw, and milk for feeding) used per animal activity level. The input allocation for feed considers the nutrient requirements of animals and is formulated based on requirement functions. The input coefficients governing the allocation of feeding materials are carefully calibrated to ensure that the energy, protein, and other essential nutrient requirements of the animals are adequately met. Furthermore, post-implementation, these coefficients undergo evaluation to ensure congruence with regional fodder production levels and the overall demand for feed at the national level, the latter derived from comprehensive market balances.

The regional supply models are linked with a global multi-commodity model of the agricultural markets, employing a sequential calibration approach. The integration of EU agricultural supply dynamics with global market dynamics enables capturing price feedbacks resulting from simulated policy changes. The market model is a static, deterministic, partial, spatial model with comprehensive global coverage. It encompasses approximately 60 primary and secondary agricultural products across roughly 80 countries worldwide. International trade is modelled based on the Armington assumption, which differentiates goods by their place of origin, covering bilateral trade flows and establishing consumer preferences for import demand according to historical trade patterns. Moreover, bilateral import prices are derived through the consideration of trade policy measures at the border, including tariffs, tariff-rate quotas (TRQs), variable levies, and the entry-price system for fruits and vegetables. Where relevant, further market measures like public intervention and export subsidies are also implemented. This detailed modelling approach ensures a nuanced representation of international trade dynamics within the agricultural sector.

CAPRI has been frequently used to analyse the impacts of different agricultural, climate change, environmental, and trade-related policies and scenarios upon agricultural production, prices and income, trade, as well as environmental aspects. Such ex-ante impact assessments include, for example, the removal of the EU quota systems for milk (Witzke et al. 2009) and sugar (Burrell et al. 2014), possible EU trade deals (Himics et al. 2018) and trade disruption scenarios (Thom et al. 2023), climate change mitigation in the agricultural sector in the EU (Pérez Domínguez et al. 2016, Fellmann et al. 2018, Himics et al. 2020, Fellmann et al. 2021) and at global level (Hasegawa et al. 2018, Van Meijl et al. 2018, Frank et al. 2019), CAP greening measures (Gocht et al. 2017), the role of landscape features in natural pest control (Klinnert et al. 2024), dietary change scenarios (Latka et al. 2021, Himics et al. 2022, Rieger et al. 2023), and possible future pathways for the CAP (M'barek et al. 2017).

2.1.2 IFM-CAP

As CAPRI, the IFM-CAP (Individual Farm Model for Common Agricultural Policy Analysis) model (Kremmydas et al. 2022) is also a comparative static model based on a positive mathematical programming approach. However, its main difference is that the IFM-CAP model simulates the behaviour of individual farms instead of regions: it can be pictured as a template model consisting of a number of individual farm models — one for each of the 81,107 individual farms included in the Farm Accounting Data Network (FADN) in 2017. The individual farm models all share the same structure but use different farm-specific parameters that determine their eligibility for specific policy measures. IFM-CAP encompasses all FADN activities for crops (arable crops, vegetables, and permanent crops, fodder and grassland, fallow) and livestock (cattle, pigs, small ruminants, poultry, and other animals), providing comprehensive geographical and production coverage across the EU. Simulating the individual FADN farms makes IFM-CAP representative of the effects of CAP policy on commercial farms in the EU[1].

IFM-CAP simulates a farmer's decision-making process for resource allocation across various crop and livestock activities as an optimization problem. Each FADN farm selects the level of crop and livestock activities that maximizes its expected income utility. This expected utility is calculated as the expected gross income minus the risk premium, representing the uncertainty in farm decision-making. All CAP decoupled and coupled payments, as well as payments dependent on eligibility rules and compliance with environmental measures, are included in the farm's expected income.

The decision problem includes also technical constraints related to resource endowments, production relationships, and policy. For example, a farm's overall activity area cannot exceed the available land in the reference year, and there are constraints related to feed requirements and supply for livestock. The model also incorporates technical constraints for the CAP 2023-2027 (enhanced conditionality and eco-schemes). The model utilises data directly from the FADN database or estimates using FADN and other variables. The observed crop and animal activity levels, subsidies, and activity costs are based on the model's base year (currently 2017), while time series data (2012-2016) are used to calculate expected yields and prices. In addition, specific characteristics of farms, such as resources endowments, production relationships or policy support can be used to construct scenarios or

[1] A commercial farm is defined as a farm large enough to provide a main activity for the farmer and a level of income sufficient to support his or her family. In practical terms, to be classified as commercial, a farm must exceed a minimum economic size. Because of the different farm structures across the European Union, a different threshold is set for each Member State. This means that small, non-commercial farms are not included. Overall, FADN covers approximately 90% of the EU total utilised agricultural area (UAA).

simulations. IFM-CAP provides several economic (e.g. land allocation, herd sizes, animal feed composition, production, intermediate use, CAP payments, gross farm income) and environmental indicators (e.g. biodiversity, soil erosion risk, nitrogen surplus, GHG emissions). These indicators are available both at farm level, allowing to explore the distributional impacts, and as averages at various aggregation levels (Member State, farm type, economic size, and any combination).

Overall, the IFM-CAP model is particularly suitable to analyse farm-specific patterns and policies such as voluntary measures, and to report on the distribution of impacts, as for example demonstrated in recent applications to analyse the CAP legal proposal (Petsakos et al. 2023) and the Green Deal's organic target (Kremmydas et al. 2023, 2024).

2.2 Scenario setting

The CAPRI and IFM-CAP models have been employed to assess the impacts of various hypothetical scenario assumptions on the EU agricultural sector to assess the interplay between demand and supply. We build on the rationale for a sustainable and resilient EU protein transition within a food systems approach. Thus, beyond focusing solely on directly supporting EU plant protein production, a broader approach is taken that also considers changes to human food and animal feed demand, to explore potential synergies within the context of a food systems framework. Therefore, subsequent to establishing a baseline scenario, which serves as a benchmark representing business-as-usual conditions, we assess the impacts of a combined scenario (COMB), which integrates the following assumptions:

— CS: Increased coupled support for EU protein crop production, with all MS fully using 2% of their direct payment budget as coupled support for protein crops. This policy intervention aims to further incentivise domestic EU production of protein-rich crops.

— FEED: Increased adoption of low-nitrogen-feeding (LNF) practices by EU farmers. This serves as an example of an approach that focuses on increasing protein feed use efficiency within the EU livestock sector.

— LSU: Decrease in livestock production density in the EU to 2.0 livestock units. This policy aims to mitigate the potential negative environmental impacts associated with intensive livestock production systems, while allowing for redistribution of livestock production within the EU territory.

— DIET: Gradual transition towards healthier and more sustainable human diets. This approach explores the effects of changing dietary patterns, assuming a partial shift towards the dietary recommendations of the EAT-Lancet Commission.

To assess the impacts of each of these assumptions separately, we also ran the related scenarios individually, in addition to the COMB scenario. While the combined scenario was implemented in both the CAPRI and the IFM-CAP model, the individual scenarios were only run with the CAPRI model.

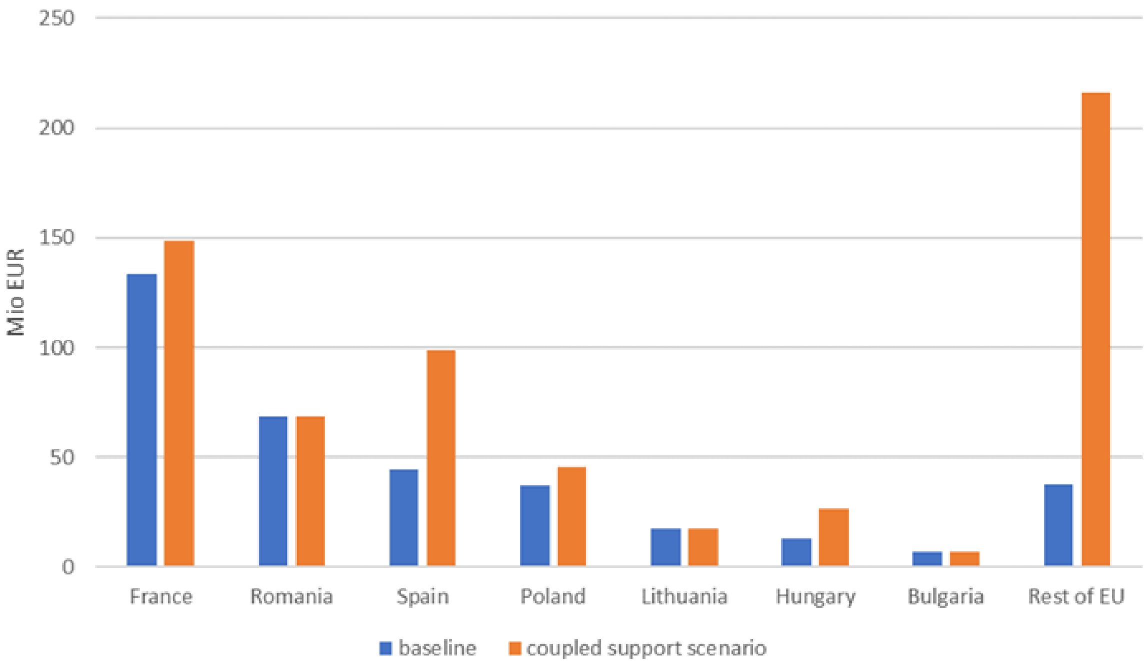
In the following, we briefly explain the background and main assumptions underlying the four individual scenarios, and consequently, the COMB scenario.

CS scenario: Increased coupled support for protein crop production

The EU livestock sector's dependency on high-protein feed imports is a significant concern of stakeholders and EU policymakers, as it makes the sector vulnerable to supply chain disruptions. Consequently, there is an interest to diminish EU reliance on feed imports as part of a broader transformation of the EU's food system, which includes the further development of the EU's plant protein sector (EC 2022). Therefore, in this scenario we simulate that all MS would use 2% of their direct payment budget as coupled support for protein crops. It has to be noted that the possibility of using coupled support to incentivise domestic EU production of protein crops is already available within the current CAP. While several MS make use of this possibility, generally this policy intervention is not fully utilised.

The aim of the CS scenario is to simulate the impacts of providing full coupled support for protein crops under the current CAP rules. In the context of this scenario analysis, the protein crops encompass soya beans and pulses (peas, beans, lupins, etc.), whereas fodder legumes are not included. The economic reasoning motivating this scenario is that a higher specific payment would encourage farmers to allocate more land under protein crops and increase their domestic production. We simulated, therefore, that all EU countries make use of the maximally available 2% of their national ceiling of direct payments to provide specific protein crop support payments to their farmers (Figure 1). The scenario assumes a budget neutral shift in CAP direct payments: total pillar 1 direct payments do not increase, whereby the (decoupled) basic income support is reduced with the increasing coupled support for protein crops.

Figure 1. Coupled protein crops payments in selected EU countries (Mio EUR, CS scenario)



Source: CAPRI scenario assumptions

FEED scenario: Increased adoption of low-nitrogen-feeding practices

In this scenario we focus on increasing protein feed use efficiency within the EU livestock sector. While there are many ways to increase the efficiency of protein feed use, we use the example of LNF practices. LNF practices are designed to optimise feed strategies with the aim of reducing the dietary crude protein (CRPR) intake by animals. CRPR plays a vital role in livestock health and productivity. Nitrogen (N) is a basic component of CRPR, and while animals use a portion of the ingested protein N for the production of meat, milk, eggs, body tissues, and offspring, a significant portion is excreted as faeces and urine. The relationship between the dietary nitrogen input and nitrogen excretion is almost linear, and on average, livestock typically excrete approximately two-thirds of the dietary nitrogen intake through urine and faeces, while only one-third is converted into the protein of animal products (Oenema 2006, Sajeev et al. 2018, Angelidis et al. 2019,). Concerns among farmers regarding animal productivity and health, coupled with practical constraints and management challenges, may result in the provision of dietary CRPR in excess of animals' optimal nutritional and growth requirements. This oversupply of CRPR contributes to a higher nitrogen content in manure, consequently increasing ammonia and nitrous oxide emissions as well as nitrate leaching to groundwater and surface waters (van Vuuren et al. 2015, Sajeev et al. 2018).

Research indicates that by aligning animal diets with nutritional requirements, it is feasible to decrease CRPR in animal diets without compromising animal performance and health. Essentially, reducing the nitrogen content in feed leads to decreased nitrogen excretion by animals and, consequently, lower levels of ammonia emissions. Additionally, there are positive secondary effects on nitrous oxide, which are contingent upon the amount of nitrogen excreted by animals. Therefore, a reduction in nitrogen excretion resulting from lower nitrogen content in feed positively impacts N2O emissions from livestock (van Vuuren et al. 2015, Sajeev et al. 2018).

In CAPRI, LNF as a feeding practice is integrated as an optional production system for the EU livestock sector. The model implementation assumes that LNF achieves a maximum reduction of 50% in CRPR oversupply through the adjustment of the feed mix[2]. The recognition that a complete elimination of oversupply may not be feasible acknowledges the difference between controlled field trials and real farm conditions, where some waste is inevitable. Furthermore, given that this feeding practice is not universally applicable across all livestock production systems, it is assumed that LNF can be applied for all monogastrics, for 100% of the indoor time of dairy cows, and for 50% of the indoor time of other ruminants. As nitrous-oxide (N2O) emissions are directly related to nitrogen excretion, CAPRI can also quantify the impact of broader LNF adoption on GHG emissions (Perez Dominguez et al. 2020, Fellmann et al. 2021).

LSU scenario: Decrease in livestock production density in the EU

Maximum limits on livestock units (LSU) per hectare can serve as a mechanism to align agricultural practices with the objectives outlined in the European Green Deal of promoting sustainable agriculture and protecting the environment, and have been proposed in several MS in their CAP Strategic Plans (CSPs). These limits primarily aim at mitigating environmental impacts of high-density livestock production, for example by reducing nitrate leaching and methane emissions from enteric fermentation and manure management. Reducing livestock density is particularly relevant in some EU "hotspot" regions with high livestock densities and nitrogen surplus (more details are provided in the respective results section 3.5.1).

For this analysis, we focus on a maximum livestock density of 2 LSU per hectare of utilized agricultural area (UAA). This threshold has been used to approximate the value of 170 kg N/ha of manure in the organic farming regulation (EC 2018) and in various CSPs. In the CAPRI LSU scenario, the livestock density threshold is enforced at the NUTS2 regional level. Hence, for each region, the ratio of total livestock units (comprising all animal activities) to UAA is constrained to 2 LSU/ha. This approach enables the CAPRI model to depict the re-allocation of livestock production within and among EU regions in response to market dynamics (i.e., due to changing relative profitability of livestock production).

2 The feed mix in CAPRI is adjusted according to the relative marginal costs of feedstock, assuming that 50% of the CRPR oversupply does not need to be covered with the LFN feeding practice.

DIET scenario: Gradual transition towards healthier human diets

The modelled dietary changes align with a transition to dietary recommendations and include a shift towards a higher share of plant-based protein, reducing substantially the consumption of animal-based protein sources (e.g., meats and dairy products), while increasing the consumption of plant-based protein sources (e.g., pulses).

Plant-based proteins have emerged as critical element of sustainable food systems due to their lower environmental footprint compared to animal-derived protein sources (Springmann et al., 2018). Pulses are valued for their versatility and nutritional benefits, contributing significantly to the development of sustainable and healthy dietary patterns. Dried pulses offer multiple health benefits. These benefits include a low glycemic index due to their slow digestibility and a high fibre content. Additionally, they are characterised by low fat content and are rich in essential micronutrients and bioactive compounds known for their antioxidant properties. Research indicates that diets high in pulse consumption may positively influence cardiovascular health, diabetes management, and obesity-related conditions (Willett et al. 2019; Ferreira et al. 2020).

In general, dietary shifts from animal-based protein sources towards plant-based alternatives can facilitate more balanced and healthier diets, reduce adverse environmental impacts linked to livestock production, and concurrently amplify the beneficial production effects associated with integrating protein crops into crop rotations. Accordingly, this scenario focuses on dietary shifts based on the targets of the EAT Lancet recommendations (see Annex 1, based on Willett et al. 2019).

The EAT-Lancet Commission on Food, Planet, and Health advocates for a healthy and sustainable diet aimed at safeguarding both human health and the environment. The recommended diet emphasises a plant-forward approach with whole grains, fruits, vegetables, nuts, and pulses forming a significant part of the diet. While meat and dairy remain an important part of the diet, it suggests considerable smaller proportions than for the plant-based foods, also given that the latter are considered less resource-intensive than animal-based foods. Thus, the EAT-Lancet dietary recommendations do not only address health-related considerations, but also environmental ones (Hoekstra 2017; Willett et al. 2019).

