TRADE4SD

Fostering the positive linkages between trade and sustainable development

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Report on impact of trade policies on agri-food value chains

Sergio Rene Araujo Enciso[1], Thomas Chatzopoulos[1], Verena Laquai[2], Mavis Boimah[2], Marlen Haß[2], Holger Matthey[1]*, Martin Banse[2]**, Błażej Jendrzejewski[3], Jan Hagemejer[3], Katarzyna Zawalińska[3], Vitaliy Krupin[3], Mona Abdelhady[2], Tamas Revesz[4]

[1] FAO, [2] THUENEN, [3]CASE, [4]CORVINUS

* Deliverable leader

** Work-package leader

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About the TRADE4SD Project

Trade is a central factor in shaping not only global, but also regional and local development. Trade policy has an especially important part to play in achieving the UN Sustainable Development Goals (SDGs). The premise of the TRADE4SD project is that trade has the power to produce positive outcomes when the policies which define the rules of the game are framed and designed in a way to promote access to markets, fair prices and standards of living for farmers, as well as alleviating rural poverty and ensuring sustainable farming practices. Addressing the relation between trade and SDGs requires an integrated approach to policy-making and inclusive governance.

The main objective of the TRADE4SD project is to contribute to build new opportunities for fostering the positive sustainability impacts of trade supported by improved design and framing of trade policy at national, EU and global level, including WTO modernisation, increased policy coherence at different domains including agricultural, energy, climate, environmental and nutritional policies.

To meet this objective, the project will develop an integrated and systematic approach that combines quantitative models from different perspectives, and several qualitative methods recognising that SDGs and trade are highly context-related. On the one hand, a robust analysis of economic, social and environmental impacts is given by using diverse but integrated modelling techniques and qualitative case studies. On the other hand, a wide consultation process is implemented involving stakeholders both in the EU and in partner countries as well as those with a wide international scope of activity, providing opportunities for improved understanding, human capital building, knowledge transfer and dissemination of results. To this extent, the consortium involves, as co-producers of knowledge, a number of research and stakeholder participants with different backgrounds who will use their networks to facilitate the civil society dialogue and build consensus on the subject of gains from trade in view of sustainability.

Project Consortium

No.	Participant Organisation Name	Country
1	Corvinus University of Budapest (CORVINUS)	HU
2	University of Kent (UNIKENT)	UK
3	Consiglio per la Ricerca in Agricoltura e l’Analisi dell’Economia Agraria (CREA)	IT
4	Johann Heinrich von Thünen-Institut, Bundesforschungsinstitut für ländliche Räume, Wald und Fischerei (THUENEN)	DE
5	The University of Sussex (UOS)	UK
6	University of Ghana (UG)	GH
7	Luonnonvarakeskus (LUKE)	FI
8	Centrum Analiz Spoleczno-Ekonomicznych-Fundacja Naukowa (CASE)	PL
9	Food and Agriculture Organization of the United Nations (FAO)	IT
10	Institut national de recherche pour l’agriculture, l’alimentation et l’environnement (INRAE)	FR
11	Confederazione Generale Dell’Agricoltura Italiana (CONFAGRICOLTURA)	IT
12	Truong Dai Hoc Kinh Te Thanh Pho Ho Chi Minh (UEH)	VN
13	Luminaconsult Sprl (LUMINA)	BE

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Abbreviations and acronyms

AFOL	Agriculture, Forestry and Other Land Use
AVE	Ad-valorem equivalent
Bn	Billion
c.w.e.	Carcass weight equivalent
CAP	Common Agricultural Policy of the European Union
CES	Constant elasticity of substitution
CGE	Computable general-equilibrium
CO2	Carbon dioxide
CO2eq	CO2 equivalent
CS	Consumer prices
DDGs	Dried distiller's grains
est	Estimate
EU	European Union (27)
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GHG	Greenhouse gas
ha	Hectares
HIC	High-income countries (>13,000 USD per capita in 2018)
IDR	Import-dependence ratio
IPCC	Intergovernmental Panel on Climate Change
kcal	Thousand calories
kg	Kilogrammes
kha	Thousand hectares
kt	Thousand metric tonnes
LDCs	Less Developed Countries
LIC	Low-income countries (<1,550 USD per capita in 2018)
LMC	Lower-middle-income countries (<3,895 USD per capita in 2018)
LLCF	Land use, land use change and forestry
MIC	Middle-income countries (LMC and UMC)
Mt	Million metric tonnes
NTMs	Non-tariff measures
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
p.a.	Per annum
PE	Partial-equilibrium
PS	Producer prices
r.w.e.	Retail weight equivalent
RoW	Rest of the World
SDG	Sustainable Development Goal
SMP	Skim milk powder
SSR	Self-sufficiency ratio
t	Metric tonnes
TRQ	Tariff-rate quota
UMC	Upper-middle-income countries (<13,000 USD per capita in 2018)
UN	The United Nations
WMP	Whole milk powder
WP	Work package

1. Introduction

Work Package 3 (WP3) of the TRADE4SD project comprises a *'quantitative model-based analysis of the sustainability impacts of agricultural trade'*. WP3 specifies four interrelated tasks:

- A scoping exercise on linking SDG indicators with specific simulation models from the TRADE4SD toolbox (Task 3.1);
- Estimation of social and distributional impact of trade and sustainability policies (Task 3.2);
- Estimation of the environmental impact of trade and climate policies (Task 3.3); and
- Estimation of the impact of trade and sustainability policies on agri-food value chains (Task 3.4).

This deliverable addresses Task 3.4. It aims at investigating the potential impact of agricultural and food trade liberalisation at the global level on two Sustainable Development Goals (SDGs): *Zero Hunger* (Goal 2), with focus on the four dimensions of food security (availability, access, utilization, stability), and *Climate Action* (Goal 13), with focus on agricultural emissions. For this purpose, a set of simulation exercises were carefully designed and implemented with two partial-equilibrium (PE) models of agricultural commodity markets from the TRADE4SD toolbox: Aglink-Cosimo and AGMEMOD. By linking these models with indicators that measure directly or indirectly progress towards SDGs 2 and 13, this deliverable examines the potential manifestation of agricultural and food supply, demand, and prices attributable to trade liberalisation at the global level (Aglink-Cosimo) as well as focusing on selected EU sustainability aspects (AGMEMOD).

The first set of scenarios have a global perspective and draw on the Aglink-Cosimo model. The core scenario examines the *direct* impact of trade liberalisation on selected SDGs. It assumes a partial and gradual reduction by 2032 in the ad-valorem equivalents (AVEs) of all import tariffs and import-distorting non-tariff measures (NTMs) covering food and feed. Two further scenarios examine the *moderating* impact of trade liberalization on SDGs assuming regional convergence in crop-yield productivity or a global dietary shift.

The AGMEMOD model focuses on the development of EU agricultural markets. Hence, the AGMEMOD scenarios focus on the environmental aspect of sustainability, which is at the forefront of current EU policies. An increase in non-productive areas in agricultural landscapes compared to the current EU policy, i.e., fallow land[1], is assumed with and without trade liberalization. The *moderating* impact of trade liberalization on domestic EU production is examined if fallow land rose to maintain the EU biodiversity targets.

[1] EU definition of fallow land: Fallow land is all arable land either included in the crop rotation system or maintained in good agricultural and environmental condition (GAEC), whether worked or not, but which will not be harvested for the duration of a crop year. The essential characteristic of fallow land is that it is left to recover, normally for the whole of a crop year. (see: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Fallow_land)

The remainder of this is report is structured as follows. The subsequent part of section 1 integrates theoretical and empirical viewpoints to evaluate the potential impact of agricultural and food trade liberalisation on SDGs 2 and 13. Due to the versatility of the designed scenarios, section 2 (Aglink-Cosimo) and section 3 (AGMEMOD) follow a model-based structure: each section describes the deployed model and the corresponding scenario assumptions and simulation results. Section 2 and 3 conclude with summaries of scenario-specific findings, while section 4 wraps up with joint concluding remarks.

Trade liberalisation and SDGs 2 and 13: what does the literature tell us?

Several theoretical frameworks have been proposed to shed light on the potential impact of trade liberalization on SDG 2. Advocates of Ricardo's comparative advantage theory, including the World Trade Organization, argue that trade liberalization can enhance food security and alleviate hunger by increasing efficiency and productivity. Conversely, proponents of the dependency theory emphasize the risks of increasing dependency on imports, which include increased food insecurity and perpetuating hunger (Jenkins and Scanlan 2001). Finally, proponents of food sovereignty argue that trade liberalization may exacerbate hunger by prioritizing export-oriented production and overly relying on imports. Each perspective highlights valid concerns and considerations underscoring the complexity of the issue and the need for more comprehensive, context-, and policy-specific analyses.

While trade policies are considered strategic in shaping national food systems, the ultimate impact of trade openness on food security is highly debated in the literature. Empirical evidence yields mixed results due to contextual factors and moderating effects. Some studies indicate that trade liberalization could increase food availability by expanding access to global markets, thereby leading to greater food diversity at lower prices. For example, Anderson and Martin (2005) find that trade liberalization could reduce global food prices and improve food access for vulnerable populations. Similarly, Dithmer and Abdulai (2017) conclude that trade openness increases average dietary energy and food quality. Other studies highlight the potential negative impacts of trade liberalization on food security in developing countries. For instance, Deaton and Dreze (2009) suggest that trade liberalization can undermine domestic production in favour of imports, and thus exacerbate food insecurity. Mary (2019) concludes that trade openness increases the prevalence of undernourishment. Research also emphasizes the importance of considering distributional effects: in the absence of targeted policy measures, trade openness may exacerbate inequalities and potentially worsen hunger among the poor (Cornia and Martorano 2012).

An explanation for such diverse impacts can be found in the definition of food security itself. Food security encompasses multiple dimensions that are interrelated and difficult to contextualize, measure, and analyse holistically. Box 1 explains these dimensions from the perspective of trade liberalisation.

The impact of agricultural trade liberalization on SDG 13 is equally complex and context-dependent. Some studies suggest that trade openness may lead to increased emissions due export-driven production expansion and intensification of carbon-intensive farming practices (Burney and Naylor 2012), what would be further amplified with expanded land conversion.

Others highlight the potential for emissions reduction through improvements in agricultural productivity and incentivized adoption of more sustainable practices and technologies (Martin et al. 2010). Ultimately, trade liberalization can both create pressures to increase or decrease emissions, but the net effect of these pressures may vary depending on country-specific policies and global market dynamics.

Box 1: Trade liberalisation and the four dimensions of food security

Increased imports due to trade liberalisation can enhance food **availability** by providing access to diverse foods that may not be locally produced at competitive prices. In regions where biophysical and land constraints or the lack of know-how limit domestic production, food imports can help bridge the domestic supply-demand gap. Furthermore, opening markets to international competition can incentivize domestic producers to become more efficient and competitive in the long term, potentially leading to increased production and lower prices. This increased efficiency can contribute to higher overall food availability. However, reliance on imports can also pose risks. Heavy dependence on a few key suppliers means higher exposure to sudden supply disruptions. Domestic producers who may struggle to compete with cheaper imports are negatively affected too, thus leading to lower production and overall food availability.

Lowering trade barriers can often result in cheaper imported food and thus improve food **access**. Having more options to choose from, consumers can improve their dietary diversity and nutritional intake. However, if domestic producers struggle to compete with cheaper imports, lower incomes may impact their own food access.

Higher food availability can lead to greater dietary diversity and even reshape cultural preferences and food habits. Therefore, trade liberalisation can also improve food **utilization**. Greater dietary diversity, then, can reduce the prevalence of malnutrition by reducing the risk of nutrient deficiencies. However, increased access does not necessarily imply better utilisation without policies that promote healthy diets over unhealthy aspects of diets. For example, while processed and convenience foods can offer appeal to consumers with busy lifestyles, they may also be high in unhealthy fats and additives.

Finally, trade liberalization can have significant impacts on food **stability**. These impacts can vary due to changes in agricultural production systems, policies, market dynamics, and global economic, environmental and political conditions.

2. The global impact of trade liberalization on SDGs 2 and 13

2.1 Methodology: the Aglink-Cosimo model

Aglink-Cosimo is a global recursive-dynamic PE model of agricultural commodity markets.[2] The model is developed and managed jointly by the OECD and the FAO secretariats. It is a tool mainly used in the generation of agricultural market projections that are updated and published on a yearly basis in the OECD-FAO Agricultural Outlook (henceforth *'OECD-FAO Outlook'*). Based on commodity market expertise and the submission of structured questionnaires by national agencies, the two Organizations jointly validate and parameterize effective and expected agricultural policies as well as relevant market and trade developments. The resulting medium-term consensus ('baseline') serves a threefold purpose. First, it is a consolidated forward-looking analysis. Second, it is used as reference for the assessment of stylised what-if scenarios that allow researchers and policymakers to evaluate the implications of shocks or policy alternatives. And third, it is increasingly used as reference for baseline harmonisation and soft-linking exercises with other large-scale PE, computable general-equilibrium (CGE), land-use, or agro-economic models.

The 2023 model version, which is used in this study, covers 80+ commodities (incl. cereals, oilseeds, pulses, meat, dairy, sugar crops, cotton and biofuels), 38 world-reference prices, and simulates annual supply and demand from 2023 to 2032.[3] It consists of over 60,000 structural equations organized into 1,500 templates, linear or linearized, behavioural (calibratable) and identities, that solve as a problem of nonlinear programming with discontinuous derivatives. Supply and demand equations are controlled by elasticities conforming to micro-economic theory as well as by technical parameters representing technology, market trends and policies. Markets for agricultural commodities are assumed to be competitive and typically clear on prices both at the domestic level, where total supply equals total demand (Eq. 1), and at the world level, where net trade[4] is zero (Eq. 2):

$$PP_{r,c,t} \;\; s.t. \;\; QP_{r,c,t} + IM_{r,c,t} + ST_{r,c,t-1} = QC_{r,c,t} + EX_{r,c,t} + ST_{r,c,t} \quad (1)$$
$$XP_{WLD,c,t} \;\; s.t. \;\; \Sigma(EX)_{WLD,c,t} = \Sigma(IM)_{WLD,c,t} \quad (2)$$

where PP is the market (producer) price, QP is production, QC is consumption (sum of all uses), IM is total imports, EX is total exports, ST is ending stocks (public and private), and XP is the world-reference price. Subscripts *r*, *c* and *t* are the region (country), commodity, and year identifiers, respectively.[5]

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[2] Market specificities and market equilibria at year *t* affect economic outcomes and market equilibria at *t+1*, *t+2*, or even *t+3* (recursion). This process continues iteratively over time (dynamics). The PE approach means that only agricultural markets attain equilibrium; non-agricultural variables are exogenous.

[3] Marketing years (e.g., '2023' refers to 2023/2024).

[4] Adjusted for imbalanced trade statistics.

[5] Markets are modelled for 35 single countries and 14 regional aggregates (incl. the European Union). Unless mentioned otherwise, the terms 'regions' and 'countries' are used interchangeably in this report.

Commodities are modelled with detailed supply and demand equations based on equation templates. Crop production is the product of yield and area harvested. Yield projections are driven by economic drivers (e.g., farm-gate prices deflated by production costs), policy instruments and technological progress. Area harvested is projected using relative prices of competing crops, policy incentives, physical land-allocation constraints, as well as multi-cropping potential. Total consumption is the sum of the different uses (e.g., food, feed, crush, biofuels and other industrial uses) each one of which is determined endogenously depending on own- and cross-price elasticities, income, population, and trends in dietary preferences and technology. Private stocks depend on overall transaction volumes and –naively– on speculative motives about market surpluses and prices. The modelling of trade is discussed in detail below. Population, energy (crude oil) prices and macroeconomic factors, such as the gross domestic product, inflation, and exchange rates, are exogenous and remain unchanged in the scenarios implemented herein. Recent model extensions include a land-use system that accounts for competition of arable land with other uses of land (e.g., forests), endogenous fertilizer use, and post-model calculations on calorie availability GHG emissions. More information on the core model as well as post-model calculations can be found in OECD/FAO (2022a) and https://www.agri-outlook.org/. A stylized consideration of NTMs, designed and implemented particularly for the scenario needs of this report, is detailed in the next subsection.

