

D1.5 - Modelling future scenarios of food resilience



**Eco
Ready**

Saeed Moghayer^{1,*}, Marcos Dominguez Viera¹, Masoud Ghaderi Zefreh², Zuzana Kristkova¹, Andrea Doeschl-Wilson², Ioannis Manikas³

¹Wageningen University & Research

²Roslin Institute, University of Edinburgh

³Czech University of Life Sciences



The ECO-READY project has received funding from the European Union's Horizon Europe Research and Innovation Programme under grant agreement n° 101084201

Technical References

Project Acronym	ECO-READY
Project Title	Achieving Ecological Resilient Dynamism for the European food system through consumer - driven policies.
Project Coordinator	Czech University of Life Sciences (CZU)
Project Duration	48 months

Deliverable No.	
Dissemination level ¹	
Work Package	WP1
Task	Task 1.4.
Lead beneficiary	CZU
Contributing beneficiary(ies)	WUR, Edin, CZU
Due date of deliverable	30 November 2024
Actual submission date	

¹ PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Author
1	12-11-2024	WR	Saeed Moghayer
2			



Summary

This report (D1.5) details the modeling of future scenarios for food resilience, a key component of Task 1.4 within the broader project framework. Building upon the key drivers and storylines influencing food security identified in Task 1.3 and the ‘Living Labs (LLs) scenario modelling workshop¹’ this work quantifies the potential impacts of a selection of these scenarios with economy-wide characteristics on food security, environmental sustainability, and economic performance. The primary modeling tool employed was MAGNET, a multi-regional, multi-sectoral, applied general equilibrium model tailored for agri-food analysis. The resulting scenarios project a range of potential impacts on the target regions—the EU aggregate as well as the individual member states in which the Living Labs (LLs) are situated—offering insights for the Living Labs (WP3) and providing context for the product- and region-specific LCA analysis in WP3, the AI tool in WP4, and informing policy recommendations (WP5). This scenario and modelling foresight illuminate the complex interplay of factors affecting food resilience at the larger scale and provide a basis for evidence-based decision-making tools and applications in the face of future uncertainties in the other ECO-READY work packages.

This report focuses on providing quantified, contextual scenarios and projections to establish a foundation for further detailed analysis within ECO-READY LLs projects. Due to limitations in product and spatial detail, the detailed elements of the scenario narratives could not be directly implemented within the MAGNET model. However, this analysis serves as the basis for more detailed analyses using LCA models and other intermediary models. This can be achieved by directly using MAGNET projections of the overall scenarios or by linking to MAGNET in follow-up tasks and other work packages (WPs). To illustrate these steps, we present two case studies conducted in Task 1.4 utilizing the MAGNET model, where it is linked with other intermediary models to explore region- or product-specific scenarios. These cases examine the impact of climate change on wheat production in the Czech Republic and genomic breeding as a climate adaptation strategy. These examples illustrate the subsequent steps of Task 1.4 (WP4 and WP5), involving a "global to local to global" analysis, which provides a more comprehensive understanding of the impacts of specific scenarios identified in Task 1.3.

Disclaimer

This publication has been produced within the ECO-READY project which has been funded by the European Union Horizon Europe Research and Innovation Programme under grant agreement n° 101084201. This publication reflects only the views of the authors. The European Commission and Research Executive Agency cannot be held responsible for any use which may be made of the information contained therein.

¹ ‘Co-creation and Training Workshop for Scenario Development’, 27-28 June 2024, The Hague, the Netherlands.



Table of contents

Contents

Technical References	2
Document history.....	2
Summary.....	3
Disclaimer.....	3
Table of contents.....	4
1 Introduction	6
2 Methodology	9
2.1. Foresight scenario approach	9
2.2. Living Labs involvement in scenario modelling	10
Drivers and Challenges by Product	10
Development and Interventions in different regions.....	11
2.3. Scenario framework	12
2.3. Foresight modelling	14
The Model.....	14
The Model database	16
3 Scenario narratives and simulation	17
3.1. Scenario narratives	17
3.2. Simulation setup	20
4 Results	21
4.1. Drivers.....	21
4.1.1. Income and population	22
4.1.2. Land productivity	23
4.1.3. Labor and capital	24
4.2. Food Sustainability and resilience impact	25
4.2.1. Agri-food consumption, prices, and trade.....	25

4.2.2. Food & nutrition security.....	29
4.2.2. Environmental impact	32
4.3 Sustainable Development Goals (SDG) indicators.....	33
4.4. Summary results and trade-off analysis	35
5 Case study I: Bridging Global to Local to Global analysis: A Protocol for Modeling Agricultural Climate Resilience.....	36
5.1. Model Setup	37
5.2. Results.....	38
5.3. Discussion	38
6 Case study II: Breeding as mitigation strategy for climate change on livestock sector and food security.....	38
6.1. Modelling set-up	39
6.2. Overall Results.....	40
6.3. Discussion	43
7 Conclusion	44
8 References.....	45
Anex 1: Co-creation and Training Workshop for Scenario Development, The Hague, NL, 27-28 June 2024.....	49
Introduction	49
Drivers	51
Key take aways and next steps	55
Scenarios	56
Key Takeaways and Next Steps.....	60
Summary.....	61
Annex 2 The Green, the Middle, and the Rocky Roads; Percentage change in selected indicators across EU member states + Ukraine, 2025-2050.....	63

1 Introduction

Assessing the resilience of food systems within future possible pathways for the contextual development of the agri-food sector is crucial. Such an assessment must consider the main global drivers and uncertainties, rather than only viewing the EU agri-food sector or specific products in their current situation and in isolation. By evaluating how agri-food systems might respond to various economic, social, environmental, and technological changes, we can identify potential vulnerabilities and develop strategies to enhance resilience at the finer scales. This integrated approach enables informed decision-making and proactive measures to ensure food security and sustainable agri-food systems in the face of future challenges. For example, a study by Tendall et al. (2015) highlights the importance of considering the interconnectedness of food systems with other sectors when assessing resilience. Rasmussen et al. (2019) emphasize the need to incorporate diverse perspectives and uncertainties, including climate change, population growth, and economic shocks, in food system resilience assessments. By integrating these considerations into future pathway assessments, policymakers and stakeholders can make informed decisions to promote resilient and sustainable agri-food systems that can withstand future shocks and stresses.

This report (D1.5) details the modeling of future scenarios for food resilience, a key component of Task 1.4 within the broader ECO-READY project framework. Building upon the key drivers and storylines influencing food security identified in Task 1.3 and the LLs scenario modelling workshop, this work quantifies the potential impacts of a selection of these scenarios with economy-wide characteristics on food security, environmental sustainability, and economic performance. The primary modeling tool employed was MAGNET, a multi-regional, multi-sectoral, applied general equilibrium model tailored for agri-food analysis. The resulting scenarios project a range of potential impacts on the target regions—the EU aggregate as well as the individual member states in which the Living Labs (LLs) are situated. These projections offer valuable insights for the Living Labs (WP3) and provide a broader context for subsequent analyses within the project. This includes the product- and region-specific LCA analysis in WP3, the AI tool development in WP4, and the formulation of policy recommendations in WP5. Due to limitations in product and spatial detail within the MAGNET model, the detailed elements of the scenario narratives could not be directly implemented. However, this analysis serves as a foundation for more granular analyses using LCA models and other intermediary models. This can be achieved

by directly using MAGNET projections of the overall scenarios or by linking to MAGNET in follow-up tasks in other work packages (WPs). To illustrate these steps, we present two case studies conducted in Task 1.4 utilizing the MAGNET model, where it is linked with other intermediary models to explore region- or product-specific scenarios. These cases examine the impact of climate change on wheat production in the Czech Republic and genomic breeding as a climate adaptation strategy. These examples illustrate the subsequent steps of Task 1.4 (WP4 and WP5), involving a "global to local to global" analysis, which provides a more comprehensive understanding of the impacts of specific scenarios identified in Task 1.3.

Assessing the resilience of food systems within future possible pathways for the contextual development of the agri-food sector is crucial. Such an assessment must consider the main global drivers and uncertainties, rather than only viewing the EU agri-food sector or specific products in their current situation and in isolation. By evaluating how agri-food systems might respond to various economic, social, environmental, and technological changes, we can identify potential vulnerabilities and develop strategies to enhance resilience at finer scales. This integrated approach enables informed decision-making and proactive measures to ensure food security and sustainable agri-food systems in the face of future challenges. For example, a study by Tendall et al. (2015) highlights the importance of considering the interconnectedness of food systems with other sectors when assessing resilience. Rasmussen et al. (2019) emphasize the need to incorporate diverse perspectives and uncertainties, including climate change, population growth, and economic shocks, in food system resilience assessments. By integrating these considerations into future pathway assessments, policymakers and stakeholders can make informed decisions to promote resilient and sustainable agri-food systems that can withstand future shocks and stresses. To this end, this report (D1.5) details the modeling of future scenarios for food resilience, a key component of Task 1.4 within the broader ECO-READY project framework. Building upon the key drivers and storylines influencing food security identified in Task 1.3 and the LLs scenario modeling workshop, this work quantifies the potential impacts of a selection of these scenarios with economy-wide characteristics on food security, environmental sustainability, and economic performance.

The primary modeling tool employed was MAGNET², a multi-regional, multi-sectoral, applied general equilibrium model tailored for agri-food analysis. The resulting scenarios

² <https://www.magnet-model.eu/model/>

project a range of potential impacts on the target regions—the EU aggregate as well as the individual member states in which the Living Labs (LLs) are situated. These projections offer valuable insights for the Living Labs (WP3) and provide a broader context for subsequent analyses within the project. This includes the product- and region-specific LCA analysis in WP3, the AI tool development in WP4, and the formulation of policy recommendations in WP5.

Due to limitations in product and spatial detail within the MAGNET model, the detailed elements of the scenario narratives could not be directly implemented. However, this analysis serves as a foundation for more granular analyses using Life Cycle Assessment (LCA) model and other ECO-READY intermediary models with a more micro perspective. This can be achieved by directly using MAGNET projections of the overall scenarios or by linking to MAGNET in follow-up tasks in other work packages (WPs). To illustrate such linkages, we conducted two additional case studies in Task 1.4 utilizing the MAGNET model, where it is linked with other intermediary models to explore region- or product-specific scenarios. These cases examine the impact of climate change on wheat production in the Czech Republic and genomic breeding as a climate adaptation strategy. These examples illustrate the subsequent steps of Task 1.4 (WP4 and WP5), involving a "global to local to global" analysis, which provides a more comprehensive understanding of the impacts of specific scenarios identified in Task 1.3.

We follow a four-step approach for the development of Scenario and Foresight Modeling. To create our quantified scenarios and foresight analysis, we consider both global and EU-specific influences. We use the IPCC-based Shared Socioeconomic Pathways (SSPs) to represent different global socioeconomic trends, which provide a range of plausible futures by considering factors like population growth, economic development, and technological change. Additionally, we develop specific economy-wide scenarios for the EU, including all member states hosting the ECO-READY LLs, based on consultations with Living Labs and their insights on regional trends and challenges. This two-level approach allows us to capture both the broad global context and the specific nuances of the EU economy, leading to more robust and relevant scenario development as described earlier in this section.

The subsequent sections of this report describe the specifics of our scenario development and foresight modeling process. Section 2 outlines the methodology, including the four-step approach, the role of Living Labs, and the structure of the MAGNET model. Section 3 details the scenario narratives and simulation setup, while Section 4 presents the modeling

results. Additionally, we present two case studies: Section 5 explores the impact of climate change on wheat production in the Czech Republic, and Section 6 investigates genomic breeding as a climate adaptation strategy.

2 Methodology

2.1. Foresight scenario approach

Figure 1 illustrates the framework and fundamental steps employed in the scenario development foresight modelling process for this study.

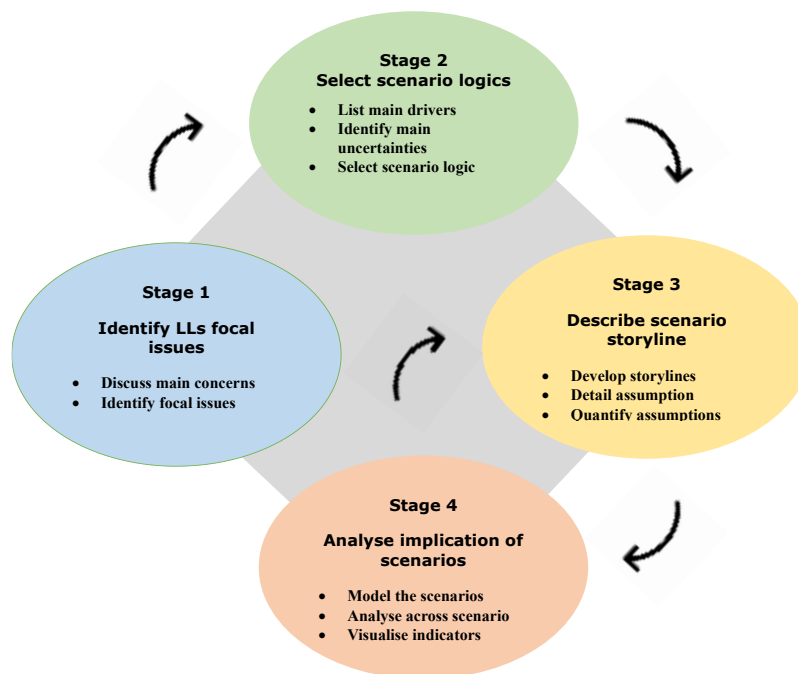


Figure 1: Scenario development and foresight modelling framework. Modified from Moghayer et. al., 2023.

The first stage, "Identify Focal Issues," begins with stakeholders discussing their main concerns and identifying the most crucial issues for future analysis. This stage was mainly covered in the LLs scenario modelling workshop with the Living Labs' representatives which is discussed in details in Section 2.2. Next, in "Select Scenario Logics," the process shifts to identifying the main drivers and uncertainties surrounding these issues, including the socio-economic global contextual narratives, ultimately defining the framework for developing different scenarios. The third stage, "Describe Scenario Storyline," involves crafting detailed narratives for each scenario, articulating and quantifying the underlying assumptions about how the future might unfold (for details see Section 2.3). Finally, in "Analyse Implication of Scenarios," the implications of each scenario are explored, using

MAGNET model and run simulations. The outcomes are then compared and contrasted across scenarios, visualizing key indicators to identify trade-offs and opportunities (see Section 3). The cyclical arrows in the diagram between Stage 3 and Stage 4 indicates an iterative approach where insights from later stage leads to revisiting and refining earlier stage.

2.2. Living Labs involvement in scenario modelling

Living Labs have a crucial role in providing grounded perspectives and real-world insights for scenario development. To foster this collaboration, we engaged with the 10 ECO-READY Living Labs to develop and refine their foresight scenarios, ensuring they captured relevant uncertainties and drivers. This involved training Living Lab representatives in scenario development, empowering them to actively participate in the foresight process. Additionally, we introduced Living Labs to the MAGNET and LCA modeling methodologies, enabling them to understand the models' purpose, structure, and key inputs and outputs. Collaborative efforts focused on identifying relevant indicators and measurable inputs for each Living Lab's specific projects. This ensured the scenarios and models could effectively assess the potential impacts of different pathways on key sustainability metrics.

The LLs scenario modelling workshop served as a central platform to facilitate these objectives. It brought together Living Lab representatives and researchers to collaboratively explore uncertainties, develop narratives, and identify key indicators for modeling. This interactive approach ensured that the scenarios and models were grounded in real-world insights and reflected to the extent possible the diverse perspectives of the participating Living Labs.

In this workshop four primary product groups were examined—greens, oils, tomatoes, and grains—each facing unique challenges influenced by climate change, consumer behavior, and technological advancements. The discussions emphasized how these drivers shape production practices, market dynamics, and future sustainability, with scenario development guiding potential solutions.

Below is a summary of the main output outlining focal issues and drivers across different products and regions. For more detailed information, please refer to Annex 1.