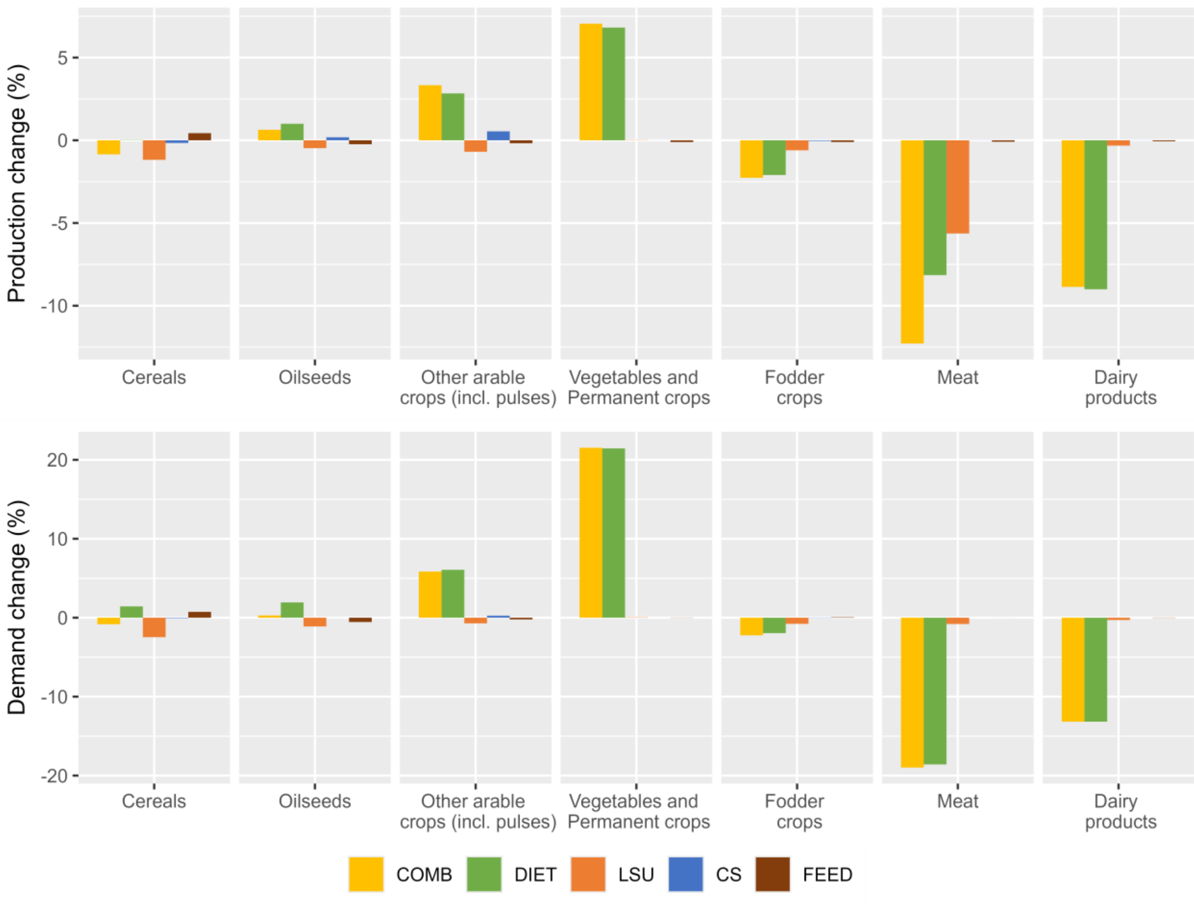
The dietary changes are implemented in the CAPRI model only in the EU. In this scenario, we assume a voluntary food demand shift among European citizens towards healthier and recommended dietary patterns, which are gradually achieved over a longer time period. Specifically, the scenario assumes that by 2035, all EU countries would experience a 25% linear shift towards adhering to the EAT-Lancet recommendations, measured by the calorie content of the food products (excluding waste). The adjustment is done in the model by shifting exogenously the behavioural demand functions, reflecting the relative change in the baseline kcal/day compared to the EAT Lancet targets (summarised in Annex 1). This shift does not necessarily involve a reduction in total caloric intake. Rather, it involves a substitution of food items within the diet, reducing the overconsumption of certain products while increasing the consumption of others to meet dietary recommendations. In this regard, the EAT-Lancet dietary recommendations, and therefore our assumptions regarding dietary shifts, entail various potential health impacts beyond only shifting protein sources in the human diet from animal to more plant-based sources. For example, the recommended reduction in sugar intake is also substantial, as well as the reduction in consuming fats.

3 Results

3.1 Production and demand changes in the EU

The simulated scenarios generate varied yet significant impacts on the production and demand of specific crops and livestock categories at the aggregated EU level (Figure 2 and Figure 3). The impacts in the COMB scenario are primarily driven by the assumptions of the dietary transition (DIET scenario). The gradual shift towards a more plant-based diet decreases demand for animal products and, therefore, EU livestock production, albeit proportionally less than demand is reduced. Additionally, the EU supply of animal products is also significantly affected by the constraint on livestock production density (LSU scenario), which further reduces production, especially of meat (-12%). As a consequence of the observed reduction in demand for livestock products, fodder production also declines (-2%). Conversely, the production of vegetables and permanent crops increases by 7%, driven by higher demand for human consumption. The production of other arable crops also increases (+3%), mainly driven by the higher demand for human consumption of pulses resulting from the transition towards more plant-based diets.

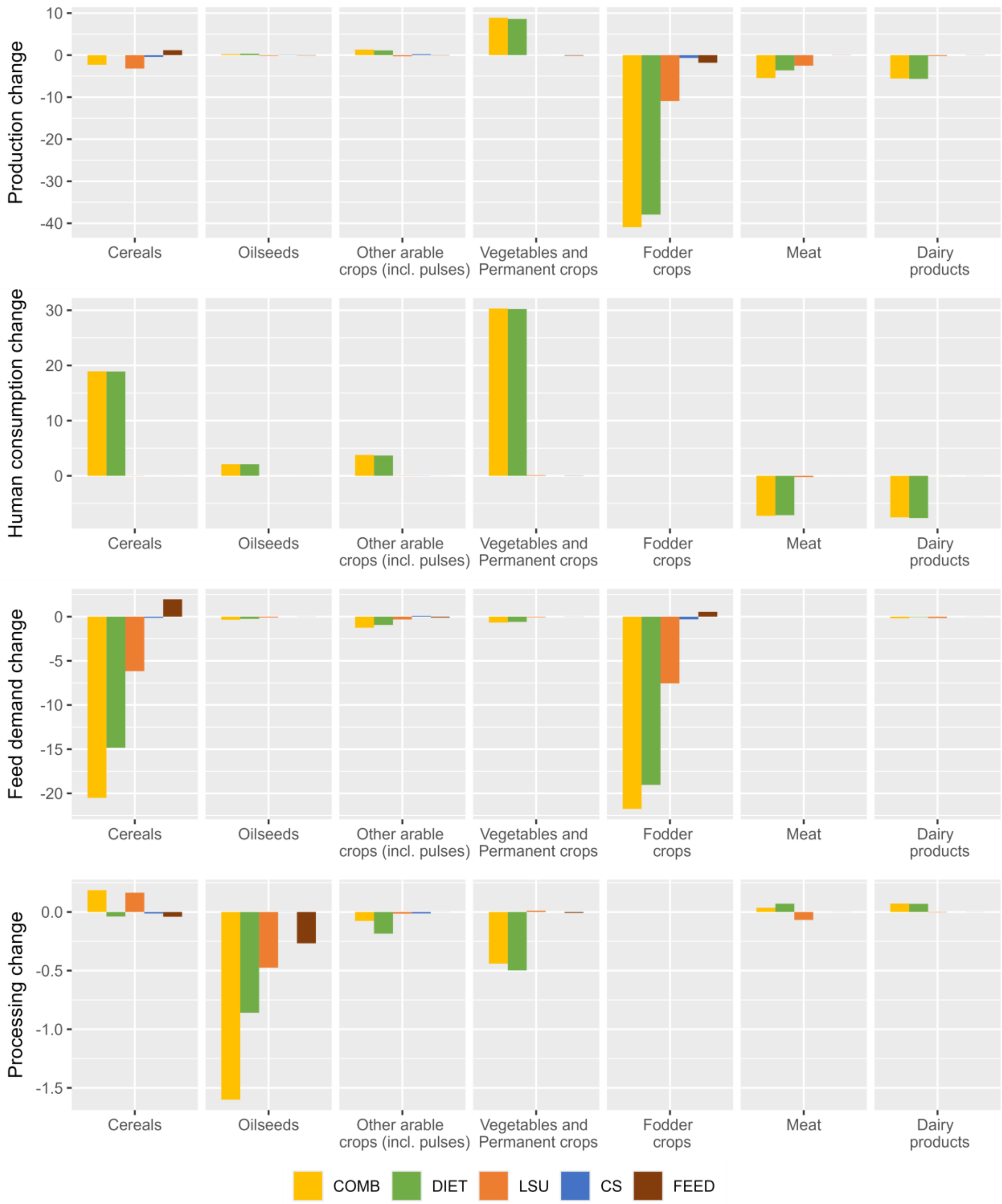
Figure 2. Relative changes in EU net production and demand, compared to the baseline (2035).



Source: CAPRI model results

Figure 2 shows that the crop categories such as oilseeds and cereals are less impacted than the other major product categories. This occurs because of two opposing dynamics (as illustrated in Figure 3): on the one hand, dietary changes increase the demand for oilseeds and cereals for human consumption, especially for wheat (see Figure 4). On the other hand, the same dietary changes and, to a lesser extent, the 2 LSU/ha limit reduce the demand for livestock production and consequently the demand for oilseeds and cereals as feed, especially for maize (Figure 4). Thus, the relative changes observed in the COMB scenario are the combined result of these two opposing forces, ultimately leading to a small increase in total production for oilseeds (+0.6%) and a small decrease for cereals (-0.8%).

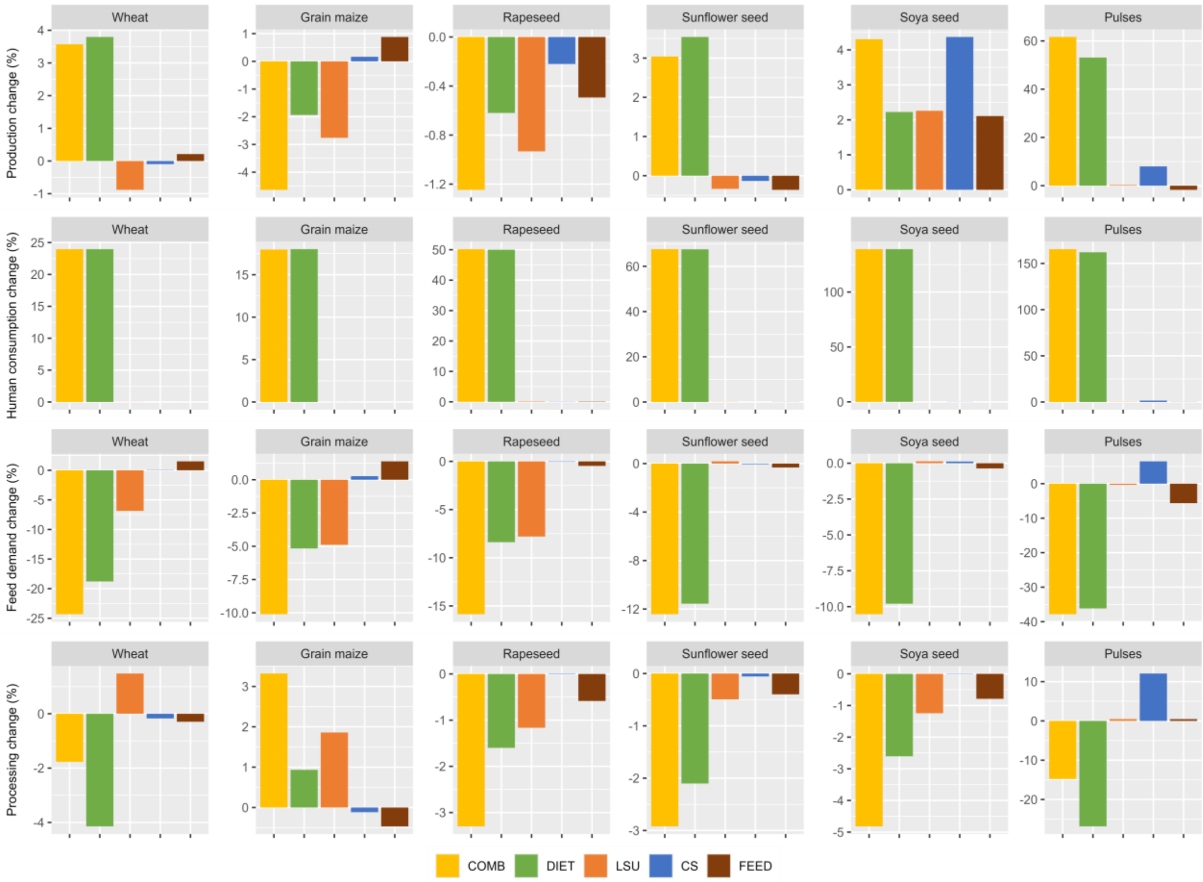
Figure 3. Absolute changes (in million tonnes) in EU net production and demand components, compared to the baseline (2035).



Source: CAPRI model results

Compared to the effects of the assumptions of the DIET and LSU scenarios, increased coupled support for protein crops under the CAP (CS scenario) and increased adoption of LNF practices (FEED scenario) have minor impacts on both production and demand at the aggregated EU level. Among the most relevant effects in the FEED scenario, we observe an increase in the relative demand for energy-rich feeds compared to protein-rich feeds, especially from the pig and poultry sectors. Conversely, in the CS scenario the main effects are observed in an increase of pulses and soya bean production by 8 % and 4.4 %, respectively (Figure 4), gaining crop shares from cereal cultivation areas.

Figure 4. Relative changes in EU net production and demand components for individual commodities, compared to the baseline (2035).



Source: CAPRI model results

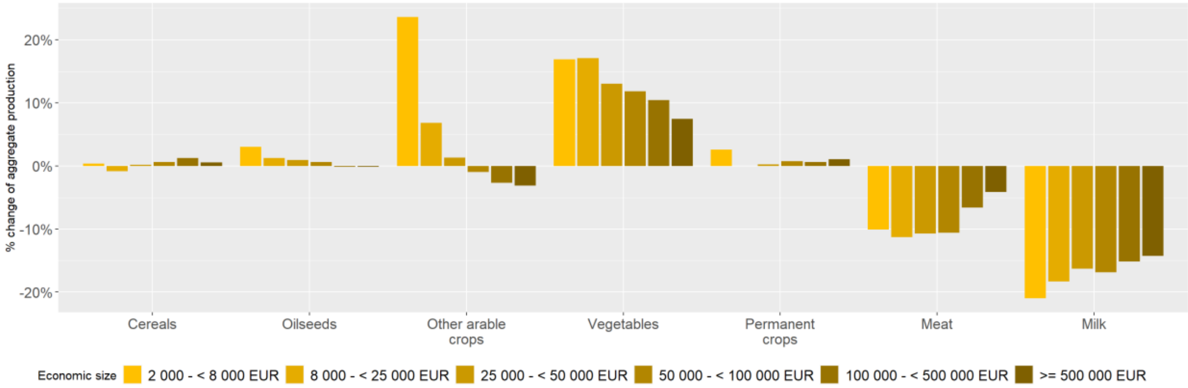
The IFM-CAP model provides insights into the distribution of the production changes in the COMB scenario (relative to the baseline) across different farm economic sizes[3]. Figure 5 presents bar charts illustrating the relative production changes according to various economic sizes and production categories. The y-axis reflects the relative change in production, while the x-axis groups bars by economic size and specific production category. For example, the first bar shows that the farms within the economic size range of 2000 to 8000 EUR increase their cereal production by 0.4%.

An interesting pattern is that the production changes differ between smaller and larger farms. With the exception of cereals, smaller farms expand their crop production more (in relative terms) than larger farms. Conversely, smaller farms reduce their meat and milk production more than larger farms. The difference in the relative production impacts can be attributed to several factors. On the one hand, differences in price and profit margins between smaller and larger farms play a role, with smaller ones experiencing greater pressure on their margins in the livestock sector due to the projected price decreases for meat and milk production. On the other hand, smaller farms may benefit from lower transaction and fixed costs, allowing them to react more flexibly to market shocks. This flexibility can

3 The economic size of a farm, expressed in Euro, equals its total output value.

enable smaller farms to switch their production more readily towards more profitable crops, for example pulses. Within the "Other arable crops" category, smaller farms (up to 50,000 EUR of annual total output) increase production, while larger farms (above the 50,000 EUR threshold) decrease it. This different impact is due to the farms' different specialisation in crop production within the category. Larger farms are more specialised in sugar beet and potatoes, with both products experiencing net reductions, whereas for smaller farms, the share of pulses areas is larger (with pulses experiencing a net increase).

Figure 5. Relative changes in production across farms of different economic sizes, compared to the baseline (2035); COMB scenario.

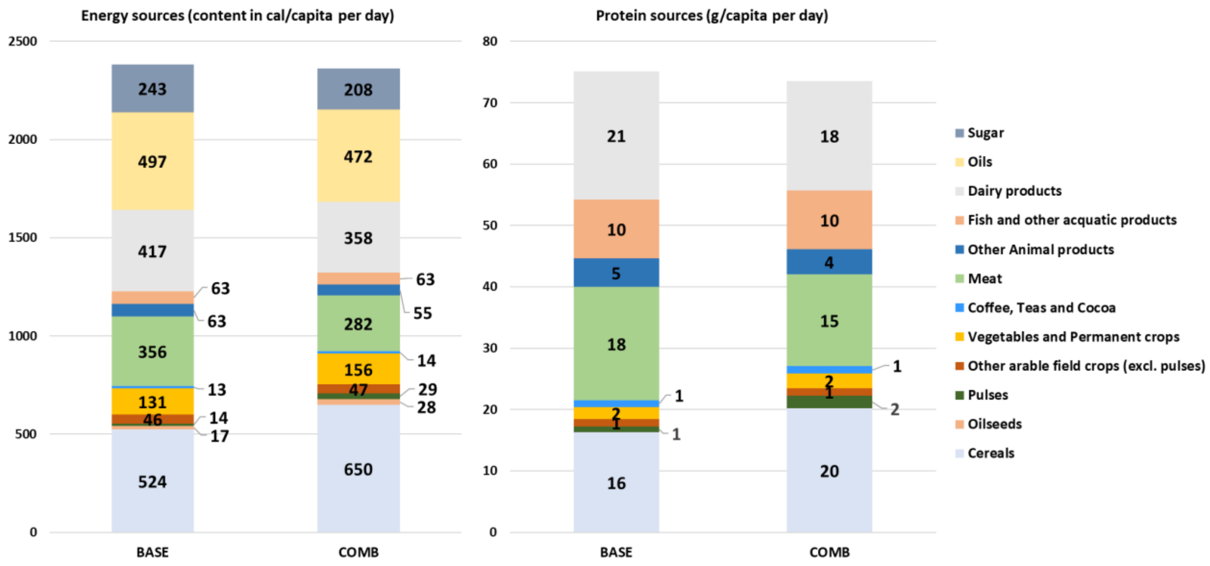


Source: IFM-CAP model results

3.2 Protein and energy sources in human diets and in animal feed in the EU

As the dietary transition emerges as one of the main drivers in our simulation results, we describe the modelled changes in consumption patterns in more detail here. The consumption patterns are discussed in terms of protein and calorie intakes (Figure 6). The COMB scenario incorporates the dietary transition outlined in the DIET scenario, with minimal alteration to the overall caloric intake. Calorie intake from plant-based products increases by 6%, whereas calorie intake from animal products decreases by 6%. The largest increase in calorie intake is indicated for the human consumption of cereals (+126 calories per capita per day). Similar changes in consumption patterns are assumed in terms of protein intake, which decreases from about 76 to 75 grams per capita per day (-1.1%), with 9% of animal-based protein being substituted by plant-based protein intake, mainly through increased consumption of cereals and other arable crops, including pulses.