Modelling of trade

Agricultural commodities modelled in Aglink-Cosimo are treated as homogeneous goods and thus perfect substitutes. Product quality and variety are not explicitly modelled, and therefore no Armington assumption is made. Modelled imports and exports in each country make up total quantities traded with the Rest of the World (RoW). Therefore, trade is specified by default without bilateral flows.[6]

Total imports (IM; in volume) are determined endogenously as a function of prices and policy instruments:

$$\log(IM_{r,c,t}) = \alpha_{r,c} + \beta_{r,c} \times \log(PP \div IMP)_{r,c,t} + \log R_{r,c,t} \qquad (3)$$

with

$$IMP_{r,c,t} = XP_{WLD,c,t} \times XR_{r,c,t} \times (1 + TAVI_{r,c,t}) \qquad (4)$$

where PP is the domestic producer price (domestic currency/t), IMP is the import price (USD/t), XP is the world-reference price (USD/t), XR the exchange rate (domestic currency/USD), and TAVI denotes import tariffs (AVE, %).[7] The intercept and error term serve calibration purposes. Subscripts *r*, *c* and *t* are the region (country), commodity, and year identifiers, respectively.

6 Bilateral trade flows can be modelled explicitly but selectively and through further extensions.
7 To facilitate the interpretation of scenario results herein, the import price in Eqs. (3-4) is presented in a slightly different way than in OECD/FAO (2022a).

Import tariffs are weighted averages based on the World Bank's WITS database.[8] The data used in this study draw on OECD/FAO (2023) and are projections or extrapolations of the values available in December 2022. Import tariffs are modelled exogenously or endogenously. In the latter case, they depend on tariff-rate quotas (TRQs), imports, and import prices, through a logistical function that approximates real-world fluctuation patterns (see Pieralli et al. 2022).

The exogenous parameter β in Eq. (3) shows the responsiveness of import quantity demanded to a change in market prices and tariffs.[9] It is, therefore, an elasticity of import demand. This country- and commodity-specific parameter takes on positive values. Import elasticity values are based on model-based exercises, such as shocking world prices and assessing the change in import demand. A higher (lower) import elasticity means that the degree to which domestic and world prices co-vary with one another is assumed to be higher (lower), and hence reflects stronger (weaker) market integration and price transmission. This link is explained in detail in Adenauer et al (2023). Lower import elasticities may reflect, therefore, high transport costs, infrastructure constraints, lack of access to finance, or low productive-capacity investments.

Exports are specified separately from imports but in a similar way. Prices and export-oriented policies, such as subsidies or export restrictions, determine the endogenous response of export volumes given equation-specific export elasticities and calibration parameters.

Model enhancement: Accounting for NTMs

PE models typically do not include NTMs. However, the agricultural sector is subject to a multitude of NTMs that affect trade volumes and import prices (Box 2). Therefore, a trade-liberalization modelling exercise that does not explicitly address NTMs would generally bias downward any gains from trade. For this reason, synthesized recent literature results were used as input to the Aglink-Cosimo model, and a calibration exercise was designed and implemented to construct model-specific baseline AVE estimates of import-distorting NTMs (Appendix A). That calibration exercise led to an adjustment in the original specification of the import price (Eq. 4), where an exogenous NTM term was added next to the TAVI term. The AVE of baseline NTMs, therefore, is reduced simultaneously with tariffs in the core scenario, which is described next.

8 Most Favoured Nation (MFN), Bound (BND), and Effectively Applied (AHS).

9 In the default model structure, this parameter may be exogenous or endogenous. In the latter case, it is specified as a minimax function with arguments pertaining to relative prices. The model version used herein relies on fixed import elasticities to avoid confounding effects and potentially spurious results.

Box 2: NTMs in agriculture

Examples of NTMs comprise trade restrictions, prohibitions, regulations, conformity assessment, and other quantitative and border control measures that vary in scope and design. Agricultural and food products are more intensively regulated than manufactured products and natural resources (i.e., many measures are applied to agri-food imports; Disdier and Fugazza 2020). In fact, agri-food products face on average eight different NTMs, while products from other sectors less than two. More than 80% of agri-food products are subject to at least a sanitary and phytosanitary (SPS) provision, and more than 50% to at least a technical barrier to trade (TBT) (Gourdon et al. 2020). Animal products are the most highly NTM-regulated products both in frequency and intensity (WTO, ITC, UNCTAD 2021, Gourdon et al. 2020, Disdier and Fugazza 2020).

NTMs limit the functioning of free agricultural markets by inflating trade costs. This perspective facilitates the interpretation of the NTM effect as AVE, and therefore makes the NTM effect comparable with that of a tariff. The impact of NTMs on agricultural trade is always price-raising, in most cases trade-hampering, and in some cases marginally trade-enhancing. Higher trade costs and lower trade are typically the result of customs formalities, such as pre-shipment inspections and port-specific entry requirements, import restrictions or prohibitions (e.g., non-automatic licensing), and conformity-assessment requirements. Higher trade along with higher trade costs may be the result of SPS regulations that aim at ensuring the health of consumers, animals, plants, and environmental protection, or TBT regulations on food packaging and labelling. In this case, NTMs ensure the acceptance of imported goods by consumers and therefore facilitate trade. Overall, the price-raising effect of trade-hampering NTMs is considerably higher than that of trade-enhancing NTMs (Gourdon et al 2020).

Empirical studies employing gravity models and CGE simulations highlight various difficulties in estimating the AVE of NTMs, such as the lack of comprehensive databases and harmonized methodologies (Sanjuán et al. 2019). To facilitate the implementation of trade-liberalization scenarios, this study relies on a model-based calibration exercise using literature-based ‘ballpark’ estimates of trade-hampering NTMs. The procedure is detailed in Appendix A.

2.2 Scenarios and assumptions

This section sets out the assumptions behind the what-if scenarios. The latest *OECD-FAO Outlook* baseline projections serve as reference (OECD/FAO 2023) along with a modified version of the Aglink-Cosimo model (inc. NTMs) that was calibrated to those projections.

Table 1: Scenarios implemented with Aglink-Cosimo

Block	Main assumption	Notation
Trade	Lower AVEs of import tariffs and distorting NTMs, higher TRQs	A
Productivity	Partial closing of regional crop-yield gaps	B
Diet	Dietary shift	C

Note: Combined scenarios follow joint assumptions (e.g., scenario AB considers blocks A and B simultaneously).

Of the 765 country-commodity combinations examined, 60% are assumed to have at least one tariff or NTM. In that subset, 45% display only tariffs, 25% only NTMs, and 30% both tariffs and NTMs. In the full sample, the mean joint AVE of tariffs and NTMs is 16%. Considering only cases where import measures exist in the baseline, the mean joint AVE of tariffs and NTMs is 26%.

On average, the baseline AVE of tariffs (NTMs) increases as we move from lower- to higher-income countries: 10% (5%) for low-income countries (LICs), 14% (7%) for middle-income countries (MICs), and 33% (18%) for high-income countries (HICs). This pattern may be the result of various factors, such as higher bargaining power, higher degree of lobbying, and more complex regulatory standards, such as SPS and TBT provisions, with increasing levels of economic development.

Scenario A assumes that the AVEs of all import tariffs and import-distorting NTMs are halved by 2032. Simultaneously, TRQs are doubled to render the import-quota fill significantly less inhibitory. The shocks were simulated to occur progressively in the period 2023-2032 in equally spaced increments. For example, the AVE of import tariffs and NTMs drops by 5% in 2023, 10% in 2024, 15% in 2025, and so on, reaching a 50% drop against the baseline value in 2032. Similarly, TRQs culminate in a 100% increase against the baseline value in 2032. The approach of global and gradual trade liberalisation implies smooth negotiation, implementation, and market-adjustment processes.

Scenario A relaxes the baseline AVE of measures imposed only on imported goods. This assumption is based on empirical findings indicating that import barriers in the agricultural and food sector are significantly more frequent than export barriers. For example, the global value of imported goods subject to NTMs is twice as much the value of exported goods, and imported goods need to comply with more NTMs than exported goods (WTO, ITC, UNCTAD 2021).

Figure 1: Baseline import tariffs and NTMs

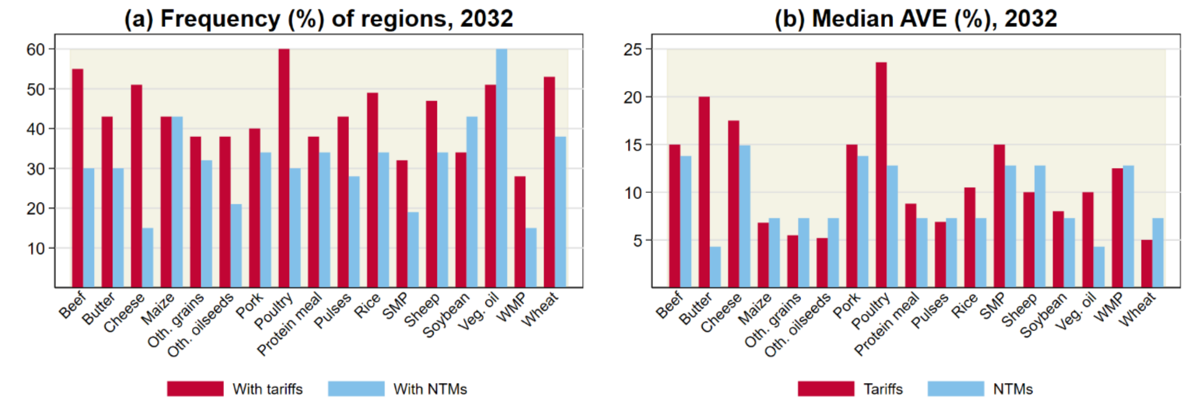


Figure 1: Baseline import tariffs and NTMs

Note: Panel (a) shows the frequency of modelled regions with import tariffs and import-distorting NTMs. Panel (b) shows median AVEs in the baseline. Example: 49% (34%) of modelled rice markets are assumed to have import tariffs (NTMs) in 2032 with a median baseline AVE of 11% (7%).

Source: Authors' calculations based on an extended version of the Aglink-Cosimo model and the OECD-FAO Agricultural Outlook 2023-2032 (OECD/FAO 2023).

Scenario AB is the result of adding the overall assumption of higher agricultural productivity (block B) to trade liberalization (block A). Raising total factor productivity –that is, gaining output from improved agricultural practices– is fundamental to achieving various SGDs. Previous scenario analysis estimated that crop yields, which partially measure total factor productivity, and animal productivity would have to rise simultaneously by 24% and 31%, on average, to achieve SDG 2 and a 6% global reduction in direct agricultural GHG emissions (OECD/FAO 2022b). Block B herein adopts a more conservative approach based on closing regional yield gaps for key commodities (wheat, maize, rice, other coarse grains, soybean, other oilseeds, pulses). First, modelled countries were grouped into clusters that combine the geographic and economic dimensions (6 continents × 4 income groups, per commodity). The highest crop yield in each cluster served as a surrogate measure of potential yield within the cluster. Yields in the other countries of each cluster were then adjusted over time to reduce the gap with the corresponding reference yield by 5% in 2032. A numerical example is shown in Appendix B. This framework results in assumed yield gains that range from 0.05 t/ha (oilseeds) to 0.19 t/ha (maize), on average.

Scenario AC is the result of adding a partial dietary shift (block C) to trade liberalization (block A). Consumption of protein-rich foods generally increases with income level mainly due to greater purchasing power, accessibility, and availability. A typical diet in higher-income countries includes protein-rich foods such as beef, chicken, eggs, dairy products, and seafood. In contrast, lower-income countries rely more heavily on grains and legumes, with limited consumption of animal products due to economic constraints. In this regard, scenario AC, examines whether trade liberalization would boost or attenuate a global transition toward a reference level of animal-sourced calories in total available calories. Based on the Healthy Diet Basket methodology used in the 2023 State of Food Security and Nutrition in the World report (FAO, IFAD, UNICEF, WFP and WHO 2023; Herforth et al. 2022), we set the global reference level at 13%.[10] Scenario AC assumes that the baseline level of animal-sourced calories in each modelled country is adjusted over time to reduce 10% of the gap with the global reference level in 2032. A numerical example is shown in Appendix C. This framework results in increased shares of animal-sourced calories for all LICs and most lower-middle-income countries (LMCs), and in reduced shares for most upper-middle-income countries (UMCs) and all HICs.

Output indicators

The analysis of results in section 2.3 draws on various indicators. These are summarized in Table 2.

Primary indicators are key output variables from the simulation analysis. They include market-balance items and clearing prices.

First-level post-model indicators include calculations that are performed using the simulation output. The self-sufficiency ratio (SSR) shows the extent to which a country's supply of commodities is derived from its domestic production. Using the nomenclature of Eq. (1), it equals QP ÷ (QP + IM − EX). Higher values imply greater self-sufficiency –i.e., that domestic food production capacity exceeds domestic needs–, and vice versa. The import-dependence ratio (IDR) indicates the extent to which a country's supply of commodities comes from imports. It equals IM ÷ (QP + IM − EX). Higher values imply greater dependence on imports, and vice versa.

Table 2: Output indicators

SDG	Indicator used herein	Relevance
2 – Zero Hunger	Market-balance items, calories	Proxies for food availability
	Prices, tariffs, NTMs*	Proxies for food access
	Macronutrients	Proxies for food utilisation
	Self-sufficiency, import dependence	Proxies for food stability
13 – Climate Action	Agricultural emissions*	Official SDG indicator 13.2.2

Note: Asterisk denotes an indicator that was developed or adjusted in the Aglink-Cosimo model for the needs of this study.

Second-level post-model indicators draw on external databases that may be examined along, or even linked, with the model's primary and first-level post-model indicators to assess high-profile policy agendas and strategic goals, such as the SDGs. In most cases, such indicators are linked with model variables and then projected on a 1:1 basis or through regression-fitted models. In other cases, they may be projected independently and subsequently used in calculations.

[10] Reference calorie intakes based on the Healthy Diet Basket methodology are intended to facilitate country comparisons. They are not intended to serve as dietary recommendations.

An example of a second-level post-model indicator is per capita calorie supply (availability), which is based on FAO's food balance sheets. Another example pertains to direct agricultural emissions, which are based on FAOSTAT and follow the IPCC's Tier 1 approach (i.e., a fixed activity-based emission factor is multiplied by the model's endogenous solution). The methodology of obtaining and projecting such indicators is explained in OECD/FAO (2022a, chap. 5).

2.3 Results

The shocks described in the previous section affect model outcomes in the following ways:

1. In scenario A, reducing the AVE of tariffs and NTMs and increasing TRQs causes supply and demand adjustments –i.e., changes in the behavioural parameters of Eq. (1) as well as Eq. (2). These adjustments move domestic and global markets to new equilibria that satisfy the balance conditions. The simultaneous reduction in trade barriers operates as a positive import demand shock at the world level: more of the commodities whose trade is liberalised will be demanded domestically at a new price. Producers will respond to new price incentives by adjusting cropland, yields and livestock production, and consumers will adjust their demanded quantities to changing prices.

2. In scenarios AB and AC, trade liberalization accentuates or attenuates the supply-demand responses driven by changes in crop productivity (block B) or relative calories (block C). A new global situation will emerge where the simulated shocks are transmitted over commodities through own- and cross-price effects, over regions through price transmission, and over time through contemporaneous and lagged effects, altogether impacting market balances and prices that adjust simultaneously in domestic and global markets.

2.3.1 Scenario A: Trade liberalization

Prices

Tariffs and NTMs act as taxes on trade. A reduction in the total AVE of these measures leads to a decrease in the cost of trade, and thus to lower import and export prices. Resulting from the simulated trade liberalization in Scenario A, imports become more competitive, which drives down domestic prices in trade-liberalizing markets mainly in HICs and MICs. The initial shock triggers a deficit in global markets putting upward pressure on global prices.

The world price response to the trade liberalization counteracts the initial reduction in a liberalizing country's import price. Depending on the relative size of the effects, domestic prices and hence signals to producers and consumers will differ. Of the domestic market-clearing prices in the model, 60% rise and 40% drop (Figure 2b).

For countries with responsive sectors and globally integrated trade, the initial domestic price reduction caused by the partial trade barrier removal, outweighs the subsequent increases in the domestic and international prices. Domestic prices remain below the baseline level.

Domestic prices will increase in countries where the magnitude of the initial liberalization trigger is outweighed by the subsequent responses in domestic and international markets.

