Pathways toward sustainable livestock farming in the EU: a macroeconomic analysis.

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Abstract

This paper aims to present how storyline creation can be linked with macroeconomic impact assessment in order to provide quantification and validation of future pathways creation. As such, it starts from the development of different pathways for the European livestock sector, which are then fed to a macroeconomic model, and it evaluates their social and environmental trade-offs. The five selected pathways focusing on different potential objectives of the sector aim to represent different priorities that could be adopted as targets for the policy makers. As such, it proves that the connection between storylines and modelling, i.e. scenario assessment, can be a useful tool for the development of future policies while providing a perspective of the pros and cons of different futures for a key development sector in the European Union.

1. Introduction

The upcoming decades are expected to bring an increasing population and production of value-added, which will inevitably affect the demand for animal products (Godfray et al.2018). At the same time, an increase in the resources needed to sustain the required increase in production is expected, and, consequently, their impact on the environment and, particularly, on greenhouse gas emissions (Van Zanten et al., 2018; Willett et al., 2019). This poses the question of how to integrate increasing production requirements with environmental and economic viability (van Wagenberg et al., 2017) and the increasing concerns in terms of animal welfare and human health (Willett et al., 2019; Mehrabi et al., 2020). On the other hand, the livestock sector also presents potential to contribute to the development of a sustainable circular (bio)economy and agroecology, which is generally underestimated (Van Zanten et al., 2019, Díaz de Otálora et al., 2021; Hocquette et al., 2018). The ability of this sector and the overall economy to achieve the prospective targets depends on multiple stakeholders, each driven by their specific interests, priorities, and visions. Some stakeholders might indeed prioritise production efficiency and resilience against environmental and economic challenges, while others might prioritise climate mitigation, biodiversity conservation and animal welfare. These diverse perspectives highlight the need for an inclusive and integrated anticipatory approach to explore different potential futures (Nobles et al., 2022, Zaharia et al., 2021, Mitter et al., 2020, Smulders et al., 2025). In particular, this paper uses a storyline-based approach (Larsson & Vik, 2023, Vinnari & Tapio, 2009, Kuhmonen, 2017, Odegard and van der Voet, 2014). Within this framework, this paper aligns with Riera et al. (2025), which distinguished between exploratory and normative scenarios, choosing to assess the first type, allowing the use of quantitative tools and scenarios to create strategic frameworks that would be informative without disregarding the issue of uncertainty. Therefore, it creates scenarios, i.e. a combination of storylines with quantitative assumptions (van Vuuren et al. 2014) to explore the implications and trade-offs of different future pathways of the European livestock sector. To this aim, section 2 introduces the model used to quantify the impact of the scenarios, the Modular Applied GeNeral Equilibrium Tool (MAGNET) and the assessed scenarios; section 3 presents the main results, and section 4 discusses their implications and draws the main conclusions.