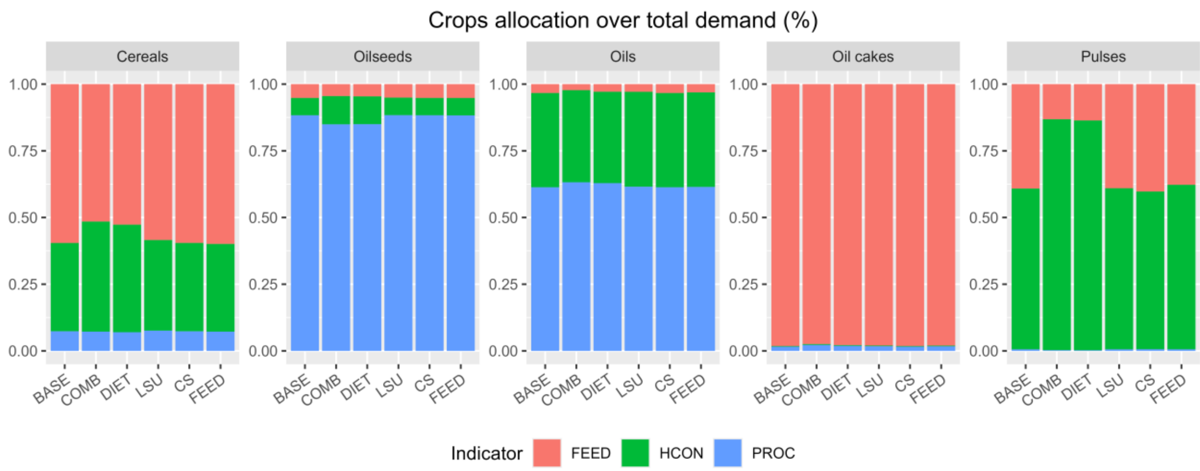
Figure 6. Energy and protein sources in human diets at the EU level



Source: CAPRI model results

The relative shares of the balance items for demand (human consumption, feed, processing) change considerably in the COMB scenario. The changing proportions of food versus feed use are the combination of the indirect impact of the modelled dietary shift (altering the composition of protein and energy sources in human diet) and the indirect impact of decreasing feed demand for EU livestock production. Figure 7 illustrates that the DIET scenario drives the simulated changes in the composition of total EU demand for crops in the COMB scenario. Compared to the baseline, in the COMB scenario the share of human consumption in final demand increases from 33% to 41% for cereals, from 6% to 11% for oilseeds. The increase in human consumption of pulses is the most pronounced (from 60% to 87%), at the expense of feed use and in line with the dietary shift assumptions emphasising a greater reliance on plant-based protein sources.

Figure 7. Composition of total EU demand (human consumption, feed, and processing) across the scenarios.



Note: FEED= Feed consumption; HCON = Human consumption; PROC= Processing for industrial use (incl. biofuels processing)

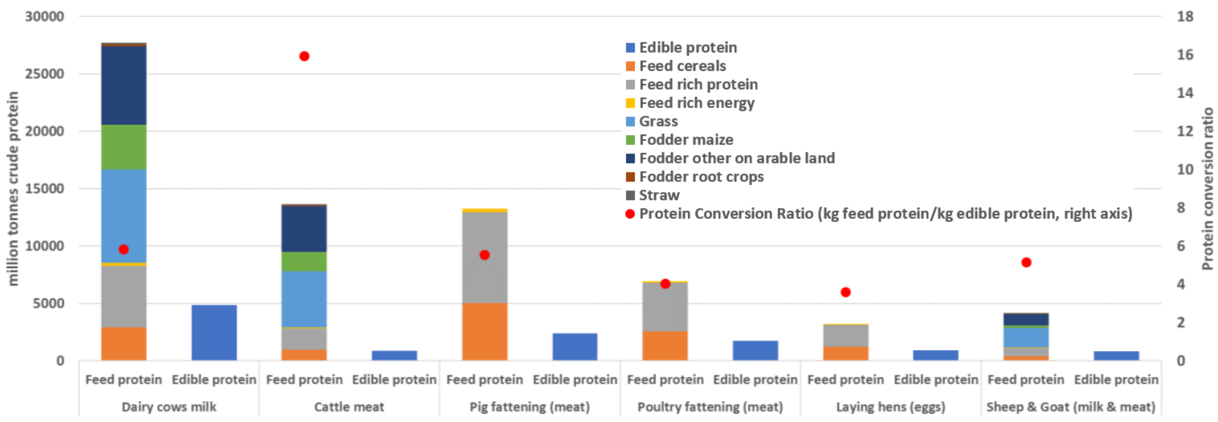
Source: CAPRI model results

Regarding the protein use of the livestock sector in the EU, the total crude protein intake amounts to approximately 71 million tonnes[4]. The share of feed protein from non-EU sources is around 24% of the total (17 million tonnes of crude protein), showing a significant reliance on imported feed protein in the EU. The animal activity using the largest share of the protein feed in the EU is dairy, covering its protein feed demand mostly from roughage (65%) and protein-rich feed (21%, Figure 8). The pig and poultry sectors are also major consumers of protein feed, covering the protein intake mainly from protein-rich feed and feed cereals (60% and 38%, respectively).

A systematic comparison of the feeding efficiency of EU livestock activities provides relevant insights for developing a plant protein strategy and assessing the EU's reliance to imported protein feed. The CAPRI database allows us to calculate feed conversion ratios with a focus on the utilisation of protein in animal feed. The conversion ratios presented here are defined as the ratio of edible protein produced by the animal activity relative to the protein intake of the animals. The fact that livestock production activities are multi-output ones makes the direct comparison of the ratios often complicated. For example, the cattle activities in the CAPRI model are divided to activities with a focus on fattening, milking, raising calves, etc[5]. Nevertheless, most cattle activities in CAPRI produce both milk and meat as edible outputs.

In general, monogastric livestock activities (pigs, poultry meat and eggs production) tend to be more efficient in terms of the above feed conversion ratio, compared to ruminant livestock activities. Similarly, milk production activities tend to have higher feed protein to edible protein conversion ratios than meat production activities, at least within the ruminant livestock activities. In the CAPRI scenarios, the livestock activities change their feed use according to a cost minimization approach, i.e. the feed mix in the scenarios adjusts to the relative changes in the costs of the feed items. At the same time, the balance between the energy and nutrients requirements of the animals and their supply from the feedstock is ensured.

Figure 8. Feed conversion ratios



Source: own calculation based on CAPRI database

4 2023/24 forecast from the EU Feed Protein Balance sheet (DG AGRI 2024)

5 The need to match categories used for the statistical data sources also introduce additional animal categories in CAPRI. For a complete list of animal activities in CAPRI see (Britz and Witzke, 2014).

3.3 Production changes in the EU by Member State

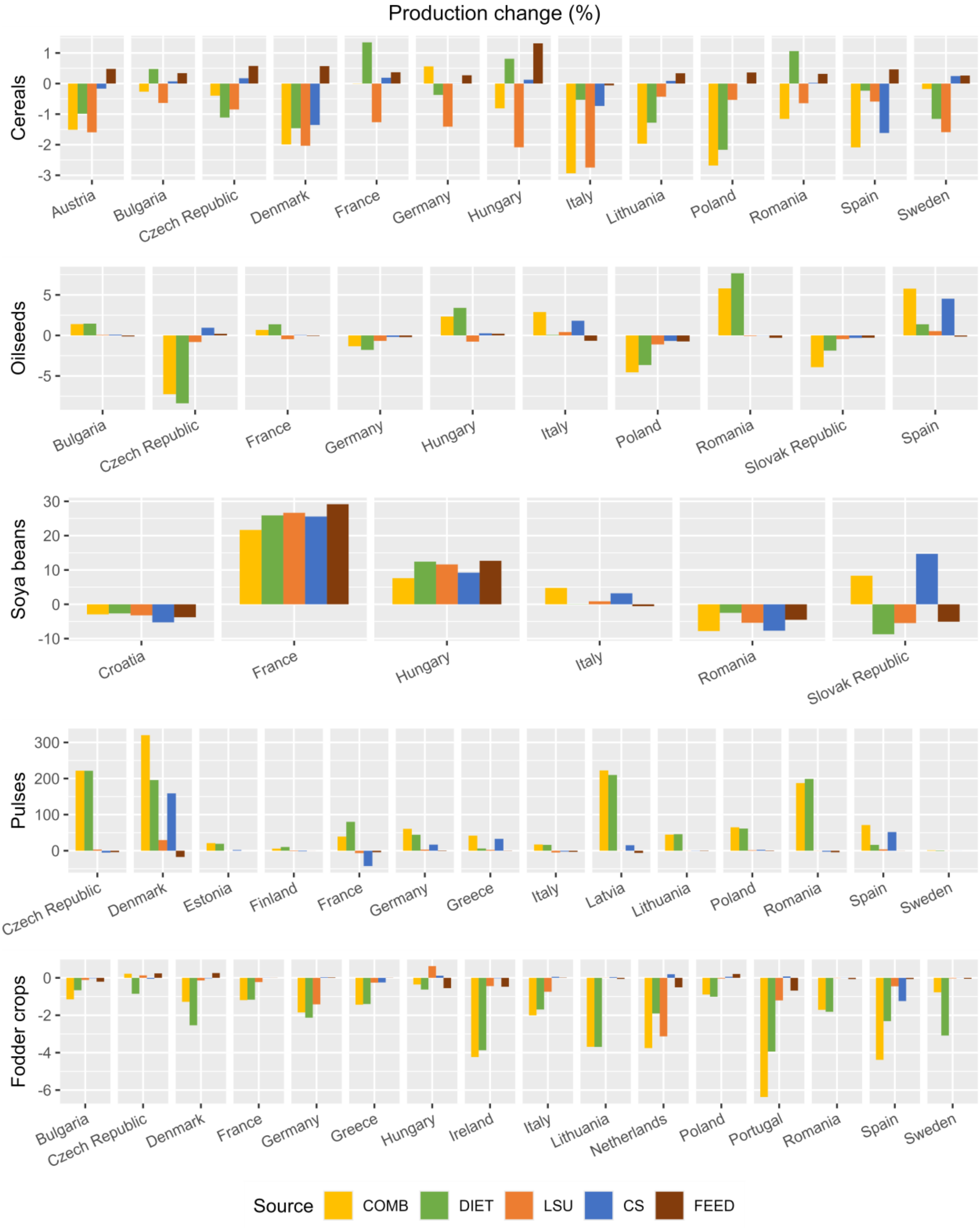
Simulated changes in production are different across agricultural products and across MS and regions in all scenarios. Animal production significantly decreases across major producing MS under the COMB scenario (Figure 9). Changes in demand due to shifts in plant-based dietary habits are the main drivers for the decrease in dairy products, while the largest (relative) reductions in meat production (in the Netherlands and Belgium) are due to the LSU restrictions. This pattern holds true for both poultry and beef production. While dietary shifts remain the primary driver for reduced production in both poultry and beef sectors, in major producing countries the impact of restricting production to 2 LSU surpasses that of dietary shifts. Similarly, the increase in pulses production across all major producing MS is mostly driven by their increased use in the human diet. As stated in section 3.1, the explanatory power of the DIET scenario assumptions within the COMB scenario diminishes for crops used for both human consumption and feed use, such as cereals, due to opposing dynamics on human consumption and feed use. For instance, among the main cereals producing countries in the EU, Germany is projected to even offset the loss of feed use with a higher increase in human consumption. The increase in human consumption triggers an increase of wheat production across all MS (up to 14% at MS level). Barley and maize, which are considered more significant grains for animal feed compared to wheat, exhibit less consistent responses under the COMB scenario. However, they generally experience a slight decrease, with the reduction in feed usage outweighing the increase in human consumption.

A closer look into the DIET scenario reveals that meat production across MS experiences reductions ranging from 3% to 9%. Pulses production substantially increases, albeit with notable variability among MS. Among major MS in pulses production (exceeding 100 thousand tonnes), the average pulses production increase stands at 56%, ranging from modest gains of 1% to 6% for Sweden and Finland, respectively, to substantial spikes of up to 187% in Romania. This variability reflects the relative profitability between pulses and the remaining crop mix in a MS. Furthermore, under the DIET scenario, and as mentioned earlier, changes in cereals and oilseeds production are of smaller magnitude due to opposing forces. The impact on fodder crops is more evident, as with reduced feed demand, fodder crop production decreases by up to 4%.

Impacts in the LSU scenario vary across MS, depending on initial LSU density levels and resulting changes. Countries with high LSU/ha, such as the Netherlands and Belgium, witness significant meat production reductions of 70% and 40%, respectively, while others like Spain and France observe increases. Furthermore, the LSU scenario minimally affects pulses production, with reductions in cereals production due to decreased feed demand. Similarly, the decline in feed demand leads to a reduction in production for fodder crops, with production decreasing by up to 3%, as observed in the Netherlands.

As can be seen in Figure 9, the CS and FEED scenarios exert negligible effects on production for most crops. Under the CS scenario, the modelled payments for protein-rich crops prompt shifts towards higher pulses production. Similarly, LNF practices as assumed in the FEED scenario minimally impact meat and dairy production directly but only influence major crop planting areas, notably driving cereals (wheat, maize and barley) increases across all MS to compensate for the increased demand of LNF products. EU averages are presented further below, in the 'Global production' section (3.4.2).

Figure 9. Relative changes in crops production quantities of the MS contributing 90% of the respective total EU production, compared to the baseline (2035)



Note: Oilseeds include rapeseed, sunflower seed, and soya beans. Soya beans are also presented separately due to their importance as high-protein crop,

Source: CAPRI model results

Figure 10. Relative changes in livestock production quantities of the MS contributing 90% of the respective total EU production, compared to the baseline (2035).

Source: CAPRI model results

3.4 EU trade and global production

Scenario assumptions are only made on EU agriculture. However, the simulated impacts extend beyond the EU because the EU is linked to global agricultural markets. International trade of agri-food commodities transmits the impact from the EU to other countries.

3.4.1 EU trade

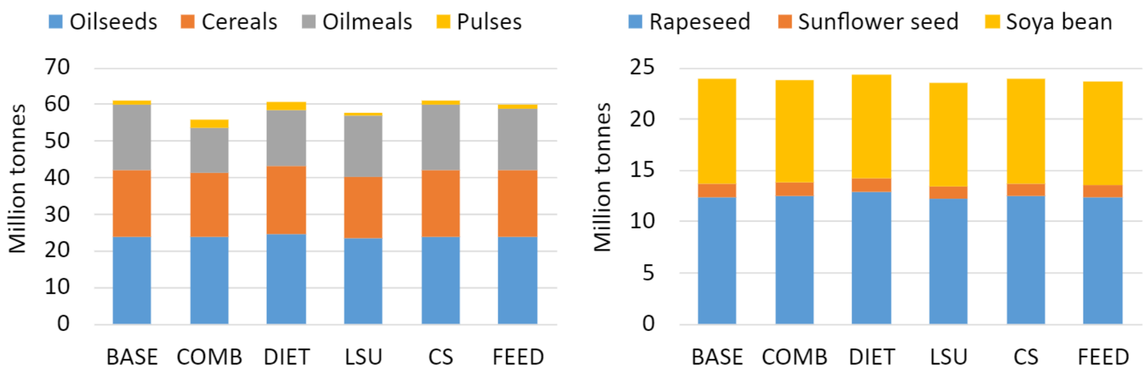
EU imports of crop products which serve as primary feed protein sources in 2035, show a notable decline in the COMB scenario (Figure 11). Specifically, the imports of oilmeals—predominantly soya cake, for which the EU relies on imports for 97% of its demand (see Table 1) — experience a 30% (4.6 million tonnes) reduction in the COMB scenario. This significant decline is largely attributed to a projected reduction of 20% in feed demand based on the assumptions underlying the DIET and LSU scenarios. Additionally, there is a slight shift towards substituting these oilmeals with cereals for feed, evident in a 1.6% increase in cereals use within the FEED scenario.

Imports of oilseeds remain largely unchanged in the COMB scenario, with a slight 2% increase observed in the DIET scenario offset by a 1.5% decrease in the LSU scenario, with additional import reductions due to the coupled support for EU protein crops production (CS scenario). This results in a slight decrease in oilseeds imports by approximately -0.6% (150 thousand tonnes) in the COMB scenario. Notably, there is a 3% reduction in soya beans imports in the COMB scenario, attributed to reductions across all individual scenarios. Additionally, there is an overall increase in EU domestic production of soya beans, prompted by the CS payments, which also leads to lower imports of this commodity. It is important to note that the demand for oilseeds is affected both negatively and positively in the COMB scenario. While lower feed use can decrease the demand for oilmeals, increasing human consumption of vegetable oils (partly substituting animal protein driven by the DIET assumptions) can increase demand for oilseeds. For instance, in the COMB scenario, results indicate a 63% increase in the human consumption of oilseeds and a 13% reduction in feed use. Conversely, there is an increase in imports of sunflower seeds by 7.7% and rapeseed by 0.4%, both driven by the DIET scenario assumptions. However, the EU's net trade position is not altered for both crops.