Figure 2: Prices

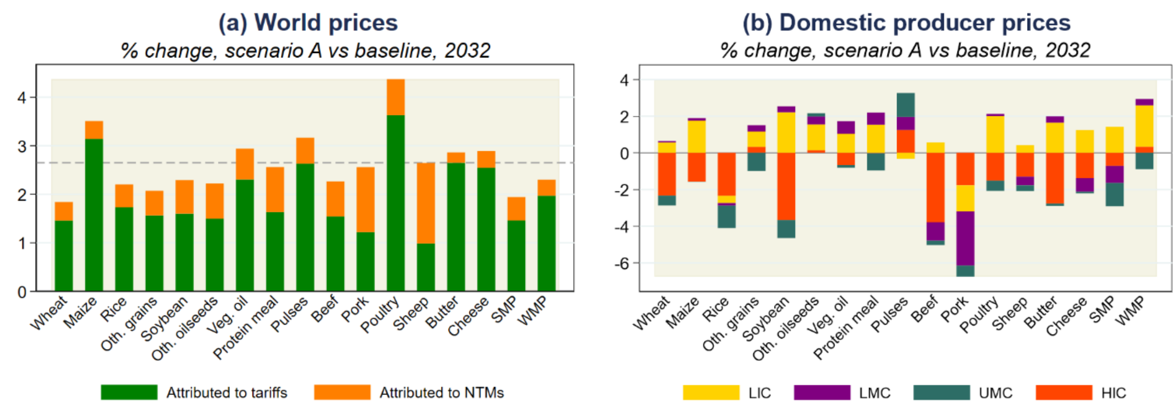


Figure 2: Prices

Note: Panel (a) shows the total change in world prices (in USD) decomposed into tariff-based measures (green) and NTMs (orange). These two components are additive. The grey dashed line shows the mean change across commodities. World prices are listed in Appendix A2. Panel (b) shows the average change in domestic market prices (in domestic currency/t) per income group: LIC – Low-income countries; LMC – Lower-middle-income countries; UMC – Upper-middle-income countries; HIC – High-income countries. Example: Soybean prices decline in HIC (-3.7%) and UMC (-0.9%) and rise in LIC (2.2%) and LMC (0.3%).

Source: Authors' simulations based on an extended version of the Aglink-Cosimo model and the OECD-FAO Agricultural Outlook 2023-2032 (OECD/FAO 2023a).

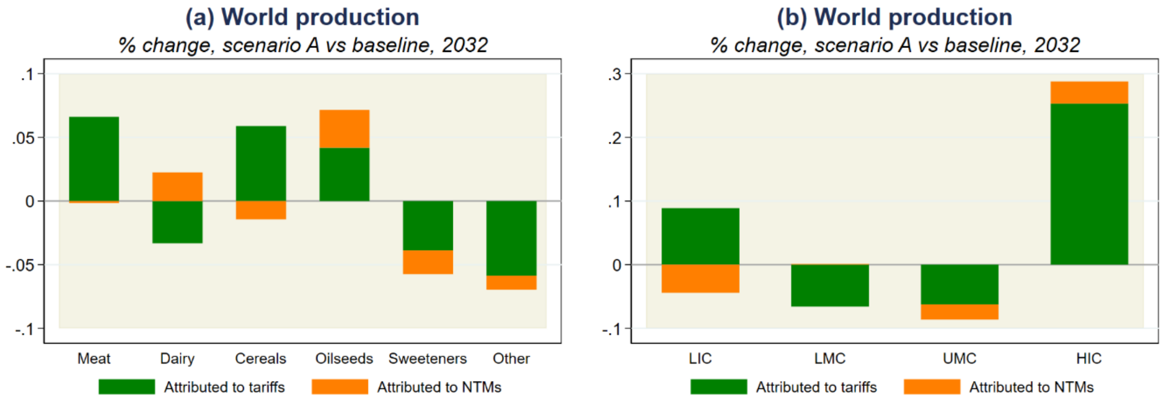
World prices increase by about 3% on average from the baseline level due to increased world demand from the liberalization induced in scenario A that is met by an inelastic global supply requiring higher prices to mobilize additional resources (Figure 2a). World meat prices increase owing to higher meat demand as a result of tariff and NTM reductions in most countries. The rise in the world price of poultry meat is attributed particularly to the demand response to the reduction of high baseline tariffs and NTMs in various HICs. The increase in the world price of maize is driven by the removal of high baseline tariffs, TRQs and NTMs in China, resulting in a strong demand growth for imported feed maize. The increase in the world price of pulses is driven by additional demand from India, the largest producer and importer of this commodity. The increase in the world price of vegetable oil is driven by consumption incentives in various MICs that have high baseline tariffs and NTMs. In absolute terms, world prices of dairy products increase the most owing to demand responses to high tariff reductions in HICs.

Overall, price movements reflect a new equilibrium where lower tariffs and NTMs result in a higher degree of market integration where price signals are better transmitted across regions by means of increased trade and decreased trade costs.

Production and emissions

Agricultural production adjusts to the new price dynamics induced by trade liberalization. About two-thirds of domestic sectors are exposed to a domestic-price reduction that results in a decline in production. Liberalizing countries tend to shift away from domestic production to imports. Producers likely experience a negative effect, and they might seek compensation from other provisions such as direct payments. In the remaining sectors, mostly in countries that did not change their trade policies in the scenario, higher domestic prices lead to increased production, mostly in export-oriented sectors. Globally, the total net production impact of trade liberalisation is a small increase, which results from commodities directly affected by liberalization, as the production decline in commodities that are affected only through cross-price effects is weaker.

Figure 3: Production



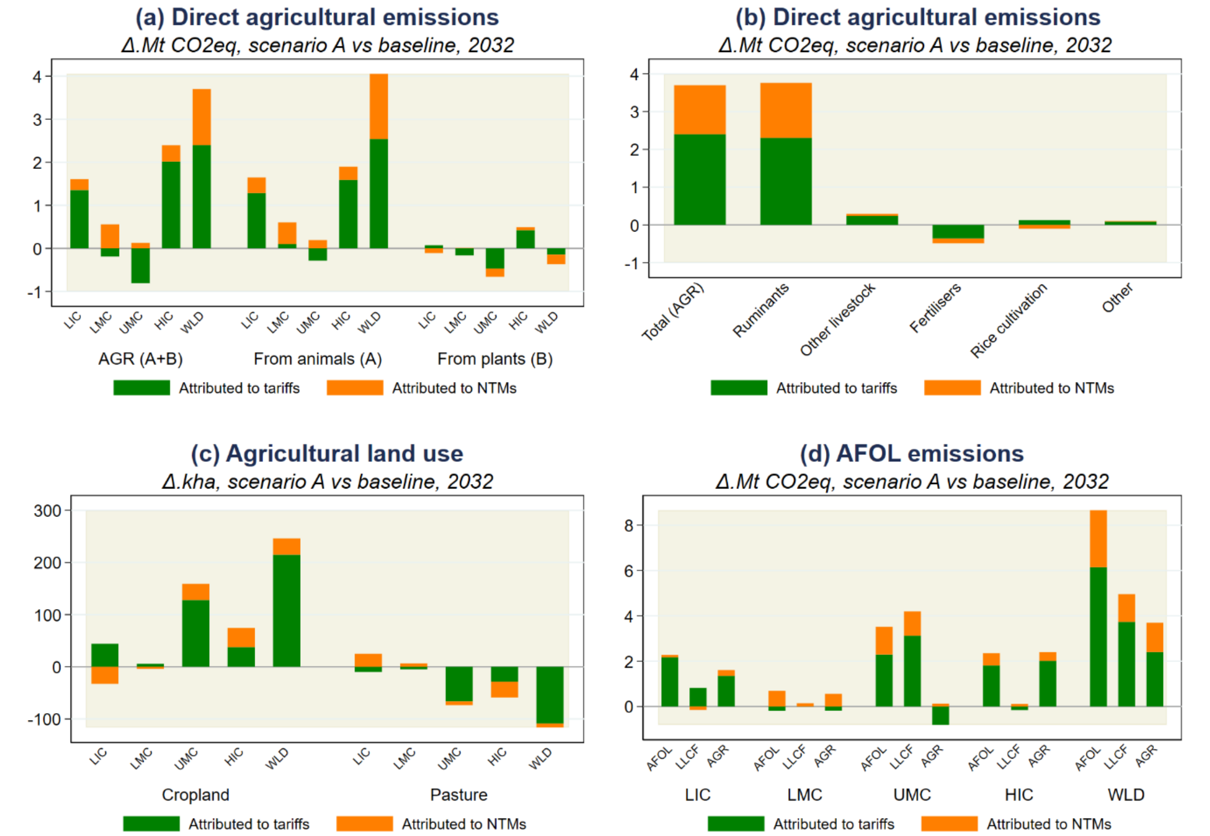
Note: The total effect is decomposed into tariff-based measures (green) and NTMs (orange). These two components are additive. LIC – Low-income countries; LMC – Lower-middle-income countries; UMC – Upper-middle-income countries; HIC – High-income countries.

Source: Authors' simulations, based on an extended version of the Aglink-Cosimo model and the OECD-FAO Agricultural Outlook 2023-2032 (OECD/FAO 2023).

The agricultural production response varies across commodity and income groups (Figure 3). HICs drive the expansion of meat production, driven by lower feed prices and higher import demand in various MICs (pork and poultry) and the EU (beef). US maize production responds strongly to China's reduction of import barriers. Brazil leads the expansion of soybean, mostly to supply LMCs that reduce import barriers. Indonesia and other Asian UMCs increase vegetable oil production. MICs account for the net reduction in global dairy production, as their decline outweighs the production increase in HICs. LICs increase production in all commodity groups in response to the increased domestic prices.

The *OECD-FAO Outlook* projects that global *direct* agricultural emissions will increase by 7.6% (+454 Mt) from the 2020-2022 level and thus reach 6,447 Mt CO2eq in 2032. Scenario A adds 3.7 Mt CO2eq to the baseline projection (Figure 4a, b). These additional emissions are mostly attributed to an increase in livestock-based emissions in HICs, where ruminant production increases more than in other income groups. Other direct agricultural emissions change marginally. For example, rice production merely increases, and so do the corresponding methane emissions. Assuming fixed emission factors at the country level and per activity from 2023 to 2032, emissions from the application of synthetic fertilisers drop by 0.5 Mt CO2eq (Figure 4b) due to reduced production of cereals other than maize at the world level.

Figure 4: Emissions



Note: The total effect is decomposed into tariff-based measures (green) and NTMs (orange). These two components are additive. The change in direct agricultural emissions (AGR) is the sum of animal- and plant-sourced emissions in panel (a) and the sum of activities in panel (b). In panel (d), the change in AFOL emissions is the sum of AGR and land-use change emissions (LLCF, inc. forestry). LIC – Low-income countries; LMC – Lower-middle-income countries; UMC – Upper-middle-income countries; HIC – High-income countries

Source: Authors' simulations, based on an extended version of the Aglink-Cosimo model and the OECD-FAO Agricultural Outlook 2023-2032 (OECD/FAO 2023).

Assuming on-trend technological progress, the *OECD-FAO Outlook* projects that global agricultural production will grow by 12.8% and direct agricultural emissions by 7.6%, respectively, from 2020-2022 to 2032. In scenario A, the production incentives that are provided by the trade liberalization slightly increase cropland while reducing pasture. Land use changes yield an increase of 8.7 Mt CO2eq (Figure 4d)

Consumption

The consumer price changes induced by the trade liberalization scenario would induce changes in food use and resulting calorie availability in each income group. The response in calorie availability tends to be negative for LICs, because the impact of higher world prices on domestic consumer prices offsets any potential decline from reduced trade barriers. Conversely, consumers in HICs and to a lesser extent UMCs would benefit from a domestic price effect of liberalizing their own trade measures.

Mapping country-level calorie changes from scenario A to baseline populations revealed that calories drop in 58% and rise in 42% of the global population projected (2032). This could have potential nutrition and food-security implications in LICs where a decline in caloric availability may be caused by a reduction in imports owing to world price increases. Consumers in all other income groups would increase their consumption, mostly meat, dairy and vegetable oils due to lower domestic prices.

Potential trends in changes in macronutrients indicate that UMCs may increase mostly fat and protein consumption. LMCs would increase mainly fat demand, as vegetable oil food availability increases; at the same time, protein and carbohydrates availability slightly declines, because food demand for cereals declines. LICs would reduce consumption of all macronutrients due to higher domestic prices of all food groups.

The results of scenario A provide indicative trends on how consumption of agricultural commodities would respond to a global trade liberalization. The potential magnitude of total consumption change is likely underestimated in the scenario since the potential income impacts of the price and production shifts are not included. Changes in caloric and macronutrients availability are therefore marginal. However, following the price movements, indicates that on average HIC and middle-income country consumers would benefit from lower domestic prices, whereas food bills in LICs would increase to maintaining a similar level of food consumption.

Trade

The share of production traded for the commodities shown in Figure 1 rose from 17.2% (2010-2012) to 20.6% (2020-2022). Due to a slower import demand growth in China and other MICs, the *OECD-FAO Outlook* projects a stable share of production traded over the next decade at about 20%.

Because of the trade liberalization's effects on domestic markets, total volume of trade (measured by the imports) is 4.4% higher relative to the baseline. Partially offset by a marginal production expansion at the world level, the share of production traded in 2032 rises to 21.1%. Trade volumes increase the most for meat, a market with relatively high tariffs and NTMs to protect domestic producers. Roughly 60% of the increase in trade can be attributed to the decrease in tariffs, whereas the remaining 40% is due to the NTM reduction. The remaining commodity groups - cereals, oilseeds, and dairy – increase trade by about 4% (Figure 5a).

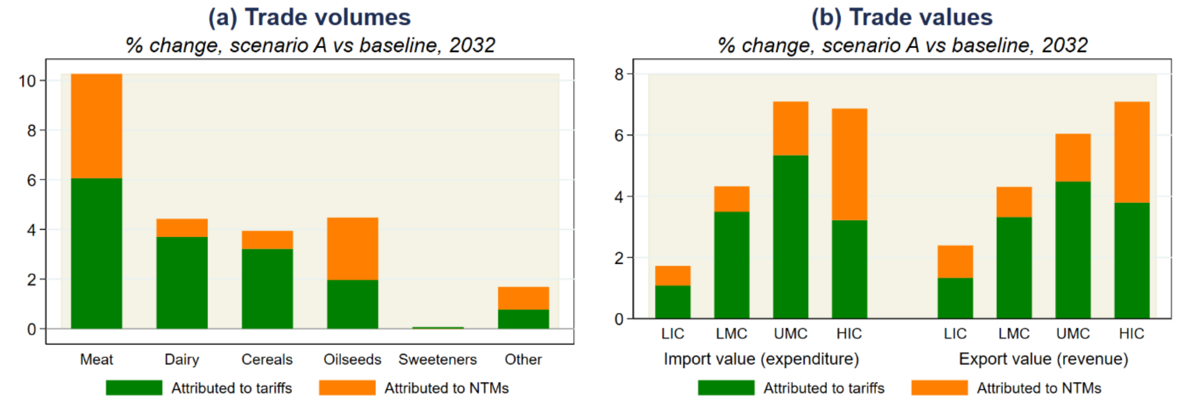
The simulation results indicate that high-income countries increase their net exports of meat by 8%, cereals by 4% and dairy products by 1.5%, while net exports of oilseeds decrease by (1.5%), overall total net exports (by volume) increase by nearly 3%. The HIC group consists of large net exporters, as well as importers, depending on the commodity. Overall, production increases in HIC, which could improve the net trade balance if those gains offset increases on the demand side. Such is the case of USA beef and veal meat where net imports are reduced. However, increasing production of value added or processed commodities which rely on primary commodities, could increase net imports of the primary commodity if domestic supply is not meeting domestic demand. For example, production of protein meals and vegetable oils increases in the EU, but the additional demand for oilseeds cannot be meet by the domestic production, hence the net imports increase.

A part of the HICs' surplus flows to UMCs whose total net exports decrease by around 3%; however, the magnitude varies by commodity. In the baseline, UMCs have small net exports of meat, which are fully eliminated in the scenario, by contrast, cereal net exports are only reduced by 20%. Small increases in the net exports of oilseeds and dairy products are expected, with oilseeds potentially flowing to HICs.

The total net imports in LMCs would marginally increase, based on the meat net imports increasing by about 7%, which is partially offset by a slight decrease in the net imports of cereals, oilseeds and dairy.

In LICs, the total net imports would decrease marginally, mainly because of cereals. Net imports of meat would decrease by 3% due to the increase of world prices of meat.

Figure 5: Trade



Note: The total effect is decomposed into tariff-based measures (green) and NTMs (orange). These two components are additive. Trade values are calculated per commodity (world market price in USD × traded volume), aggregated at the country level, and then averaged per income group. LIC – Low-income countries; LMC – Lower-middle-income countries; UMC – Upper-middle-income countries; HIC – High-income countries.

Source: Authors' simulations, based on an extended version of the Aglink-Cosimo model and the OECD-FAO Agricultural Outlook 2023-2032 (OECD/FAO 2023).