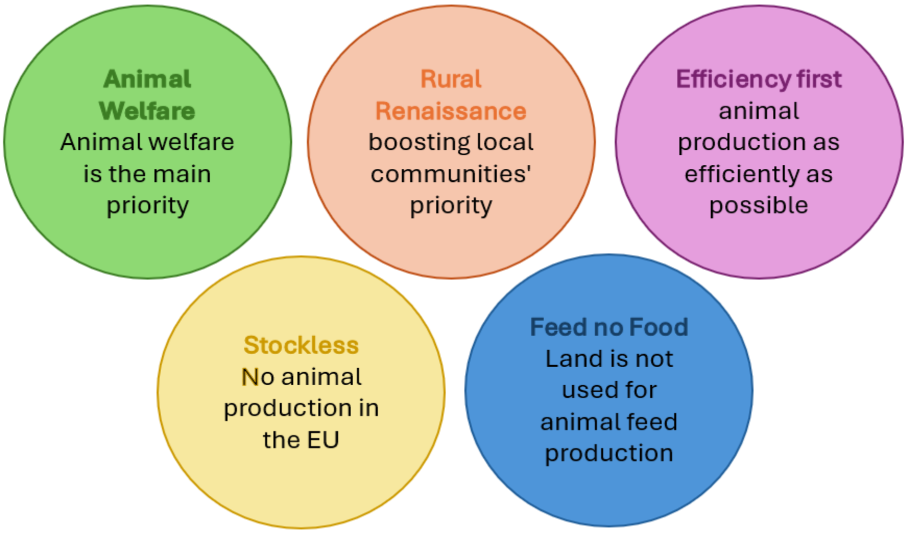
2. Methodology

For the analysis developed in this paper, we applied the Computable General Equilibrium model MAGNET (Woltjer and Kuiper, 2012), which has been extended to address crucial material flows such as manure, to allow a better representation of both the livestock and crop sectors and their relative environmental footprint. Moreover, it refined the production structure of the livestock sectors by adding a specific type of live capital (i.e., breeding livestock), which was separated from the standard overall capital (e.g., machinery), and improved the use of food loss and waste from several stakeholders (i.e., producers, food processing, retail and food service sectors), and added crop residues as a supplementary sources of animal feed.

As any CGE model, the basis for an impact assessment is setting the starting point, which consist of a database for the base year and some assumptions for the construction of the baseline. In this case, MAGNET is calibrated to version 11b of the GTAP database (Aguiar et al., 2023) with base year 2017. The database is aggregated into 37 countries or regions and 87 activities (Annex 1). For what concerns the scenario, the standard practice in impact assessment is to design a baseline or business-as-usual scenario [REFERENCE]. This allows to create a base against which the specific measures or policies are evaluated against in order to isolate the relative implications. In this case the Business-As-Usual (BAU) scenario has been constructed in coherence with the prevailing socio-economic projections: the Shared Socioeconomic Pathways (SSP) (O'Neill et al., 2017). These pathways provide a trajectory for population and gross domestic product (GDP) in different mitigation and adaptation to climate change options, which are considered as a standard way to calibrate baselines in the modelling and impact assessment communities [REFERENCES]. In particular, this work adopts SSP2, the "Middle of the Road" scenario, as its basic projection up to 2050. Embedding these insights into MAGNET allows for capturing the interaction between the production-specific developments of the livestock sector and the developments in the rest of the economy. This enhances the understanding of livestock's role in terms of diets, income, employment and emissions in relation to broader economic developments. The SSP macro shocks are then integrated with additional land and forestry productivity shocks, agricultural and biofuels policy. Growth in yields is taken from the IMAGE model suite (Kram and Stehfest, 2012; OECD, 2012; Stehfest et al. 2014) and is based upon FAO projections up to 2050 (Bruinsma, 2003).

The paper then tests five different pathways regarding how sustainable livestock can develop in the EU. These scenarios, while not entirely realistic, aim to represent the implications of different futures for the European livestock sector. Indeed, these storylines, built on an iterative process between experts and different stakeholders, assess five possible simplified stories that are both simple enough to give a clear perspective of the possibility evaluated and the implementation into modelling exercises. The scenarios, summarised in Figure 1, are the following: 1) "efficiency first", which focuses on improved technology to combat the negative impacts of livestock farming and to improve the overall income of the livestock farmers; 2) animal welfare", which assumes improved animal welfare in livestock farming; 3) "Feed no Food", which simulates the most efficient food production system and does not allow animal crops production on land suitable for crops fit for human consumption; "rural renaissance", which focusses on improving welfare in rural areas, 5) "Stockless" scenario which is a counterfactual scenario in which livestock will disappear from Europe. All the scenarios attempted to provide insights to support the transitions to sustainability of both the livestock supply chain and the European countries overall, by looking at different aspects livestock can contribute.

Figure 1. Storylines for the future of the European Livestock sectors.