Similar impacts are projected for cereals, where imports decrease in the LSU scenario due to reduced livestock production and feed demand, while increasing in the DIET and FEED scenarios due to higher consumption of cereal products and adoption of LNF practices, respectively. In the COMB scenario this results in an overall decrease of 3.3% (593 thousand tonnes) in cereals imports. Additionally, pulses imports see a significant increase in the COMB scenario, mainly driven by the DIET scenario assumptions positioning pulses as a healthier substitute for protein intake from livestock products. In the COMB scenario, human consumption of pulses increases to 5.8 million tonnes (+166%), while net production also rises to 4.9 million tonnes (+62%). The CS and DIET assumptions are driving farmers to produce more pulses, which can be seen by an 8% and 53% increase in net production in the respective standalone scenarios. However, this increase in EU pulses production is not enough to meet the growing demand for human consumption driven by the DIET assumptions, i.e. the EU is unable to fulfil the demand with domestic production alone. Consequently, pulses imports rise from 1 million tonnes in the BASE to 2.2 million tonnes in the COMB scenario (+112%). This happens despite less demand for feed in the LSU scenario, higher internal incentives for pulses production in the CS scenario, and the substitution of pulses by cereals in the FEED scenario as lower-nitrogen-feeding practice.

Considering only the crude protein content of key imported feed protein sources, namely cereals, oilseeds and oilmeals, their imports decrease by 13% (2.2 million tonnes of crude protein) in the COMB scenario compared to the BASE scenario. This overall decrease in imports is driven by a 18% (5.4 million tonnes of crude protein) reduction in use for animal feed, although the human consumption of these protein sources increases by 35% (3.4 million tonnes of crude protein). Considering only crude protein contents, soya meal's contribution to the total crude protein imports diminishes from approximately 38% in the BASE scenario to 30% in the COMB scenario, signalling a reduced reliance on soya meal as a feed protein source. Conversely, there is an increase in the shares of the total crude protein imports from rapeseed (+4%), soya bean (+3%), and pulses (+2%).

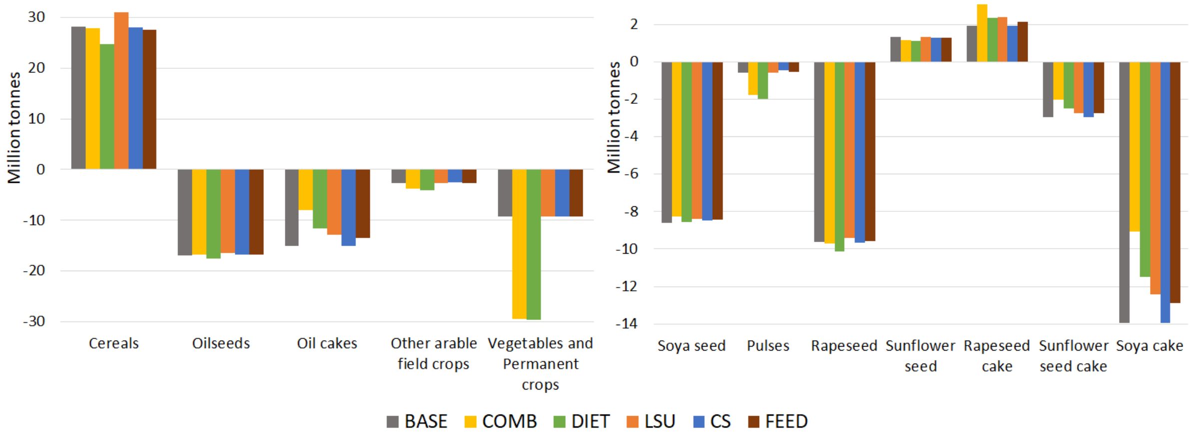
Figure 11. Imports (without intra trade) of main source of protein products (left) and oilseeds (right) in 2035



Source: CAPRI model results

Across all scenarios, EU net trade (defined as exports minus imports) of oilseeds, including soya beans, remains relatively stable. The net trade for oilmeals, however, shows a significant reduction in trade deficit in the COMB scenario due to simultaneous reductions of imports and increased exports. This trend is driven by lower livestock production and reduced feed demand in both the LSU and DIET scenarios, alongside the substitution with cereals in the FEED scenario. In the COMB scenario, the net trade for cereals is only slightly impacted, even though notable differences are observed in the LSU and DIET scenarios individually. Restrictions on livestock units at the NUTS2 level lead to reduced livestock production in the LSU scenario, resulting in surplus cereals not utilised for domestic animal feed being redirected to exports (+3%), which alongside with reduced imports (-7%) contributes to a further improved EU net trade balance (Figure 12). Conversely, the dietary shift in the DIET scenario leads to a substantial increase in the consumption of plant-based products, including cereals (+1.9 million tonnes or +24% compared to the baseline), and vegetable and permanent crops (+32.5 million tonnes; +25%). This, in the DIET scenario, leads to higher imports and lower exports, causing a deterioration of the EU cereals net trade position. In this scenario, the decrease in feed use of cereals (-14.9 million tonnes) is lower than the increase in human consumption (+18.9 million tonnes). Furthermore, the COMB scenario demonstrates a similar effect on the net trade of other arable field crops and pulses, driven by the impacts of the DIET scenario assumptions. Although for pulses the CS scenario results in higher production and exports due to increased coupled support for protein crops, this effect is not sufficient to offset the increased imports driven by the DIET scenario assumptions.

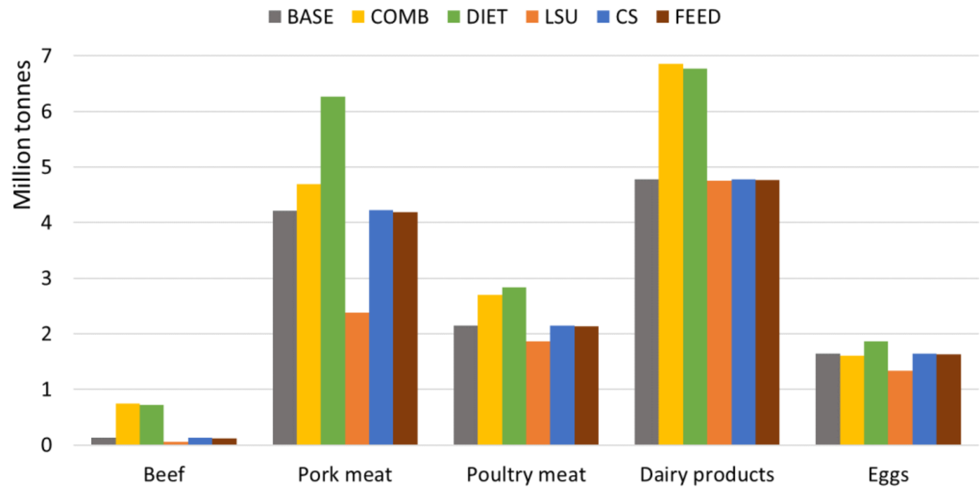
Figure 12. EU net trade of main crops (left) and individual oilseeds (right) in 2035.



Source: CAPRI model results

The EU net trade balance in the COMB scenario is improved for most animal products (except eggs), characterised by decreasing EU imports and increasing exports. EU exports of dairy products and pork meat (in which the EU is already an important net exporter in the baseline) increase the most, but the increase is also significant for beef and poultry. This effect is largely driven by the DIET assumptions, which drive a downward shift in demand for livestock products and require a minimum calorie intake from certain plant-based products. This leads to a substantial decline in EU consumption of animal products and livestock production, reflected by reductions in their imports in the COMB scenario (Figure 13). As also producer prices decline for livestock products (as illustrated in the next section in Figure 15) the EU's competitiveness in international markets is enhanced. As a result, a significant portion of the EU production, previously consumed internally, is redirected towards exports. The exception is with eggs, for which the increased exports seen in the DIET scenario are offset by a larger decrease in exports shown in the LSU scenario. In the LSU scenario, beef, pork and poultry meat also see their trade balances worsening due to sharp decreases in exports. However, the positive effect on the net trade balance seen in the DIET scenario outweighs the LSU effects, leading to an overall positive impact on the EU net trade balance in the COMB scenario.

Figure 13. EU net trade of main livestock products in 2035.



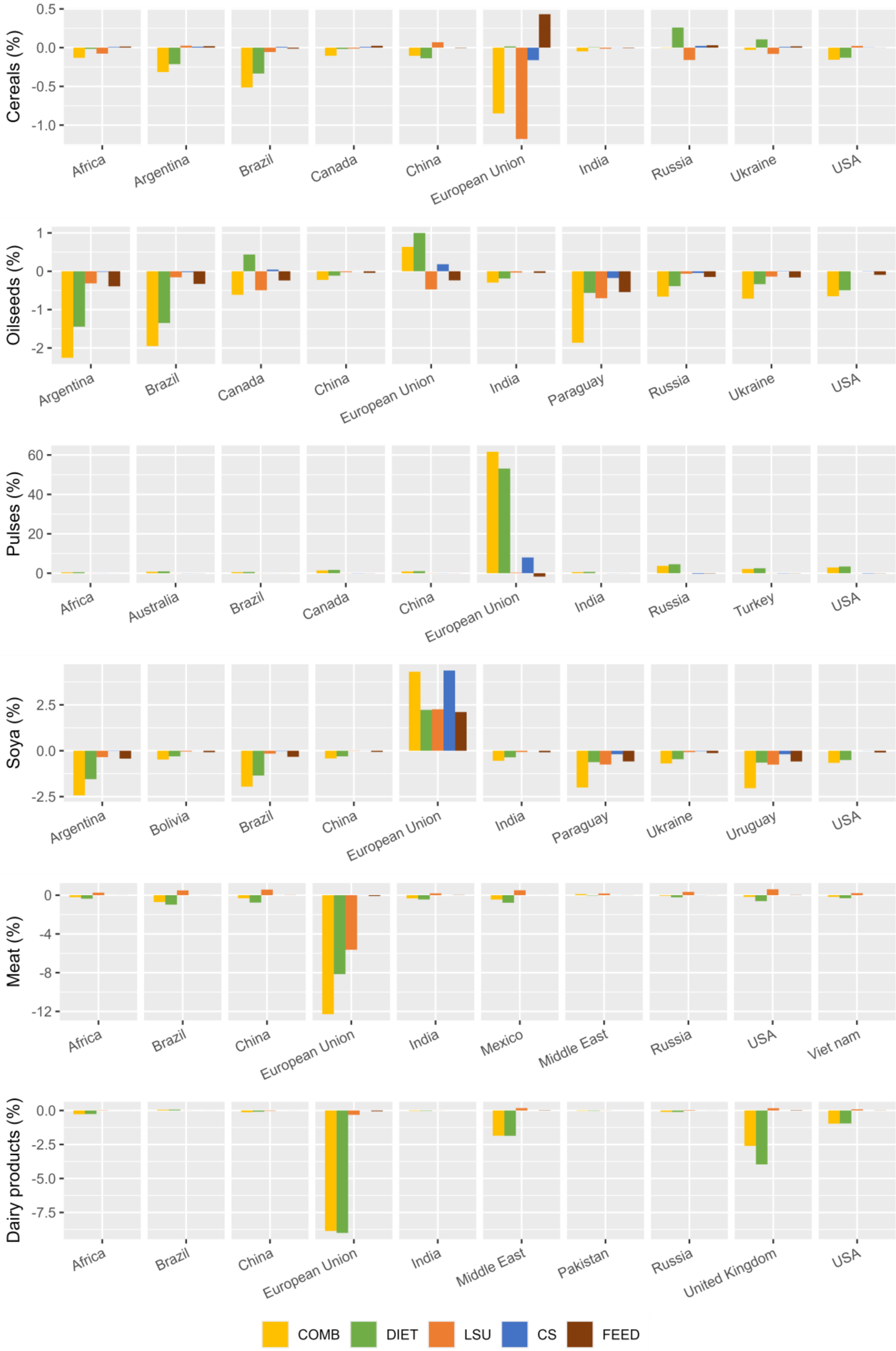
Source: CAPRI model results

3.4.2 Global production

The changes in EU production and demand, and the resulting trade dynamics affect the production of agricultural commodities in the other world regions. For instance, in the combined scenario (COMB), the increased EU demand for pulses lead to production increases in other world regions (approximately 1%), notably North America (USA, Canada, Mexico), which experiences a 2% increase due to the higher EU imports (Figure 14). Conversely, the combination of increasing soya bean production in the EU and decreasing demand, lead to relatively small production reductions for oilseeds in the rest of the world. Non-EU oilseeds production decreases by 1%, dominated by soya bean production decreases in Mercosur (-2%) and the USA (-0.7%). Regarding cereals, reduced demand in the EU leads to a marginal overall production decline in non-EU regions (-0.15%). As the EU's demand for imported maize and meat declines, non-EU regions experience a corresponding decrease in maize production. This reduction in maize production is twofold: directly due to the lower demand for maize imports from the EU, and indirectly because of the reduced need for maize as animal feed in countries exporting meat to the EU in the BASE scenario, with both being a result of decreased meat consumption in the EU. Furthermore, the production of wheat increases slightly in the non-EU to partially compensate for reduced EU exports.

The decrease in EU meat demand in the COMB scenario triggers only a small decrease in meat production in the other world regions (-0.3% across non-EU, and, for example, -0.7% in Mercosur), and a decrease in non-EU meat exports of 2.6%. Dairy production in non-EU decreases by 0.3%, which is partially due to decreasing EU imports, but especially due to considerably increases in EU dairy exports. Production changes in non-EU regions driven by EU demand and supply shocks are also analysed in terms of their impact on GHG emissions and leakage in chapter 3.5.2.

Figure 14. Relative changes (%) in production of the ten major producing countries in the world, compared to the baseline (2035).



Source: CAPRI model results

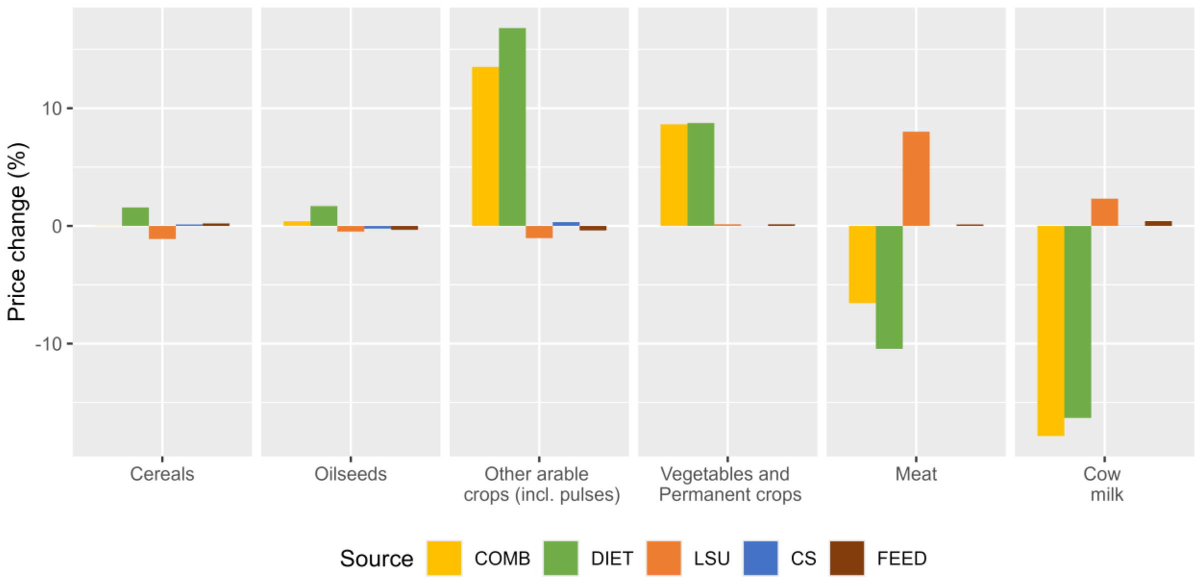
3.5 Producer prices and gross value added

3.5.1 Producer prices

Figure 15 and Figure 16 illustrate the impact of the scenarios on producer prices. As with the previous sections, the changes in demand and supply due to the DIET and LSU assumptions are the main drivers of the observed changes in EU producer prices in the COMB scenario.

Looking closer into the DIET scenario, the transition towards more plant-based products leads to higher producer prices for all major crops. Other field crops show the largest increase (+16.8%), mainly driven by significant changes in the prices of pulses (+42.3%), followed by vegetables and permanent crops (+8.7%). Prices for cereals and oilseeds also increase, but considerably less, as the increase in demand of human consumption is offset by the decrease in demand for animal feed. In the livestock sectors, producer prices decline due to reduced demand, with beef (-15.0%) and cow milk (-16.3%) showing the most pronounced relative decreases.