Drivers and Challenges by Product

Greens (Leafy Greens and Microgreens)



In Sweden and Hungary, vertical farming faces energy supply instability due to geopolitical and trade challenges. Rising costs of artificial lighting and skilled labor further strain economic viability. Consumer awareness and demand for sustainable food remain inconsistent. While climate change creates opportunities as outdoor farming becomes unreliable, it also raises energy costs. A balance between automation and human labor, supported by public education and advanced technologies, is essential for sustainable growth.

Oils (Olive and Rapeseed Oils)

Regions producing oils (Spain, France, and Germany) confront climate-induced droughts, heat waves, and pest pressures, leading to decreased yields and rising costs. Integrated pest management and crop resilience strategies are vital. Political trade barriers add complexities to global oil markets, while socio-environmental factors, such as wildlife impacts on crops, underscore the interconnectedness of agricultural systems.

Tomatoes

In Greece and Italy, extreme weather events, salinity issues, and labor shortages challenge tomato production. The shift toward low-carbon agriculture necessitates investments in precision farming and resource-efficient practices. Developing salt-tolerant varieties and addressing migrant worker conditions are key to long-term viability.

Grains

Grain production in Poland and the Czech Republic faces region-specific issues. While buckwheat benefits from extended growing seasons, it is vulnerable to extreme weather and unstable organic seed supply. Barley thrives in Poland's temperate climate but risks yield loss from future heatwaves and soil depletion. Maize, a newer crop in Masuria, contends with fungal diseases and climate unpredictability, necessitating sustainable crop rotations and biodiversity-focused farming practices.

Development and Interventions in different regions

Spain prioritizes drought-resistant crops, improved irrigation, and soil management to combat water scarcity. The Czech Republic emphasizes soil health, crop rotation, and local supply chain resilience against extreme weather and economic shocks.



Greece focuses on flood and drought mitigation through nature-based solutions and drought-tolerant cultivars. Germany explores nutrient loss reduction and bio control practices to enhance land resilience amid climate extremes.

Sweden highlights energy optimization and vertical farming innovations to address water and nutrient management challenges. France advocates for crop diversification, nature-based solutions, and advanced water and energy strategies to adapt to extreme droughts.

Denmark's approach centers on biodiversity, CO2 taxes, and sustainable land use. Italy targets *Xylella fastidiosa* prevention in olives, addressing labor shortages with incentives, and enhancing worker conditions.

Hungary aims to diversify vertical farming products, switch to renewable energy, and create resilient trade agreements. Poland emphasizes regenerative agriculture to mitigate climate stress, promote local grain markets, and address heat wave impacts on Masurian farms.

The main focal issue drivers with economy-wide and sector-specific characteristics, derived from the Living Labs consultation to be included in this study, are the impact of climate change and climate policies, overall technical developments and productivity, changes in consumer behavior, and trade, especially in relation to geopolitics in the EU region. Product and detailed technological-specific as well as sub-national issues will be addressed in subsequent ECO-READY tasks in WP4 and WP5 by LCA model and other intermediary product and technology-specific micro models using the contextual and economy-wide results of this study.

2.3. Scenario framework

To create our quantified scenarios and the foresight analysis, we considered two levels of influence:

1. **Global Context:** We used the IPCC-based Shared Socioeconomic Pathways (SSPs) to represent different global socioeconomic trends. Our baseline scenario assumes a "middle-of-the-road" pathway (SSP2), where the world experiences moderate economic and social challenges with moderate GDP and population growth. Our baseline scenario assumes a "middle-of-the-road" pathway (SSP2), where the world experiences moderate economic and social challenges with moderate GDP and



population growth. To explore a wider range of possibilities, we also considered two alternative pathways:

SSP1: This pathway represents a shift towards a more sustainable future with lower challenges to mitigation and adaptation.

SSP3: This pathway represents a fragmented world with high challenges to mitigation and adaptation.

Table 1 presents the main characteristics of the macro-economic and global agri-food sector development in the coming decades under each of the SSPs. You can find detailed explanations of the SSP narratives in O'Neill et al. (2016).

Table 1: SSP-specific characteristics for macro-economic development in agri-food sector and specific land-use components (for more details, see Doelman et al. 2018). Notation: LIC: 'Low Income Country'; HIC: 'High Income Country'.

Global Contextual Scenario	SSP1	SSP2	SSP3
GDP growth	High in LICs, MICs; medium in HIC	Medium, uneven	Slow
Population growth	Low	Medium	High
Inequality	Reduced across and within countries	Uneven moderate reductions across countries	High, especially within countries
Land use change regulation	High	Medium	Low
Agricultural productivity	High	Medium	Low

2. Specific Scenarios for the EU including all LL member states:

Essentially, we combined global trends with specific factors relevant to the specifics of the relevant co-developed ECO-READY narratives (Section 2.2.) to create a range of plausible

future scenarios. The specific scenarios were developed within four categories of drivers derived from the outputs of the first two stages of the scenario development and foresight modeling framework (see Section 2.1). These categories are:

- **Socio-economic development:** This includes factors like population growth, income distribution, and labor supply.
- **Productivity:** This involves technological advancements and changes in input efficiency (labor, feed, land, yields).
- **Policy:** This encompasses government regulations, incentives, and international agreements related to climate and trade.
- **Intrinsic Motivation:** This refers to factors like individual values that influence consumer behavior.

The scenario framework and narratives are described in detail in the next section.

2.3. Foresight modelling

The Model

For quantifying the scenarios, this study utilized the MAGNET model (Woltjer et al., 2014), a specialized macro-economic model tailored for agri-food analysis. MAGNET is a multi-regional, multi-sectoral, Computational General Equilibrium (CGE) model grounded in neo-classical microeconomic theory (Nowicki et al., 2009; Woltjer et al., 2014; Van Meijl et al., 2018; Van Meijl et al., 2020a). Its database is constructed upon the GTAP dataset (Aguilar et al., 2016).



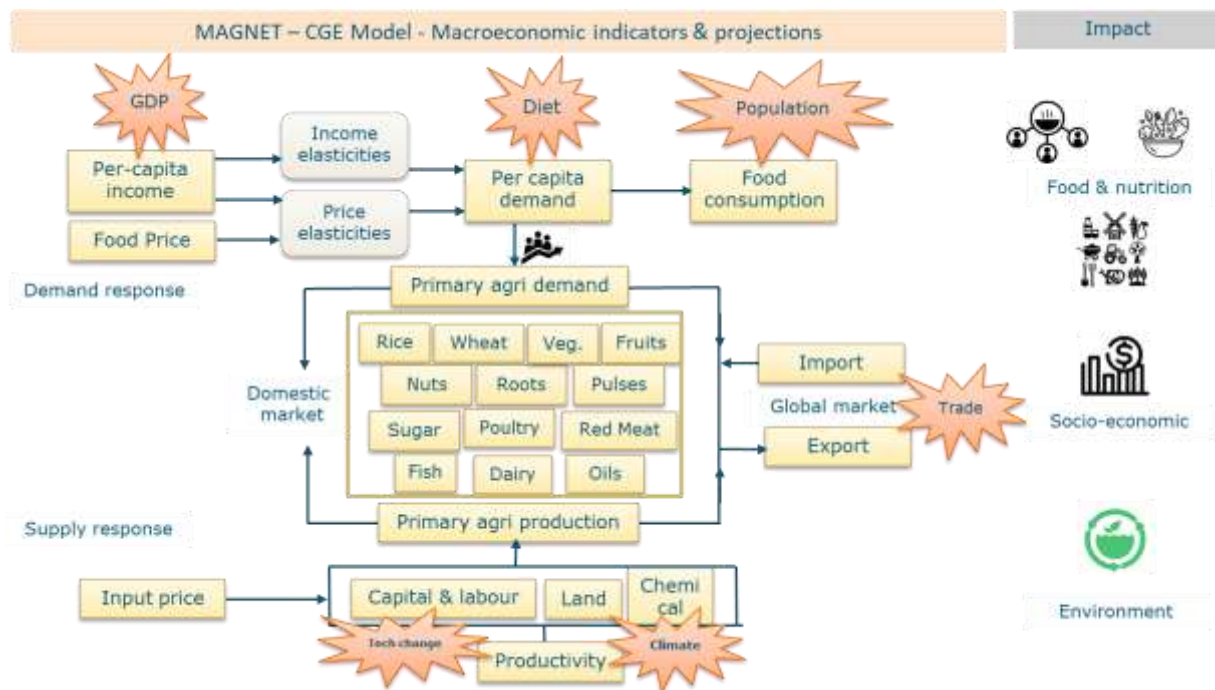


Figure 2: MAGNET modelling framework.

Figure 2 illustrates the framework of MAGNET, a modular CGE model designed to analyze agricultural markets and policies. MAGNET operates under the assumption of perfect competition, where producers select the most cost-effective combination of imperfectly substitutable inputs, including labor, capital, land, natural resources, and intermediates. At its core, MAGNET employs an input-output (IO) model, linking industries within value-added chains. This spans from primary goods to progressively higher stages of intermediate processing, culminating in the final assembly of goods and services for consumption.

CGE models like MAGNET use real-world economic data within a system of equations to represent the workings of an economy, allowing researchers to simulate various shocks and policies and assess their impacts. The model is driven by external factors, called exogenous shocks, represented by stars in the diagram. These include changes in GDP, population shifts, evolving dietary preferences, fluctuations in input prices like fertilizer, and variations in climate patterns.

At the core of the model is the interplay between demand and supply. Demand is influenced by macroeconomic factors like GDP and population, which affect per-capita income. This income level, combined with how changes in income affect demand (income elasticities), drives the demand for food. Food prices and their influence on demand (price elasticities) further shape the overall demand response. Together, these factors determine the primary

agricultural demand for various products like rice, wheat, and vegetables. This demand is then met through a combination of domestic production and imports, with the balance influenced by the global market.

On the supply side, agricultural production is influenced by factors such as input prices, the availability of capital and labor, land resources, chemical inputs, technological advancements, and overall productivity. The model captures how producers adjust their output in response to changes in these factors.

The model seeks to find a balance, or equilibrium, where demand matches supply for each agricultural product, considering both domestic and international markets. With a specific focus on modeling agri-food markets, MAGNET incorporates the Armington assumption (Armington, 1969), which posits that internationally traded products are differentiated based on their country of origin.

It then assesses the impacts of these interactions on various aspects, including food consumption patterns and their nutritional implications, import and export levels, social and economic factors like income distribution, and environmental consequences such as land and chemical use.

This CGE model captures the interconnectedness of different economic sectors, demonstrating how changes in one area can ripple through the entire system. For example, changes in demand can affect production, prices, and trade. It ensures that supply and demand are balanced in all markets through adjustments in prices and quantities, and it incorporates how sensitively both demand and supply react to changes in prices and income. By considering the interdependencies across all markets, the model provides a comprehensive picture of how various shocks and policies can affect the agricultural sector, food security, and the broader economy and environment.

The Model database

The MAGNET database used in this study is an extension of the GTAP database V11, with 2017 as the reference year (Aguiar et. al., 2022). The database captures detailed information on the global economy, including production, consumption, and trade of goods and services, as well as primary factor use across various sectors. This data is organized at a highly detailed level, allowing for flexible aggregation of regions and products to suit specific research questions.



3 Scenario narratives and simulation

3.1. Scenario narratives

As explained in Section 2.3, two key levels of influence were considered in developing the quantified scenarios: global socioeconomic development (contextual scenarios) and the specific scenarios detailed in the previous section.

The three contextual scenarios highlight divergent trajectories for socio-economic and environmental outcomes (represented in columns in Table 2). **Green Road** represents an optimal path of balanced growth and sustainability, while **Middle Road** showcases partial success amidst persistent challenges. **Rocky Road**, on the other hand, underscores the risks of inaction and fragmented global cooperation. These pathways underline the critical need for proactive investment in education, technology, and governance to secure a resilient future.

These contextual scenarios provide a framework to include potential specific scenarios in four categories including economic growth, population dynamics, productivity, climate adaptation/mitigation, trade policies, and intrinsic motivation (represented in rows in Table 2).

The *Green Road* specific scenarios envisions are in line with a sustainable development path characterized by steady but inclusive economic growth. Here, GDP growth progresses at a slower pace, prioritizing inclusiveness and ecological stability over traditional economic measures. Population growth declines significantly due to widespread investments in education, particularly in low-income regions. Productivity growth, particularly in agriculture, is guided by ecological limits, utilizing innovative techniques such as crop rotation, precision farming, and nature-based solutions. Feed productivity becomes integral to advancing agro ecological systems, while strong local markets and technologies like agricultural robotics bolster supply chain efficiency. Effective climate mitigation strategies—such as drought-resistant crops and regenerative agriculture—ensure resilience against environmental shocks. International trade thrives under an open and globalized economy, with scenarios assuming Ukraine's integration into the EU by 2030, fostering reduced trade barriers. Climate policy is robust, with governance and institutions facilitating carbon reduction targets in alignment with the 1.5°C global warming limit. Intrinsic motivation among populations reflects high environmental awareness, resulting in relatively low meat consumption and a shift toward sustainable dietary habits.



The specific scenarios within *Middle Road* represent a more moderate trajectory, balancing progress and persistent challenges. Economic growth replicates trends of recent decades but slows due to partial success in addressing environmental degradation and climate vulnerabilities. Population growth remains high as educational investments are insufficient to curb it, particularly in low-income countries. Agricultural productivity is initially driven by input-heavy practices but encounters ecological limitations over time.

Feed productivity shows uneven progress, while moderate advancements in supply chain efficiency fail to meet the demands of a rapidly growing population. Climate adaptation efforts yield intermediate success, addressing issues like air pollution and vulnerability, though significant risks persist. Trade and regional integration remain partially functional, fostering moderate global connectivity. Climate policies show slow progress, with resource and energy efficiency improving at historical rates. Meat consumption trends mirror existing patterns, with a rise in demand, particularly in low-income regions adopting Western dietary preferences.



Table 2: The scenario matrix: detailed description of the implemented scenario shocks, their narratives and implementation assumptions³.