3. Results of the scenario assessment

3.1. Macro-economic impacts

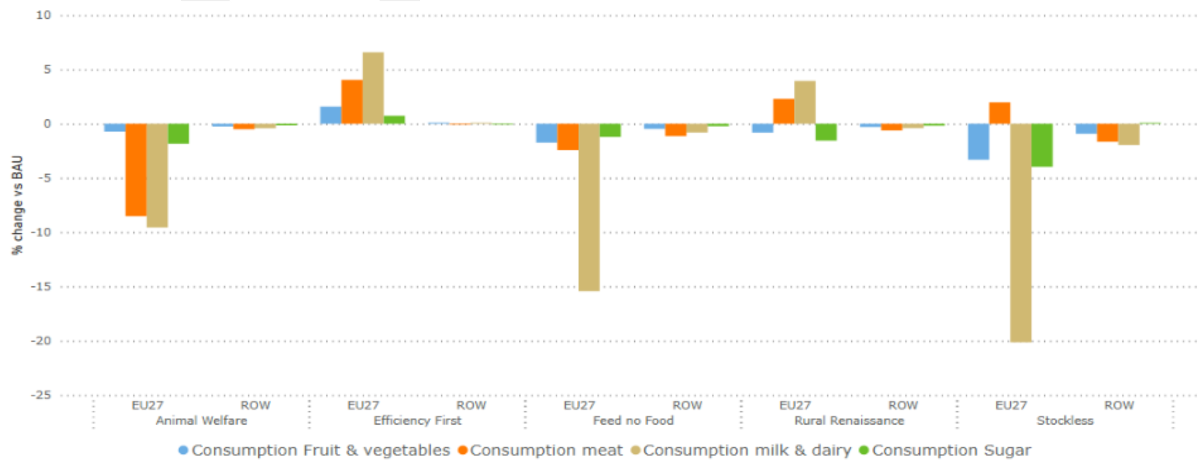
The different scenarios have different macroeconomic implications when compared to the baseline. Indeed, Figure 2 shows that concerning food trade repercussions in Europe, the exports of EU products generally decline. This result can be generally attributable to two reasons: 1) scenarios like Rural Renaissance, High Animal Welfare, and Feed no Food, by construction, introduce costs in the production structure, whether because of investments to ensure higher animal welfare, need for additional land. As a consequence, agricultural production declines, consequently leading to a reduced export capacity. The only scenario that does not show these trends is the Efficiency First. Indeed, in this scenario, by narrative definition, the EU will have a technical advantage in livestock and, therefore, food production, allowing for a higher potential export amount, though livestock products will also become cheaper with respect to other global regions.

Figure 2. Impact of the alternative storylines across selected economic indicators for the European Union and the Rest of the World (% compared to the BAU in 2050).

3.2. Nutritional impacts

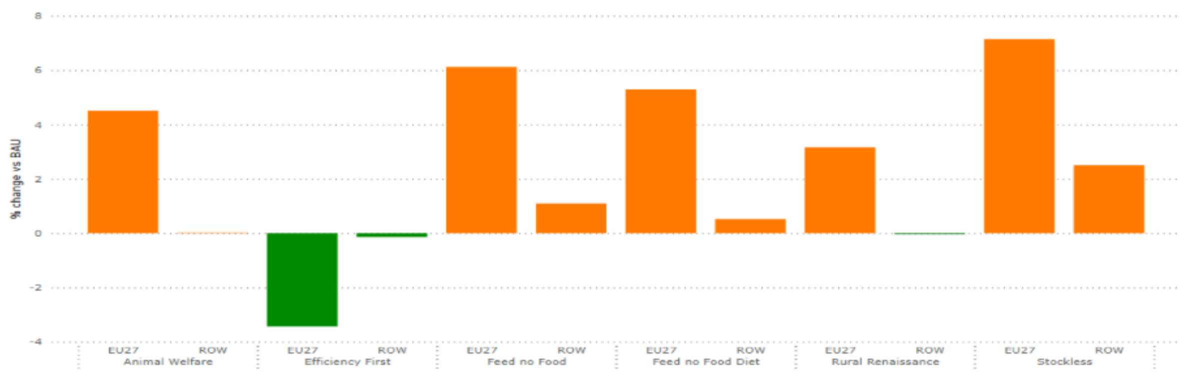
The prospective changes in food production and the role of livestock will have direct repercussions on both the European and global nutritional outcomes (Figure 3). Most of the scenarios actually lead to a reduction in consumption of animal products, with the exception of Efficiency First and Rural Renaissance. In particular, in the Efficiency First, due to efficiency increases, meat products become cheaper, which leads to an increased demand for meat products. On the other hand, the an increase in the consumption of animal products. In Rural Renaissance is due to the decrease in trade of both food products and fertilisers, which is limited due to the structure of the storyline. The reduction of fertiliser trade, in particular, has a negative impact on the production of crop sectors, which leads to a reduction of crop commodity availability, which is partly replaced by the consumption of meat.

Figure 3. Impact of the alternative storylines across selected nutrition indicators for the European Union and the Rest of the World (% change compared to the BAU in 2050).



The changes in food consumption in the different scenarios are reflected in the changes of the percentage of income that the representative consumer uses for food consumption (Figure 4). As such, in most cases, the amount of income needed to satisfy the food demand increases, with the exception of Efficiency First scenario. Therefore, it appears that if changes or improvements will be developed in the European livestock system without any technological advantages, this will probably lead to increasing costs, which will be felt by consumers.