Figure 15. Relative changes in EU producer prices for major crop groups and animal products, compared to the baseline (2035)

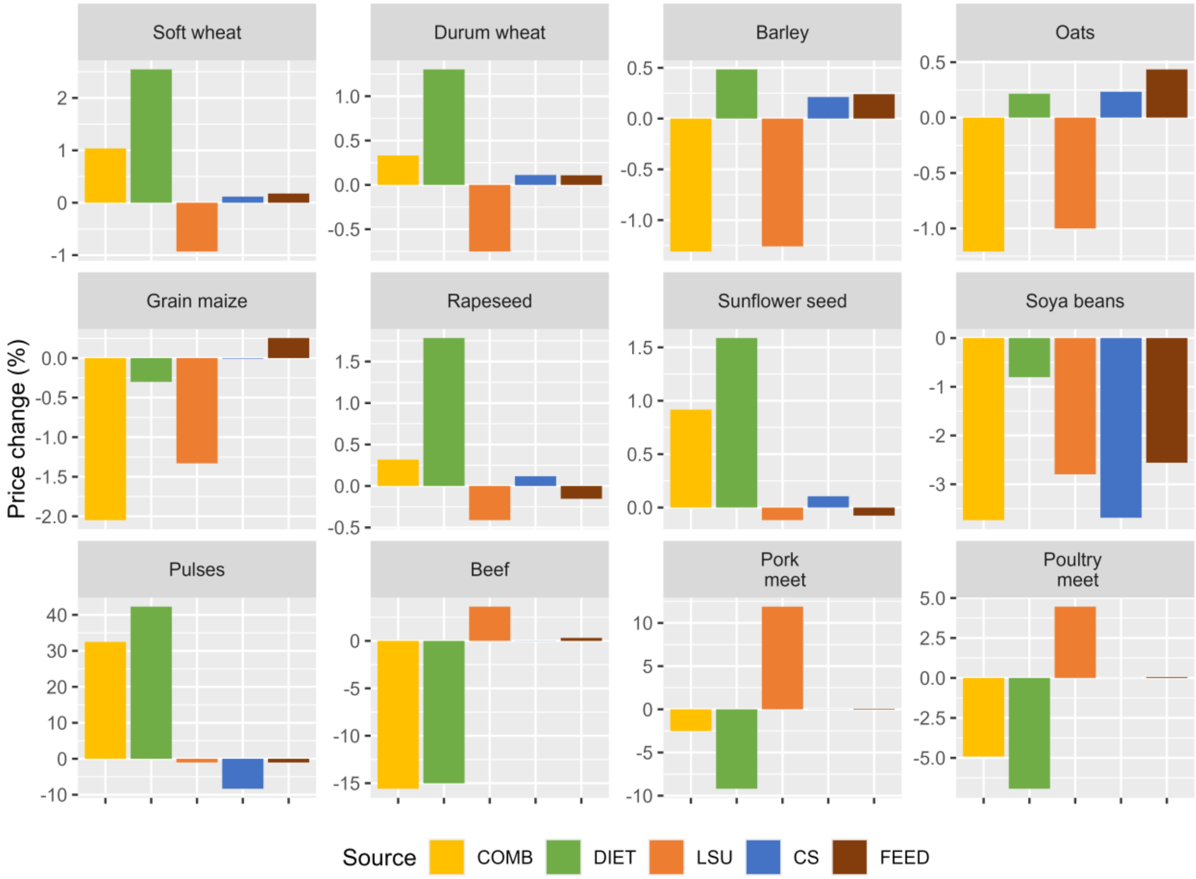


Source: CAPRI model results

In contrast to the DIET scenario, the LSU scenario shows opposite patterns affecting the supply side. The livestock sectors experience producer price increases due to the reduced supply resulting from lower livestock density, with pork production showing the most notable increase (+11.9%). The shift in supply also reduces demand for inputs related to animal production, leading to a decrease in prices for cereals, oilseeds, and other arable crops used for feed. In the LSU scenario, human consumption of these crops does not increase sufficiently to offset the decrease in feed demand, and reductions in EU livestock production are largely substituted by imports. Conversely, vegetables and permanent crops experience a relatively small increase in demand due to higher meat prices.

The CS and FEED scenarios lead to minor changes in EU producer prices for both crops and livestock. Specifically, the increased supply of pulses and soya beans caused by increased coupled support in the CS scenario leads to price reductions of 8.3% and 3.7%, respectively (Figure 16). The FEED scenario also induces small changes, especially for pulses (-1%) and soya beans (-2.6%), but in this case driven by the LNF practices, i.e., the reduction in the dietary crude protein intake by animals, leading to decreased demand for these crops. The livestock sector experiences modest price changes, which is an indirect effect of increasing marginal costs for producers, as the adoption of LNF practices comes at increasing production costs.

Figure 16. Relative changes in EU producer prices for single commodities, compared to the baseline (2035)



Source: CAPRI model results

3.5.2 Gross value added and gross farm income

The results indicate that the various scenario assumptions have significant impacts on the agricultural Gross Value Added (GVA)[6] and the farm gross income. In this section, we report how these impacts vary across scenarios, agricultural production activities, MS, and farm size. It should be noted that no structural changes are modelled. The analysis assumes a standard number of farmers and no change in farm typology.

Overall, the COMB scenario results in a -3.8% decrease in the GVA of EU agriculture[7]. The shift to a more plant-based diet is the main cause of this reduction, as illustrated by the similar GVA-impact (-

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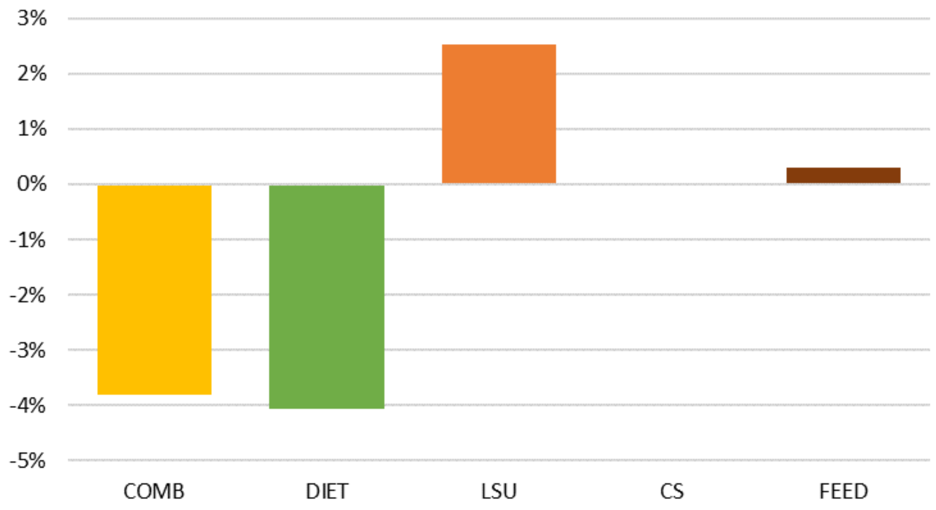
6 In this section, we refer to GVA as GVA at producer prices plus premiums. This is computed as follows: GVA = Revenues – Inputs + Premiums, with: revenues as output quantities valued at producer prices; intermediate inputs as costs of input quantities, with the exception of the primary factors land, capital and labour, valued at producer prices; and premiums as payments paid under the CAP. For IFM-CAP, GVA is equal to the farm gross income. Also, for CAPRI, GVA is defined at the activity level, while at the farm level in IFM-CAP.

7 Based on historical references, combined with trend analyses and expert consultations, the supply elasticities in CAPRI implicitly reflect the ability of producers to adapt to changing circumstances and adjust output in the short to medium term. However, other structural adjustments, such as vertical and processing integration, are not explicitly captured in the model. This limitation could lead to either over- or underestimation of the results.

4%) in the DIET scenario. In contrast, assuming a maximum 2 LSU/ha livestock density in the LSU scenario leads to a +2.5% increase in GVA, given the price increase for animal productions due to inelastic demand for animal products. The assumptions of the other scenarios (CS and FEED) only have limited impacts on the GVA at producer prices (Figure 17).

Figure 17. Relative changes in EU total agricultural gross value added, compared to the baseline (2035)

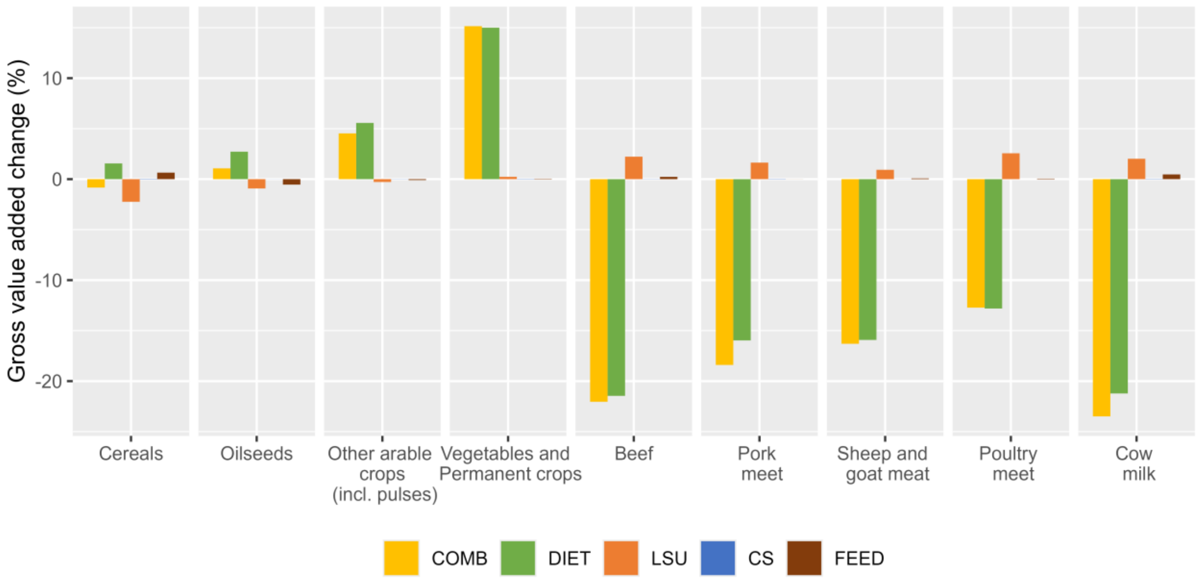


Source: CAPRI model results

Figure 18 shows the relative changes in the agricultural GVA by production activity at the EU level in the scenarios compared to the baseline scenario. In line with the changes in production and producer prices, the economic performance of livestock production is considerably impacted under the COMB scenario assumptions. GVA of dairy activities is the most affected in relative terms (-23%), followed closely by beef activities (-22%). By contrast, GVA of crop activities generally benefits by the demand and supply shifts, especially vegetables and permanent crops (+15%), with cereals being the exception (-1%). In this latter case, the increase in GVA due to the higher human consumption of cereals driven by the DIET scenario assumptions does not fully compensate for the loss of income due to the decrease in feed demand from the DIET and LSU scenario assumptions. In the DIET scenario, producers of meat and livestock products can partially offset the decline in domestic EU demand through exports, as prices decline and become more competitive in international markets. Nevertheless, livestock producers still face significant GVA reductions, ranging from -21% to -12%, indicating that increased exports cannot fully compensate for all GVA losses resulting from reduced domestic demand.

Conversely, if only the LSU scenario assumption is considered, livestock producers experience a GVA increase, as the price increase for animal products (Figure 15) does not significantly discourage consumers from consuming animal products due to relative inelastic demands. Thus, the price effect (increases in meat producer prices) outweighs the production effect (deceases in the meat quantity produced), resulting in higher GVA, especially for poultry (+2.6%), beef meat (+2.2%), and pork meat activities (+1.6%), which also benefit from lower cereal prices (Figure 16). The CS scenario shows a slight increase in GVA for soya bean production (+0.6%), whereas the one of pulses basically remains unchanged (i.e. for pulses the decrease in prices offsets the increase in coupled support and the related production increase). The FEED scenario leads to small changes in GVA, with modest positive changes in GVA for livestock productions, notably beef meat (+0.2%) and dairy activities (+0.5%), and also GVA for cereals increases (+0.6%) due to the higher demand of cereals for low-nitrogen feeding, at the expense of oilseeds (-0.5%).

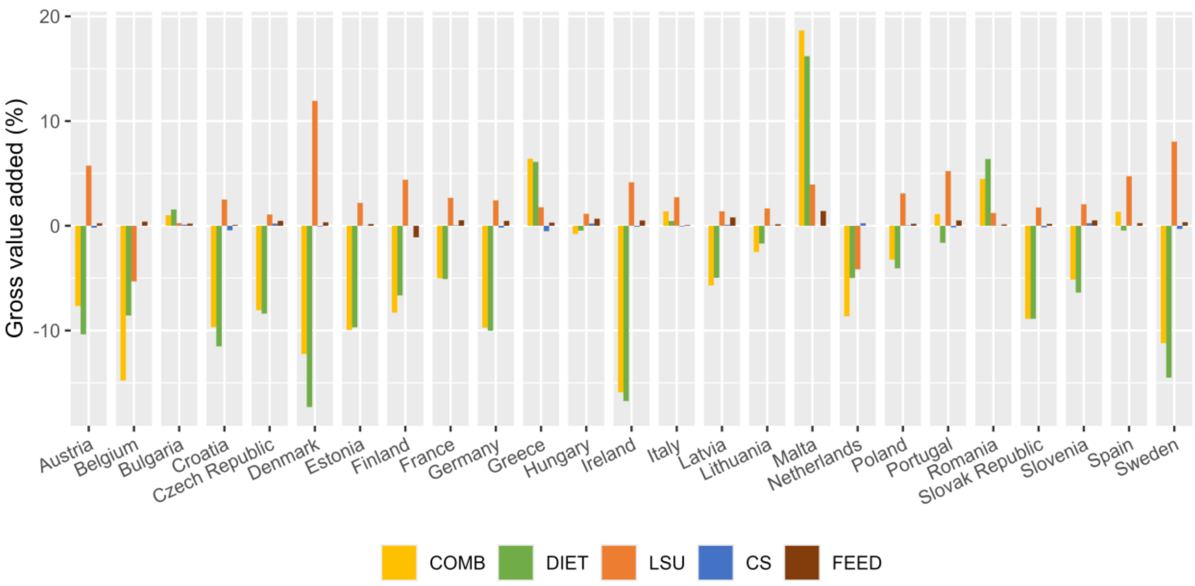
Figure 18. Relative changes in EU total agricultural gross value added for major crop and livestock activities, compared to the baseline (2035)



Source: CAPRI model results

As with the changes in GVA at the EU for different activities, significant differences also exist across MS and regions in all scenarios. Figure 19 shows the total agricultural GVA changes between the scenarios at MS level, ranging from about -16% to +19% in the COMB scenario. The most sizable negative impacts are simulated in the countries with the highest share of GVA from livestock activities in total GVA (e.g. Ireland and Denmark). By contrast, MS where agricultural income is less reliant on animal production in terms of GVA, such as Greece, Italy and Romania, benefit the most in the COMB scenario. Conversely, if only a 2 LSU/ha limit is considered (LSU scenario), most MS experience an increase in GVA due to a relative inelastic demand for animal products and the relocation of livestock production to less intensive areas, resulting in a reduction in supply. The exceptions are Belgium and the Netherlands, which show a decrease in livestock GVA due to their higher livestock density in the baseline, i.e., for these two MS the increase in producer prices does not outweigh the reduction in production.

Figure 19. Relative changes in total gross value added at MS level, compared to the baseline (2035)



Source: CAPRI model results

IFM-CAP calculates farm income for each individual farm, enabling subsequent aggregation to analyse the impacts of different scenarios across various farm groups (i.e., the type of farming and economic size categories of FADN).

Figure 20 shows the distribution of income change for different farm economic sizes. In each economic size category, the shaded area represents a density graph showing the share of farms with an income increase or decrease above a certain threshold. For example, the area above the dashed line shows the farm share with a positive income change (38.5% for the 2000 to 8000 EUR economic size). The density plot provides a visualisation of the distribution's shape, including its peaks, modes, and other patterns. Additionally, we have added a boxplot next to each density graph. The beginning and the end of the coloured rectangle in the boxplot show the Q1 and Q3 of the distribution. For example, in the first panel (2000 to 8000 EUR of total output), 50% of the farms (from Q1=25% to Q3=75%) have an income change between +2% to -15%. The bold line in the boxplot represents the median value (-2.6% for the first panel).

Interpreting the distributions, rather than only relying on the average and standard deviation, offers the advantage of providing insights into how the effect intensity is distributed across farms. For example, although the mean and the median are negative for all economic classes, most farms have an effect very close to zero (the peak of the distribution is at zero income change). It is also evident that in all economic classes, farms with positive income change are outnumbered by farms with negative income change. Moreover, especially in the higher economic-size classes, there are clusters of farms with income losses of more than 20%, as indicated by the peaks at the bottom of the density plot.

Finally, the most compelling insight from this graph is the trend of the income change. Smaller farms have a lower median income loss (-2.7% for "2000-8000 EUR" compared to -4.3% for ">500,000 EUR"), with a consistent pattern (indicating that the smaller the farm, the lower the average income loss). Similarly, in the lower economic-size classes, a higher number of farms have a positive income change (38.5% for the "2000-8000 EUR") compared to the higher classes (28.6% for the ">500,000 EUR").