Category of scenarios	Specific scenarios/shocks	Contextual Scenario A - Green Road	Contextual Scenario B - Middle Road	Contextual Scenario C - Rocky Road
Socio-economic assumptions	GDP & Capital growth	Good economic growth at a slow pace. Less focus on GDP as a measure of economic growth and more on inclusiveness and environmental stability.	Economic growth replicates trends in recent decades and then slows down because of intermediate success in addressing environmental degradation and vulnerability to climate change and other global changes.	Slow down in economic growth in high-, middle-, and low-income regions due to little international cooperation and low investments in technology development and education.
	Population & Labour growth	Population growth is lower due to investments in high levels of education.	Population growth is quite high, as educational investments are not high enough to rapidly slow down this growth, particularly in low-income countries.	Population growth in this scenario is high, as a result of the negative trends in education and the global economy.
Productivity	Land productivity: agri production per hectare	Slow growth and a push for productivity but within ecological limits. Extended use of: crop diversification and rotation; developments of new seeds and improved breeds; optimization in energy and water use (e.g., via AI); nature-based solutions; soil health management (e.g., reduce nutrient losses).	High productivity driven by inputs use (e.g., fertilizer). Push for intensification, but ecological roadblocks limit productivity eventually.	Land productivity is unequal. Low investments in technology development and adoption of environmentally friendly strategies.
	Feed productivity (efficiency): feed use per unit of livestock production	Feed productivity essential to the success of the agro ecological system.	Different kind of technical change, there is a slow pace of growth in productivity because of patchy implementation of policy.	Feed productivity highly efficient in HICs; modern technology and advances help improve livestock but only for HICs!
	Efficiency in supply chains to reduce food losses.	Strengthen local supply chains and markets, explore agricultural robotics.	Moderate progress results in the same level of efficiency in the future.	Little international cooperation results in increased inefficiencies in supply chain.
	Mitigation of climate impacts to ensure crop productivity.	Successful implementation of strategies to reduce vulnerability to climate change: drought-tolerant cultivars, regenerative agriculture, precision farming, smart irrigation, biocontrol to create resilient land conditions to absorb water. Specific shocks with higher mitigation effort with respect to crops, livestock and labor as in 'Middle Road'.	Intermediate success in addressing air pollution or other factors that reduce vulnerability to climate. Specifically: Crops: we used IPSL GCM Average of GCGMI crop model ensemble (RCP 7.0) for soybean, maize, wheat, and rice. Livestock: Livestock productivity shocks (RCP 7.0) from Thornton et al. (2022) based on changes in higher temperatures. Labor productivity shocks (RCP 7.0) for agricultural labor from Nelson et al. (2024)	Institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.
Policy	Trade (tariffs and subsidies) and changes in trade agreements with other regions: Hungary & Ukraine	The world is characterized by an open, globalized economy with well-functioning trade markets. In this scenario we assume Ukraine joining the EU starting in the period 2025-2030, with trade tariffs gradually decreasing to reach 0% rates by 2050.	Most economies are politically stable with partially functioning and globally connected markets.	The world has de-globalized, and international trade, including energy resource and agricultural markets, is severely restricted. Policies are focused on ensuring national self-sufficiency. In this scenario, we assume a slow and probable exit of Hungary starting in the period of 2025-2030, with trade tariffs reaching similar rates as UK by 2050.
	Climate policy including carbon tax on emissions to reach reduction targets	High level of awareness regarding environmental degradation, so existing governance and institutions facilitate achieving carbon reduction targets in line with NDCs and 1.5 degree targets.	Delayed progress is achieved towards development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency.	World failing to achieve global development goals due to weak governance and institution. Thus, there is little progress in reducing resource intensity, fossil fuel dependency, or addressing local environmental concerns.
Intrinsic motivation	Trends in meat consumption	Relatively low consumption of animal products	Existing trends towards western diets continue, so meat consumption keeps rising, particularly in lower-income countries.	Fast population growth and lower environmental awareness lead to higher meat demand

In contrast, the specific scenarios within *Rocky Road* context paints a bleak picture of stagnation and vulnerability. Economic growth slows significantly across high-, middle-, and low-income regions due to weak international cooperation, limited technological investment, and poor educational systems. Population growth accelerates, driven by negative trends in education and the global economy. Agricultural productivity becomes highly unequal, with limited technological adoption and environmental degradation undermining output. Feed productivity achieves high efficiency only in high-income countries, deepening global disparities. Supply chains have become increasingly inefficient due to de-globalization and lack of international collaboration. Institutional failures and weak governance hinder efforts to mitigate climate impacts, leaving large populations

³ In the table some RCP assumptions are mentioned. RCPs (Representative Concentration Pathways) are scenarios of future greenhouse gas concentrations used to assess potential climate change impacts. They are characterized by their radiative forcing levels in 2100, measured in watts per square meter (W/m²), with higher values indicating greater warming. See the IPCC Fifth Assessment Report (AR5) for details.

vulnerable to environmental shocks. Trade policies focus on national self-sufficiency, with scenarios assuming Hungary's gradual exit from the EU by 2030, mirroring Brexit, which exacerbates trade fragmentation. Climate policy remains ineffective, with little progress in reducing fossil fuel dependency or addressing resource intensity. In this context, population growth and low environmental awareness drive increased demand for meat, further straining global resources.

In summary, these scenarios underscore the critical choices the EU agriculture sector faces in shaping its future. The Green Road offers a vision of balanced growth and resilience, while the Middle Road highlights the potential of partial progress. The Rocky Road serves as a stark warning of the consequences of inaction and fragmented global efforts. The comparison reveals the urgent need for proactive investment in education, technology, governance, and environmental sustainability to ensure a stable and equitable future for all.

3.2. Simulation setup

The scenarios were analyzed quantitatively using MAGNET. Each scenario was ranked against the baseline 'Middle Road' scenario based on its socioeconomic characteristics. These rankings served as input for the MAGNET model, which generated a variety of output variables for analysis.

As described in detail in Section 3.1 the 'Middle Road' contextual scenario assumes the Shared Socioeconomic Pathway (SSP2) until 2050. The other two alternative contextual scenarios follow the Shared Socioeconomic Pathways SSP1 and SSP3 (see Section 2.3. for details). Table 2 provides a summary of the quantification assumptions. The main data which are used for the quantification of the SSP scenarios, and their drivers are used from SSP Database Version 2.0 (van Vuuren et. al., 2017; Fricko et al, 2017; Fujimori et al, 2017).

The scenarios have been quantified and implemented in MAGNET at the level of individual member states including all member states hosting the ECO-READY 10 living labs. They are also implemented at the following primary agriculture product level: Nuts, Wheat, Milk, Crops, Fruit, Vegetables, Paddy and processed rice, Rest of Cereal grains, Oil seeds, Sugar cane, sugar beet, Wild Fish, Pig, Poultry, Other cattle, Aquaculture, cattle, seaweed, Roots and tubers, Pulses.

4 Results

This section presents the results of the scenario simulation and MAGNET model projections. First, we present the projections of the main model drivers. Then, we present the food system resilience impact output indicators. Next, we present the relevant Sustainable Development Target indicators to show the overall sustainability progress for each scenario. Finally, the overall results are summarized in a trade-off analysis of the main socio-economic, food security, and environmental indicators.

As mentioned previously, the scenarios and their simulations were conducted in MAGNET at the level of individual EU member states, including all EU member states with an ECO-READY Living Lab (LL) representative. Moreover, we have included a detailed level of food groups (see Section 3.2); however, for simplicity of reporting, in most cases, we show the EU average results and aggregated agri-food sector to show the overall results of each scenario. A summary of the main output indicators for each LLs' country is provided in Annex 2, but the overall detailed results at the country level and for specific food groups are presented in an online interactive PowerBI dashboard⁴ with the option to choose different aggregations and scenario comparisons for all drivers and indicators. The dashboard is intended to serve the LLs and Work Package 3 (WP3), as well as the ECO-READY researchers for further and detailed modeling of products and region-specific scenarios in WP4 and policy analysis in WP5.

4.1. Drivers

MAGNET model projections are derived from a combination of exogenous *drivers* (based on scenario assumptions and at the level of individual member states) and endogenous model dynamics within a general equilibrium framework. These drivers include projections of income, population, labor supply, land, capital, natural resources, and land and feed productivity. Based on the scenario narratives described in Section 3.1 and the projected long-term global development of the EU and its member states, projections of the main macroeconomic and natural resource drivers for the period 2025-2050 are presented in the following sub-sections.

⁴ Here is the link to the online Ecoready Power-BI dashboard: [ECOREADY_Nov2024 - Power BI Report Server](#). The Magnet Power BI dashboard is currently undergoing final testing and will be publicly available early next year. In the meantime, Ecoready partners and reviewers can request access.

4.1.1. Income and population

The **Green Road** consistently shows the highest GDP growth (Figure 3), indicating robust growth under this scenario's assumptions (likely sustainable practices, technological advancements, and favorable socioeconomic conditions). The **Middle Road** projects a moderate increase in production, reflecting a more balanced scenario with a mix of positive and challenging factors. The **Rocky Road** scenario, however, shows a concerning decline in production volume, suggesting that under this scenario's assumptions (climate change impacts, geopolitical instability, or economic challenges), the EU faces significant hurdles.

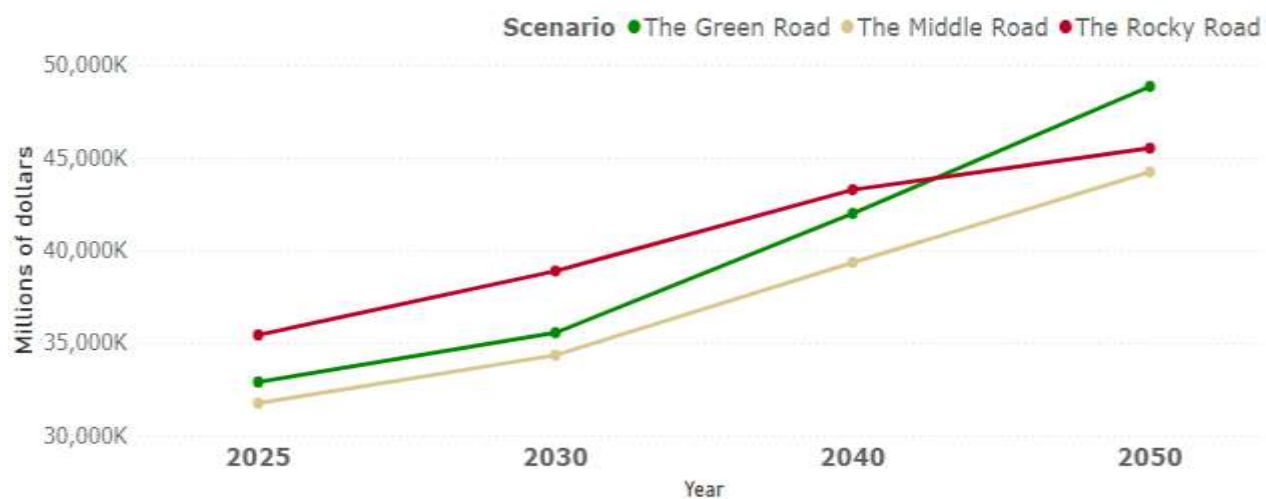


Figure 3: Real GDP in EU member states across scenarios, 2025-2050

In all scenarios, the EU population is projected to decrease, with Rocky Road showing a much larger decline than the others (Figure 4).

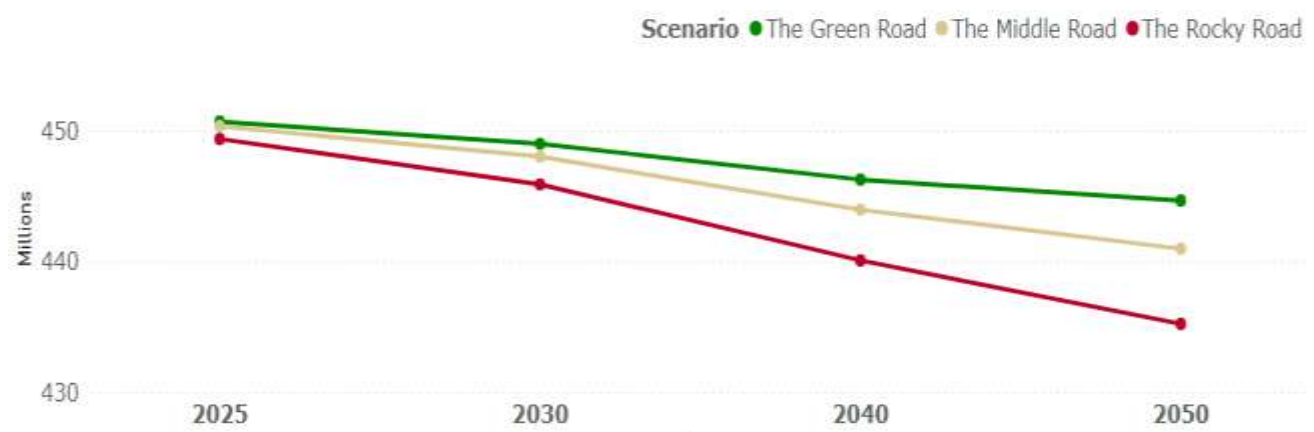


Figure 4: Population in EU member states across scenarios, 2025-2050

4.1.2. Land productivity

Changes in land productivity in the model are influenced by both exogenous (scenario assumptions) and endogenous components. Endogenous changes are mainly driven by shifting prices, which lead to the reallocation of economic resources and land-based activities, ultimately impacting land productivity. On the other hand, exogenous factors reflect assumptions about overall technical progress, such as fertilizer application and irrigation, as well as improvements in land management (see Table 2). In all scenarios, exogenous changes in land productivity are generally expected to be positive. However, land productivity in Green Road shows a negative trend over the projected periods (Figure 5). This is due to the underlying assumptions of slow growth and a push for productivity but within ecological limits considering optimization in energy and water use, nature-based solutions, and soil health management (e.g., reduce nutrient losses).

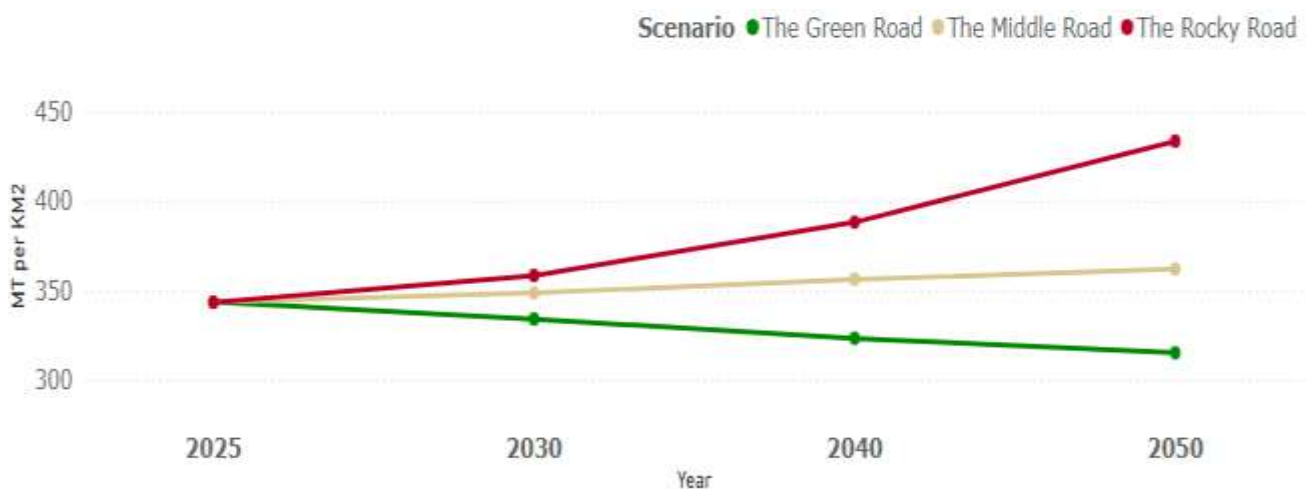


Figure 5: Land productivity in EU member states across scenarios, 2025-2050

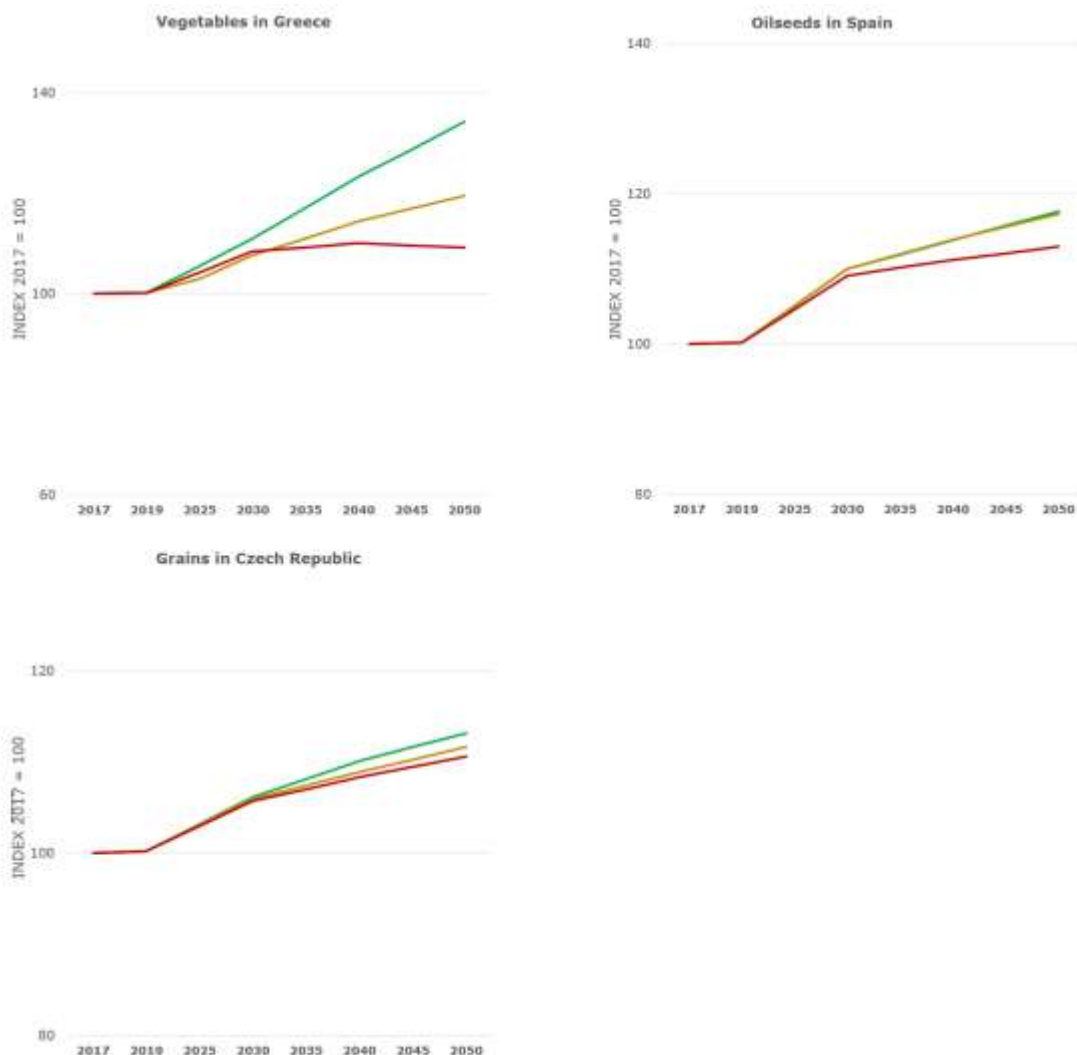


Figure 5: Projected yields for selected countries and crops across scenarios, 2025-2050 (index 2017=1).