The movements in trade value suggest that HICs increase their net export value by nearly 9% owing mainly to increasing net exports of meat combined with higher world meat prices (Figure 5b). The net export value of UMCs decreases by 2% owing to the additional inflow of meat from HICs at higher prices. The net import value of LMCs increases by around 4%, mostly owing to additional meat net imports from HICs at higher prices. In spite of importing less meat, LICs total net import value increases by about 1.5%, with the increase primarily driven by higher cereals prices, particularly rice and wheat, for which this group of countries relies significantly on global markets.

The induced changes in trade by the new policy setting, suggest that HICs and UMCs will remain net trade value surplus regions, whereas LMCs and LICs would remain as net trade value deficit regions. In this regard, trade liberalization by itself is unlikely to revert the trade position of a country, unless the country is close to a neutral net trade position. Moreover, among the four income groups, only the net trade value surplus of HICs increases, whereas the net trade value surplus for UMCs decreases and the net trade value deficits for LMC and LIC increase. While there is not a significant change in absolute terms, it indicates that for this group of countries the current level of market integration is not primarily determined by trade policy, but rather by other structural characteristics of domestic markets and the economy.

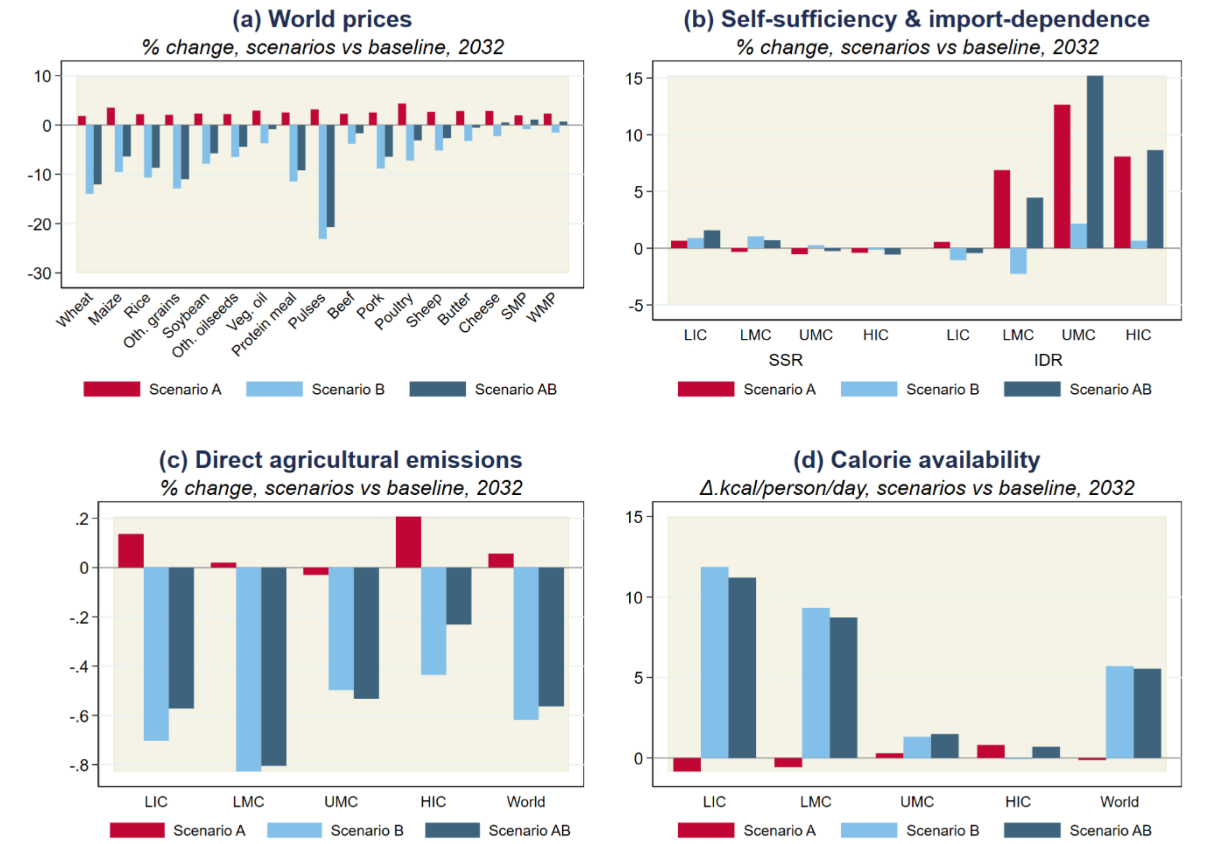
2.3.2 Scenario AB: Higher crop yields and trade liberalization

In scenario block B crop-yield gaps are partially closed for most countries. The higher crop yields shift the baseline market equilibrium by exerting downward pressure on commodity prices. World and domestic prices fall by about the same amount with trade liberalization (AB) or without (A) (Figure 6a). At the world level, the price-raising effect of trade liberalization pales in comparison with the price-lowering effect triggered by higher yields. At the domestic level, lower trade barriers accentuate the drop in domestic prices resulting from higher yields in higher-income countries. In lower-income countries, higher yields entirely reverse the domestic-price signal.

The effect of higher yields on global agricultural production is positive, which combined with trade liberalization leads to an increase of about 0.2% (AB). Increasing crops yields have positive second round effects on meat production, by reducing feed costs.

Global direct agricultural emissions decrease by 36.3 Mt CO2eq (-0.56%). This is the result of a reduction in all components of AFOL emissions in scenario block B. First, emissions from the application of synthetic fertilisers decrease because scenario block B is essentially a productivity shock where application rates increase (endogenously) at a much slower pace than yields. Furthermore, following the price signals produced by yield changes, harvested areas for the various crops change, which leads to a reduction in the total nitrogen fertilizers use. Second, animal-based emissions are lower than the baseline level due to reduced emissions in LICs and MICs.

Figure 6: Impact of higher crop yields with and without trade liberalization



Note: LIC – Low-income countries; LMC – Lower-middle-income countries; UMC – Upper-middle-income countries; HIC – High-income countries. SSR – Self-sufficiency ratio; IDR – Import-dependence-ratio.

Source: Authors' simulations, based on an extended version of the Aglink-Cosimo model and the OECD-FAO Agricultural Outlook 2023-2032 (OECD/FAO 2023).

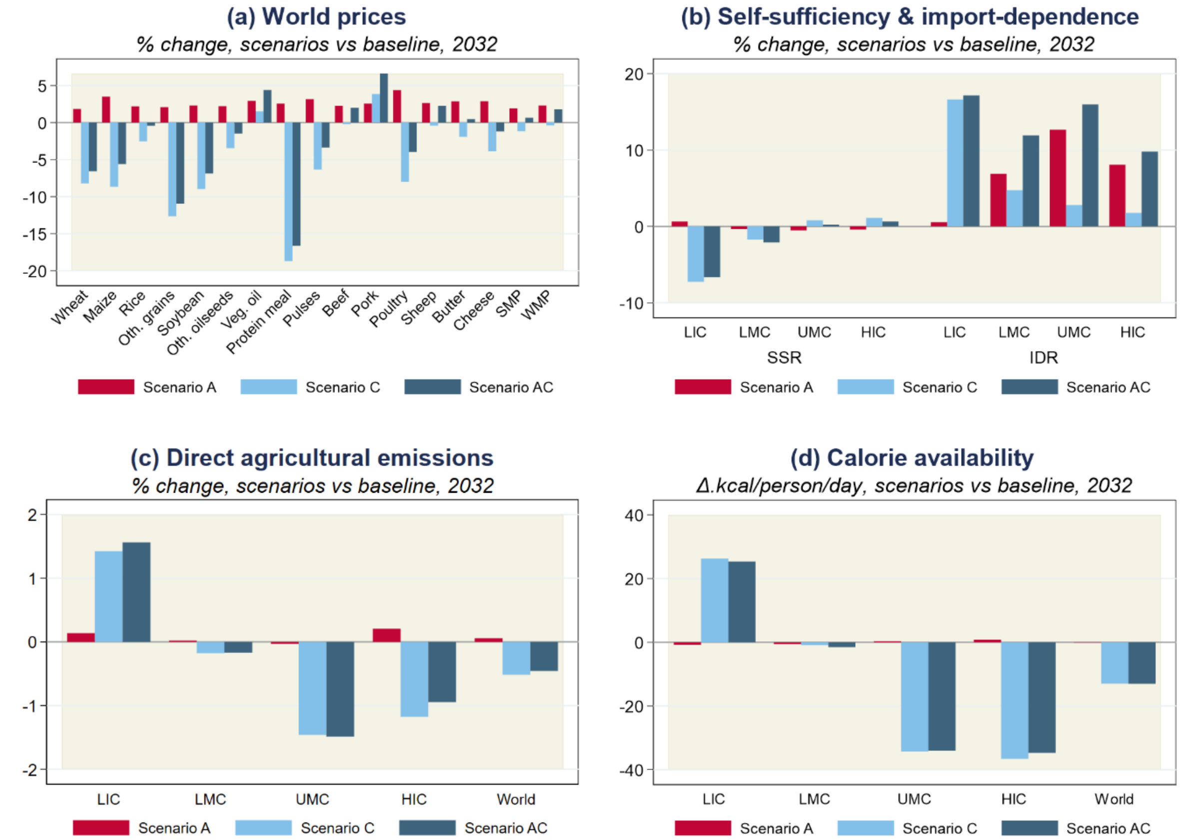
In scenario AB, crop-yield improvements mostly in lower-income countries increase calorie availability (Figure 6d). This happens because yield gaps are typically larger there than in developed countries. Therefore, higher yields render a greater quantity of domestically produced food available at lower prices. Conversely, higher-income countries have greater dietary diversity less based on staples, and lower yield gaps to close, on average, what implies a lower potential for calories to increase due to yield improvement.

While improved yields increase domestic output for LICs and LMCs, both groups remain as net importers. Their total net imports are reduced by 1.5% and 5% respectively. The reduction in the net imports combined with lower world prices decrease the net trade value deficits in LICs by 6% and in LMCs by 9%. Productivity improvement in net importing regions reduce shipments by net exporters, namely UMC and HIC, where net trade value surpluses are reduced by 0.5% and 17% respectively. The significant decline in HICs is mainly driven by cereals and pulses. Net trade movements not only have an effect on self-sufficiency ratios in LICs and UMCs, they also increase food availability and stability.

2.3.3 Scenario AC: A dietary shift and trade liberalization

Scenario block C essentially looks into the impact of dietary change on global agricultural markets. The scenario simulates increasing the demand for animal-based products in lower-income countries and reducing the demand in higher-income countries beyond the preference trends that are embedded in the baseline. The aggregated effect of increasing demand in countries below the target value of 13% (animal-sourced calories in total calories) combined with the diet composition produces different convergence aggregated patterns by commodity, which results in different price movements. World reference prices for beef and veal, pork, sheep, butter and milk powders would increase as the dietary shifts increase global demand. Poultry and cheese world prices would decline following the reducing in demand in UMCs and HICs (Figure 7a). Global cereal prices decrease due to the trade liberalization effect.

Figure 7: Impact of a dietary shift with and without trade liberalization



Note: LIC – Low-income countries; LMC – Lower-middle-income countries; UMC – Upper-middle-income countries; HIC – High-income countries. SSR – Self-sufficiency ratio; IDR – Import-dependence-ratio.

Source: Authors' simulations, based on an extended version of the Aglink-Cosimo model and the OECD-FAO Agricultural Outlook 2023-2032 (OECD/FAO 2023).

Scenario AC has a marginal effect on total global agricultural production, however meat and dairy production slightly decline in HICs and UMCs reflecting the shift in demand, which is reducing production incentives. Conversely, meat and dairy production increases in LMCs (4%) and LICs (6%). This outcome in LICs combined with the observed increase in domestic prices can be interpreted as an improvement for dairy and meat producers. However, increasing meat and dairy production requires additional feed supply, which is mostly imported as the domestic supply remains mostly unchanged.

Global direct agricultural emissions (Figure 7d) decline by 66 Mt CO2eq in scenario AC. This is the result of a reduction in all components of AFOL emissions and particularly animal-sourced, mainly in HICs and UMCs. The increase of emissions in LICs is driven by the expansion of the livestock inventory, which adjusts to meet the increased domestic demand.

The dietary shift yields improvements in LICs by increasing calorie availability (Figure 7d). LMCs do not appear to be affected, thus reflecting that on average these countries already include sufficient calories from animal origin on their diets. However, these results are largely influenced by India and Pakistan where dairy consumption is relatively high. Concerning UMCs and HICs, the scenario shows a decline in the calorie availability, which is mainly attributed to the decrease in cereals, meat and dairy products, including butter which influences the calories from fat.

While this dietary shift stimulates domestic output in LICs, the group still increases total net imports by 3%. LMCs would increase their net imports by 4%. Net exporting regions, namely UMC and HIC increase their net exports by 3% and 4% respectively. The increase in the net imports combined with the higher world prices increase of some dairy and meat products would increase net import values of LICs and LMCs by 9% and 11% respectively. This result is anchored to the historical data on which poultry is primarily produced domestically and other meats such as pork and beef are imported. Increasing demand in net importing regions increases shipments by net exporters, namely UMC and HIC, where net export values increase by 4% and 19% respectively.

2.4 Conclusions

Trade liberalization is represented by a gradual 50% reduction by 2032 of all import tariffs and import-distorting NTMs, which triggers a reduction of domestic prices relative to world prices. This initial shock moves domestic prices to a new equilibrium, which is determined by the relative magnitude of the initial shock, the degree of international market integration of a domestic sector, and the relative responsiveness of supply and demand in each domestic market.

In countries with relatively higher levels of protection, significant global market integration and a price-responsive demand and supply, the domestic price of a commodity is likely to move below the baseline level as a result of the trade liberalization in scenario A.
Consumers in these countries, mostly HICs and UMCs, would expand domestic consumption. Generally, domestic production would decrease due to the reduced protection. Meat and oilseeds constitute a special case, because the production decision is driven by margins, so even at lower product prices, margins may increase, if input prices fall even more, incentivising a production expansion.

The combined signals of these domestic markets to the global market lead to an increase in the international reference price. This higher price is transmitted back into the domestic markets, but in the aforementioned cases it is not sufficient to offset the initial trigger shock, leaving a deficit to be covered by an increase in net imports.
In countries with very low tariffs and NTMs, mostly LMCs and LICs, the international price increase that was triggered by these deficit countries, will outweigh the liberalization effect, if the sector is sufficiently integrated into the global market. The domestic price in scenario A is above the baseline level resulting in a reduction of the domestic consumption. Domestic production will be stimulated and the relative magnitudes of the two responses will determine the size of the net import decrease.

A global improvement in crop yields represents an increase in land productivity that would boost global supply and subsequently lower domestic and world prices of agricultural commodities. The scenario assumes that yield gains can be attained globally and without additional use of resources. Lower consumer prices boost food consumption, the higher domestic production tends to improve self-sufficiency, particularly for LICs. Global direct agricultural emissions decrease as a result of the reduction in cultivated areas for various crops, and lower animal-based emissions, mostly in LICs and MICs.

The scenario increasing the demand for animal-based products in lower-income countries and reducing the demand in higher-income countries beyond the preference trends embedded in the baseline has a marginal effect on total global agricultural production, however meat and dairy production slightly decline in HICs and UMCs reflecting the shift in demand, which is reducing production incentives. The dietary shift yields improvements in LICs by increasing calorie availability.

3. The impact of trade liberalization on SDGs 2 and 13 in EU countries

3.1 Methodology: the AGMEMOD model

The focus of the AGMEMOD model is on the individual EU Member States and their main agricultural –and several processing– sectors. Consequently, domestic EU policies and foreign policies affecting the EU can be simulated with the model.

AGMEMOD is a dynamic, multi-country, multi-market, econometrically estimated, PE model (Chantreuil, Hanrahan and van Leeuwen, 2012). It covers the main agricultural and its processing sectors for all EU Member States and some EU neighbours. The model exists since 2000 and is regularly updated and extended jointly by Wageningen Economic Research, the Thünen Institute, and country experts.

Its basic theory and realization are described in Chantreuil, Hanrahan and van Leeuwen, 2012. Based on a set of commodity-specific model templates, country-specific models have been developed to reflect the detail of agriculture at member state level, while allowing for their combination in an EU model. This approach allows the inherent heterogeneity of agricultural systems across the EU to be captured in the model parameterisation, while ensuring analytical consistency across country models by adhering to the agreed commodity model templates.

In the core model, most behavioural equations are specified as linear equations, whose parameters have been estimated from the model database. Moreover, identity equations ensure that logical relations between variables hold. Thus, for each time period equilibrium is ensured at the market clearing commodity price.