Figure 20. Distribution of relative changes in farm gross income across economic sizes, COMB scenario

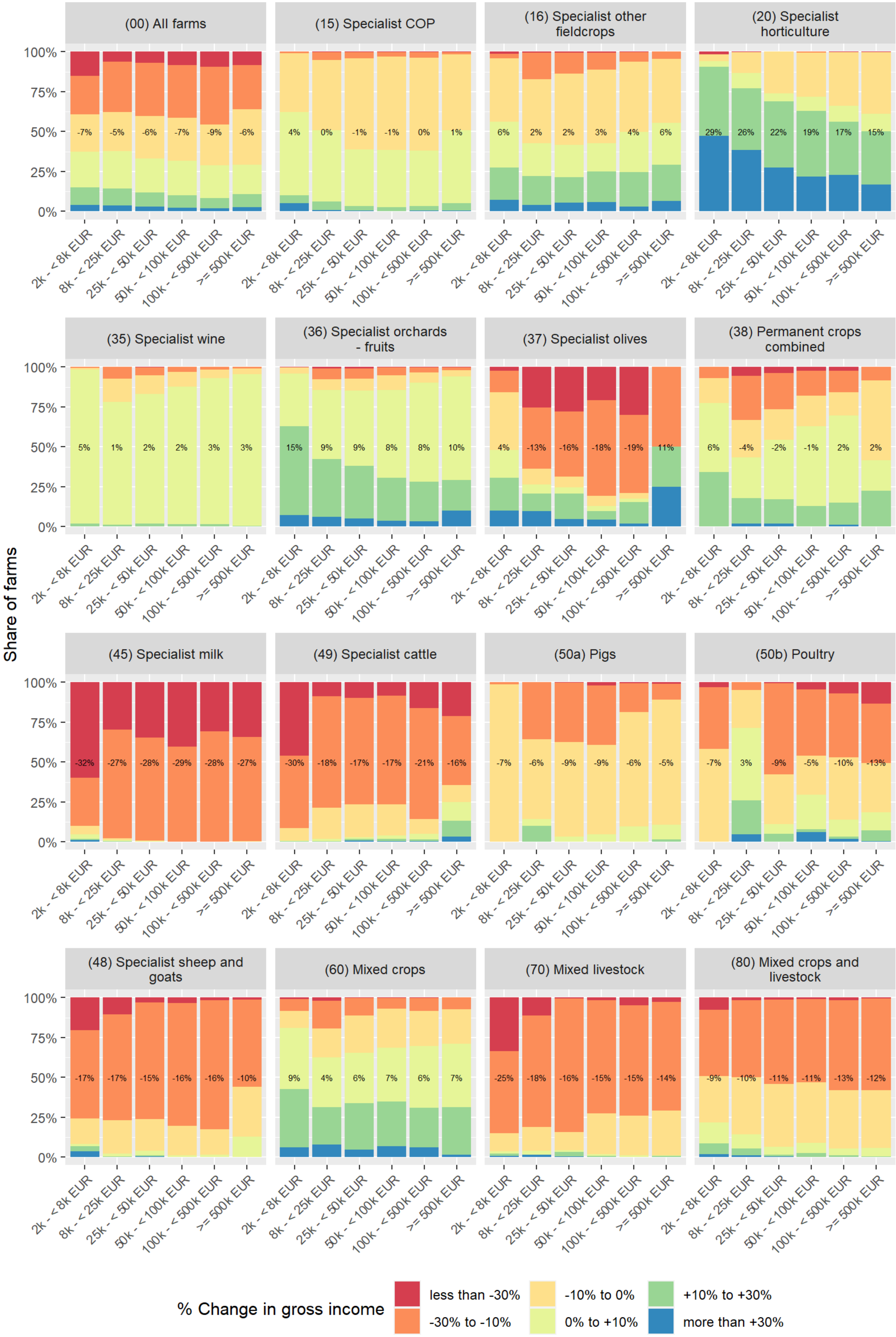
Source: IFM-CAP model results

Approximately 60% of the variation in the farm income change is explained by the farm type to which the farm belongs. Figure 21 presents income changes for the cross-section of economic size and farm types. The results are organised into panels, each corresponding to a specific farm type, with the first panel representing the entire agricultural sector. The colours represent income change classes. A greenish colour represents an income increase class (+0% to +10%, +10 to 30%, >30%), while a reddish colour indicates an income decrease class (0% to -10%, -10% to -30%, < -30%). Within each panel, each stacked bar corresponds to an economic-size class. In these bars, we display the share of farms belonging to the income change classes. For example, in the first panel (All farms), almost 5% of the farms have an income increase of more than 30% (blue shade), 15% of the farms have an income increase between +10% and +30% (green shade), etc. For each farm type and economic size, the average income change is provided, e.g., in the first panel (All farms), the "2000-8000 EUR" economic-size class has an average income change of -7%.

The main findings are as follows: For "specialist horticulture (20)" farms, the smallest standard output farms would see the most significant benefits (+35% increase in income, compared to a +16% increase for the largest farms). A similar pattern exists for the "specialist orchards and fruits (36)" farms, with the smallest farms experiencing a +15% income increase compared to +12% for the largest. For farms experiencing income losses, particularly livestock farms, the impacts tend to be more substantial (higher income loss) for larger farms (in terms of economic size). However, significant income losses are also observed for the smallest farms in some cases. For example, in the "mixed livestock (70)" farms that belong to the largest economic size category, there is a 34% income loss, while those in the smallest category have a 25% loss. Similarly, specialist milk farms experience a 37% loss compared to 32% for the largest and smallest economic size categories, respectively, and specialist cattle farms will see a 33% loss compared to 22% for the same economic size categories.[8]

8 In Figure 21, also income losses for the Specialist olives farm type can be noted. These losses are driven by the assumed dietary shifts in the scenario, as olive oil is considered a fat in the EAT Lancet dietary recommendations. More specifically, there is a substantial decrease in sugar intake, as well as the reduction in fats consumption in the recommendations. This latter leads to a decrease in the consumption of olive oil and a consequent reduction in prices, negatively affecting the gross income of the Specialist olives farm type.

Figure 21. Change in farm gross income by type of farms (FT14) and economic size (ESC6), COMB scenario, compared to the baseline



Source: IFM-CAP model results

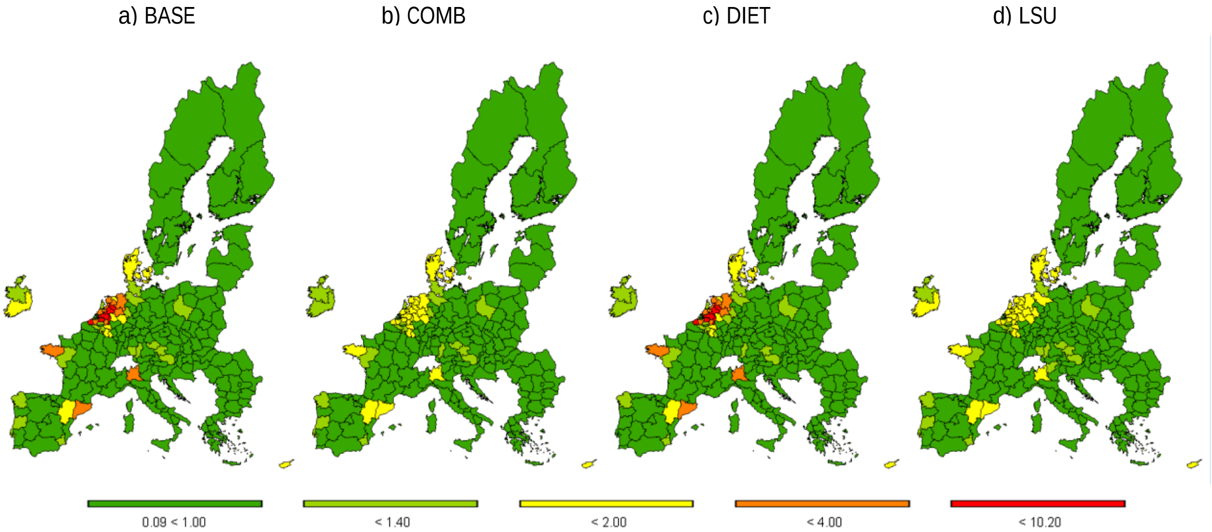
3.6 Environmental indicators

3.6.1 Nitrogen surplus

Managing nitrogen (N) surplus is critical for sustainable agriculture, as it involves optimising nitrogen use efficiency to support crop productivity while minimising environmental impacts. N-surplus is endogenously calculated in CAPRI as the sum of N inputs to land (fertiliser, manure and biosolids, atmospheric N deposition, biological fixation and net mineralisation) minus crop removal. N-surpluses tend to be most pronounced in regions with intensive agricultural activities, such as large-scale crop production or high livestock densities. High N-surplus can lead to excessive nitrogen losses that negatively affect soil, air, and water quality, contributing to both environmental and health challenges. Particularly, in areas with high livestock density, i.e. where a large number of animals are concentrated, the amount of manure produced can exceed the capacity of the land to effectively absorb and utilise the nutrients, resulting in a surplus of nitrogen. This underscores the significance of understanding and addressing livestock density as a primary driver of nitrogen surplus. Therefore, we first outline how livestock density, as a primary driver for N surplus, is affected in the baseline and scenarios, highlighting the importance of the LSU assumption within the COMB scenario.

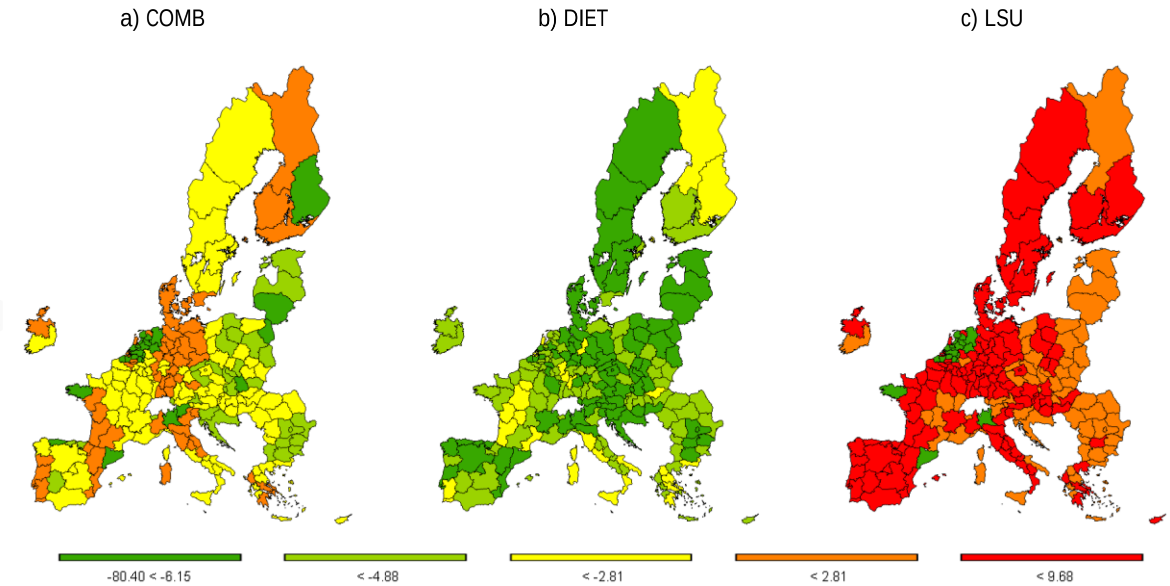
The LSU scenario assumes a maximum livestock production density equal to 2 LSU per hectare of UAA. Accordingly, this limitation on LSUs is also integrated in the COMB scenario. Figure 22 (b & d) illustrate that the hotspot regions effectively decrease livestock density to the desired level. This leads to a redistribution effect, with regions being below the 2 LSU/ha limit in the baseline experiencing an increase in livestock production and LSU levels (Figure 23c). However, it is important to note that despite this redistribution effect, there is no deterioration in the LSU level in these regions, as evidenced by the similarity to the baseline depicted in Figure 22 (b & d). On the contrary, Figure 23b indicates that the dietary shifts can promote and have the potential to reduce the livestock density across EU, mainly driven by the reduced demand for meat products. However, the effect here is limited given that the LSU levels of the NUTS2 regions in Figure 23c, especially for the hotspots, remain within the same cluster. Nevertheless, this indicates that a higher adherence to dietary recommendations of the EAT Lancet may trigger a stronger change in LSU levels.

Figure 22. LSU density (LSU per ha UAA) in selected scenarios in 2035



Source: CAPRI model results

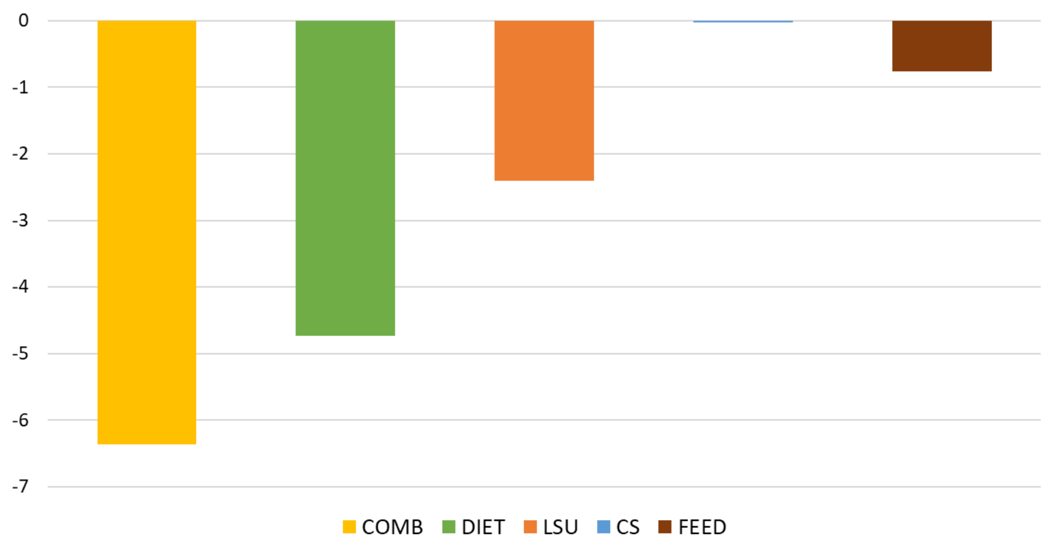
Figure 23. Change in LSU density (LSU per ha UAA) compared to the baseline in 2035 (% change)



Source: CAPRI model results

In the COMB scenario, an overall decrease in livestock production drives the reduction in N-surplus since manure output is considerably reduced. This reduction is primarily achieved through the limitation of livestock density to 2 LSUs and the shift towards less protein intake from animal products in food (DIET). Additionally, the increase in feed use efficiency (FEED) also contributes to the decrease in N-surplus. The main reductions occur in N-surplus at soil level (-434 thousand tonnes) and the gaseous N-losses from manure (-246 thousand tonnes). Under the COMB scenario, the EU average N-surplus per ha UAA decreases by 6.4% (Figure 24).

Figure 24. Change in EU average N-surplus per ha UAA, relative to the baseline (%-change, 2035)

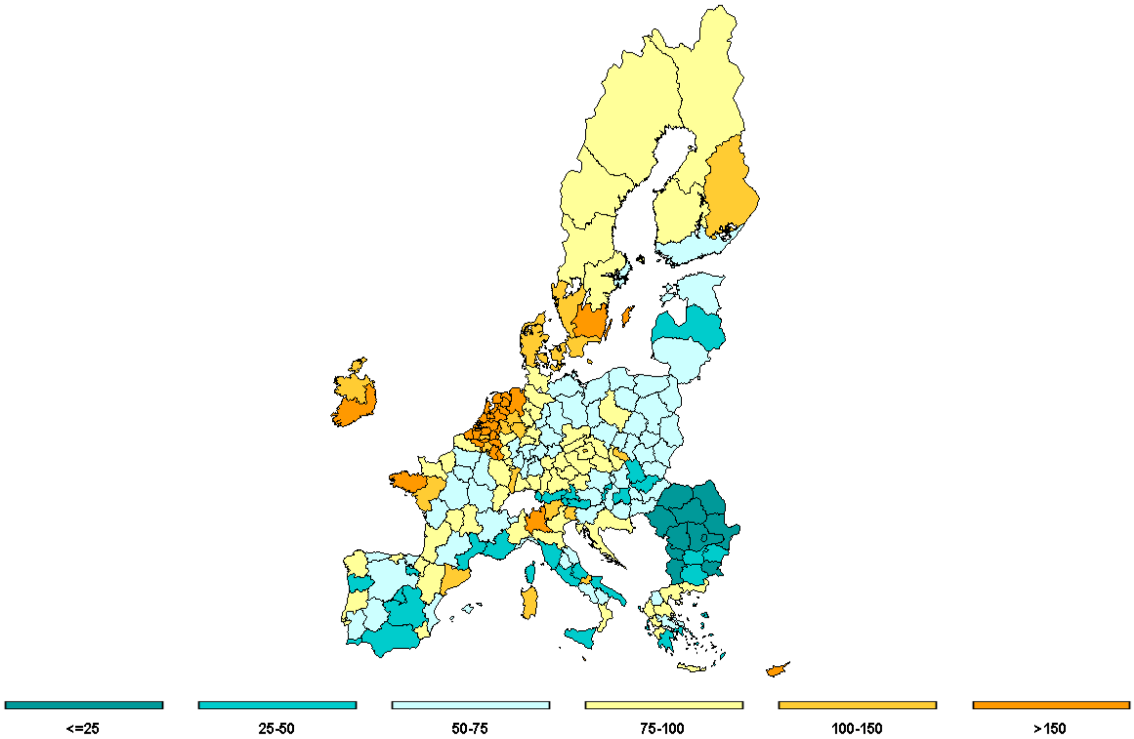


Note: N-surplus includes gaseous N-losses (from mineral fertilisers, manure, crop residues and atmospheric deposition), N-surplus at soil level and the run-off of N from mineral fertiliser and manure.

Source: CAPRI model results

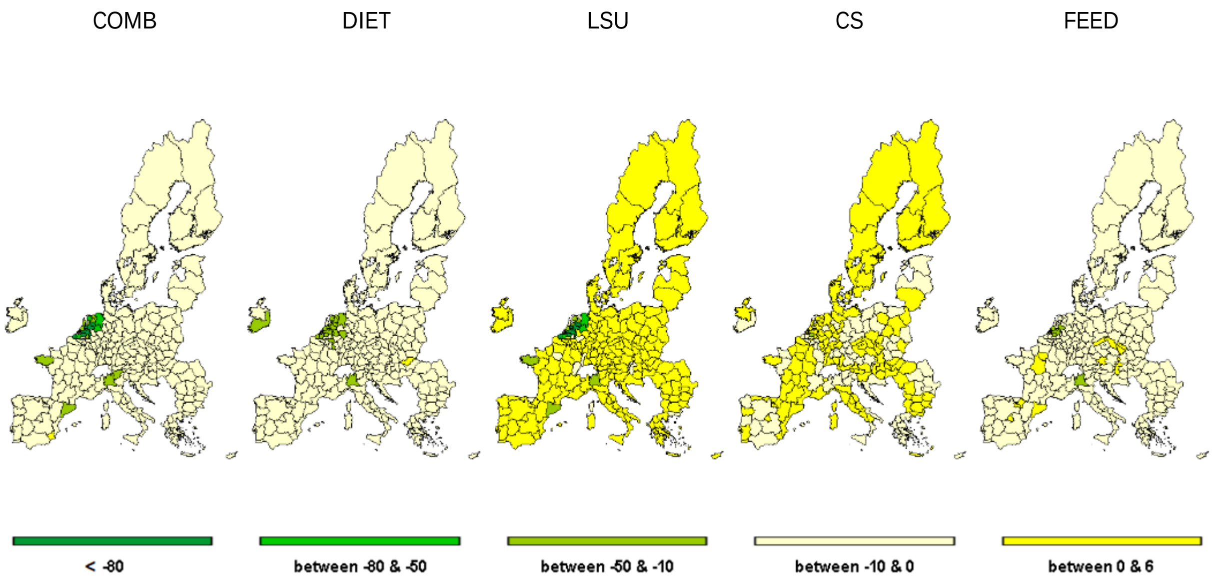
The COMB scenario shows mainly a combination of the effects of the LSU and DIET scenarios, emphasising that the decrease in livestock production density and the dietary changes towards a higher share of plant-based protein have the potential to significantly reduce nitrogen surpluses across the EU. The implementation of the LSU scenario assumptions plays a significant role in diminishing N-surplus in regions with the highest baseline levels (e.g., Noord-Brabant, West-Vlaanderen, Limburg-NL). In regions not characterised by the highest N-surplus, the LSU scenario leads to minor impacts, resulting in slight increases in N-surplus, however, none of these increases is higher than 6 kg/ha. The DIET scenario leads to a general decrease in N-surpluses, and also impacts specifically the regions exhibiting high livestock densities, and implicitly high N-surplus levels as these are mainly regions with intensive meat production, and therefore specifically affected by the dietary transition from meat towards more plant-based proteins. The FEED scenario offers modest benefits in reducing N-surplus, albeit limited to specific regions with reductions ranging from 11 kg/ha to 18 kg/ha. Conversely, the CS scenario results in slight increase in N-surpluses across many EU regions. However, it is crucial to note that these increases are minor, not exceeding 6 kg/ha for any region (Figure 26). The relative changes in the EU N-surplus compared to the baseline can be found in Annex 2.