Figure 4. Change in share of income spent on food in the alternative storylines for the European Union and the Rest of the World (% change compared to the BAU in 2050).



Nevertheless, not all the scenarios show the same consumption patterns. Indeed, for example, in the Efficiency First, production and consumption of all food products, boosted by increased productivity, will increase, while in the Stockless scenario, consumption of livestock products declines. This leads to a significant increase in calorie consumption, since the dietary composition shifts towards more calorie-intensive types of foods such as sugar. Nevertheless, it is important to notice that while limited in its entity, the implementation of different improvements in the livestock sectors in Europe would lead to an increase in calorie consumption in the rest of the world, allowing the region to contribute to overall SDG objectives like ending hunger (SDG2).

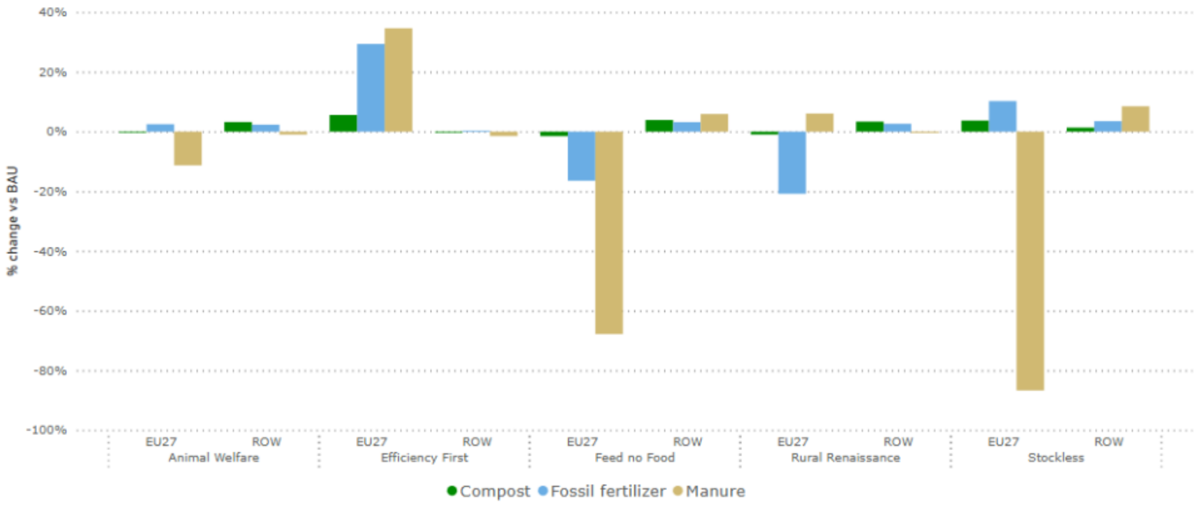
3.3. Environmental impacts

For what concerns the impacts of the scenarios on the environment, the different storylines provide different impacts on the main environmental indicators. For example, Figure 5 shows the implications of the different pathways with respect to emissions, for both the EU and the rest of the world. In general, most of the scenarios lead to a decrease in emissions both at the EU and global levels. This is due mostly to the high level of emission intensity of livestock, which implies that a decrease in the production and consumption of these goods can lead to significant reductions in the overall emission levels. As for the previous results, the only exceptions are the Efficiency First scenario (in the EU) and the Stockless scenario (in the rest of the world). For what concerns the first one, EU emissions increase due to the increase of livestock production, since by default it is assumed that technological advancement would not necessarily translate to emissions savings, but just production efficiency. In the Stockless scenario, instead, EU agricultural emissions drop significantly, but since this is not connected (by narrative) to a relevant change in diets and consumer preferences, EU citizens start importing livestock products from the neighbouring regions, raising their agricultural, but also overall, contribution to GHG emissions.

Figure 5. Impact of the alternative storylines across GHG emissions for the European Union and the Rest of the World (Absolute change compared to the BAU in 2050).