AGMEMOD has been constantly extended in country and product coverage. Further, coverage in terms of content has been extended (e.g., Sturm et al. 2023, Haß 2021, AGMEMOD Consortium 2023) and a focus was laid on communication, harmonization and linkage with other models (e.g., Gonzalesz-Martinez et al. 2021, Laquai 2023). Currently, most recent enhancements – outside of the TRADE4SD project – are being made in the improved depicting of the CAP policies 2023-2027 and the inclusion of the palm oil sector. The enhancements as identified for the TREADE4SD project in Deliverable 3.1 are the development of a bilateral trade module and the inclusion of GHG emissions, which are described in more detail here.

Model enhancement: Accounting for bilateral trade

In the core version, trade flows are not modelled bilaterally. Instead, countries trade with the RoW. This implies that trade policies, such as tariffs and tariff-rate-quotas, can only be modelled in a highly aggregated way. For this project, the core model was extended with a bilateral-trade module based on the Spatial Price Equilibrium (SPE) approach introduced by Enke (1951) and further developed by Samuelson (1952) and Takayama and Judge (1971). SPE models are typically solved as a nonlinear optimization problem that maximizes total quasi-welfare net transportation costs subject to market equilibrium constraints. For reasons of transparency and flexibility, however, the AGMEMOD trade module is formulated as a mixed complementarity problem (MCP) rather than an optimization problem (see also Nolte 2008; Haß, 2022). The following block of equations describes the applied version of the SPE module: The detailed equations can be found in Appendix B1. Supply, demand and ending stocks are modelled by Cobb-Douglas functions depending on the prices of the respective product as well as on the prices of other products and subsidies (eq. B1-B3). Market clearing is ensured by equations B4 and B5, which require that domestic supply covers total exports (including domestic sales) and that total imports (including domestic sales) cover domestic demand plus changes in stocks.

Bilateral trade between countries is modelled based on the spatial arbitrage condition (eq. B6 in Appendix B1). Trade routes between countries are used, if the demand price in the importing country is larger than the producer price in the exporting country. In addition, the demand price needs to cover trading costs, i.e., transportation costs, tariffs and quota rents. Tariff-rate quotas can be modelled explicitly by limiting the traded quantity between two countries (eq. B7), one exporting country and a group of importing countries (eq. B8), a group of exporting countries and one importing country (eq. B9) or among country groups (eq. B10). Moreover, countries are allowed to trade under different tariff regimes, i.e., at most-favoured-nations (MFN) or preferential tariff rates.

The module has a global coverage including about 70 countries/regions and 21 agricultural products. In the baseline, the supply, demand and ending stocks functions of the EU member states are calibrated to the projections of the Agmemod core model, while the behavioural functions of all non-EU countries are calibrated to the outcome of the Aglink-Cosimo model (OECD/FAO 2023b). Supply and demand elasticities are borrowed from the ESIM and Aglink-Cosimo model (Grethe et al. 2012; OECD/FAO 2022), transportation costs are obtained from the SPE model developed by Nolte (2008) and Haß (2022). As the model of Nolte (2008) only includes transportation costs for sugar, the freight rates for other products were corrected for product-specific premiums or discounts. These premiums and discounts were derived from the OECD Maritime Transport Costs database (Korinek 2011). Data on MFN and preferential tariff rates (AVEs) are extracted from the MacMap database (ITC 2023) and aggregated to the required product level (simple averages over HS codes). In the model version applied in this report, only the EU tariff-rate-quotas for sugar as well as all tariff-rate-quotas between the EU and Ukraine are modelled explicitly.

Model enhancement: Accounting for GHG emissions

Methane (CH_4) and Nitrous Oxide (N_2O) are two main gases produced in the agricultural sector, especially from crop and livestock production. Therefore, in this section, we focus on estimating the emission of these gases for all EU countries using the tier 1 and 2 methodologies of the IPCC (Hergoualc'h et al., 2019) in AGMEMOD.

Methane (CH_4) and Nitrous Oxide (N_2O) emissions from enteric fermentation and manure management were estimated for sheep, cattle (beef and dairy), and swine. The estimation dwelt on the IPCC's proposed methodology (Hergoualc'h et al., 2019) which requires the definition of livestock subcategories and annual livestock population (head numbers).

Focusing on enteric fermentation and manure management and dwelling on the tier 1 methodology, GHG emissions per head of animal and total GHG emissions (tonnes of CO_2eq) were estimated for the animal species mentioned earlier. The equations are listed in Appendix B2.

Default emission factors for the animal species considered in the estimations were taken from the UNFCCC database. Annual animal population data was part of the standard AGMEMOD version collected from official EU and national statistics and the latest updates included data up to 2023.The CO_2 equivalent values of 27 (CH_4) and 273 (N_2O) are used in accordance with the IPCC's 2022 100-year Global Warming Potential time horizon (GWP100) to convert all emissions to a common unit, i.e., tonnes of CO_2eq.

Table 3: IPCC Methodology (tier) applied

	Direct		**Indirect**			
Country	EF1		$Frac_{LEACH}$		$Frac_{GASF}$	
	Tier 1	**Tier 2**	**Tier 1**	**Tier 2**	**Tier 1**	**Tier 2**
Austria		x		x		x
Belgium	x			x		x
Bulgaria	x		x		x	
Croatia	x		x		x	
Cyprus	x		x		x	
Czech Republic		x		x	x	
Denmark		x		x		x
Estonia	x			x	x	
Finland		x		x		x
France	x			x		x
Germany		x		x		x
Greece	x			x		x
Hungary	x			x	x	
Ireland		x		x		x
Italy		x		x		x
Latvia	x			x	x	
Lithuania	x		x		x	
Malta	x		x		x	
Netherlands		x		x	x	
Poland	x		x		x	
Portugal		x		x		x
Romania	x		x		x	
Slovakia	x			x	x	
Slovenia	x		x		x	
Spain		x		x		x
Sweden	x			x		x

Source: own compilation

The emissions of N_2O resulting from N inputs occur through a direct path (i.e., directly from the soils fertilized, EF1) and indirectly through two paths: (1) leaching and runoff of N ($Frac_{LEACH}$), and (2) volatilization of Nitrogen oxides ($Frac_{GASF}$). Although the direct and indirect emissions dwell on the same activity data, they are estimated separately. For this report, we dwell on emissions specifically from the use of mineral nitrogen fertilizers, and the tier 1 and

2 methodologies of the IPCC. The tier 2 methodology was used in the estimation for countries with specified emission factors (see Table 3) which were directly sourced from peer-reviewed journal articles and national reports. Mineral nitrogen fertilizer application rate ($kgha^{-1}yr^{-1}$) per crop data of the International Fertilizer Association (IFA) (IFASTAT FUBC 2022) served as the activity data in our analysis. As the fertilizer data was not complete for all the years considered in our estimations, we resorted to interpolation for the missing years.

In cases where country-specific emission factors, for direct emissions were missing, the IPCC's default value of 0.016 for direct emissions (IPCC 2019) were used. Also, neighboring country clusters were used to select the emission fractions where country-specific fractions for leaching and volatilization were unavailable. In instances where the emission fractions are missing for all neighboring countries, the IPCC's default value of 0.3 (leaching) and 0.1 (volatilization) were used. The detailed equations used in estimating the direct and indirect emissions are listed in Appendix B2. In all, 20 products were covered and are wheat, barley, rye, triticale, oats, rice, corn, rapeseed, sunflower, potatoes, sugar beets, soya beans, vegetables, durum wheat, other grains, protein crops, tobacco, cotton, permanent crops, and grassland.

3.2 Scenarios and assumptions

The AGMEOMD baseline is based on the assumptions in the EU Medium-Term Agricultural Outlook (European Commission 2023; henceforth *'EC Outlook'*). The *EC Outlook* is based on the latest *OECD-FAO Outlook* (OECD/FAO 2023) and includes updates for the EU region only. In AGMEMOD, exogenous variables taken from the *EC Outlook* are world market prices, population, GDP, exchange rates, and GDP deflator.

Further the baseline includes a detailed representation of the current policies regarding non-productive area (AGMEMOD Consortium 2023). The combinations of eco-schemes and conditionality requirements leads to an increase in fallow land of 1.6 million hectare in 2032 compared to the observed value in 2022. The changes in fallow land are very heterogenous across countries (compare Appendix B3) with largest percentage increase observed in Ireland, the Netherlands and Estonia. In some countries, namely Cyprus, Sweden, Austria, Italy and Malta, fallow land even decreases given the new policy.

Additionally, the representation of the Common Agricultural Policy (CAP) for the period 2023 – 2027 is depicted by including the newest available data (Isbasoiu and Fellmann 2023) for coupled and decoupled payments in the baseline. Additionally, coupled income support (CIS) has been depicted in more detailed, i.e., at the lowest product level possible (compare AGMEMOD Consortium 2023).

In the baseline, all concluded trade agreements are assumed to remain in place. Figure 9 shows the applied MFN tariffs rate in 2032. In addition, the three tables in the Appendix B4 give an overview about the applied tariff rates for countries with preferential access to the EU market.

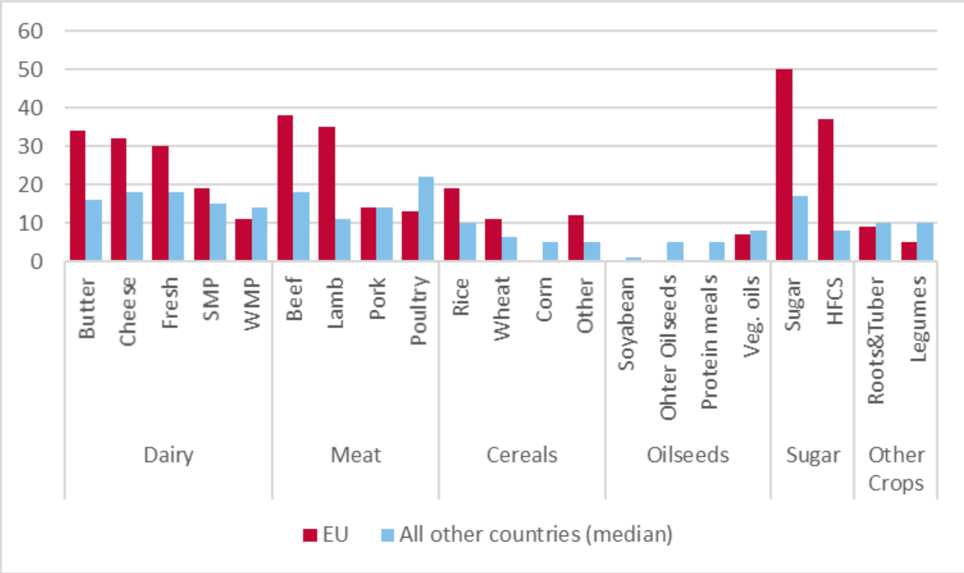


Figure 9: Baseline MFN import tariffs (AVEs), 2032 in %

Source: Authors' calculations based on ITC (2023), simple average over HS6 codes.

To test the model enhancements, two scenarios and their combination are modelled with AGMEMOD (Table 4). The trade scenario aligns with the Scenario A of Aglink-Cosimo, while the biodiversity scenario focuses on a specific EU policy target, i.e., increasing non-productive areas in agricultural landscapes.

Table 4: Scenarios implemented with AGMEMOD

Block	Main assumption	Notation
Trade	Lower AVEs of import tariffs, higher TRQs	A_EU
Biodiversity	Increase of fallow land to 10% of arable land	F_EU
Joint	The above two combined	AF_EU

Scenario A_EU

The scenario assumes that all MFN and preferential tariffs (see Figure 9 above) are cut by 50 percent, while tariff-rate-quotas are doubled. The policy changes are implemented progressively in the period 2028 to 2032. In the scenario A_EU, the tariff cuts result in strongest absolute reduction of tariffs for the products with highest initial tariffs, e.g., sugar, beef, HFCS, lamb, and butter.

Scenario F_EU

The EU aims at increasing biodiversity in the EU, especially in agricultural landscape (European Commission 2020). At least 10% of agricultural area under high-diversity landscape features is one target to achieve this goal as laid out in the EU's biodiversity strategy (European Commission 2020). The implementation of this target as a direct policy reduces arable land for active agricultural production. In the scenario F_EU, fallow land is set to 10% of arable land for each EU member state to mimic this policy option from 2028 onwards, i.e., at the end of the current funding period.

Consequently, setting fallow land to 10% of arable land results in a total increase of fallow land in the EU by 4 million hectares in F_EU compared to the baseline in 2032. Depending on the original share of fallow land, this increase is very heterogenous across the EU member states for 2032 (Figure 10 and Appendix B4). In absolute terms, France, Poland, and Romania would need to increase fallow land the most, while in percentage terms Poland, Austria and Croatia would need to increase their fallow land the most. Spain, Portugal, and Cyprus are already above the 10% share in the baseline, consequently, there is no change in fallow land. In Greece, fallow land might even decline because its share increases in the baseline above 10% due to the voluntary eco-schemes which do not exist in the scenario anymore.

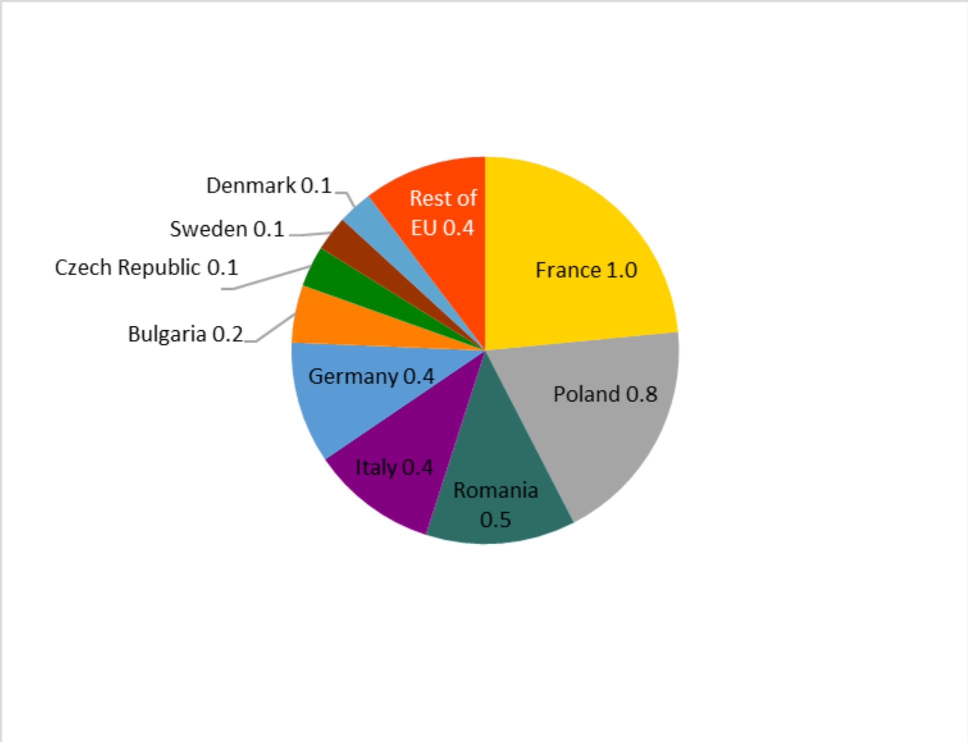


Figure 10: Change of fallow land in F_EU compared to baseline, 2032, million hectares

Source: AGMEMOD simulations.

Scenario AF_EU

This scenario combines trade liberalisation as specified in A_EU and the F_EU scenario. The SPE module is calibrated to the outcome of the F_EU_scenario. In the simulation run, the same trade liberalisation shocks as describe in the A_EU scenario are applied.

Output indicators

The chosen output indicators align with the indicators of Aglink-Cosimo (Table 5). Even though food security is not an actual thread in Europe, it is again on the political agenda of the EU after the Russia invasion of Ukraine. Similar to Aglink-Cosimo, primary indicators are key output variables from the simulation analysis. They include market-balance items and prices.

First-level post model indicators are directly derived indicators from the primary indicators, namely the self-sufficiency-ratio (calculated as production divided by domestic consumption) and the share of import dependence (calculated as positive net-imports divided by domestic consumption). A self-sufficiency-ratio above 1 (below 1) indicates that production exceeds domestic consumption (domestic consumption exceeds production). The share of import dependence ranges from 0 to 1 with 0 for all net-exporting and self-sufficient countries and can increase to 1 if a country's domestic consumption entirely relies on imports.