As previously mentioned, the scenarios were implemented at the member state level with a detailed product breakdown. However, this report presents EU averages for the aggregated agri-food sector. Figure 5 illustrates projected land productivity drivers for each contextual scenario. This example demonstrates the level of detail available in the online Power BI dashboard.

4.1.3. Labor and capital

The model assumes exogenous supplies of labor, capital, and natural resources in the EU and its member states. Labor supply, encompassing both skilled and unskilled labor, is projected based on population growth trends. Capital supply is linked to GDP growth, while natural resource supply is modeled at one-quarter of the underlying GDP growth rate. These

assumptions align the supply of primary factors with projected GDP and population growth (See Figure 6).

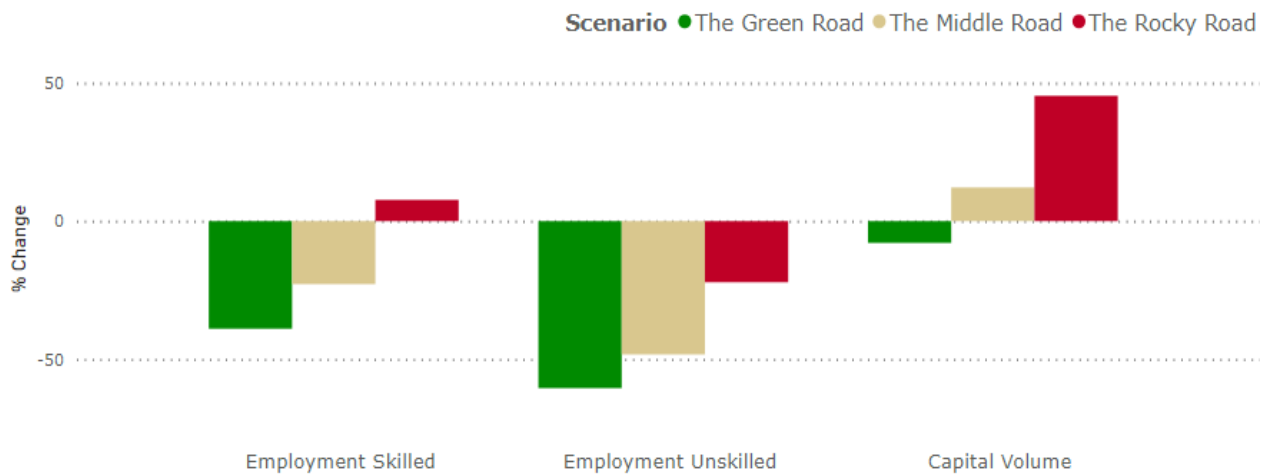


Figure 6: Employment and capital in EU member states across scenarios, % change 2025-2050.

4.2. Food Sustainability and resilience impact

4.2.1. Agri-food consumption, prices, and trade

A key aspect of MAGNET is its coverage of the agri-food system, crucial for analyzing food sustainability and resilient impact. The model projects various factors, including agricultural and food consumption, and prices for individual commodities and sectors in the EU. The following Figures present the projected changes in total private consumption, trade and consumer prices within the EU agri-food sector across all three contextual scenarios.

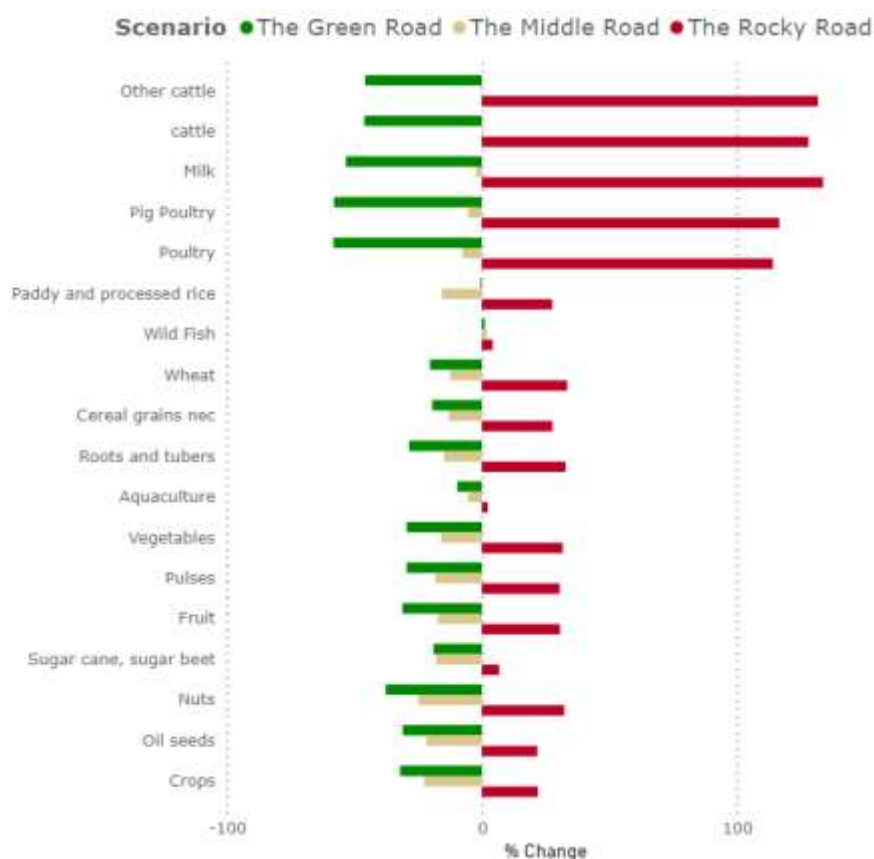


Figure 7: Consumption in agri-food sector in EU member states across scenarios, % change 2025-2050.

Error! Reference source not found. Figure 7 presents projected changes in EU agri-food consumption between 2025 and 2050 under three different scenarios. The Green Road, likely emphasizing sustainability, shows a significant projected increase in the consumption of pulses, vegetables, and nuts, suggesting a shift towards plant-based protein sources. This aligns with the projected decreases in cattle, pig, and poultry consumption in this scenario. The Middle Road presents a more moderate version of this trend, with less pronounced changes. In contrast, the Rocky Road, potentially representing a business-as-usual approach, projects increased consumption of most animal products.

Across all scenarios, "Paddy and processed rice," "Wheat," and "Cereal grains" show relatively small changes, suggesting these remain dietary staples. "Sugar cane, sugar beet" and "Oil seeds" show slight decreases in the Green Road and Middle Road, potentially indicating a trend towards healthier diets. "Wild Fish" shows a notable decline in all scenarios, likely reflecting concerns about overfishing, while "Aquaculture" shows increases, suggesting it may be viewed as a more sustainable alternative.

Overall, the Green Road scenario projects the most significant dietary shifts, with a move away from animal products and towards plant-based options. The Middle Road shows similar trends but with less pronounced changes, while the Rocky Road generally shows increases in consumption across most categories.

Error! Reference source not found. Figure 8 shows the projected changes in agri-food commodity prices in the EU from 2025 to 2050 under three different scenarios. The Green Road scenario shows a steady decline in prices, suggesting increased affordability of food due to factors like improved production efficiency and sustainable agriculture policies. The Middle Road scenario initially follows a similar trend but then sees prices stabilize around 2040, possibly due to a less aggressive pursuit of sustainable practices. The Rocky Road scenario, however, shows a continuous increase in prices, indicating that food becomes more expensive over time due to potential factors like resource scarcity and geopolitical instability.

These projections highlight the potential impacts of different policy approaches and economic conditions on food prices in the EU. The Green Road suggests that prioritizing sustainability and inclusive growth can lead to more affordable food in the long term. The Rocky Road warns of potential price increases if challenges related to economic growth, international cooperation, and technology development are not addressed.

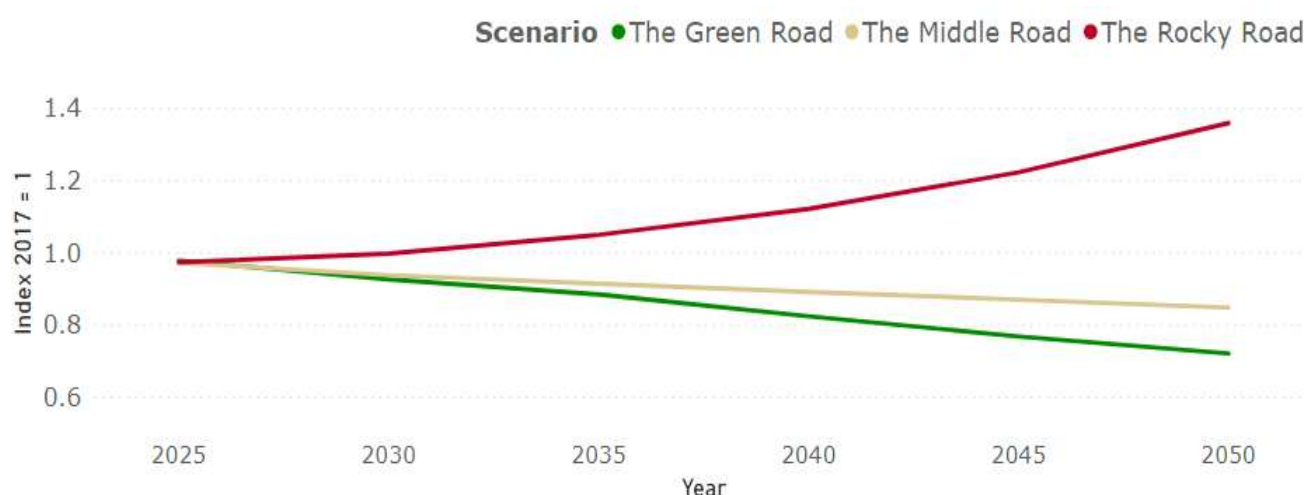


Figure 8: Evolution of agri-food commodities' price index (2017=1) in EU across scenarios, 2025-2050.

Figure 9 shows the projected evolution of the agri-food commodity trade balance between the EU and the rest of the world from 2025 to 2050 across the three scenarios. The trade balance represents the difference between the value of agri-food exports and imports.

In the Green Road scenario, the trade balance steadily improves after 2035. This suggests that while the EU continues to be a net importer of agri-food commodities, the deficit decreases over time. This could be attributed to increased efficiency and competitiveness of EU agriculture, potentially driven by sustainable practices and technological advancements, as well as trade liberalization and Ukraine joining the EU, leading to more favorable trade conditions.

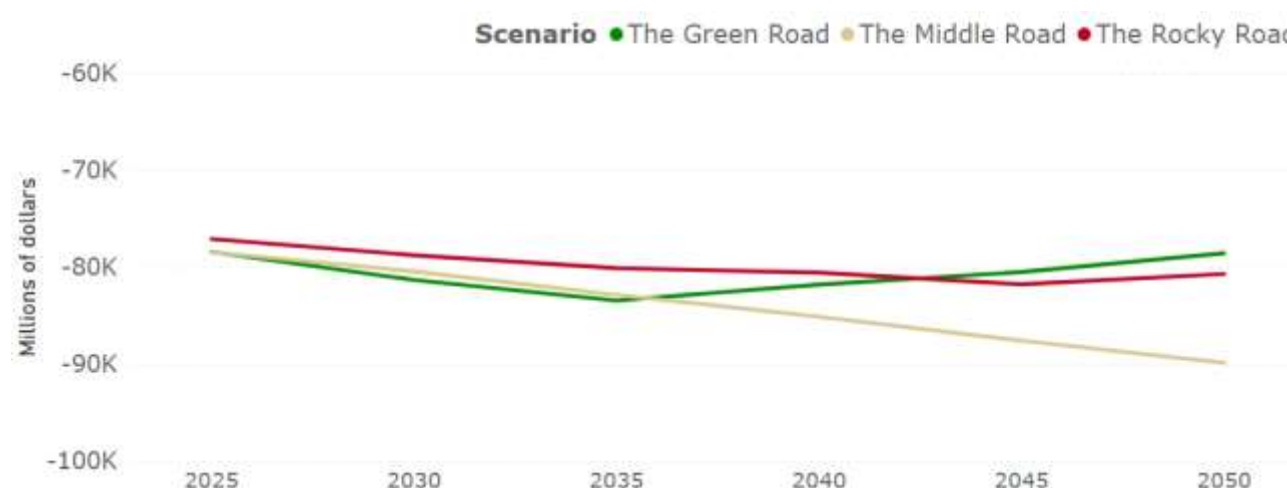


Figure 9: Evolution of agri-food commodities' trade balance in EU member states across scenarios, 2025-2050.

The Middle Road scenario shows a more moderate improvement in the trade balance, with the deficit remaining relatively stable throughout the projected period. This could indicate a less dynamic agricultural sector compared to the Green Road, with moderate productivity gains and a less pronounced impact from trade liberalization.

In the Rocky Road scenario, the trade balance significantly declines, with the deficit increasing over time. This suggests a decline in the competitiveness of EU agriculture, potentially due to factors like limited technological progress, slower economic growth, and a more restricted trade environment. The scenario's narrative of deglobalization and a focus on national self-sufficiency could further exacerbate this trend.

These projections highlight the potential long-term impacts of different policies and economic pathways on the EU's agri-food trade balance. The Green Road suggests that a focus on sustainability, technological advancement, and trade liberalization can in long-term strengthen the EU's position in the global agri-food market (e.g. Ukraine joining the EU). The Rocky Road, on the other hand, warns of a potential decline in competitiveness

and a widening trade deficit in a less cooperative and more protectionist global environment (e.g. Hungary exits the EU).

4.2.2. Food & nutrition security

To account for the various aspects of food security, we follow the FAO's distinction of *availability*, *access*, *utilization*, and *stability*⁵ (FAO, IFAD, UNICEF, WFP-WHO, 2018). We derive model-based indicators for the first three dimensions: food availability, food access, and food utilization.

Availability

We measure *food availability* in kcal per capita per day (food available for consumption, e.g., Nelson et al., 2014; Von Lampe et al., 2014). This includes all domestically produced and imported food available for consumption at the household level. Figure 10 presents projections of change in the daily per capita calorie availability in the EU from 2030 to 2050 across the three scenarios. Calorie availability is an indicator of food security and overall food supply. In the Rocky Road scenario, calorie availability is consistently the highest, showing a trend of increasing calorie availability over time. This might seem positive, but it indicates a diet high in processed foods and potentially unsustainable consumption patterns, aligning with the narrative of high population growth and lower environmental awareness leading to higher meat demand in this scenario. The Green Road scenario consistently shows the lowest calorie availability, though still sufficient to meet dietary needs. This could indicate a shift towards healthier and more sustainable diets with reduced consumption of calorie-dense, processed foods, and a greater focus on plant-based options. This aligns with the scenario's narrative of a shift towards plant-based diets and a focus on environmental sustainability.