Similar trends emerge for what concerns the use of organic and chemical fertilisers, and the relative application of nitrogen and phosphorus on land (Figure 6). In this case, as well the the Efficiency First, due to its significant increases in livestock and agricultural production, leads to an increase in the use (and footprint) of these inputs, while the Stockless scenario, declining in production, has the highest decrease. Interestingly, this trend is mirrored quite closely by manure application, as manure is a byproduct of the livestock sectors. Feed no food and High Animal Welfare are the two scenarios that show the lowest level of use of fertilisers. As such, they are the best performing pathways for this specific environmental indicator. Nevertheless, it is important to notice that the total composite use of fertiliser is never negative, meaning that for a significant reduction of this environmental variable, there is no perfect storyline, but, potentially, a mix of measures would be required.

Figure 6. Impact of the alternative storylines across fertiliser use for the European Union and the Rest of the World (% change compared to the BAU in 2050).



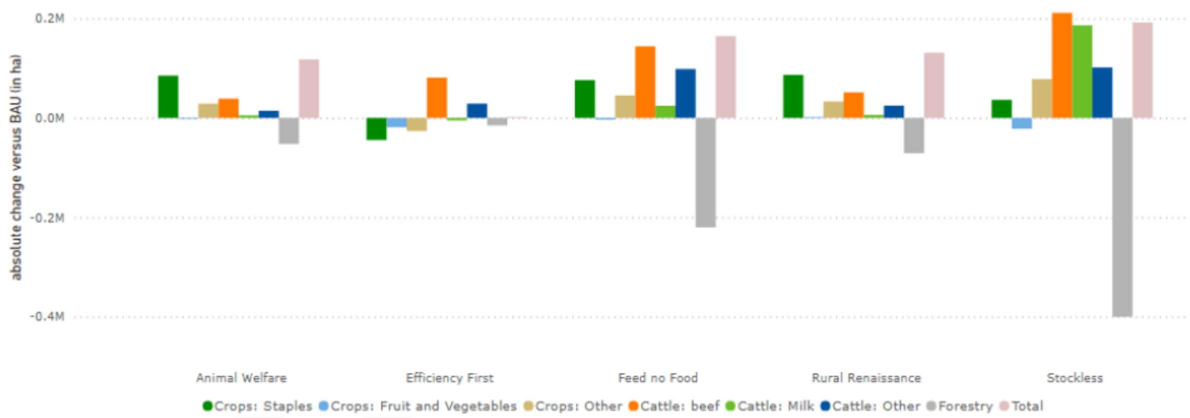
Finally, for what concerns land use, different trends can be identified with respect to the other environmental indicators (Figure 7). Indeed, at least in the EU, positive impacts in the land use can be achieved only under a the assumption of a significant production change.

Indeed, In Efficiency First, even if a significant reduction in land use for livestock is created by increases in the efficiency of the sector, this land is immediately redistributed to other production processes, so that the overall pressure on EU land use remains overall the same. Similarly, in the Feed no Food scenario, more land is needed to keep up production of livestock; therefore, land get transferred from feed to livestock production (grazing). In the Stockless scenario, on the other hand, only part of it is redistributed to other production processes, leading to less EU land pressure. Due to the increase in demand for livestock products from outside the EU, in most scenarios, there is an increase in the demand for grazing or crop production areas in the rest of the world, which increases land pressure.

Figure 7. Impact of the alternative storylines on Land Use for the European Union (Panel A) and the Rest of the World (Panel B) (Absolute change in hectare compared to the BAU in 2050).

Panel A - EU

Panel B – Rest of World



4. Discussion and Conclusions

Based on the development of different storylines for the future of the livestock sector in Europe, this paper aims to build and quantify the trade-offs of these scenarios to provide information about the pros and cons of these different futures. As such, the paper shows that all the pathways lead to different social and environmental trade-offs for both the EU and the rest of the world, as summarised by Table 1.

Table 1. Summary of impacts for storylines vs. baseline scenario for the European Union and the Rest of the World (% change compared to the BAU in 2050).