Table 5: Output indicators from AGMEMOD

SDG	**Indicator used herein**	**Relevance**
2 – Zero Hunger	Market-balance items	Proxies for food availability
	Prices	Proxies for food access
	Self-sufficiency, import dependence	Proxies for food stability
13 – Climate Action	Agricultural emissions	Official SDG indicator 13.2.2

Second-level post-model indicators used data from additional external databases and are calculated after the model is run, i.e., cannot influence the model outcome as such. For AGMEMOD, these are agricultural emissions linked to sectors and countries. Depending on exogenous assumptions about changes in the emission factors and fertilizer application (compare section 2.2.1.2), GHG emissions can vary in the scenarios. However, currently they are kept constant in our analysis. Consequently, GHG emissions only change because of changes in the animal population and the area in the projections and scenarios.

3.3 Results

AGMEMOD depicts the EU and its agricultural sectors in more detail than Aglink-Cosimo. Hence, the product aggregation differs and individual EU member state results can be presented. However, the trade module which was used for the A_EU and AF_EU scenarios, depicts the same product aggregation as Aglink-Cosimo because it relies on its input for all countries except the EU.

The results of the scenarios are expressed in percentage changes compared to the baseline for 2032 if not stated otherwise. The intention here is (a) to show the overall changes in the EU, (b) the range of changes occurring in the EU member states and (c) the output that can be produced with the enhanced AGMEMOD model.

Prices

In the A_EU scenario compared to the baseline in 2032, EU prices for agricultural products change between -6% to +5% depending on the product and EU member state (Figure 11). Figure 11 shows the median producer and consumer price changes of the main agricultural products as well as the total range across all EU countries. In general, the change in producer prices (PS) is stronger than the change in consumer prices (CS). Grain, oilseed, meals and vegetable oil prices increase in most EU member states with the most prominent exception being the producer price of soybeans for Slovenia which declines by 1.8%. This general increase is due to reduced tariffs and the stronger feed demand from the dairy sector. The reduction in sugar and HFCS prices is due to increased imports. Price changes are minor in the meat sectors because the tariff reductions and the increased fallow land affect the meat sector only slightly. The production and exports of dairy products increase due to the tariff reductions but result in mixed price changes. Butter and WMP prices decrease, while cheese and SMP prices increase.

Figure 11: Price changes for main agricultural products

Note: PS= producer prices. CS= consumer prices If no country is indicated, more than one country does not have a change in prices.

Source: AGMEMOD simulations.

In the F_EU scenario, EU prices for crops increase in the EU in general given the reduction in production. However, the EU is well integrated into the global world market so that changes are small in general with exceptions for specific crops and countries (compare Figure 12). Figure 12 shows the median price changes of selected crop products as well as the total range across all EU countries. The strongest price increases can be observed in Romania for rye and corn, while the median price changes often fluctuate around one percent. The price changes in the livestock sector are very small and, hence, not shown here.

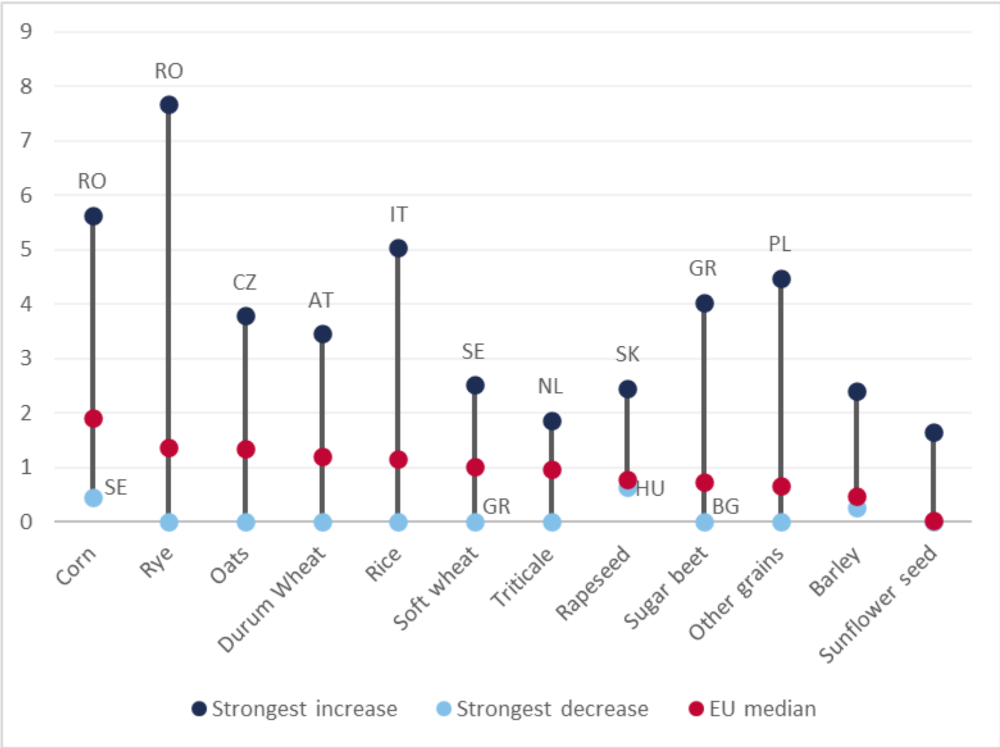


Figure 12: Price changes for crops, % F_EU vs. Baseline in 2032

Note: If no country is indicated, more than one country does not have a change in prices.

Source: AGMEMOD simulations.

Production

Figure 13 shows the changes in production for the main agricultural products for all scenarios in 2032 compared to the baseline in percentages. Trade liberalization (scenario A_EU) leads to increased production in the EU except for sugar, poultry, and sheep. For the latter, the EU import tariffs protect the domestic market and the 50% reduction in tariffs leads to stronger competition from non-EU countries as these tariffs are not prohibitive anymore. The EU is a large exporter of dairy products and stays competitive after tariff reductions on the world market. Consequently, its dairy sector can increase production due to import tariff reductions in non-EU countries.

Due to the increase in fallow land in F_EU, arable land is decreased and consequently crop production declines the most. Trade liberalization in addition to increased fallow land leads to a further reduction in production in the crops sector. Hence, liberalized trade act as a buffer to domestic policy changes. In the dairy sector, production expansions due to liberalized trade are reduced if fallow land is increased. In this case, domestic policies partly mitigate the positive effects of trade liberalization and the EU becomes less competitive on the world market.

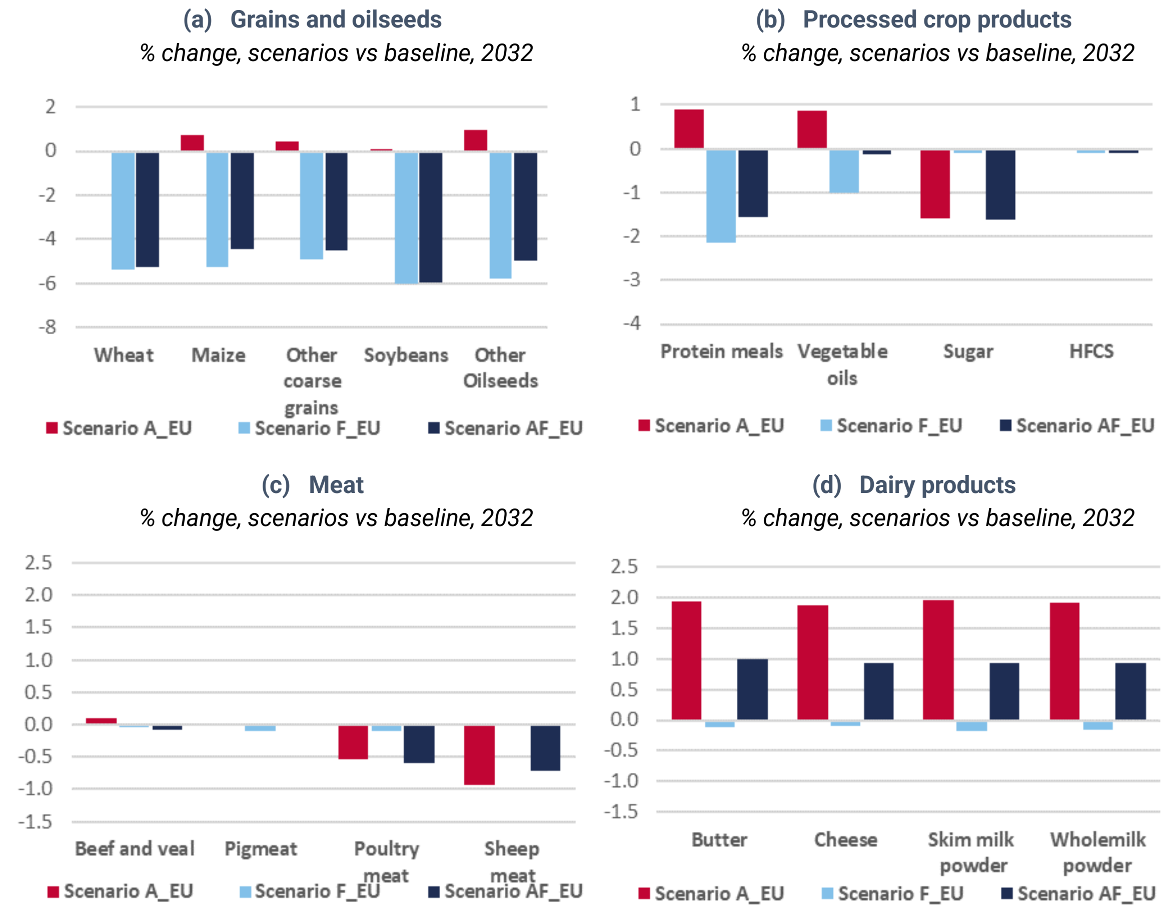


Figure 13: Change in EU production

Source: AGMEMOD simulations.

The EU changes are the combinations of the different changes in the individual EU member states. Figure 14 shows the range of percentage changes in the EU member states as well as the EU average. Slovenia increases its dairy production the most if trade is liberalized (A_EU and AF_EU scenario). Additionally, decreases in the production of dairy products are minor with the strongest decrease in Croatia, i.e., -0.8% for whole milk powder.

The reduced availability of arable land (F_EU and AF_EU scenario) result mainly in reduced crop production with stronger changes in the EU member states observed for grains than oilseeds. However, overall EU oilseed production declines stronger than grain production. In some member states slight increases for certain products can be observed. This is due to the relative price changes between the crops which make some more profitable than others and, hence, the share of this crop increases in arable land expansions. In Greece, the increase in crop production is due to the fact that less land will lie fallow under the scenario (10% of arable land) compared to the baseline (17% of arable land).

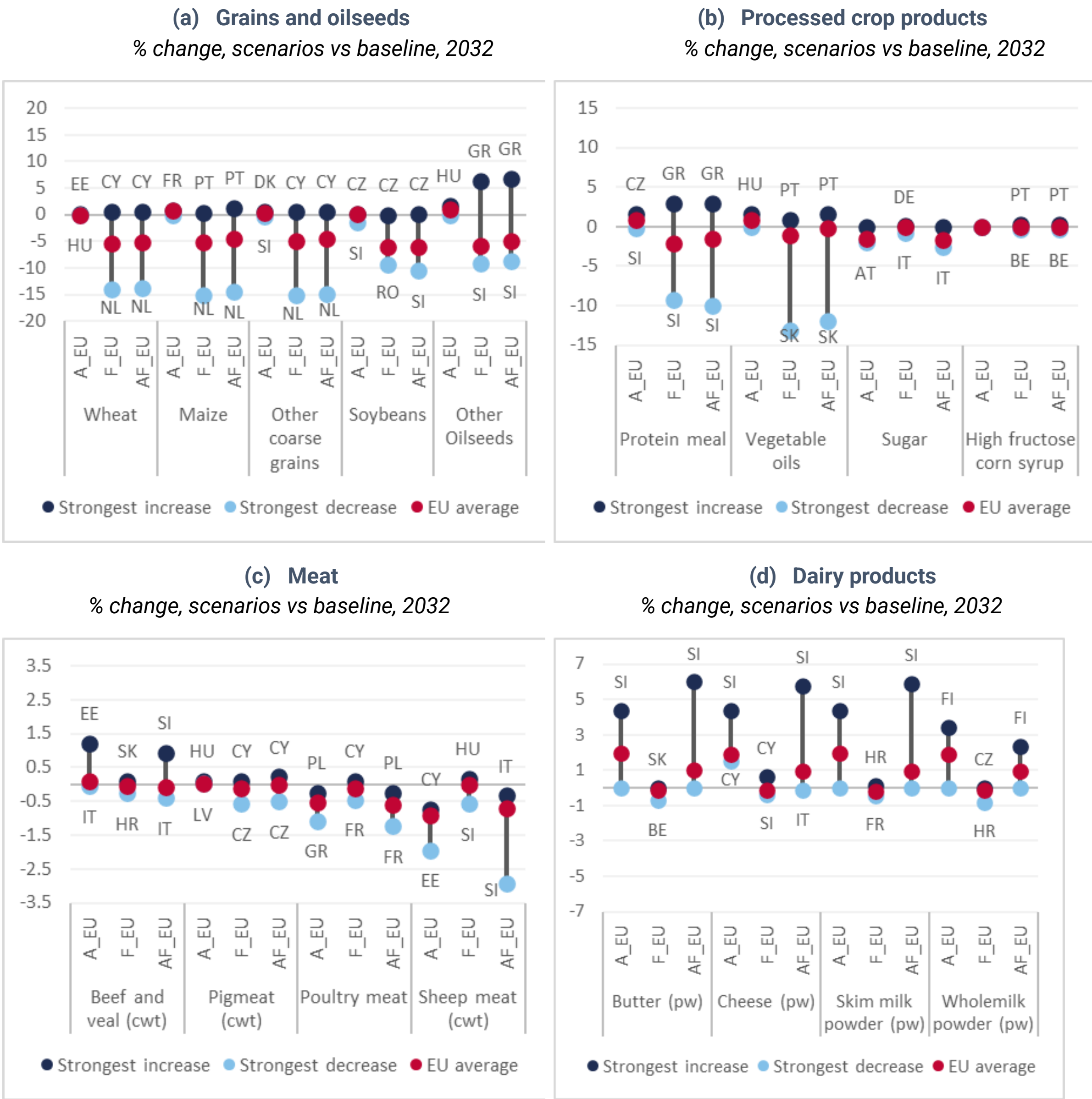


Figure 14: Range of changes in agricultural production

Note: If no country is indicated, more than one country does not have a change in prices.

Source: AGMEMOD simulations.

GHG emissions

The primary aim of the policy to increase non-productive area in agricultural landscapes is to increase biodiversity. Additionally, this policy contributes to the aim of reducing GHG emissions. Setting land fallow results in a reduction of 3 Mio t. CO2eq in 2032. This is a reduction of 1% of total agricultural GHG emissions in the EU. France, Spain, Germany, Poland and Italy are the largest emitters of agricultural GHG emissions in the EU (Figure 15a). Their contribution to a reduction in GHG emissions is very heterogenous. There is no policy impact in Spain because Spain has already more than 10% of fallow land in the baseline. France, Poland, and Italy contribute more than the EU average to the reduction in GHG emissions, while Germany contributes less (Figure 15b). In fact, Estonia, Czech Republic and Sweden reduce their emissions from crops (i.e., mineral fertilizer use) the most in terms of percentage change when comparing the F_EU scenario to the baseline in 2032. Total GHG emissions are reduced the most in percentage changes in Slovakia, Bulgaria, and Estonia when comparing the F_EU scenario to the baseline in 2032.