Figure 25. Regional N-surplus (kg of N per ha of UAA) in the baseline



Source: CAPRI model results

Figure 26. Absolute change in EU N-surplus (kg of N per ha of UAA) compared to the baseline (2035)



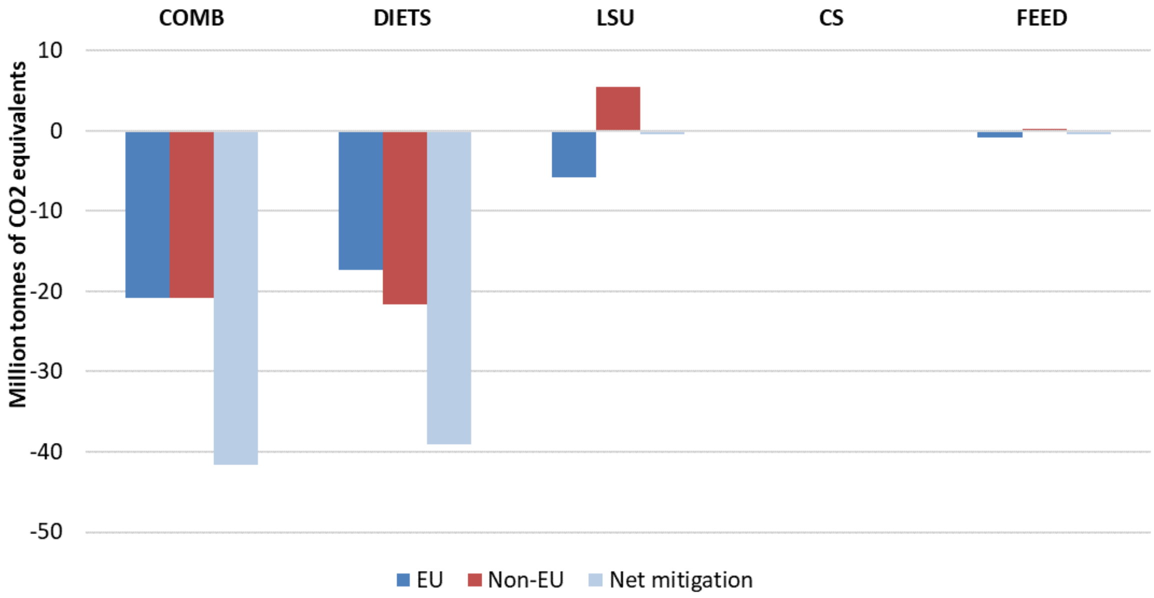
Source: CAPRI model results

3.6.2 GHG emissions

The simulated changes result in an enhanced contribution of the agricultural sector to EU GHG mitigation efforts. In the COMB scenario, agriculture GHG emissions (measured in CO_2 equivalents) in the EU decrease by 5.6% (-20.8 MtCO2e). This reduction entails a decrease in agricultural methane emissions by 6.6% and a decrease of nitrous oxide emissions by 3.3%. Figure 27 presents GHG emission changes in the EU and non-EU countries across the different scenarios compared to the baseline.

In the EU, the CS scenario shows basically no change in agriculture emissions (less than -0.1% reduction), while the FEED (-0.2%), LSU (-1.6%), and DIET (-4.7%) scenarios indicate decreases in EU emissions, resulting in reductions ranging from 0.8 to 17.4 MtCO2e. The dietary shift towards more plant-based protein sources is essential to avoid high rates of emission leakage in the scenarios. When the dietary change is removed from the COMB scenario, the global emission savings become marginal, i.e. most of the emission savings in the EU are counterbalanced by increasing GHG emissions in non-EU countries. Emission leakage is almost exclusively observed in the LSU scenario, where the reduction in EU emissions (-5.8 MtCO2e, -1.6%) is almost entirely offset by the production increases and the related rise in non-EU GHG emissions (+5.4 MtCO2e). Conversely, the dietary change towards more plant-based protein intake in the EU under the DIET scenario leads to additional reductions in non-EU GHG emissions (-21.6 MtCO2e) that are even higher than the EU reductions (-17.4 MtCO2e, -4.7%). This is attributed to decreased production in non-EU, especially due to reduced meat exports to the EU. Consequently, the simulated dietary change in the EU leads to considerable global GHG emissions savings (-39 MtCO2e). In the COMB scenario, the dietary change also lowers the increase of non-EU emissions observed in the LSU scenario. The EU's emission reduction of 20.8 MtCO2e is matched by an additional reduction in non-EU emissions of a similar magnitude, leading to global decreases in agriculture GHG emissions of 41.7 MtCO2e. This underscores the importance of dietary shifts towards plant-based protein sources in achieving significant reductions in both EU and global GHG emissions.

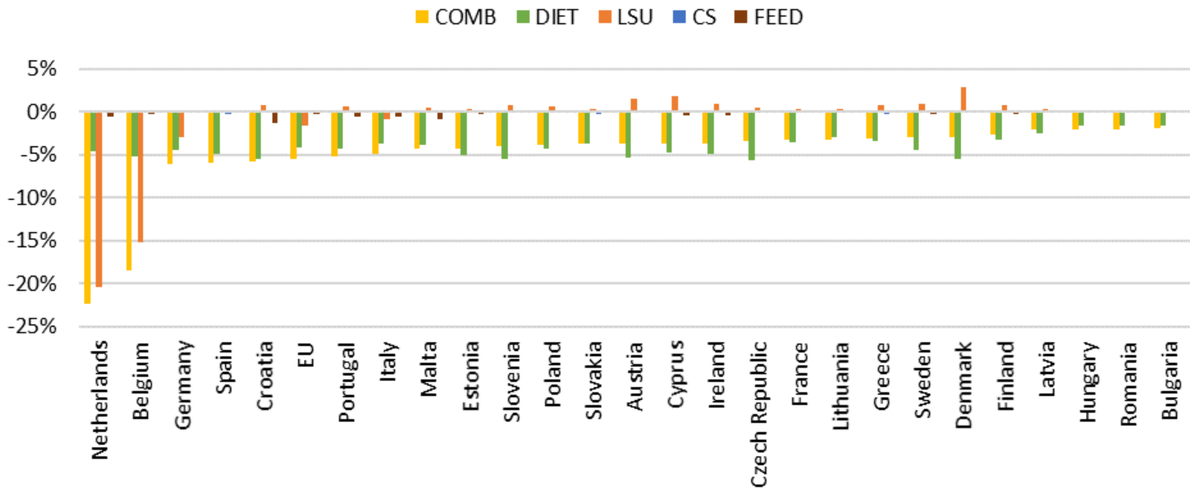
Figure 27. Change in agriculture GHG emissions in the EU and Non-EU compared to the baseline



Source: CAPRI model results

In the COMB scenario, all MS reduce their agriculture GHG emissions (Figure 28), although we can identify different patterns driving these reductions. The DIET scenario primarily lowers GHG emissions in all MS due to its impacts on livestock production. Conversely, the LSU scenario mainly reduces GHG emissions in countries with high LSU/ha densities in the baseline (BASE). In this scenario, the reallocation of livestock production to regions with lower LSU/ha levels in the BASE (as depicted in Figure 22 and Figure 23) leads to an increase in LSU in MSs such as Denmark, Austria France and Ireland, consequently leading to an increase in their GHG emissions. Conversely, the Netherlands see a reduction of 20% (4 million tonnes) of GHG emissions and Belgium observes a reduction of 15% (1.5 million tonnes) in the LSU scenario compared to BASE. These reductions are primarily driven by decreases in methane emissions from enteric fermentation and manure management, as well as nitrous oxide emissions from manure application. Additionally, Germany, Italy, and Hungary also reduce GHG emissions in the LSU scenario. To a lesser extent, the FEED scenario also shows GHG emissions reductions across most MSs, particularly in Italy, Germany, the Netherlands, France, and Ireland in absolute terms, driven by decreases in nitrous oxide emissions from manure management and application, but also emissions from grazing.

Figure 28. Change in agriculture GHG emissions in EU MS, relative to the baseline 2035



Source: CAPRI model results

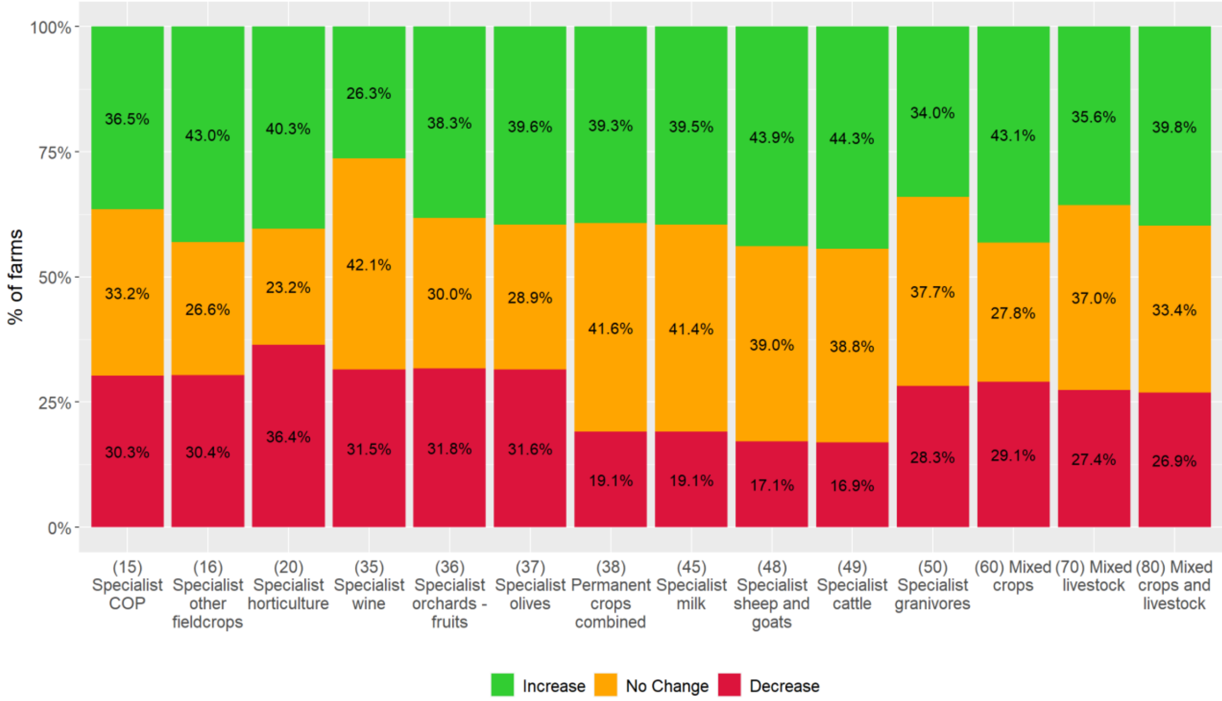
3.6.3 Crop diversity

We use the Shannon index to measure the diversity of crops cultivated on the farm[9]. A higher Shannon index indicates a more even distribution of crops shares, which serves as a proxy for a higher level of biodiversity across the agricultural area of the farms. In the COMB scenario, the Shannon index increases marginally (+0.4%) at the EU level. However, the impact is heterogeneous at the regional level. The majority of NUTS2 regions experience an increase in the Shannon index, albeit a smaller number of NUTS2 regions show a decrease. As the Shannon index is calculated using the logarithm of the relative shares of cropping areas within the farm, the percentage change of the Shannon index in the scenarios is difficult to interpret. To provide a more intuitive measure than the percentage change, we rather analyse the share of farms with increasing or decreasing Shannon index. In the COMB scenario, the Shannon index increases for 39.5% of the EU farms, decreases for 26.4%, while it does not change significantly for 34.0%.

The impact on the Shannon index is heterogeneous among different farm types (see Figure 29). The biggest number of farms with an increased Shannon index can be found among the livestock farms, whereas relatively more arable farms experience a decrease. Overall, the change in the Shannon index is positive, i.e., more farms register an increase than a decrease.

[9] The Shannon index in IFM-CAP is a crop diversity metric that can serve as a proxy index for biodiversity, rather than a direct assessment thereof. Enhanced crop diversity within a farm typically correlates with improved biodiversity performance. However, caution should be exercised in interpreting the Shannon index as a sole measure of biodiversity, as it does not incorporate considerations such as species rarity or ecosystem function.

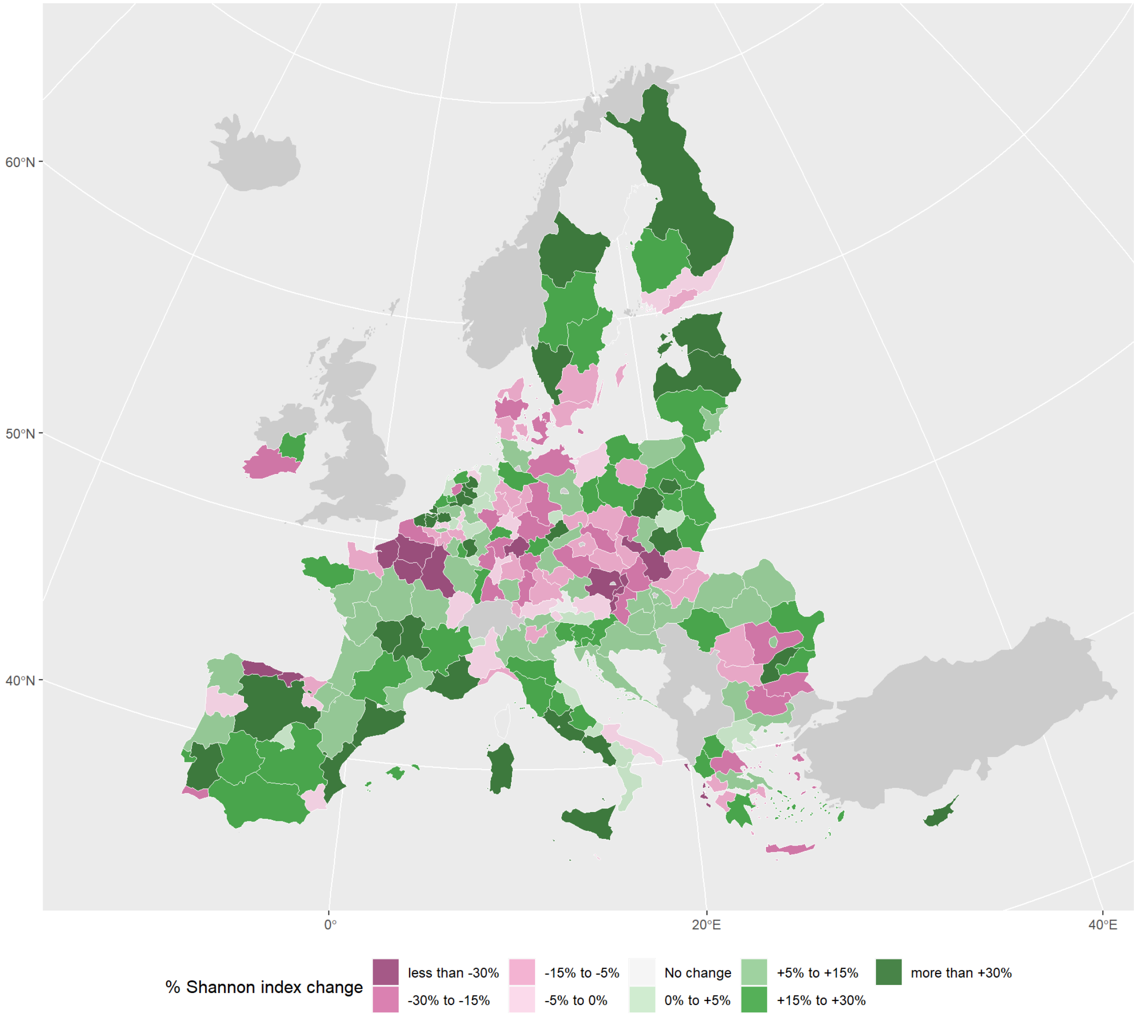
Figure 29. Share of farms with an increase/no change/decrease of Shannon index across type of farming; COMB scenario



Source: IFM-CAP model results

To examine the spatial distribution of changes in crop diversity, we estimate the net share of agricultural land with increase or decrease of the Shannon index, i.e., the share of land with increase minus the share of land with decrease (Figure 30). Green areas indicate a greater share of the agricultural land where the Shannon index has increased compared to the area where it has decreased. Conversely, red areas signify a higher share of land experiencing a decrease in the Shannon index relative to those with an increase. The intensity of the colour reflects the magnitude of this net share. For example, the greenest colour (indicated in the legend as "more than 30%") denotes a difference of over 30% between the share of land with an increase and those with a decrease. A red colour in a NUTS2 means that the land area of farms with a decrease is higher than those with an increase. As shown in Figure 30, Central Europe has more land with a decrease in the Shannon index compared to areas with an increase. The rest of the EU shows a higher proportion of land with an increase in the Shannon index than those experiencing a decrease. Pinpointing the exact drivers of this pattern is challenging. For example, while certain livestock areas experience an expansion of land with an increased Shannon index, others show the opposite trend.