Region	GDP	Wages Livestock	Added value Livestock	Self-sufficiency food	Land use Livestock	GHG emissions Livestock	Food Affordability
EU27							
Animal Welfare	-0.1	4.0	19.8	-2.0	7.4	-6.5	4.2
Efficiency First	0.6	-25.1	-9.4	5.7	-19.6	34.0	-8.9
Feed no Food	-1.0	7.0	-4.6	-47.3	25.6	-65.2	6.1
Rural Renaissance	-0.6	4.2	11.5	-3.1	8.6	-1.3	4.3
Stockless	-4.3	14.2	-29.3	-79.9	-80.6	-81.8	19.2
ROW							
Animal Welfare	-0.6	-0.1	0.3	0.4	0.2	-3.7	0.1
Efficiency First	0.0	-2.0	-1.2	-1.1	0.4	-4.7	-1.0
Feed no Food	-0.4	6.6	6.0	4.8	0.9	0.4	3.0
Rural Renaissance	-0.8	0.5	0.9	0.6	0.3	-3.0	0.4
Stockless	-0.3	20.1	8.9	8.0	1.7	6.1	9.7

As such, we see that for the Stockless scenario, the GDP in the EU declines by 4.3%, in connection to the significant shrinkage of the livestock sectors, though this would create a positive environmental impact. In the High Animal Welfare storyline, there is an increase in agricultural wages and a decrease in emissions, which are positive, but a negative impact on self-sufficiency and food affordability. The Efficiency First scenario presents a decrease in wages, due to an increased use of machinery in the livestock sectors, with marginal GDP impacts. All in all, all of the storylines show an improvement in the agricultural wages and a decrease in livestock emissions, with the exception of the Efficiency First scenario. Nevertheless, the latter has a positive impact on the European self-sufficiency and food affordability, and it would potentially free some land for other productive uses. This shows that overall, most storylines present pros and cons in different areas, which is a sign that careful evaluation of different storylines, and potentially a mix of them, will be necessary to achieve a future that is sustainable from all its three main components, economic, social and environmental. Nevertheless, the most positive scenario overall seems High Animal Welfare, with increases both in the economy/production side and the emission component, and only mild nutritional repercussions and impact on GDP. This provides a key finding as it contributes to establish the importance of linking storylines creation to scenario assessment, as it highlights a relatively unexpected conclusion with respect to the one commonly assumed in the field, that sees Animal Welfare improvement as a potential for (macro) economic losses.

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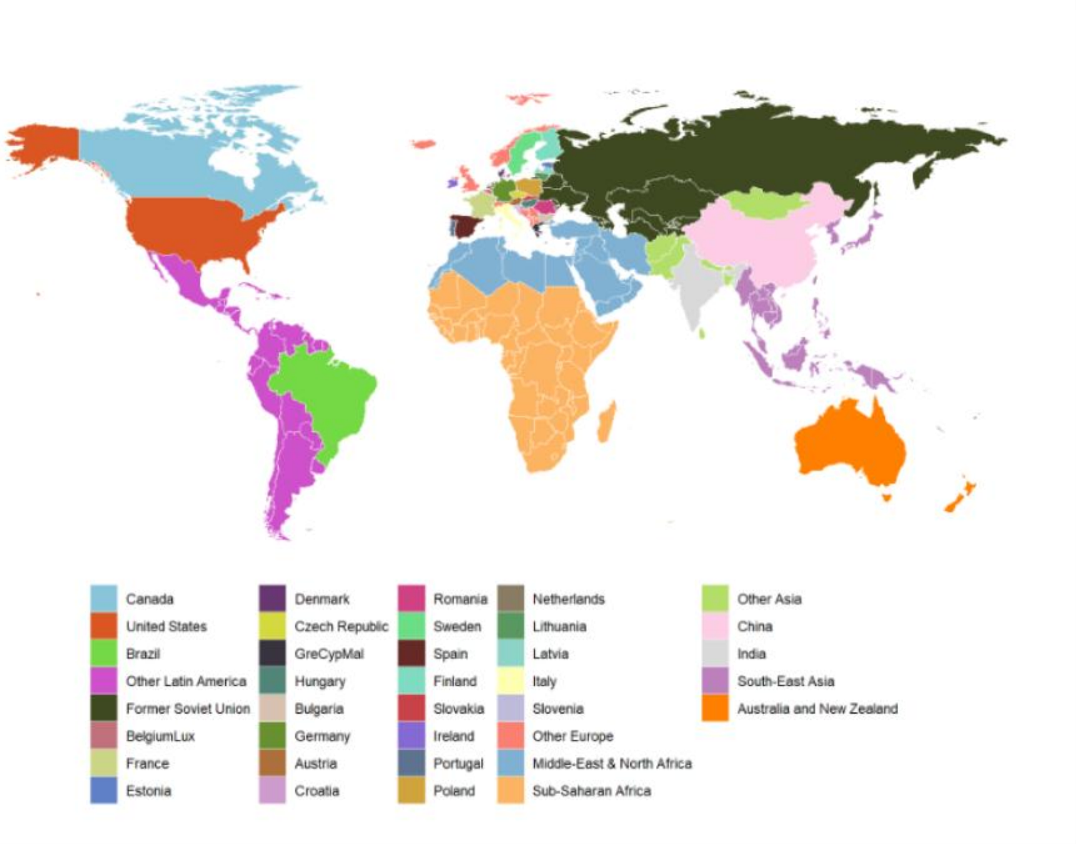
Supplementary Information