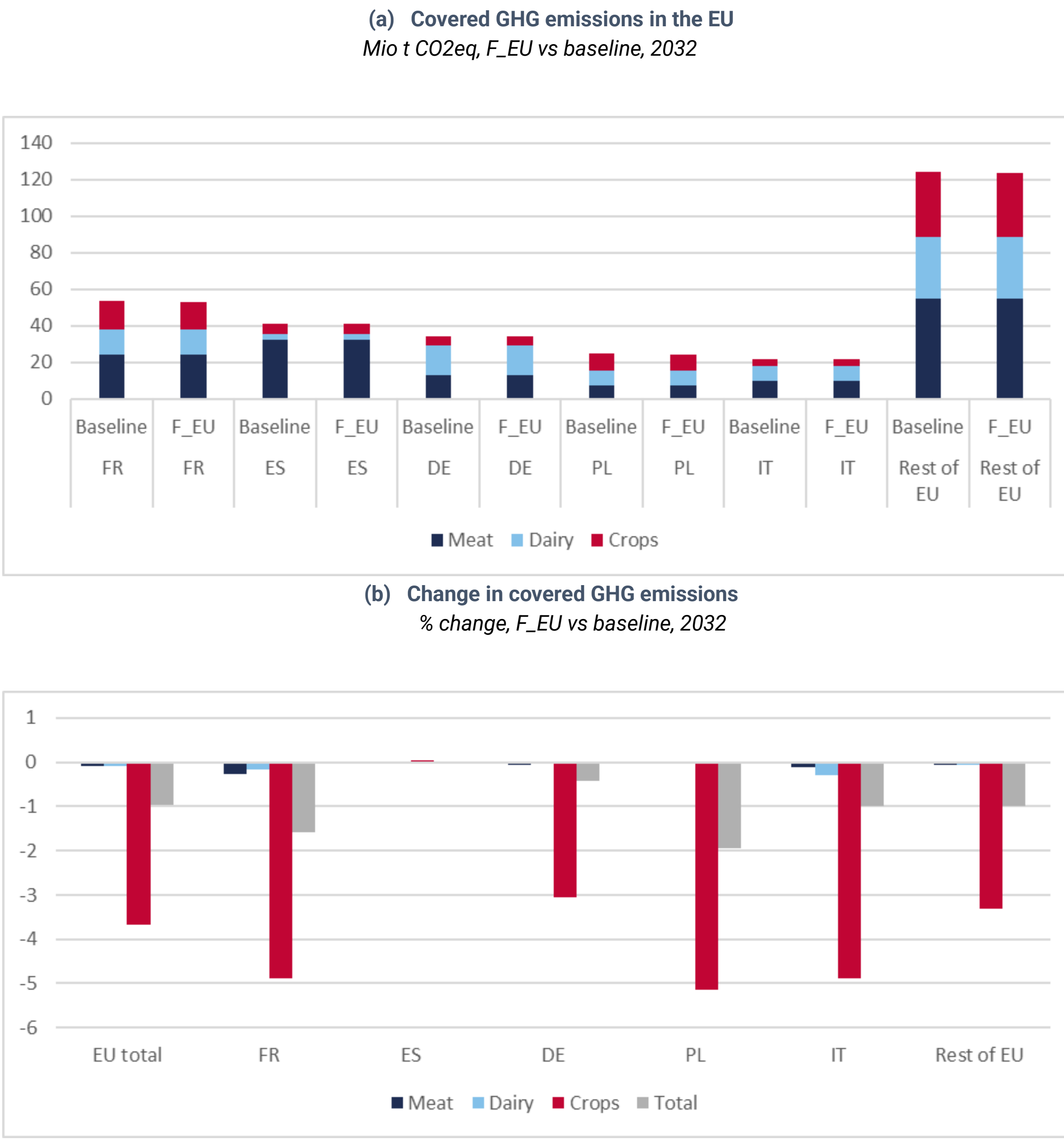


Figure 15: GHG emissions in the EU

Source: AGMEMOD simulations.

Trade

The EU is and stays a net importer for maize, soybeans, other oilseeds, protein meals, sugar, HFCS, and sheep meat in all scenarios (Figure 16). In the scenarios with increased fallow land (F_EU and AF_EU), the EU becomes a net importer of other coarse grains and decreases its grain net exports (= negative net imports). Further, net imports of oilseeds and protein meal increase. In the trade liberalization scenarios (A_EU and AF_EU), net exports of dairy products as well as pig meat increase the most, while poultry net exports decline and sugar net imports increase.

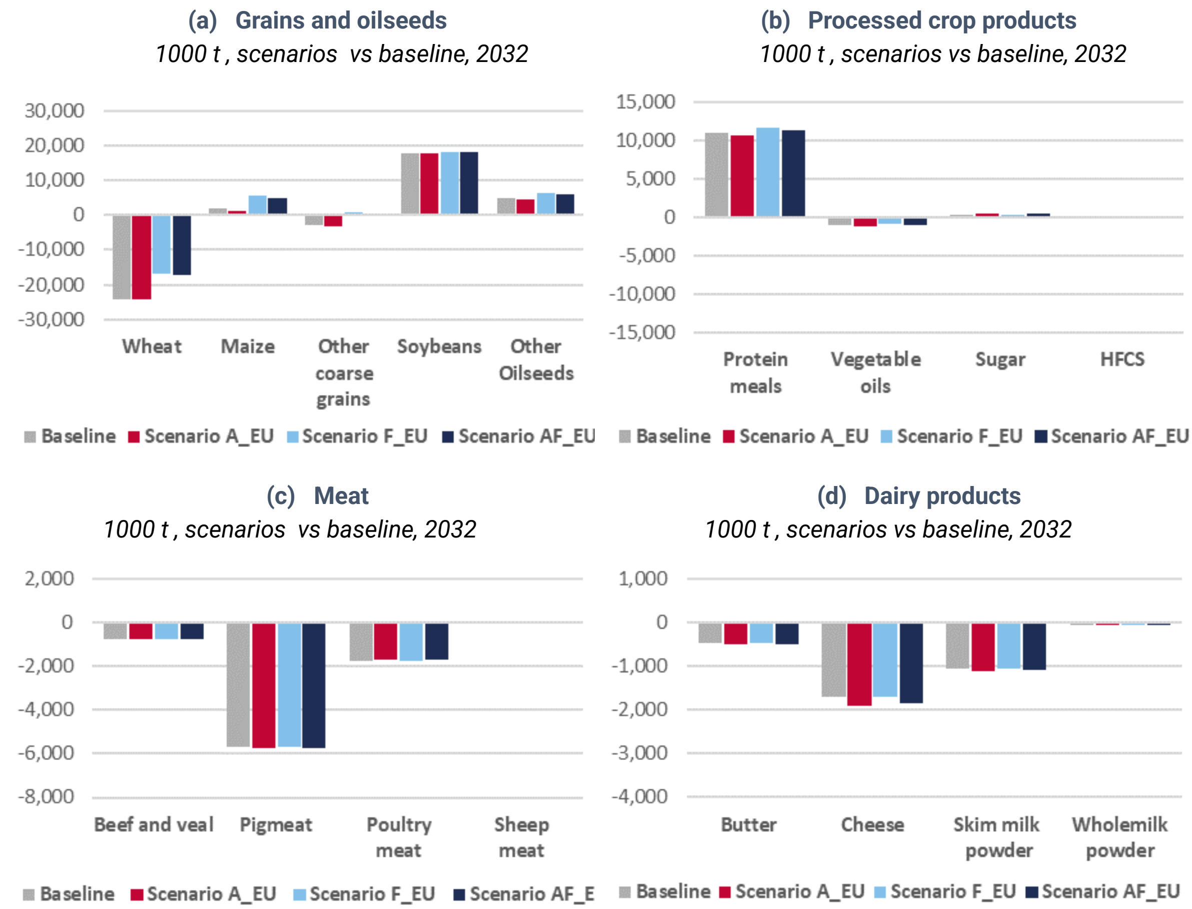


Figure 16: EU net imports

Source: AGMEMOD simulations.

Besides the main crops mentioned above, the EU is also a net importer of rice. The import dependency, measured by the import dependence ratio, increases for the scenarios F_EU and AF_EU for all products, while it decreases for protein meals, other oilseeds, rice and maize in the A_EU scenario (Figure 17).

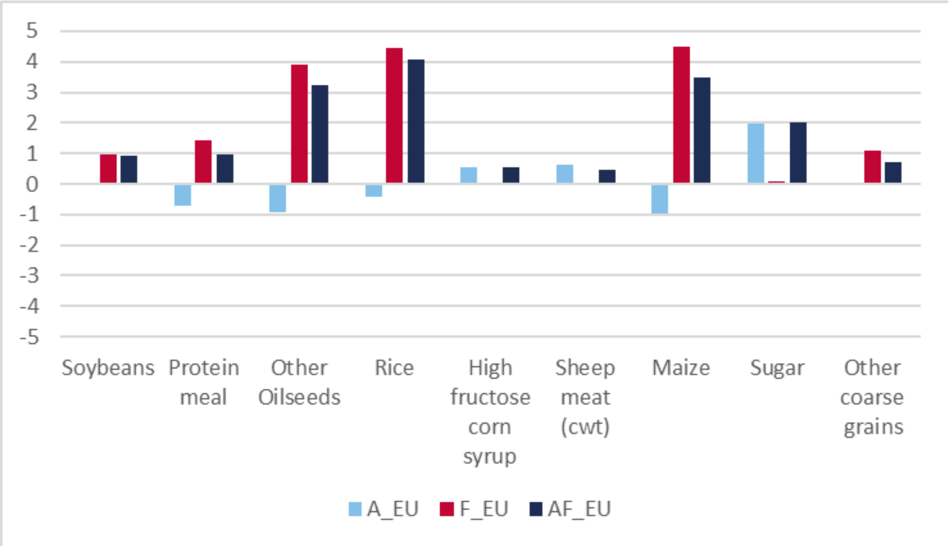


Figure 17: Change in Import dependence ratio, Percentage points, scenarios vs baseline, 2032

Note: one percentage point = 1.

Source: AGMEMOD simulations.

Figure 18 shows the range of changes in net imports of the nine sectors of which the EU is a net importer. The strongest increases for net imports are observed in Germany for other oilseeds and maize if arable land is restricted (scenarios F_EU and AF_EU). Despite the reduced availability of arable land, some countries decrease net imports of crops because the effect of the price increase outweighs the effect of the resource restrictions. This argument does not hold for Spain, Portugal and Greece because their resources are not restricted (compare Appendix B4). Hence, in these countries only the price effect causes the adaptation in trade.

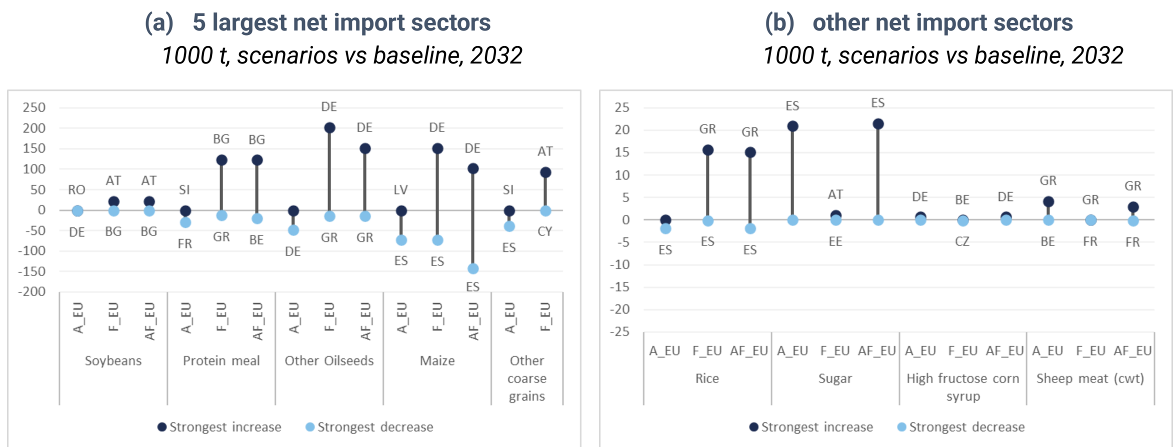


Figure 18: Range of changes in net imports of the EU member states

Source: AGMEMOD simulations.

Consumption

In contrast to production, consumption changes less strongly in all scenarios, products and countries. Figure 19 give an overview of the EU changes for the main agricultural sectors. These small changes contribute to stronger increases in prices and imports, especially in the scenarios where crop production declines (F_EU and AF_EU).

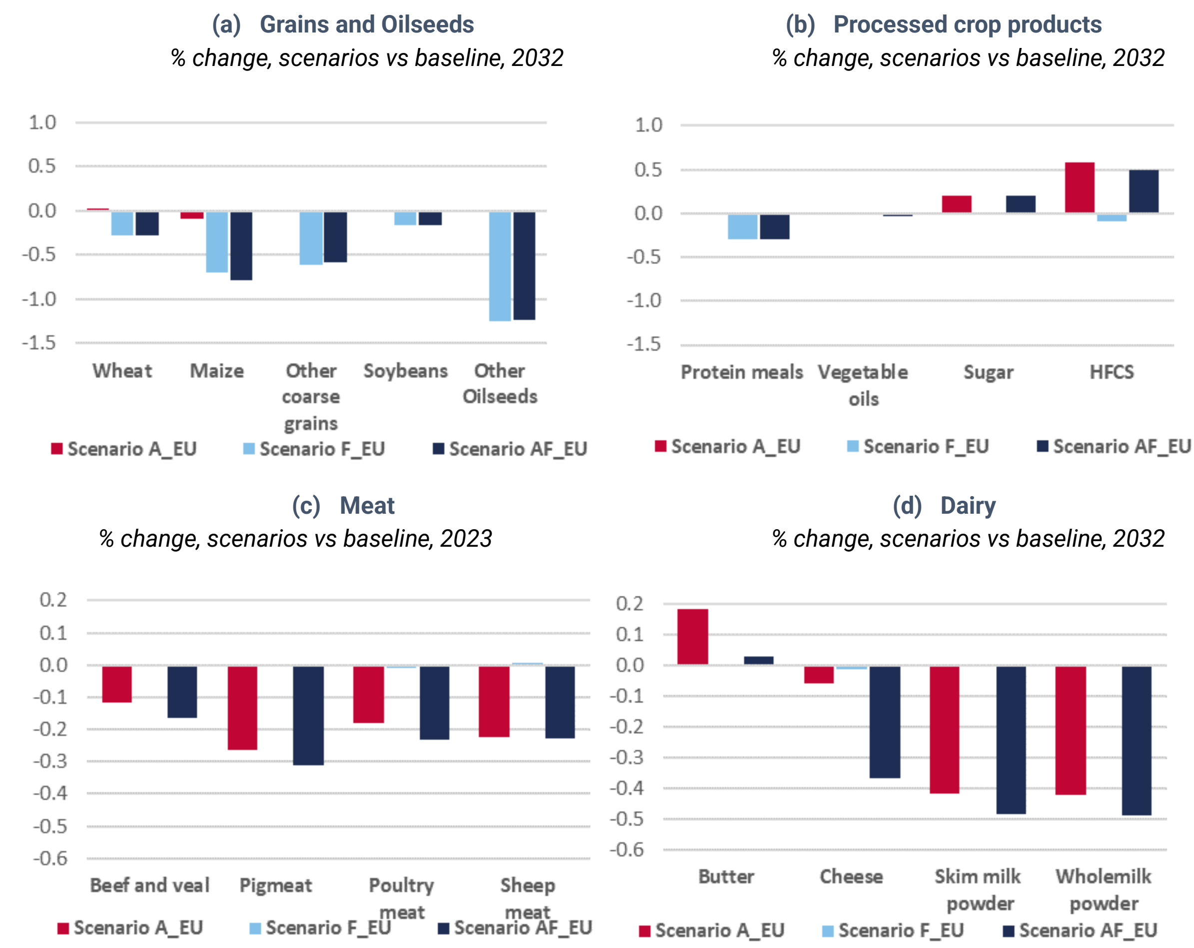


Figure 19: Change in EU consumption relative to baseline (%), 2032

Source: AGMEMOD simulations.

The EU is self-sufficient in most main agricultural products. Further, the self-sufficiency ratio is mostly high, i.e., above 80%, for the products in which the EU is not self-sufficient. The only exceptions are protein meals and soybeans (Figure 20).

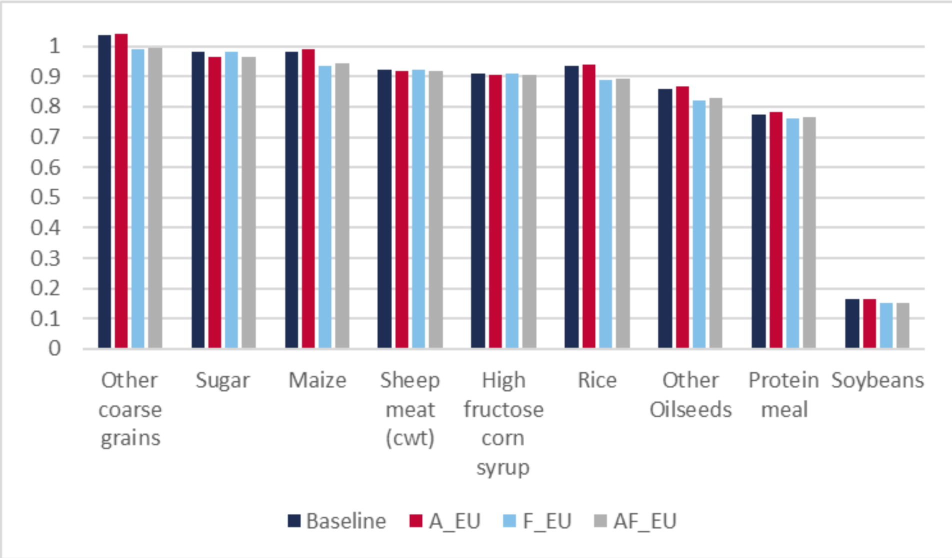


Figure 20: Self-sufficiency ratio of main agricultural products with a level below 1 in at least one scenario in 2032, index 1 = self sufficient

Source: AGMEMOD simulations.