These projections highlight how different socioeconomic pathways and policy choices can influence food availability and consumption patterns. The Green Road suggests that a focus on sustainability and inclusive growth can lead to a more balanced and environmentally conscious food system, even with slightly lower overall calorie availability. The Rocky Road, on the other hand, raises concerns about potential overconsumption and unsustainable

⁵ "Stability" in food security means consistent access to food, even during shocks like economic crises or natural disasters. The MAGNET model captures this by projecting food access over time under various socio-economic and climate conditions within three scenarios.

dietary trends. The Middle Road represents an intermediate pathway with moderate calorie availability and a less pronounced focus on sustainability.

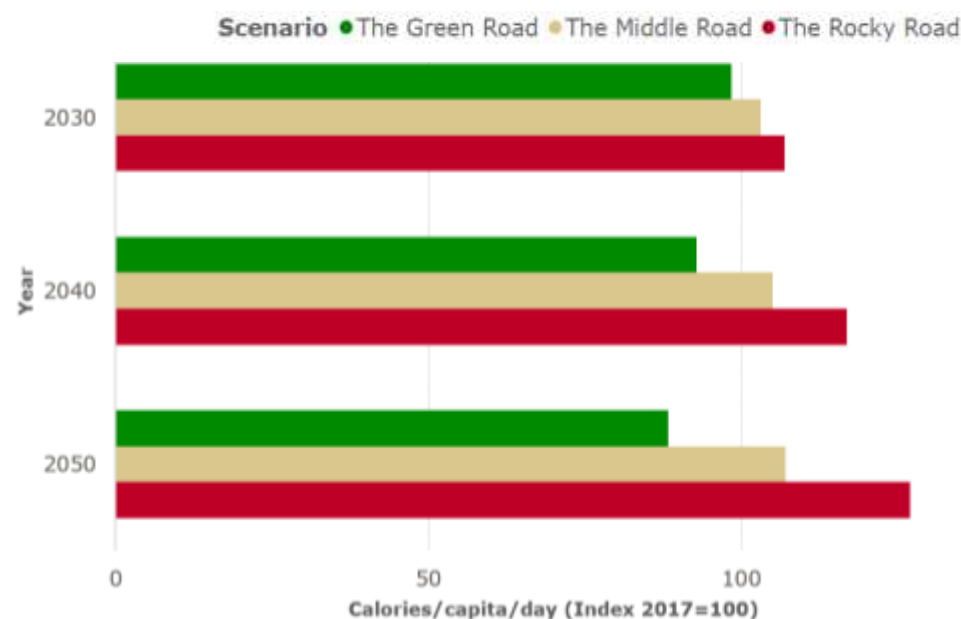


Figure 10: Food availability measured in percentage change of total kcal/capita/day for an average EU household in the period 2025-2050. (Index 2017=100).

These projections highlight how different socioeconomic pathways and policy choices can influence food availability and consumption patterns. The Green Road suggests that a focus on sustainability and inclusive growth can lead to a more balanced and environmentally conscious food system, even with slightly lower overall calorie availability. The Rocky Road, on the other hand, raises concerns about potential overconsumption and unsustainable dietary trends. The Middle Road represents an intermediate pathway with moderate calorie availability and a less pronounced focus on sustainability.

Accessibility

Food access relates to people's food purchasing power (FPP) and, therefore, to food prices, dietary patterns, and income development (Lele et al., 2016). A first and crude proxy for food access is the change in agri-food prices. The income dimension of food access is neglected in this often-used indicator. The "food purchasing power" (FPP) indicator considers the income dimension by relating the price development of a specific food consumption basket to the income development of a particular income group. In line with Van Meijl et al. (2020), we use the consumption of cereals (rice and grains) for the food basket as a proxy for the diet of people potentially in poverty. For the income component of low-income groups, the wages of unskilled workers is used as a proxy.

Figure 11 shows the food accessibility index for the average EU household from 2030 to 2050, across the three scenarios. These projections highlight the crucial link between economic conditions, social policies, and food security. The Green Road suggests that a focus on inclusive growth and sustainable food systems can significantly improve food access for vulnerable populations. The Rocky Road, however, warns of the potential consequences of neglecting social equity and economic resilience, leading to a deterioration in food affordability.

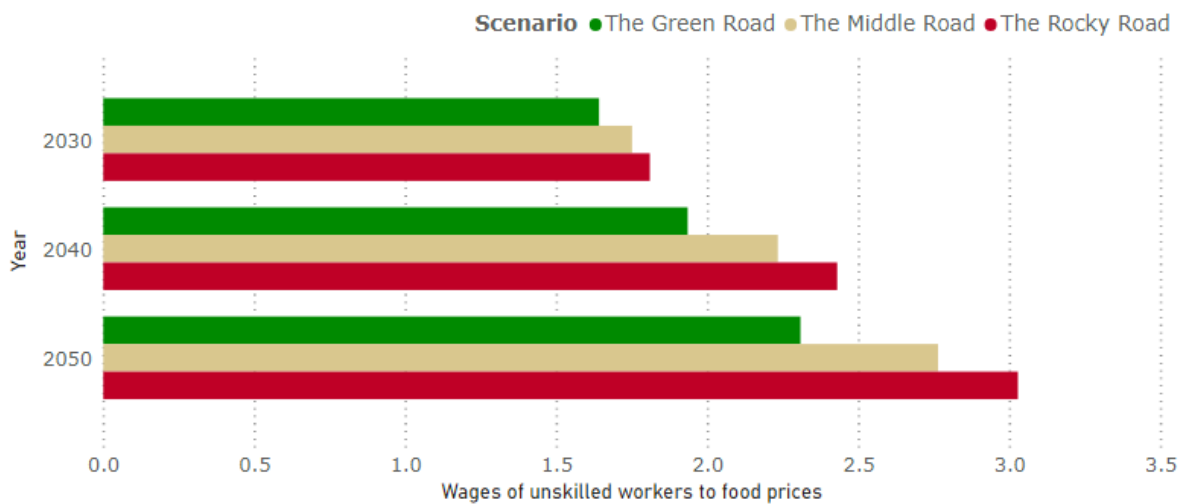


Figure 11: Food accessibility index EU average in the period 2025-2050.

Utilization

Less sophisticated proxies are used for the *food utilization* dimension. The fraction of calories derived from fruits and vegetables in total calories of food consumption is used as a proxy for food utilization, following the FAO compendium of indicators for nutrition-sensitive agriculture (FAO, IFAD, UNICEF, WFP-WHO, 2018; Van Meijl et al., 2020).

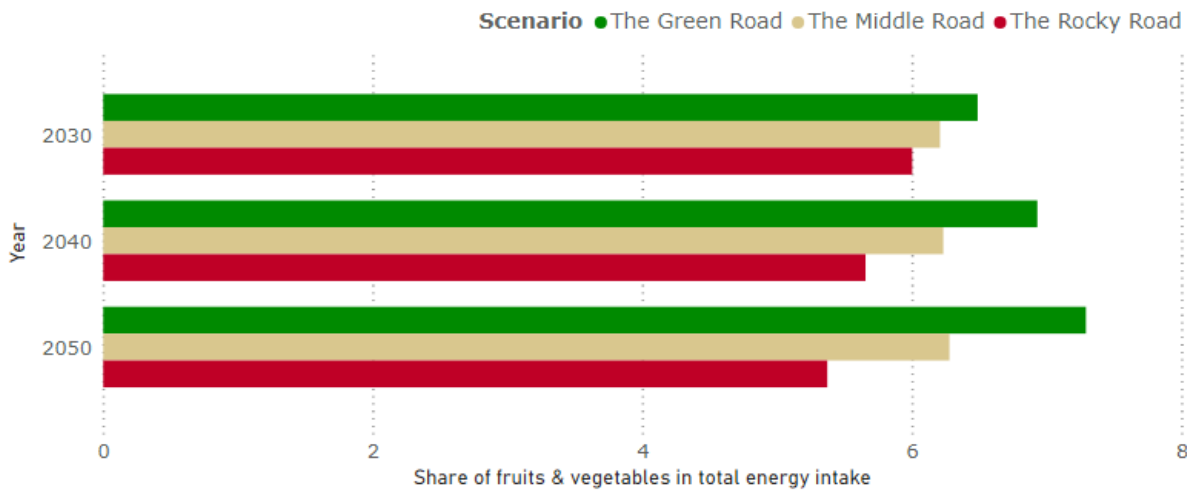


Figure 12: EU average food utilization index. 2030-2050

The graph in Figure 12 displays the share of fruits and vegetables in the total energy intake of the average EU diet from 2030 to 2050, across the three scenarios. This serves as an indicator of food utilization, reflecting dietary quality and adherence to healthy eating guidelines. The Green Road scenario consistently shows the highest share of fruits and vegetables in the diet. This indicates a shift towards healthier and more sustainable consumption patterns, aligning with the scenario's emphasis on environmental consciousness and plant-based diets. This trend likely contributes to improved public health and reduced environmental impact from food consumption. The Rocky Road scenario shows the lowest share of fruits and vegetables, with a relatively stagnant trend.

These projections highlight the interplay between dietary choices, public health, and environmental sustainability. The Green Road suggests that a focus on sustainable and healthy diets can lead to significant improvements in food utilization patterns. The Rocky Road, however, warns of the potential consequences of inaction, with a continued reliance on less healthy and less sustainable diets.

4.2.2. Environmental impact

MAGNET accounts for different emitting gases (CO₂, N₂O, CH₄, and F-GASEs) and different source fuels and activities (coal, crude oil, gas, petrol, chemicals, fertilizer, and industrial activities) as a part of its Greenhouse Gas Emission (GHG) projections, with aggregate projections across all gases and sources reported in Figure 13 for the agri-food sector.

The figure also presents land demand and chemical fertilizer use as two other environmental impact indicators.

These projections highlight the environmental consequences of different policies and economic pathways. The Green Road suggests that a focus on sustainability can significantly reduce the environmental footprint of the agri-food system. The Rocky Road, on the other hand, warns of the potential for increased environmental pressures with a business-as-usual approach. The Middle Road represents an intermediate outcome, with moderate progress but a less transformative impact compared to the Green Road.

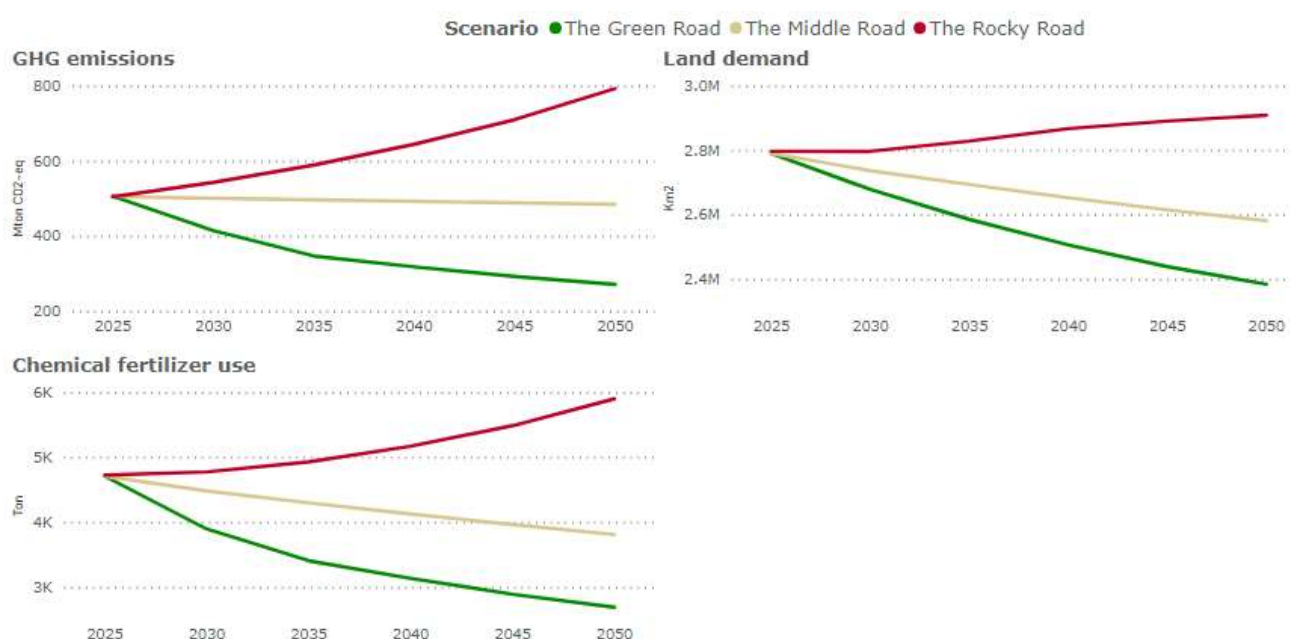


Figure 13: Selected environmental indicators in the agri-food sector in EU member states across scenarios, 2025-2050

4.3 Sustainable Development Goals (SDG) indicators

This section presents selected SDG indicators derived from the MAGNET model's SDG insight module. These indicators complement the previously reported variables and facilitate measuring progress toward the SDGs. While this module produces individual indicators aligned with the broader SDG framework, we summarize them using the "People, Planet, and Prosperity" framework. This widely recognized framework allows us to analyze a broad range of SDG indicators through a succinct yet comprehensive lens, encompassing social,

economic, and environmental dimensions.

Scenario	People: SDG 2		Prosperity: SDG 10		Planet: SDG 13	
	Protein from livestock	Share of food expenditure in total disposable income	Net trade	Real GDP per worker	Emissions per unit of GDP	Share non-agricultural land

Figure 14: Selected SDG indicators for EU member states across scenarios, % change 2025-2050.

The Green Road	-47	-20	43	70	-45	-113
The Middle Road	5	-11	37	39	-30	0
The Rocky Road	75	8	10	-35	-22	144

Figure 15: Selected SDG indicators for EU member states across scenarios, % change 2025-2050

Figure 14 presents a selection of Sustainable Development Goals (SDG) proxy indicators across the three scenarios. These indicators provide insights into the potential social, economic, and environmental impacts of each scenario.

People (SDG 2 - Zero Hunger):

The Green Road shows a significant decrease, suggesting a shift towards plant-based protein sources, which can have positive implications for both human health and environmental sustainability. The Middle Road shows a slight increase, while the Rocky Road shows a substantial increase, indicating a continued reliance on animal agriculture.

Prosperity (SDG 10 - Reduced Inequalities):

The Green Road shows a significant decrease, suggesting improved food affordability and increased disposable income for households. The Middle Road shows a moderate decrease, while the Rocky Road shows a slight increase, indicating potential challenges for food security and household budgets.

The Green Road shows a strong positive value, indicating a healthy trade balance. The Middle Road shows a moderate positive value, while the Rocky Road shows a low positive value, suggesting potential economic challenges and trade deficits.

The Green Road shows the highest value, indicating strong economic growth and productivity. The Middle Road shows a moderate value, while the Rocky Road shows the lowest value, suggesting slower economic growth and potential economic stagnation.

Planet (SDG 13 - Climate Action):

The Green Road shows the largest decrease, indicating a significant reduction in emissions intensity and a decoupling of economic growth from environmental impact. The Middle Road shows a moderate decrease, while the Rocky Road shows a smaller decrease, suggesting less progress in mitigating climate change.

The Green Road shows a significant decrease, indicating reduced pressure on land resources and potential for ecological restoration. The Middle Road shows no change, while the Rocky Road shows a significant increase, suggesting continued land conversion and potential environmental degradation.

This analysis underscores the interconnectedness of the SDGs and the importance of integrated policy approaches to achieve sustainable development. It highlights the potential for transformative change through strategic interventions that promote economic growth, social equity, and environmental protection.

4.4. Summary results and trade-off analysis

Figure 15 presents a trade-off analysis summarizing the overall results for each scenario in the EU from 2025 to 2050. It visualizes the performance of various indicators across the three scenarios, allowing for a comprehensive comparison of their potential impacts.