S1. Regional and sectoral aggregation



Sector type	Sector
Crop, forestry, fishery sectors (13)	Cereal grains; Crops; Energy crops from plantations; Fishing; Forestry; Oil seeds; Paddy and processed rice; Plant Fibers; Sugar cane, sugar beet; Vegetables, fruit, nuts; Wheat; Aquaculture; Seaweed
Livestock sectors (6)	Animal products; Beef live animals; Cattle, sheep ,goats, horses; Poultry live animals; Raw milk; Wool
Processed food sectors (13)	Beef meat; Crude vegetable oil; Dairy products; Meat products; Meat: cattle, sheep, goats, horse; Poultry meat; Processed food; Processed rice; Sugar and molasses; Vegetable oils and fats; Processed fish; Beverages and Tabacco; Vegetable oil
Energy sectors (21)	Gas distribution; 2nd gen biofuel ftfuel; Biodiesel; bioelectricity; biofuel kerosine; bio-gasoline; Coal; Crude oil; Electricity from coal; Electricity from gas; Electricity from hydro; Electricity from hydro; Electricity from nuclear; Electricity from wind; Electricity transport;

	Ethanol 2nd gen biofuel; Fossil kerosine; Gas; Biogas; Heat; Bioheat
Industry sectors (21)	Feed cattle; Feed poultry; Feed pigs; Feed fish; Fertilizer N; Fertilizer P; Fertilizer K; Manufacturing; Pellets sector and Residue sector; Textiles, leather and wearing apparel; Wood products; Paper products and publishing; Chemicals; Pharmaceuticals; Plastics; Biochemicals, biopharmaceuticals; Bioplastics; non-metallic mineral products; Other Manufacturing
Service and transport sectors (6)	Food services (trd, osg); Services; Transport; Education; Dwellings; Recreation
Waste collection and treatment sectors (7)	Waste collection glass paper; Waste collection green; Waste collection rest; Composting; Incineration; Landfilling; recycling

S2. Quantitative inputs by scenario.

T1. High Animal Welfare.

Variables	Ruminants	Monogastric
Labour efficiency	-20%	-20%
Capital efficiency	-50%	-50%
Land use	+10%	
Feed efficiency	-20%	-20%
Overall productivity	-30%	-30%
Tariffs to protect EU market	+50%	+50%

T2 Rural Renaissance.

Variables	Livestock	Crops
Labour Use	+20%	+20%
Capital Use	+20%	+20%
Fertilizer Use		-20%
Pesticides Use		-20%
Domestic Demand	+50%	
Demand Fertilizer Imports N		-100%
Demand Fertilizer Domestic N		+100%
Import Tariff Outside EU	+100%	
Export Outside EU	-20%	
Import Intra EU	-50%	
Export Intra EU	-50%	

T3. Feed no Food

Variables	Ruminants: Other Cattle	Ruminants: Beef Cattle	Monogastric	Crops
Labour Efficiency		-60%		-20%
Capital Efficiency		-60%		-20%
Fertilizer efficiency				+15%

pesticide efficiency				+15%
feed efficiency	-50%	-50%		
tax imported feed	+80%	+80%	+80%	
tax domestic feed	+80%	+80%	+80%	
biomass use (crop byproducts)	+40%	+40%		

T4. Efficiency First.

Variables	Ruminants: Other Cattle	Ruminants: Beef Cattle	Monogastric	Crops
Labour Efficiency	+200%	+200%	+100%	+50%
Capital Efficiency	+150%	+200%	+100%	+200%
Fertilizer Efficiency				+75%
Land Use	-80%	-80%		
Feed Efficiency	+90%	+90%	+22%	

T5. Stockless

Variables	Ruminants	Monogastric
Reduction in Production	-90%	-90%
Land Reduction	-90%	