Figure 30. Net share of land with increases (green) or decreases (red) in Shannon index across NUTS 2 regions; COMB scenario



Source: IFM-CAP model results

Regarding the changes in crop diversity index across the agricultural landscape of the EU, approximately 86 million hectares are projected to experience either an increase or remain unchanged, while around 30 million hectares are expected to have a decrease. Table 2 details the agricultural area exhibiting shifts in crop diversity across different farm types. Overall, the livestock sector, and especially grazing livestock, have three to five times more areas with an increase in the Shannon index than areas with a decrease.

Table 2. Agricultural area with increase or decrease in the Shannon index (in thousand hectares)

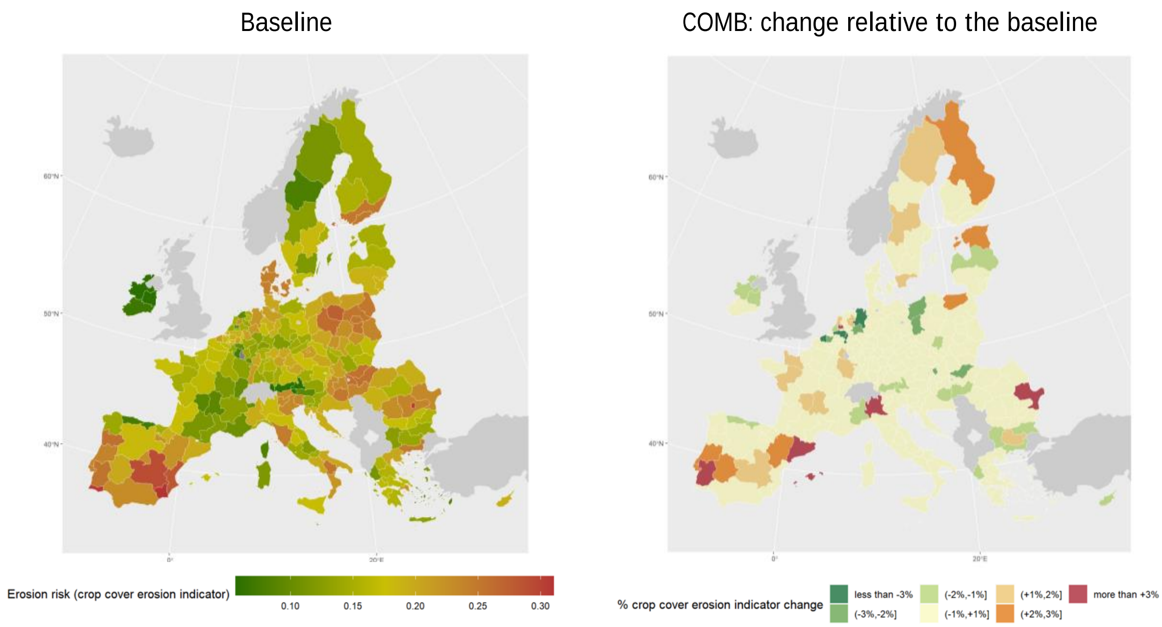
	Increase or no change	Decrease		Increase or no change	Decrease
(1) Field crops	39 579	15 869	(5) Milk	11 665	3 733
(2) Horticulture	617	182	(6) Other grazing livestock	13 136	2 137
(3) Wine	1 058	369	(7) Granivores	2 877	1 206
(4) Other permanent crops	1 565	432	(8) Mixed	16 028	6 262

3.6.4 Erosion risk

The present analysis employs a proxy indicator to simulate erosion risk at the NUTS-2 level, utilizing the crop allocation of the CAPRI model. The indicator is computed as the product of a cover-management factor (C-factor) and a support practice factors (P-factor), which account for how agricultural land cover and management practices influence soil loss compared to bare fallow areas (Panagos et al. 2015). Values of the erosion risk indicator range from 0 to 1, with lower values indicating better soil protection and hence reduced erosion risk. Figure 31 depicts the diverse levels of agricultural soil erosion risk in the baseline and their relative changes in the COMB scenario, driven by the alterations in the levels of crops cover[10].

In the COMB scenario, minor alterations in agricultural land erosion risk are observed in the majority of the EU regions, with 75% of these changes falling within the range of -1 to 1%. The highest relative increases are observed in specific regions, primarily attributable to increased fallow land, particularly in Spain and Italy, as fallow land carries a higher erosion risk (C-factor value of 0.5) compared to cropped land. Additionally, the expansion of maize cultivation (C-factor value of 0.38) significantly contributes to increased erosion risk in Romania. Similar relative increases in erosion risk also occur in other regions (e.g., Sweden), but this is largely due to the low baseline values for erosion risk. In contrast, the greatest benefits are observed in certain regions of the Netherlands, Denmark, and Belgium, where the erosion risk is projected to decrease, mainly due to a reduction in the cultivation of fodder crops, notably fodder maize.

Figure 31. Erosion risk (crop cover erosion indicator) in the baseline and relative changes in the COMB scenario



Source: CAPRI model results

[10] The analysis does not consider the potential regeneration and colonisation by forests, which are characterised by a low C-factor and represent an important conservation management practice option to reduce the erosion risk in a region.

4 Conclusions

While the hypothetical scenarios in this report do not reflect particular policy pathways, they provide valuable insights for policy makers and stakeholders to consider when addressing the EU protein challenge. By exploring drivers, synergies, and trade-offs within a food systems approach, the report highlights the importance of coordinating supply-side and demand-side actions to support a transition towards a more sustainable and resilient protein supply in the EU. Although not exhaustive, the analysed scenarios indicate potential positive impacts across various dimensions, including production in the EU, energy and protein sources in human diets and in animal feed, and environmental indicators, such as nitrogen surplus and GHG emissions. However, the sustainable and resilient development of plant protein production and sourcing in the EU also entails important trade-offs and challenges that required further consideration. These issues would need to be addressed by policymakers and stakeholders within the same integrated food systems approach.

The focus of the analysis is on assessing the impacts of a combined scenario (COMB), which represents a more comprehensive approach to exploring potential synergies within a food systems framework. This scenario comprises three examples of supply-side actions and a demand-side shift concerning dietary changes. Specifically, the COMB scenario encompasses the following assumptions (which are also assessed separately as individual scenarios to gain a deeper understanding of their joint effects): (i) increasing coupled support for protein crop production up to the maximum allowed under the current CAP (CS scenario), (ii) adopting LNF strategies (FEED scenario), (iii) implementing maximum livestock production densities of 2 LSU/ha UAA (LSU scenario), and (iv) transitioning towards healthier and more sustainable human diets, reaching 25% of the EAT Lancet dietary recommendations by 2035 (DIET scenario).

The DIET scenario assumptions have the most significant impact on EU protein supply and demand within the COMB scenario. In contrast to the prevailing dietary patterns observed within the EU, a diet that is more aligned with current nutritional guidelines would require an increase in the consumption of plant-based foods and a reduction in the intake of animal-based products. The modelled transition to a healthier and more plant-based diet leads to a 9% substitution of animal protein by plant-based protein intake, with a 6% increase in the intake of plant-based calories, accompanied by a corresponding 6% decrease in the consumption of animal-based calories. Consequently, the COMB scenario shows notable shifts in the composition of EU domestic demand, particularly a significant increase in the human consumption of certain crops, such as cereals and pulses, and a substantial decrease in animal feed use. This also results in reduced resource requirements to meet food needs in the EU.

The implementation of the LSU scenario assumptions induces a small redistribution effect within the EU, with the decline in livestock production in regions exceeding the 2 LSU/ha limit being largely offset by increased production in other regions that can still comply with the LSU limit. Furthermore, the livestock density limit plays a crucial role in reducing nitrogen surplus in regions currently characterised by high levels of nitrogen pollution. The CS and FEED scenarios, focusing on increased coupled support for protein crop production and the adoption of low-nitrogen feeding practices, respectively, have generally limited impacts on production and demand at the aggregate EU level. Nevertheless, the simulated coupled support has the potential to enhance the relative profitability of protein crops for farmers (i.e., soya beans and pulses), thereby increasing their competitiveness (as reflected in the decrease in their prices) compared to crops like cereals.

The changes occurring in the domestic production and consumption of food commodities under the COMB scenario affect the EU's trade balance. Notably, the EU's imports of soya beans and oilmeals (mainly soya meals) are reduced by 3% and 30%, respectively. This improves the EU's trade position, although it still remains a net importer in terms of high-protein feed. The imports of crude protein content from the main imported feed protein sources, namely oilmeals, oilseeds, and cereals, decrease by 13% (2.2 million tonnes of crude protein). In particular, the EU's dependence on soya meal as a high-protein feed source decreases from 38% of the total crude protein imports in the BASE scenario to 30% in the COMB scenario. At the global level, this decrease mainly impacts Mercosur countries, which are the primary exporters of soya beans and oilmeals to the EU. Due to the changes in the domestic demand, the EU's net trade balance also improves for most animal products. However, to support a domestic demand reflecting a healthier diet, the EU would significantly increase imports of other crops, such as vegetables, permanent crops and pulses, despite considerable increases in domestic EU production of these crops.

The COMB simulation shows significant environmental impacts both within and outside the EU. The shift in diets is the main driver of these impacts. This highlights the importance of a comprehensive combined approach that addresses both demand and supply aspects to reduce the environmental footprint of agricultural activities. Notably, the GHG emissions from agriculture decrease by 5.6% (-20.8 MtCO2e), mainly driven by lower methane and nitrous oxide emissions from enteric fermentation and manure management and application. Furthermore, there is no significant leakage of GHG emissions in the COMB scenario, as well as in the DIET scenario. Moreover, due to lower EU imports, there is an additional reduction in GHG emissions of a similar magnitude in non-EU countries, resulting in a global reduction in GHG emission from agriculture of 41.7 MtCO2e. Conversely, without the shift in demand towards healthier diets, the potential benefits of emissions reductions in the EU could be substantially diminished by emissions leakage, which is particularly evident in the LSU scenario.

The modelled transition towards more plant-based diets combined with the 2 LSU/ha limit contributes most to the reduction of the EU nitrogen surplus. In the COMB scenario, the average N-surplus per ha of UAA in the EU decreases by 6.4%. This reduction is also supported to a lesser extent by the increase in protein-feed use efficiency (FEED scenario). Moreover, the combined effects of all scenario assumptions lead to a modest increase in the diversity of the EU cropping systems, as captured by the increase in the Shannon Index. This diversification effect also has an overall positive impact on agricultural soil erosion risk. However, the increase in fallow land and the expansion of maize cultivation can potentially increase the erosion risk in certain regions due to their higher erosion coefficients.

Establishing a sustainable and resilient food system in the EU that effectively manages import dependency while preserving environmental integrity presents considerable challenges and potential economic costs. Economic performance indicators illustrate the complexity of achieving this equilibrium, with a projected reduction in the agricultural gross value added (GVA) of approximately 3.8% under the COMB scenario. Notably, small farms show a comparatively lower median income loss, being less affected by the scenarios. While livestock farms face more pronounced negative effects, the specialist horticulture and specialist orchards and fruits farms see significant income increases. The overall decline in GVA predominantly arises from shifts in both demand and supply dynamics driven by the modelled healthier dietary patterns. The modelled increase in coupled support for protein crop production and the adoption of LNF practices have generally limited impacts on production and demand, and hence on the GVA at the EU level. Conversely, the implementation of the 2 LSU/ha limit, that only affects supply without addressing consumer behaviour, can potentially lead to an increase in GVA due to the rather inelastic nature of demand for animal products. Consequently, the EU regions with the highest negative externalities per unit of land area in terms of N-surplus endure the largest losses in agricultural income. These regions often have limited land resources, which hinders their capacity to streamline supply chains and reduce import dependency on imported feed. It is important to note, however, that our analysis does not quantify the economic value of the estimated environmental benefits, which could potentially offset observed economic losses. Nevertheless, achieving a sustainable and resilient EU agri-food system will require careful policy design that considers transition costs for farmers, thereby ensuring the ability to meet present and future societal needs.

In summary, the joint COMB scenario integrates the assumptions of four hypothetical individual scenarios (DIET, LSU, CS, and FEED). The DIET and LSU scenarios are the main drivers of the observed changes. Our analysis of the combined effects of each individual scenario highlights the importance of simultaneously deploying multiple, mutually reinforcing approaches to facilitate the transition towards sustainable and resilient agricultural systems in the EU. The results of the scenario analysis show clearly that to realise substantial environmental improvements and to reduce the EU's reliance on imported feed protein, EU protein supply and demand need to be tackled jointly, by both policy-makers and stakeholders. This requires a comprehensive approach that considers the complex interactions that exist within the agricultural sector and the broader food system.

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List of abbreviations

BASE	Baseline
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regional Impact Analysis
CS	Coupled Support
CS scenario	Increased coupled support for protein crop production
CSPs	Common Agricultural Policy Strategic Plans of the Member States
CO_2	Carbon Dioxide
COMB scenario	Combined scenario
CRPR	Crude Proteins
DG AGRI	Directorate-General for Agriculture and Rural Development
DIET scenario	Gradual transformation of human diets
EAT-Lancet	The EAT-Lancet Commission on Food, Planet, Health
ES	Economic size
EU	European Union
FADN	Farm Accountancy Data Network
FEED scenario	Increased adoption of low-nitrogen-feeding practices
GHG	Greenhouse gas
GVA	Gross Value Added
Ha	Hectare
HCON	Human Consumption
IFM-CAP	Individual Farm Model for Common Agricultural Policy Analysis
JRC	Joint Research Centre
LNF	Low-nitrogen-feeding
LSU	Livestock units
LSU scenario	Decrease in livestock production density in the EU
Mercosur	Southern Common Market (Mercado Común del Sur)
MS	Member State
N	Nitrogen
NL	Netherlands
N_2O	Nitrous-Oxide

NUTS	Nomenclature of Territorial Units for Statistics
PMP	Positive Mathematical Programming
PROC	Processing
SO	Standard Output
TF	Type of farm
UAA	Utilized Agricultural Area
USA	United States of America

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Annexes

Annex 1. Healthy reference diet for an intake of 2500 kcal/day

In the DIET and COMB scenarios, it is assumed that 25% of the targets of the EAT Lancet recommendations for an intake of 2500 kcal/day are met in all EU countries by 2035 for all food products (excluding waste). The following table provides an overview of the full EAT Lancet recommendations for a healthy diet (Willett et al. 2019).

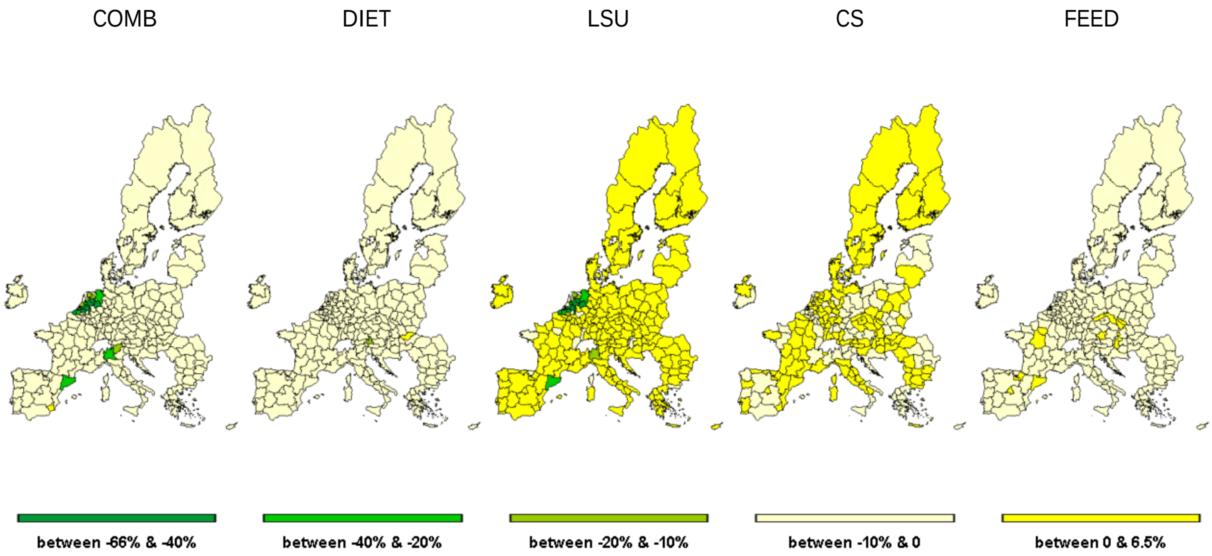
Table 3. Overview on the Eat Lancet recommendations for a healthy diet

	Macronutrient intake (possible range), g/day	Caloric intake, kcal/day
Whole grains		
- Rice, wheat, corn, and other	232 (total gains 0-60% of energy)	811
Tubers or starchy vegetables		
- Potatoes and cassava	50 (0–100)	39
Vegetables		
- All vegetables	300 (200–600)	..
- Dark green vegetables	100	23
- Red and orange vegetables	100	30
- Other vegetables	100	25
Fruits		
- All fruit	200 (100–300)	126
Dairy foods		
- Whole milk or derivative equivalents (e.g., cheese)	250 (0–500)	153
Protein sources		
- Beef and lamb	7 (0–14)	15
- Pork	7 (0–14)	15
- Chicken and other poultry	29 (0–58)	62
- Eggs	13 (0-25)	19
- Fish	28 (0-100)	40
- Legumes		
- Dry beans, lentils, and peas	50 (0–100)	172
- Soya foods	25 (0-50)	112
- Peanuts	25 (0-75)	142
- Tree nuts	25	149
Added fats		
- Palm oil	6·8 (0–6·8)	60
- Unsaturated oils¶	40 (20–80)	354
- Lard or tallow	5 (0–5)	36
Added sugar		
- All sweeteners	31 (0-31)	120

Source: Willet et al. (2019), p.5

Annex 2. Changes in EU N-surplus compared to the baseline

Figure 32. Relative change in EU N-surplus (%) compared to the baseline (2035)



Source: CAPRI model results

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