Figure 15: Summary indicators (Index 2017=1) for the EU across scenarios, 2025-2050



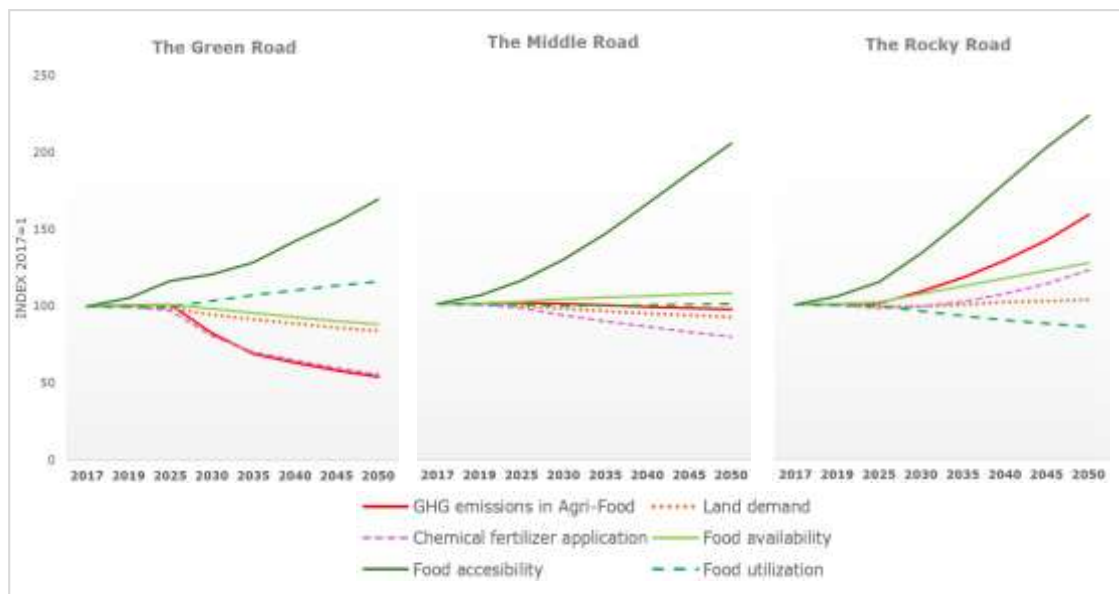


Figure 16: Summary indicators for EU member states across scenarios, 2025-2050

The Green Road: This scenario demonstrates a clear prioritization of sustainability and social well-being. It shows significant improvements in environmental indicators like GHG emissions, land demand, and chemical fertilizer use, while also achieving positive outcomes for food access, utilization, and economic performance. However, there's a trade-off with food availability, which shows a slight decrease compared to the other scenarios. This suggests that a focus on sustainable and healthy diets might entail slightly lower overall calorie availability, although still sufficient to meet nutritional needs.

The Middle Road: This scenario represents a more balanced approach, with moderate improvements across most indicators. It achieves some progress in reducing environmental impacts and improving food access and utilization, while maintaining a relatively stable level of food availability. However, it doesn't achieve the same level of environmental performance as the Green Road or the same economic growth as the Rocky Road.

The Rocky Road: This scenario prioritizes economic growth but shows negative trends in most other indicators. It leads to increased GHG emissions, land demand, and chemical fertilizer use, while also showing a decline in food access and utilization. While it achieves the highest economic growth and food availability, this comes at a significant cost to environmental sustainability and social equity.

5 Case study I: Bridging Global to Local to Global analysis: A Protocol for Modeling Agricultural Climate Resilience

This study examines the relationship between agriculture and climate resilience, focusing on winter wheat production in the Central Bohemian Region (CBR) of the Czech Republic. The CBR is a major agricultural region with favourable conditions for wheat cultivation. The study aims to understand how climate change and agricultural practices might affect wheat production in this region, with implications for both local and global food security and environmental sustainability.

In this section, we summarize the key findings from this case study. A comprehensive analysis and detailed modeling results are available in the journal article, "From local to global and from global to local: Designing the protocol to model agriculture and climate resilience," currently under review with the European Journal of Agronomy.

5.1. Model Setup

The study uses a combination of three modelling approaches: Intermediate Models, MAGNET Model, and Life Cycle Assessment (LCA).

Intermediate Models: These models focus on the direct impacts of climate change on wheat yield. They use historical climate data and crop growth models, such as the Decision Support System for Agrotechnology Transfer (DSSAT) and CERES, to simulate how changes in temperature, rainfall, and extreme weather events might affect wheat production in the CBR. Statistical regression models are used to estimate changes in wheat yield and fertilizer use under different climate scenarios.

MAGNET Model: This is a global economic model that simulates the broader economic and environmental impacts of changes in wheat production. It takes the yield projections from the intermediate models as inputs and estimates how changes in wheat supply might affect market prices, land use, fertilizer consumption, and greenhouse gas emissions. The MAGNET model is built on the Global Trade Analysis Project (GTAP) model and covers 160 regions, 65 sectors, and 8 production factors.

Life Cycle Assessment (LCA): This tool assesses the overall environmental impact of wheat production, taking into account factors such as water use, fertilizer production, and land use changes. It evaluates the environmental impacts of wheat production under different scenarios, using the ReCiPe 2016 impact assessment method.



5.2. Results

The study shows a complex interplay of factors influencing wheat production and its sustainability in the CBR. The combined results suggest that:

- **Increased wheat yield:** Warmer temperatures are likely to increase wheat yields in the CBR, but this benefit will be accompanied by more frequent extreme weather events (heat waves, droughts, and frost) that could destabilize production.
- **Economic impacts:** Higher wheat yields could lead to increased wheat output and lower market prices, benefiting consumers. However, this may also lead to increased fertilizer use, with potential negative consequences for soil health and the environment.
- **Environmental impacts:** While higher wheat yields could reduce land and water demand, the increased use of fertilizers and potential for extreme weather events pose significant environmental challenges.
- **Food security:** The results indicate positive effects on food availability (higher wheat production), food access (lower prices), and resilience (improved self-sufficiency). However, the long-term sustainability of these gains is uncertain due to the potential environmental impacts and the increasing frequency of extreme weather events.

The study underscores the importance of considering the interconnectedness of climate change, agriculture, and environmental sustainability when designing policies and strategies for the future.

5.3. Discussion

The study highlights the complex and interconnected nature of climate change, agriculture, and environmental sustainability. The results suggest that climate change could lead to increased wheat yields in the CBR, but also more frequent extreme weather events that could threaten production. The economic and environmental impacts of these changes are complex and require careful consideration. The study emphasizes the need for integrated modeling approaches to understand these complex relationships and to design effective agricultural policies that promote both food security and environmental sustainability.

6 Case study II: Breeding as mitigation strategy for climate change on livestock sector and food security



Climate change and livestock production are intricately linked, with significant implications for food security. The livestock sector will likely become an even stronger driver for climate change. Different strategies to mitigate the impact of climate change on livestock production or to reduce the environmental footprint on livestock may differ in the scale of disruption they cause on the wider economy, food security and biodiversity.

This case study investigates the impact of breeding as a mitigation strategy for climate change on the livestock sector and food security. The main findings highlight the growing importance of livestock production in meeting the increasing global demand for food, especially in regions where crop production is limited. However, climate change poses a significant threat to livestock production, affecting animal health, productivity, and feed availability. The study emphasizes the need for integrating intermediate models related to breeding into systems models to evaluate the broader impacts of breeding on the wider food system. Below we provide a summary of this study. A more comprehensive analysis and detailed results will be reported in a journal article currently being prepared for submission.

6.1. Modelling set-up

Genomic breeding, also known as genomic selection, is a modern breeding approach that utilizes genetic information to make more accurate and efficient selection decisions in breeding programs (Meuwissen et al 2001). This technique involves the use of genomic data, such as DNA markers, to predict the genetic merit of individuals for a specific trait of interest. By analyzing the entire genome of an organism, genomic breeding provides a comprehensive understanding of its genetic makeup, allowing breeders to identify and select individuals with desirable traits more effectively.

The study first incorporates intermediate models to account for the effects of climate change and breeding on livestock production. These intermediate models relate changes in temperature and humidity to livestock performance and feed conversion ratio (FCR). Then MAGNET model is used to assess the long-term impacts of breeding on livestock production, food security, and the environment.

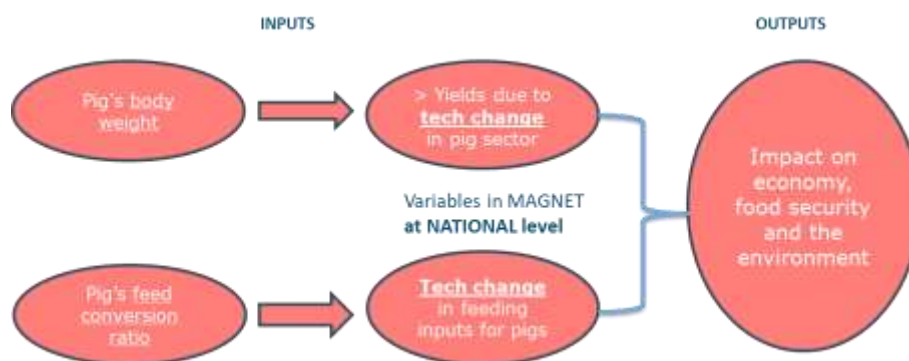


Figure 16: The model linking framework.

6.2. Overall Results

The study compares two scenarios under the SSP2 pathway: one with climate change impacting livestock but no breeding improvement, and another with climate change and breeding improvements enabled by novel technologies.

Table 3: Scenario set-up and assumptions

	Scenario I	Scenario II
Contextual socio-economic pathway	SSP2	SSP2
Climate change (CC) effect	Climate change affects livestock performance and efficiency	Climate change affects livestock performance and efficiency
Technical change: CC adaptation	None	Breeding improves livestock performance and efficiency

The main assumptions for the quantification of the scenarios are:

- **Livestock:** The analysis focuses on the following livestock categories: layer chickens, broiler chickens, pigs, sheep, goats, dairy cattle, and beef cattle.
- **Breeding:** Genetic improvement efforts are assumed to primarily focus on two traits:
 - **Production:** Increasing output such as egg production, milk yield, and animal weight.
 - **Efficiency:** Improving feed conversion ratio (FCR), which measures the efficiency of converting feed into animal products.

- **Climate change:** The analysis considers the direct impact of heat stress on animal performance and FCR, measured using the temperature-humidity index (THI). Climate projections for 2050 are based on the EC-Earth-3 model (Döscher 2022) under the SSP2-RCP4.5 scenario.
- **Socio-economic context:** Socio-economic factors influencing livestock production and consumption are based on the Shared Socioeconomic Pathways (SSP2) projections.

The tables below present the results of the intermediary models. Table 4 displays the calculated decrease in performance and efficiency per unit of Temperature Humidity Index (THI).

Table 4: Drop of performance and efficiency per THI calculated by the intermediate models

Sector	Trait	Change (%) / THI
dairy beef	milk yield	-2.03
dairy beef	feed conversion ratio	-2.32
beef cattle	body weight	0.10
beef cattle	feed conversion ratio	-2.26
chicken	body weight	-0.02
chicken	feed conversion ratio	0.00
layer chicken	egg weight	-1.81
sheep and goat	body weight	1.42
sheep and goat	feed conversion ratio	-0.91
pig	body weight	-1.30
pig	feed conversion ratio	-1.00

Table 5 illustrates the percentage change in traits attributed to breeding, calculated in 5-year increments until 2050, as determined by the intermediary models.

Table 5: Change (%) in traits due to breeding for every 5 years till 2050 calculated by the intermediate models

Sector	Trait	Change (%)
Dairy cattle	Milk yield per animal	7.18
Beef cattle	body weight worldwide	2.70
Beef cattle	body weight developed	1.00
Beef cattle	body weight developing	6.94
Beef cattle	feed conversion ratio	-7.21
chicken	feed conversion ratio	-11.65
chicken	egg rate	16.96
chicken	broiler body weight	3.54
sheep and goat	body weight	4.44
sheep and goat	feed conversion ratio	-5.62
pig	body weight	4.12
pig	feed conversion ratio	-5.62

Figure 17 shows the results of the MAGNET model projections on how these scenarios influence food security, economic, and environmental indicators. Notably, breeding can often counteract the negative impacts of climate change on food availability, calorie supply, land use, and fertilizer consumption. The observed changes in land and fertilizer use may stem from increased livestock production, which alleviates pressure on crop cultivation. Additionally, novel breeding technologies contribute to lower greenhouse gas emissions by reducing the number of animals required for equivalent food production. However, these advancements may negatively affect the labor market, particularly within the livestock sector, potentially leading to job losses and decreased wages.

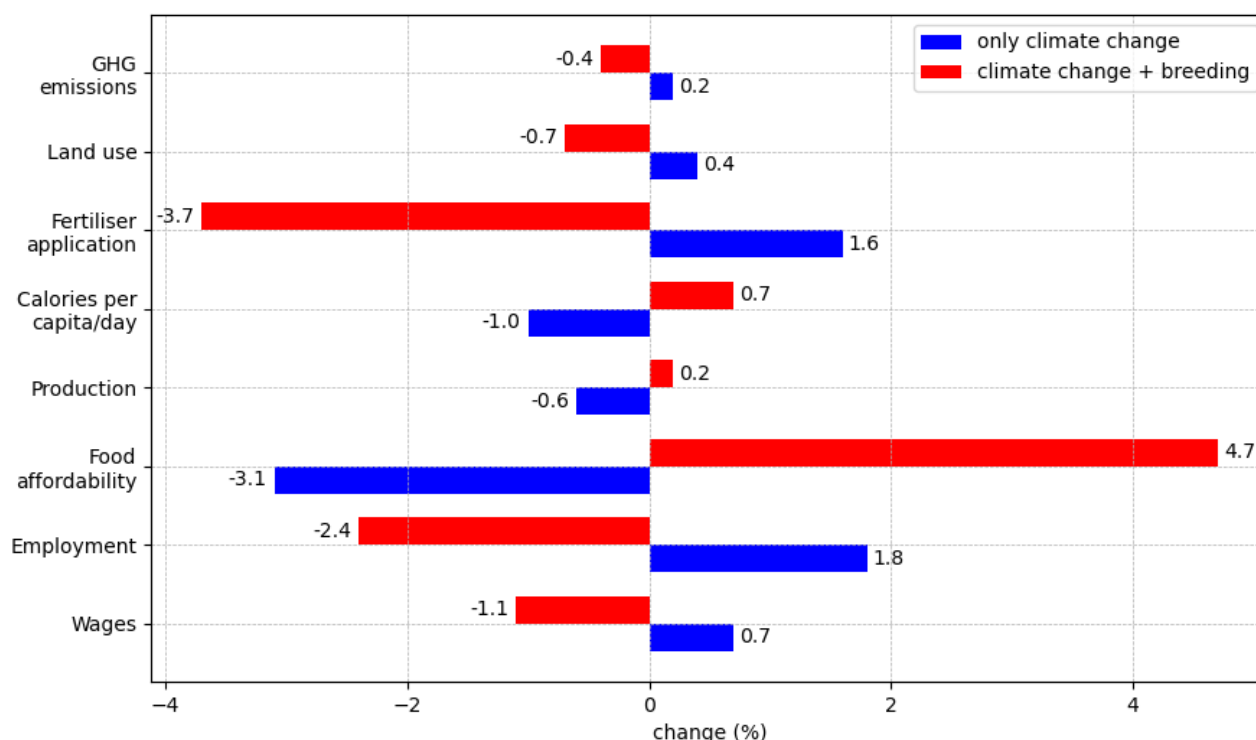


Figure 17: : Changes in world food security, environment and economy in with and without improvement in breeding in 2050 assuming climate change based on SSP2-4.5.

6.3. Discussion

The study provides a simplified assessment of breeding as a mitigation strategy, making several assumptions to facilitate the analysis. In this study we presented an assessment of breeding as a mitigation strategy for climate change. Many assumptions in this work were taken to simplify the study. First of all, we have assumed an equal global improvement for breeding. The gain from breeding is more pronounced for breeds of animals that have been less subject to selection than those lines with several generations of selection. Therefore, developing countries could benefit more from breeding. Additionally, cutting-edge technologies, e.g., genomic selection and gene editing raise the expectation on the production level in developed countries. Therefore, improvement in production level can significantly differ between countries. Furthermore, climate change has also different implications on various regions of the world (Thornton et al., 2022). While countries in temperate regions may benefit from climate change due to improvement in feed quality, various subtropical countries suffer differently from the rise of the temperature.

7 Conclusion

This report detailed the modeling of future scenarios for food resilience, a key component of Task 1.4 within the broader ECO-READY project framework. This work quantified the potential impacts of a selection of scenarios with economy-wide characteristics on food security, environmental sustainability, and economic performance. The primary modeling tool employed was MAGNET, a multi-regional, multi-sectoral, applied general equilibrium model tailored for agri-food analysis. The resulting scenarios projected a range of potential impacts on the EU and the individual member states in which the Living Labs (LLs) are situated.

This scenario and modeling foresight illuminated the complex interplay of factors affecting food resilience at the larger scale and provided a basis for evidence-based decision-making tools and applications in the face of future uncertainties in the other ECO-READY work packages. The detailed scenarios are presented within there manin contextual scenarios:

- The *Green Road* emphasized sustainability and showed the most promising results for environmental sustainability and social well-being, with significant reductions in greenhouse gas emissions, land demand, and chemical fertilizer use. However, it projected a slight decrease in food availability compared to other scenarios.
- The *Middle Road* represented a more balanced approach, with moderate improvements across most indicators. It achieved some progress in reducing environmental impacts and improving food access, while maintaining a relatively stable level of food availability.
- The *Rocky Road* prioritized economic growth but showed negative trends in most other indicators, including increased greenhouse gas emissions and a decline in food access and utilization.

The findings from the two case studies in which MAGNET is linked with intermediary micro models highlight the intricate relationship between climate change, livestock production, and food security, emphasizing breeding as a key mitigation strategy. Livestock production plays a crucial role in meeting global food demand, particularly in regions with limited crop production, but it remains highly vulnerable to climate change impacts, such as reduced feed availability and declining productivity. Breeding offers significant potential to enhance resilience, with developing countries benefiting more due to less-selected livestock breeds, while advanced technologies like genomic selection and gene editing

promise further improvements in developed regions. Regional disparities are evident, as temperate areas may gain from improved feed quality under climate change, whereas subtropical regions face heightened challenges from rising temperatures. To ensure effective implementation, breeding strategies must be context-specific and integrated into broader analyses to address economic, environmental, and biodiversity trade-offs, ultimately supporting global food security under changing climatic conditions.

Overall, the study highlighted the importance of considering the interconnectedness of climate change, agriculture, and environmental sustainability when designing policies and strategies for the future. The Green Road scenario suggested that a focus on sustainability can strengthen the EU's position in the global agri-food market, while the Rocky Road scenario warned of a potential decline in competitiveness in a less cooperative global environment.

The MAGNET model, while comprehensive, has limitations in product and spatial detail. The study also relied on several assumptions and simplifications, particularly in the case studies. However, the study's findings will inform more granular analyses using Life Cycle Assessment (LCA) models and other intermediary models. This will involve linking the MAGNET model with other models to explore region- or product-specific scenarios, providing a more comprehensive understanding of the impacts of specific scenarios and informing policy recommendations for a more resilient and sustainable EU food system.

8 References

- Aguiar, A., Chepeliev, M., Corong, E., & van der Mensbrugghe, D. (2022). The global trade analysis project (GTAP) database: Version 11. *Journal of Global Economic Analysis*, 7(2).
- Detlef P. van Vuuren, Elke Stehfest, David E.H.J. Gernaat, Jonathan C. Doelman, Maarten van den Berg, Mathijs Harmsen, Harmen Sytze de Boer, Lex F. Bouwman, Vassilis Daioglou, Oreane Y. Edelenbosch, Bastien Girod, Tom Kram, Luis Lassaletta, Paul L. Lucas, Hans van Meijl, Christoph Müller, Bas J. van Ruijven, Sietske van der Sluis, Andrzej Tabeau, Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm, *Global Environmental Change*, Volume 42, 2017, Pages 237-250, ISSN 0959-3780, DOI: [10.1016/j.gloenvcha.2016.05.008](https://doi.org/10.1016/j.gloenvcha.2016.05.008)
- Doelman, J. C., Stehfest, E., Tabeau, A., van Meijl, H., Lassaletta, L., Gernaat, D. E., ... & van Vuuren, D. P. (2018). Exploring SSP land-use dynamics using the IMAGE model:



Regional and gridded scenarios of land-use change and land-based climate change mitigation. *Global Environmental Change*, 48, 119-135.

Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arsouze, T., Bergman, T., Bernardello, R., Boussetta, S., Caron, L.-P., Carver, G., Castrillo, M., Catalano, F., Cvijanovic, I., Davini, P., Dekker, E., Doblas-Reyes, F. J., Docquier, D., Echevarria, P., Fladrich, U., Fuentes-Franco, R., Gröger, M., v. Hardenberg, J., Hieronymus, J., Karami, M. P., Keskinen, J.-P., Koenigk, T., Makkonen, R., Massonnet, F., Ménégos, M., Miller, P. A., Moreno-Chamarro, E., Nieradzick, L., van Noije, T., Nolan, P., O'Donnell, D., Ollinaho, P., van den Oord, G., Ortega, P., Prims, O. T., Ramos, A., Reerink, T., Rousset, C., Ruprich-Robert, Y., Le Sager, P., Schmith, T., Schrödner, R., Serva, F., Sicardi, V., Sloth Madsen, M., Smith, B., Tian, T., Tourigny, E., Uotila, P., Vancoppenolle, M., Wang, S., Wårlind, D., Willén, U., Wyser, K., Yang, S., Yepes-Arbós, X., and Zhang, Q.: The EC-Earth3 Earth system model for the Coupled Model Intercomparison Project 6, *Geosci. Model Dev.*, 15, 2973-3020, <https://doi.org/10.5194/gmd-15-2973-2022>, 2022.

FAO-IFAD-UNICEF-WFP-WHO (2018). The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition. Rome: FAO. Available at: <http://www.fao.org/3/a-l7695e.pdf>.

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* ¹ [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. ²

Lele, U., Masters, W. A., Kinabo, J., Meenakshi, J. V., Ramaswami, B., Tagwireyi, J., et al. (2016). Measuring food and nutrition security: An independent technical assessment and user's guide for existing indicators, 177. Rome: Food Security Information Network, Measuring Food and Nutrition Security Technical Working Group.

Meuwissen, T. H., Hayes, B. J., & Goddard, M. (2001). Prediction of total genetic value using genome-wide dense marker maps. *genetics*, 157(4), 1819-1829.

Moghayer, S., Zurek, M., Muzammil, M., Mason-D'Croz, D., Magrath, J., Tabeau, A., ... & Achterbosch, T. (2023). A low-carbon and hunger-free future for Bangladesh: An ex-ante assessment of synergies and trade-offs in different transition pathways. *Frontiers in Environmental Science*, 10, 977760.



Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., et al. (2009). Climate change: Impact on agriculture and costs of adaptation. Washington, DC: International Food Policy Research Institute.

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., ... & Van Vuuren, D. P. (2014). A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Climatic change*, 122, 387-400.

Oliver Fricko, Petr Havlik, Joeri Rogelj, Zbigniew Klimont, Mykola Gusti, Nils Johnson, Peter Kolp, Manfred Strubegger, Hugo Valin, Markus Amann, Tatiana Ermolieva, Nicklas Forsell, Mario Herrero, Chris Heyes, Georg Kindermann, Volker Krey, David L. McCollum, Michael Obersteiner, Shonali Pachauri, Shilpa Rao, Erwin Schmid, Wolfgang Schoepp, Keywan Riahi, The marker quantification of the Shared Socioeconomic Pathway 2: A middle-of-the-road scenario for the 21st century, *Global Environmental Change*, Volume 42, 2017, Pages 251-267, ISSN 0959-3780, DOI: [10.1016/j.gloenvcha.2016.06.004](https://doi.org/10.1016/j.gloenvcha.2016.06.004)

Rasmussen, L., Burns, C., & Swain, B. (2019). A framework for assessing food system resilience. *Ecology and Society*, 24(3).

Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., ... & Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global environmental change*, 42, 153-168.

Shinichiro Fujimori, Tomoko Hasegawa, Toshihiko Masui, Kiyoshi Takahashi, Diego Silva Herran, Hancheng Dai, Yasuaki Hijioka, Mikiko Kainuma, SSP3: AIM implementation of Shared Socioeconomic Pathways, *Global Environmental Change*, Volume 42, 2017, Pages 268-283,

ISSN 0959-3780, DOI: [10.1016/j.gloenvcha.2016.06.009](https://doi.org/10.1016/j.gloenvcha.2016.06.009)

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., ... & Gordon, L. J. (2015). Food system resilience: Defining the concept. *Global Food Security*, 6, 17-23.

Thornton, P. K., Nelson, G. C., Mayberry, D., & Herrero, M. (2022). Impacts of heat stress on global cattle production during the 21st century: a modelling study. *The Lancet Planetary Health*, 6(3), e192-e201. [https://doi.org/10.1016/s2542-5196\(22\)00002-x](https://doi.org/10.1016/s2542-5196(22)00002-x).



Van Meijl, H., Shutes, L., Valin, H., Stehfest, E., van Dijk, M., Kuiper, M., et al. (2020). Modelling alternative futures of global food security: Insights from FOODSECURE. *Glob. Food Secur.* 25, 100358. doi:10.1016/j.gfs.2020.100358

Von Lampe, M., Willenbockel, D., Ahammad, H., Blanc, E., Cai, Y., Calvin, K., et al. (2014). Why do global long-term scenarios for agriculture differ? An overview of the AgMIP global economic model intercomparison. *Agric. Econ.* 45 (1), 3-20. doi:10.1111/agec.12086



Anex 1: Co-creation and Training Workshop for Scenario Development, The Hague, NL, 27-28 June 2024

Introduction

This report reflects a summary of activities related to the ECO-READY Work package 1 - 2nd Workshop, The second workshop, which was scheduled for M19 and hosted by Wageningen University Research, took place to train the Living Labs participants in scenario development and the utilization of the drivers. As tasks 1.3 & 1.4 are linked, some of the scenarios or proposed interventions for the 10 Living Labs will be modelled. To provide perspective on the mid- and long-term (2030 and 2050, respectively) impacts of the interventions proposed, This workshop intends to link scenario development with modelling activities to attempt to stream-line the methodology, identify which scenario outputs link to modelling inputs, and to identify current gaps in the methodology.

During the announcement of the 10 ECO-READY Living Labs, Work package 1 - 1st Workshop, Thessaloniki 22-23 April 2024, we set a number of activities into place. Firstly, it was critical to have each living lab appoint a key representative for scenario development. The representatives provided information on the final 5 food/feed products for their regional living lab and were asked to fill out a survey on the drivers for each food/feed product, and an additional survey of their measurable indicators (what data can the living lab collect?).

Prior to the identification of the living labs, the scenario development teams were assembling background information of the regions of the living labs, including common farm practices, climatic and biodiversity conditions, and also relevant economic and policy issues. Once the representatives for the Living Labs were identified and customized team of specialists worked together with the living lab to start designing scenarios through a series of video calls. This work was in preparation for **ECO-READY Co-creation and Training Workshop for Scenario Development Workshop**. This event will be highly participatory as there will be active creation of scenarios with break-out sessions.

Aim of Session:

Aim: To work on the continued development of scenarios for each of the 10 ECO-READY Living Labs. To train Living Labs representatives in scenario development. To introduce MAGNET and LCA modelling to the Living Labs and identify indicators and key measurable inputs. Living Labs contribution to modelling and ability to measure/assess indicators.



Expected Outcomes:

1. Developed scenarios and trained representatives: Each ECO-READY Living Lab will have refined scenarios and trained representatives capable of independent scenario development.
2. Understanding of modelling and identified indicators: Living Labs will understand MAGNET and LCA modelling and identify key measurable indicators and inputs for their projects.
3. Enhanced collaboration and assessment: Living Labs will be better equipped to contribute to modelling and effectively measure/assess their indicators, leading to improved project outcomes.

Location: The Hague, The Netherlands, Wageningen Economic Research, Wageningen University & Research, World Trade Centre The Hague, Princes Beatrixlaan 582, 2595 BM the Hague,

Dates/Time: Thursday, 27 June 2024 (noon, CET) - Friday, 28 June 2024 (after lunch)

Agenda:**Thursday, 27 June, 13:00 - 18:00**

- 13:00 - 13:30 Welcome & Registration (Coffee)
- 13:30 - 14:15 Introduction and setting the scene for scenario development (Nils and Saeed - foresight tools)
- 14:15 - 14:45 Products identification for LCA
- 14:45 - 15:15 Coffee Break
- 15:15 - 16:15 Indicators for Scenarios and Modelling
- 16:15 - 16:40 Examples of scenarios
- 16:40 - 18:00 Interactive group sessions (4-5 groups/tables) - Carousel (need to prepare the big/common drivers)
- 19:30 Evening Working Dinner

Friday, 28 June 2024, 9.00 - 15.00

9:00 - 9:45 Interactive group sessions - More specific drivers (sub-category of big driver)

9:45 - 10:45 Interactive group sessions (4-5 groups/tables) - Paired - predetermined background info.

Develop one narrative scenario per group based on driver(s)

10:45 - 11:10 Coffee Break

11:10 - 12:30 Plenary from the group work (4-5 groups/tables) - One person from each table presents narratives (8-10 presentations) Q & A

12:30 - 13:30 Lunch (on-site)

13:30 - 14:15 Interactive group sessions (4-5 groups/tables) - mapping of tools/modelling capabilities

14:15 - 15:00 Conclusions and next steps

15:00 - Departure

Expected outcomes from each Breakout session:

Session I - Drivers

Session II - Scenarios

Session III - Mapping tools and models

Drivers

The objective of this session was to pair different living labs (identified by country) in a discussion of the identification of drivers for food products, but also to allow for cross regional comparisons. The products of greens (Sweden and Hungary), oils (Spain, France, and Germany), tomatoes (Greece and Italy), and grains (Poland and Czech Republic) were chosen for this session. Each session was moderated by members of the scenario development and modelling teams.

Greens (Leafy Greens and Microgreens)

The production of leafy greens and microgreens in vertical farms faces a unique set of challenges and opportunities. A primary concern across both Swedish and Hungarian



vertical farms is the rising cost and potential instability of energy supply, exacerbated by political events and trade restrictions. This has significant implications for the economic viability of vertical farming, which relies heavily on artificial lighting and climate control systems.

Another crucial driver is consumer behaviour. While there is a growing interest in sustainable and locally produced food, convincing consumers to prioritize nutritional value over price remains a challenge. Educating the public (e.g., labelling) about the benefits of vertical farming and developing effective marketing strategies are key to increasing market demand for these products.

Climate change presents both challenges and opportunities for vertical farming. Although unpredictable weather patterns can lead to increased energy costs for maintaining optimal growing conditions, they also create opportunities as conventional outdoor farming becomes less reliable. Technological advancements and automation play a crucial role in vertical farming and enable stability in production, but the cost of skilled labour, such as engineers, can be a barrier to entry and expansion. Finding a balance between automation and human labour will be essential for ensuring the long-term sustainability of this industry.

Oils (Olive Oil and Rapeseed Oil)

The production of olive oil and rapeseed oil is significantly impacted by climate change. Drought, heatwaves, and extreme weather events are major concerns in all regions, leading to decreased yields and increased production costs. Water scarcity and unpredictable precipitation patterns are particularly challenging for rain-fed crops like olives.

Another significant driver is the increasing pressure from pests and diseases, exacerbated by climate change and the development of pesticide resistance. Integrated pest management practices and the development of resistant crop varieties are essential for mitigating these challenges. Additionally, the availability and cost of fertilizers, particularly in regions without livestock, can impact production costs and require innovative solutions for nutrient management.

The global nature of oil markets also introduces challenges related to trade restrictions and competition. Political events and trade barriers can affect the availability and cost of inputs, potentially favouring local production and influencing international trade patterns. The interplay of socio-cultural factors, such as the decline in hunting and the resulting



increase in wildlife damage, further highlights the complex relationship between agricultural production and the broader ecosystem.

Tomatoes

Tomato production faces several interlinked challenges. Extreme weather events, water scarcity, and pest and disease pressure all contribute to yield losses and increased production costs. The availability and cost of fertilizers are also critical factors, particularly in regions with intensive tomato cultivation.

The emerging focus on reducing the carbon footprint of agriculture is driving the adoption of sustainable practices, such as precision farming and integrated pest management. These practices can improve resource use efficiency and reduce environmental impacts, but they may also require significant investments and changes in farming practices.

Social aspects, such as labor availability and working conditions, are crucial considerations for the tomato industry, which often relies on migrant workers. Addressing these challenges will be essential for ensuring the long-term sustainability and social responsibility of tomato production. Additionally, salinity issues, particularly in coastal areas, can impact tomato yields and require the development of salt-tolerant varieties or alternative irrigation strategies.

Grains

The production of grains face demands for use in both food and feed and experience a number of diverse challenges dependent on the type of grain and the region where they are grown.

The production of buckwheat in Czech Republic:

- **2030:** Sowing of buckwheat typically occurs in spring, but with extending of the growing season, it will be possible to grow buckwheat as a second cash crop after early harvested crops such as barley, peas or crimson clover. Buckwheat will continue to be incorporated into a crop rotation cycle helping maintain all year-round soil cover, suppressing weeds and mobilising phosphorus in the soil. Natural pest control methods like attracting beneficial insects and birds will continue to be critical to prevent chemical use.
- **2050:** The supply chain of organic seeds may not be stable due to lack of customer demand in the future. Extreme weather events like droughts or heavy rainfall could



disrupt buckwheat growth and yields and its reliance on cooler climates could also be challenged by rising temperatures. Without the use of synthetic pesticides, organic buckwheat might be more susceptible to pest and disease outbreaks. Developing effective organic pest and disease management strategies is crucial for long-term sustainability.

Barley production in Poland:

- **2030:** Barley thrives in temperate climates and prefers cooler temperatures during the grain filling stage. The region also receives a decent amount of rainfall throughout the growing season, which is beneficial for barley growth. Spring barley, the dominant variety in the region, matures faster than winter barley and is less prone to winterkill. Barley for beer brewing is also cultivated in the region. Weed management is crucial for barley cultivation, as is pest management, particularly for disease like powdery mildew or rust.
- **2050:** More frequent heatwaves and hotter summers can stress barley plants, leading to reduced yields and lower grain quality. Increased droughts will hinder barley growth and heavy rainfalls during harvest periods will damage grains. With changes in climate, new diseases pose a continued threat. Global grain price fluctuations will impact the local Masurian farms.

The production of maize in Poland:

- **2030:** Maize has not been a widely cultivated crop in Masuria, unlike other parts of Poland, but is increasing in cultivation. This region has a sub-optimal average summer temperature and short growing period for maximum yield of sunflower. Extreme weather events like prolonged droughts or heat waves could affect yields. Maize in Masuria is susceptible to several fungal disease (e.g., Northern Corn Leaf Blight, Fusarium, Smut) due to its relative cool and wet weather conditions.
- **2050:** Climate change will lead to more frequent and intense weather events like droughts, heatwaves, or heavy rainfall. These extremes will stress maize plants, reduce yields, and potentially increase susceptibility to diseases and pests. Overreliance on pesticides to manage existing diseases and pests will lead to the development of resistant populations. This can complicate pest and disease management and potentially increase production costs, as well as impact local



biodiversity. Long-term cultivation as a monoculture, will lead to depletion in the soil, reduction in soil biodiversity, as well as erosion of topsoil, unless sustainable practices are deployed.

Table A1.1 - Summary drivers per product category

Category	Climate Change	Biodiversity & Pests & fertilizers	Other
Greens	Rising energy prices, political instability, unpredictable weather patterns	Cost and availability of fertilizers, trade restrictions	Consumer behavior, technology & automation, market access
Oils	Drought, heatwaves, increased air temperature, precipitation change, extreme dryness	Fauna damage, pest invasion/resistance	Productivity fluctuations, fertilizer availability, crop variety adaptation, energy costs for processing & transport, by-products, global market dynamics, socio-cultural factors
Tomato	Extreme weather events, water demand & groundwater availability	Pest & disease pressure	Availability of fertilizers, carbon footprint, labor availability & social conditions, saltwater intrusion
Grains	Periods of drought and heavy rainfall	Emerging pests and availability of resilient varieties and seeds.	Overall, the pressure on levels of productivity and balancing of soil health management with the use of chemicals (fertilizers, pesticides). Political issues.

Key take aways and next steps

For Modeling (MAGNET and LCA models):

- Model the impact of climate change on tomato yields, quality, and production costs.

- Evaluate the effectiveness of integrated pest management practices and resistant cultivars in mitigating yield losses.
- Analyze the potential impact of fertilizer scarcity and price fluctuations on tomato production and profitability
- Assess the environmental and economic benefits of precision farming and other sustainable practices in tomato production
- Incorporate the social and economic impacts of labor availability and working conditions into the analysis.

Further Considerations:

- Explore the potential for developing salt-tolerant tomato varieties or implementing soil remediation strategies in affected regions.
- Investigate consumer preferences and willingness to pay for sustainably produced tomatoes
- Analyze the policy implications of carbon footprint reduction targets and their potential impact on the tomato industry

Scenarios

The objective of this session was to pair different living labs (identified by country) in a discussion of the how to design scenarios for their food products, but also to allow for cross regional comparisons. The team were grouped, with Spain & Czech Republic, Greece & Germany, Sweden & France, Denmark & Italy, and Hungary & Poland. Each session was moderated by members of the scenario development and modelling teams. After this session, the individual representatives of the Living Labs presented their scenario findings to all workshop attendees.

Spain

- Major Shocks: Water availability/long-term drought, heat waves, and high temperatures
- Potential Interventions:
 - Drought: Develop drought-resistant crops, implement deficit irrigation, improve irrigation infrastructure, explore alternative water sources, consider

replanting orchards or transitioning to less water-intensive crops, and implement soil health management practices.

- Heat: Test heat-resistant apple varieties, implement strategies to reduce heat stress in poultry, explore protective measures for apples, and consider agro-photovoltaic systems.

Czech Republic

- Major Shocks: Extreme weather fluctuations and economic & trade matters
- Potential Interventions:
 - Extreme Weather: Focus on soil health management practices, implement diverse crop rotations, and exercise caution with autumn sowing.
 - Economic & Trade: Educate and encourage young people to enter farming, strengthen local supply chains and markets, explore agricultural robotics and precision farming, and consider policy interventions.

Greece

- Major Shocks: Floods and droughts
- Potential Interventions:
 - Floods: Promote and cultivate quick-to-harvest varieties and implement nature-based solutions.
 - Droughts: Promote drought-tolerant cultivars, implement precision farming and smart irrigation, explore nature-based solutions, and consider using indigenous tomato varieties.

Germany

- Major Shocks: Drought and heavy rains
- Potential Interventions: This scenario explores the long-term strategies and impacts of reducing nutrient losses by at least 50% by 2050 while maintaining or enhancing soil fertility. Further, biocontrol in the agricultural sector as a means to alter farming practice to create more resilient land conditions to absorb water.

Sweden



- Major Shocks: Water circularity and nutrient management challenges and energy management issues
- Potential Interventions: Develop an AI model to optimize energy use, improve water and nutrient circularity, investigate vertical farming, and match production to consumer demand.

France

- Major Shocks: Rainfall deficit & extreme droughts and high temperatures & strong climatic hazards
- Potential Interventions: Crop diversification and rotation, implementation of technological solutions, nature-based solutions, and water and energy management strategies for indoor production.

Denmark

- Major Shocks: Periods of drought and higher precipitation.
- Potential Interventions:
 - Under this scenario, farmers use biodiversity of productive organisms (crops and farm animals) as a tool to succeed with agricultural production. The three main intervention points for farmers seem to be soil management, farm machinery, and choice of crop.
 - Land use: The impact from policies about nature restoration, climate change mitigation, or renewable energy on farmers' decision to undertake agricultural production. This scenario is relevant in a Danish context for several reasons: Denmark will impose a CO2 tax on agriculture with the expected consequences of reduced farming of wetlands, reduced number of dairy cows, and setting-aside of 100,000 hectares of farmland for nature restoration.

Italy

- Major Shocks: a wider array of climatic stressors, including extreme weather events, evolving pest and disease pressures, and the interplay of these factors with diverse agricultural practices.
- Potential Interventions:



- Prevention of *Xylella fastidiosa* in olive orchards in the Basilicata region. Invest in research to develop and propagate *Xylella*-resistant olive tree varieties. Collaborate with agricultural research institutions and universities to accelerate breeding programs. Conduct in-depth studies on *Xylella fastidiosa* to understand its biology, transmission mechanisms, and potential weaknesses that could be targeted for control.
- Addressing the lack of labour force in the agricultural sector. Increasing wages and providing better working conditions to make agricultural jobs more attractive. Offering bonuses for peak seasons to attract temporary workers. Providing affordable housing and transportation for seasonal workers to reduce the logistical challenges they face. Launching recruitment campaigns targeting local youth and unemployed individuals, highlighting the benefits and importance of agricultural work.

Hungary

- Major Shocks: No customer demand for vertically farmed products. . Rising energy price management issues due to trade barriers. Political instability (exit EU), which leads to higher costs of imported agricultural inputs (e.g., fertilizer, seeds).
- Potential Interventions:
 - This scenario intervention aims to address an evolving customer preference, as well as enhancing the nutritional properties of vertically farmed foods.
 - Bringing greater varieties of food products into vertical farms to create “food forests”.
 - Promote high tech agriculture to source seeds internally. Implement crop diversification in vertical farming.
 - Investments or subsidies to switch to renewable energy.
 - New trade agreements to import inputs.

Poland

- Major Shocks: Prolonged heat waves; large scale farming and non-sustainable land-use threaten to destroy the natural habitats of Masuria. . Increased imports of cheap



grains from Ukraine, which would lead to a substantial drop in national prices of grains (lower demand for national production of grains).

- Potential Interventions:
 - Build resilience against heat stress in developing as series of regenerative agriculture practices. The core principles place emphasis on soil health, biodiversity, and water conservation to create a more robust agricultural ecosystem. Implementation of strategies to minimize the impact of high temperatures on crops and livestock.
 - This scenario envisions the integration of modern services, technology, local markets, and policy frameworks designed to support agriculture and community well-being in Masuria, Poland. Its aim is to address challenges like climate change, promote sustainable agricultural practices, and importantly promote local livelihoods.
 - Regulate grains trade from Ukraine (e.g., trade barriers/taxes). Ukraine joins EU.
 -

Key Takeaways and Next Steps

For Modeling (MAGNET and LCA)

- Incorporate shocks and interventions into models: This will help to assess their impact on various factors, including yields, production costs, and economic viability.
- Evaluate effectiveness of mitigation strategies: Modeling can quantify the potential benefits of interventions like crop diversification, precision farming, and soil health management.
- Consider interplay of various factors: Models should account for the complex interactions between environmental, economic, and social factors.
- Explore long-term scenarios: Develop scenarios beyond the project timeframe to assess long-term impacts of climate change and other drivers.
- Incorporate specific intervention data: Detailed information on water and energy savings, yield improvements, etc., is needed.



- Consider regional and crop-specific factors: Models should account for the unique conditions and challenges in each region and for each crop.
- Evaluate trade-offs: Analyze potential trade-offs between different interventions.
- Focus on data collection and analysis: Gather data on the specific impacts of shocks and the effectiveness of interventions.

Further Considerations

- Clarify terminology and definitions: Ensure consistent understanding of key terms across the project.
- Engage with stakeholders: Collaborate with farmers and other stakeholders to gather data, refine scenarios, and ensure feasibility and acceptability of interventions.
- Communicate effectively: Clearly present findings and recommendations to a wider audience.
- Consider the interplay of environmental, economic, and social factors: Models should account for the complex interactions between these factors, including market dynamics, labor availability, and socio-cultural practices.
- Integration with other Products: While focusing on specific crops, acknowledge and explore potential impacts on other products.
- Long-term Perspective: Consider long-term implications of climate change and develop scenarios beyond the project timeframe.

Summary

The workshop was a key step in the direction of determining drivers for the priority food products of the 10 Living Labs, and further, it achieved its aim of training in the co-development of scenarios. The structure of the workshop, having brief introductory lectures at the beginning of the workshop, however being mainly organized around parallel break-out sessions, where the living labs provided the majority of the inputs, was instrumental to achieve these aims. These sessions enabled the Living Labs to further identify critical input or data which they can provide to initiate the modelling of select scenarios.

Some of the limitations uncovered during the workshop are related to low awareness of matters related to biodiversity. This has been a recurring theme, as standards, particularly

in measuring soil and insect biodiversity, are missing, and therefore not commonly considered. Additionally, the living labs have differing analytical capacities, which may impact the collection of modelling inputs. Further, the time limitations, not only with the workshop itself, but the overall time to collect and coordinate the information collection posed challenges.





Annex 2

Region	Wages in agriculture	Added-value in food system	Self-sufficiency in agri-food	% fruits&veg in calories	% sugar in calories	% red meat in calories	Water use	Land use	Fertilizer application	Agri-food GHG emissions
Czech Republic	24	31	-4	20	3	-40	-8	-5	-45	-50
Denmark	-11	19	-12	23	0	-36	-5	-3	-44	-43
France	37	20	-7	19	7	-41	-33	-23	-46	-49
Germany	22	13	-9	21	4	-38	-30	-16	-43	-47
Greece	49	34	4	9	3	-38	-2	-3	-42	-51
Hungary	44	26	-5	24	9	-36	-31	-24	-50	-45
Italy	62	21	0	7	-13	-42	-27	-15	-44	-51
Poland	12	40	1	21	5	-40	-32	-18	-46	-47
Rest of EU members	47	40	-2	18	5	-41	-33	-13	-44	-42
Spain	48	27	-5	5	-2	-43	-35	-25	-40	-44
Sweden	28	39	-7	20	3	-40	-35	-4	-47	-41
Ukraine	91	4	18	15	7	-46	-3	-8	-70	-39

Figure A2.1: The Green Road. Percentage change in selected indicators across EU member states + Ukraine, 2025-2050





Region	Wages in agriculture	Added-value in food system	Self-sufficiency in agri-food	% fruits&veg in calories	% sugar in calories	% red meat in calories	Water use	Land use	Fertilizer application	Agri-food GHG emissions
Czech Republic	87	32	-4	4	-5	2	-8	-2	-20	-11
Denmark	41	19	-7	0	-9	3	-6	-2	-15	0
France	79	19	-6	2	-5	-2	-22	-15	-23	-6
Germany	77	11	-6	3	-6	2	-24	-11	-25	-7
Greece	76	35	3	-4	-6	2	-2	-1	-24	-7
Hungary	104	30	-4	-1	-2	6	-23	-13	-21	-11
Italy	97	18	-3	-6	-10	-1	-15	-7	-26	-11
Poland	112	46	1	1	-5	4	-18	-8	-15	-6
Rest of EU members	96	40	-1	2	-6	-2	-22	-6	-20	1
Spain	80	24	-4	-5	-10	-6	-29	-17	-20	2
Sweden	109	36	-4	1	-9	-1	-10	0	-10	12
Ukraine	129	5	12	0	-5	8	0	-2	-28	-2

Figure A2.2: The Middle Road. Percentage change in selected indicators across EU member states + Ukraine, 2025-2050



Region	Wages in agriculture	Added-value in food system	Self-sufficiency in agri-food	% fruits&veg in calories	% sugar in calories	% red meat in calories	Water use	Land use	Fertilizer application	Agri-food GHG emissions
Czech Republic	141	18	-5	-12	-9	38	-6	1	21	32
Denmark	116	14	3	-17	-7	20	-19	1	59	70
France	159	15	1	-15	-12	35	13	7	30	70
Germany	166	-1	2	-14	-10	42	-6	2	17	58
Greece	165	26	3	-16	2	40	-4	1	12	39
Hungary	164	24	-2	-24	-8	45	-9	2	22	42
Italy	165	10	-2	-16	5	36	-4	1	13	40
Poland	245	43	1	-20	-14	46	-5	4	20	37
Rest of EU members	166	30	3	-12	-11	37	-3	2	18	60
Spain	157	15	1	-12	-11	45	-6	2	19	69
Sweden	211	23	6	-13	-15	33	6	2	44	81
Ukraine	157	6	8	-17	-16	75	-11	1	40	47

Figure A.3: The Rocky Road. Percentage change in selected indicators across EU member states + Ukraine, 2025-2050