At the level of the EU member states, substitution effects, especially between feed crops, are observed and lead to increases or decreases in consumption depending on the country and feed crop (Figure 21). This effect comes on top of the observed changes in livestock production. Hence, the picture is quite heterogenous.

Figure 21: Range of changes in consumption

Note: If no country is indicated, more than one country does not have a change in prices.

Source: AGMEMOD simulations.

3.4 Conclusions

The enhancements of AGMEMOD show the improvement and contribution made during this project to the model. However, both enhancements are only a first step and can benefit from further development. The trade module is currently not calibrated to the latest observed trade flows which would be a methodological improvement. Besides, the GHG emission module has not yet covered all GHG emissions from agriculture but we foresee a completion of this task within the Trade4SD project.

However, the analysis provides insightful results. The EU is a net-exporter of its main agricultural products and reaches a high self-sufficiency rate, i.e., above 90%, in the main agricultural products used as food. Import dependence exist only for soybeans, protein meals and other oilseeds which are mainly used for feed and fuel. The SDG 2 is hence not a concern of the EU in general.

However, import dependence increases with an increase in fallow land. Simultaneously, the increase in fallow land not only leads to an increase in biodiversity but also leads to a reduction in GHG emissions which contributes to SDG 13. Furthermore, liberalizing trade reduces the negative economic effects of setting land fallow in the EU while its dairy sector profits the most from liberalization.

4. Concluding remarks

Global liberalization of agricultural commodity trade, implemented as an isolated measure, triggers offsetting movements in the supply and demand of domestic markets. Their combined effects lead to an increase in world reference prices for agricultural commodities. Producers in countries that are well integrated into world markets would benefit from higher world prices by increasing export-oriented production. Consumers, mainly in middle-income, net importing countries, would benefit from lower domestic prices, induced by the removal of trade barriers. At the global level, volumes and structure of agricultural production as well as the associated direct emissions change only marginally. The overall findings suggest that trade liberalization alone does not bring the world significantly closer to meeting the SDG2 and SDG13 targets. In particular for the EU, SDG2 does not seem to be of great concern as food supply remains available and stable.

Combined with yield improvements, trade liberalization helps to improve food availability, affordability and stability. The full potential for dietary improvements might be underestimated in this scenario, because the simulations do not account for any income effects of higher productivity. The scenario on dietary changes simulates an accelerated convergence of diets across countries. The results suggest an improvement for LICs regarding food supply, stability, and utilization, which is enhanced by the simultaneous trade liberalization. With both scenarios marginally affecting production, changes in GHG emissions are small, thus achievement of SDG13 targets seems unaffected. At the EU level, trade liberalization combined with land use policies reduces the GHG emissions, thus contributing to SDG13. The liberalization effect appears to have a positive effect on the EU dairy sector that profits from such openness environment.

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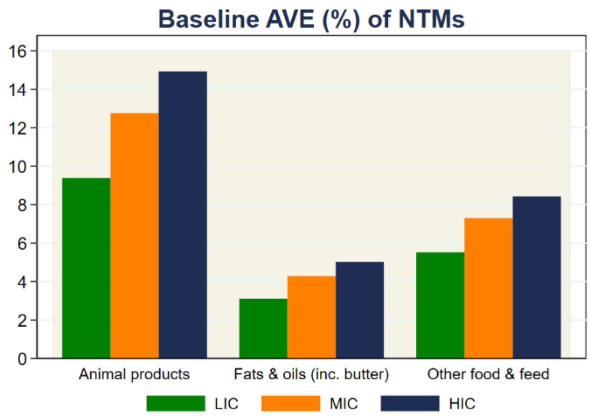
APPENDIX A (Aglink-Cosimo)

A1. Incorporation of baseline NTMs

The baseline AVEs of NTMs used in this report are based on a combination of estimates from Gourdon et al. (2020) and relative information from WB/UN (2018). The procedure to derive baseline AVEs –that are reduced in scenario block A– and subsequently test them is described below.



For each agricultural-commodity group, a system of three equations with three unknowns were solved. The example of animal products (exc. butter) is detailed below. Fats and oils (vegetable oil and butter) and all other food and feed commodities were treated in a similar way.

$$W_{LIC} \times AVE_{ANM,LIC,TOT} + W_{MIC} \times AVE_{ANM,MIC,TOT} + W_{HIC} \times AVE_{ANM,HIC,TOT} = AVE_{ANM,Gourdon} \quad (A1)$$
$$AVE_{ANM,LIC,TOT} \div AVE_{ANM,MIC,TOT} = 0.735 \quad (A2)$$
$$AVE_{ANM,LIC,TOT} \div AVE_{ANM,HIC,TOT} = 0.629 \quad (A3)$$

Eq. (A1) is a frequency-weighted mean that combines Aglink-Cosimo model data with the Gourdon et al. (2020) estimates. The weights (W) show the relative frequency of the modelled units in each income group in all 47 modelled units:

$$W_{LIC} + W_{MIC} + W_{HIC} = (4 + 29 + 14) \div 47 = 0.085 + 0.617 + 0.298 = 1$$

$AVE_{Gourdon}$ is based on Gourdon et al. (2020; their Figure 2) and is the AVE of mostly trade-distorting NTMs. These include SPS A1 and A8, TBT B1 and A8, border control, and quantity control measures. It is calculated as the AVE of all NTMs minus the AVE of mostly trade-enhancing NTMs (SPS and TBT regulations) and equals 13.12 for animal-based products without distinguishing between income groups.

To obtain an estimate of the average AVE for animal-based products that differs per income group –i.e., $AVE_{ANM,LIC,TOT}$, $AVE_{ANM,MIC,TOT}$ and $AVE_{ANM,HIC,TOT}$ –, we estimated two AVE ratios across the three income groups (Eqs. A2, A3). For this calculation, relative information from WB/UN (2018) was applied to the Gourdon et al. (2020) data. The resulting figures take into account the relative contributions of technical and non-technical measures in the total AVE.

That is important because the AVE of technical NTM has a higher weight in high-income countries while the AVE of non-technical NTMs has a higher weight in low-income countries.

Solving Eqs. (A1-3) and repeating the calculations for the other two commodity groups, starting baseline AVE values were obtained. These are graphically shown on the previous page. The assumptions behind the generation of these values can be summarized as follows:

- The AVE of technical NTMs *increases* as we move from lower-income to higher-income countries.
- The AVE of non-technical NTMs *decreases* as we move from lower-income to higher-income countries.
- The AVE of trade-distorting NTMs *increases* as we move from lower-income to higher-income countries.
- Animal products have higher AVEs, fats and oils have lower AVEs, and all other food and feed commodities lie in between.

Next, the derived AVE values were tested through a calibration exercise in Aglink-Cosimo. The original equation of import prices (Eq. 4) was amended by adding an exogenous NTM term next to the TAVI term.

$$IMP'_{r,c,t} = XP_{WLD,c,t} \times XR_{r,c,t} \times (1 + TAVI_{r,c,t} + NTM_{r,c,t}) \quad \text{(A4)}$$

and

$$\log(IM_{r,c,t}) = \alpha'_{r,c} + \beta_{r,c} \times \log(PP \div IMP')_{r,c,t} + \log R'_{r,c,t} \quad \text{(A5)}$$

The NTM term takes on the calculated AVE values from 2015, which is the start of the Gourdon et al. (2020) period, to 2032, which is the last simulation year in Aglink-Cosimo. The full model was calibrated; that is, calibration terms were re-estimated assuming all other variables remained fixed. The new calibration terms were compared with the original ones on a country and commodity basis in the Gourdon period (2015-2018) and the beginning of the baseline period (2023-2026). Two cases were distinguished.

a) *The new calibration terms (logR) got closer to zero, on average, than the original ones.* In this case, the addition of the NTM term in the denominator improved the model specification, and trade-distorting NTMs were assumed to exist. The NTM term was, therefore, retained in the import equation, its AVE value was taken as a fixed baseline value (2023-2032), and this value was reduced by 50% in scenario A.
b) *The new calibration terms diverged from zero, on average, or did not change*. In this case, the addition of the NTM term did not improve the default model specification. The original model specification was retained.

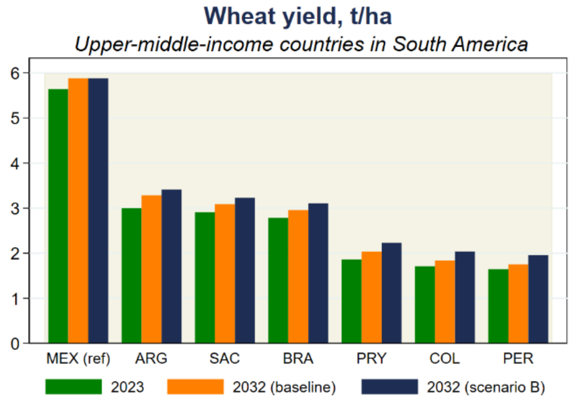
The resulting baseline is, hence, a recalibrated baseline of the published OECD-FAO Agricultural Outlook 2023-2032 (OECD/FAO 2023a). It is based on the same sets of projections but includes baseline estimates of the NTM effect (Figure 1) in those equations that supports that effect.

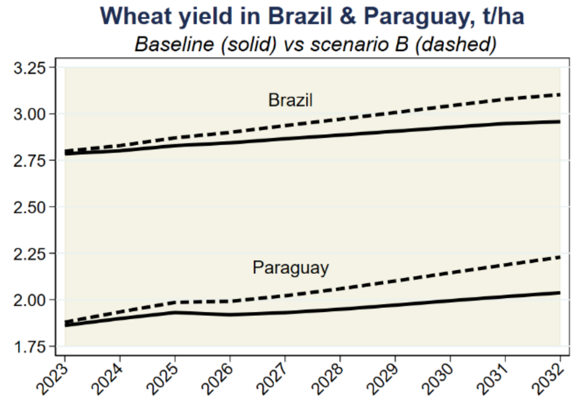
A2. List of world prices

Commodity	Reference price
Wheat	No.2 hard red winter wheat, ordinary protein, US FOB Gulf Ports (June/May)
Maize	No.2 yellow corn, US FOB Gulf Ports (Sep./Aug.)
Rice	FAO all rice price index normalised to India, indica high quality 5% broken average 2014-16 (Jan./Dec.)
Oth. grains	Feed barley, Europe, FOB Rouen (July/June).
Soybean	Soybean, US, CIF Rotterdam (Oct./Sep.)
Oth. oilseeds	Rapeseed, Europe, CIF Hamburg (Oct./Sep.)
Veg. oil	Weighted average price of oilseed oils and palm oil, European port (Oct./Sep.)
Protein meal	Weighted average protein meal, European port (Oct./Sep.)
Beef	Australia and New Zealand: beef, mixed trimmings 85%, East Coast, FOB port of entry, USD/t
Pork	US: meat of swine (fresh, chilled or frozen), export unit value, USD/t
Poultry	Brazil: meat and edible offal of poultry (fresh, chilled or frozen), export unit value, USD/t
Sheep	New Zealand: lamb 17.5kg, USD/t
Cheese	FOB export price, cheddar cheese, 39% moisture, Oceania
Butter	FOB export price, butter, 82% butterfat, Oceania
SMP	FOB export price, non-fat dry milk, 1.25% butterfat, Oceania
WMP	FOB export price, WMP 26% butterfat, Oceania

A3. Illustration of scenario B

The following example focuses on wheat in the cluster *'Upper-middle-income countries in South America'*, which includes Argentina, Brazil, Colombia, Mexico, Paraguay, Peru, and the SAC region.[11] Projected wheat yields in the cluster range from 1.75 t/ha (Peru) to 5.88 t/ha (Mexico; reference yield) and are shown below in the amber bars.





Scenario values in block B (dark blue bars) are based on the assumption that 5% of the yield gaps within the cluster close in 2032. For each country the formula is:

$$ScenYLD_{2032} = BaseYLD_{2032} + 0.05 \times (5.88 - BaseYLD_{2032})$$

By design, Peru has a low baseline value and takes on a larger increase (+0.21 t/ha; +12% *vs* baseline) while Argentina has a high baseline value and takes on a lower increase (+0.13 t/ha; +4%) in the cluster. Scenario values for the simulation period 2023-2031 were then calculated backwards in equally spaced increments, as the trajectories for Brazil and Paraguay illustrate above (dotted lines).

The average wheat-yield gain *within* the cluster above is 0.17 t/ha (2032). Average yield gains (t/ha) per commodity and income group from block B are shown below.

	Wheat	Maize	Rice	Oth. grains	Soybean	Oth. oilseeds	Pulses
All LIC	0.09	0.29	0.06	0.09	0.09	0.002	0.07
All LMC	0.16	0.17	0.12	0.12	0.05	0.04	0.15
All UMC	0.18	0.22	0.11	0.06	0.07	0.06	0.04
All HIC	0.14	0.11	0.11	0.09	0.02	0.06	0.23
All	0.16	0.19	0.11	0.09	0.06	0.05	0.13

[11] SAC is a regional aggregate for other South and Central America and the Caribbean: Antigua and Barbuda, Bahamas, Barbados, Belize, Bolivia (Plurinational State of), Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Ecuador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Puerto Rico, St. Kitts and Nevis, Suriname, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, Uruguay, Venezuela (Bolivarian Republic of).

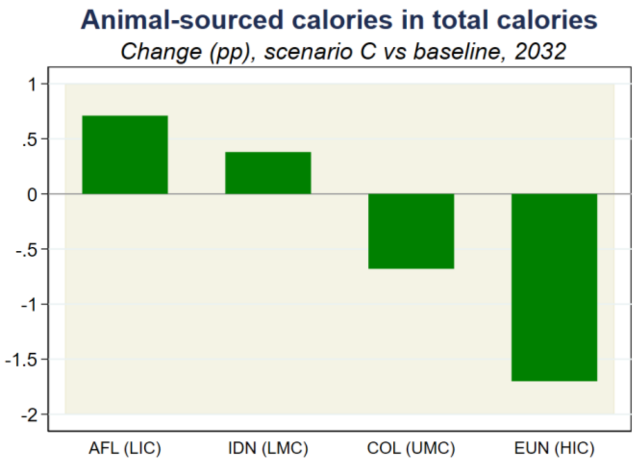
A4. Illustration of scenario C

Across individual countries, the baseline share of animal-sourced calories in total calories projected in 2032 ranges from 3% to 35%, with a mean of 20%. These range from 9% in LICs to 27% in HICs, on average. The following example shows four cases: the AFL region (LIC), Indonesia (LMC), Colombia (UMC), and the EU (HIC).[12] In these cases, baseline shares of animal-sourced calories in total calories (2032) range from 5.9% (AFL) to 30% (EU).

Scenario values in block C are based on the assumption that each country closes 10% of the gap with the reference value of 13%. For each country the formula is:

$$ScenVAL_{2032} = BaseVAL_{2032} + 0.1 \times (13 - BaseVAL_{2032})$$

By design, the AFL region has a baseline share of animal-sourced calories in total calories that is closer to the reference value than the EU share. Therefore, the increase in percentage points in the AFL share (from 5.9% to 6.6%) is lower than the decrease in the EU share (from 30% to 28.3%), as shown below.



Furthermore, total calorie availability (or intake) is higher in the EU than in AFL. Hence, the drop in the level of animal-sourced calories in the EU (-56 kcal/person/day) is stronger than the increase in the level of animal-sourced calories in AFL (+17 kcal/person/day).

[12] AFL is a regional aggregate for Least Developed Countries in Sub-Saharan Africa: Angola, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Djibouti, Eritrea, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, South Sudan, Togo, Uganda, United Republic of Tanzania, Zambia.

APPENDIX B (AGMEMOD)

B1. Equations of the trade module in AGMEMOD

Supply functions:

$$S_{p,j,y} = \alpha_{p,j,y} * \left(PS_{p,j,y} + p_{subs_{p,j,y}}\right)^{\varepsilon\_s\_own_{p,j}} * \prod_{pp}\left(PS_{pp,j,y} + p_{subs_{pp,j,y}}\right)^{\varepsilon\_s\_cross_{p,pp,j}} \quad \perp S_{j,p,y} \geq 0 \qquad \text{(B1)}$$

Demand functions:

$$D_{p,i,y} = \alpha_{p,i,y} * \left(PD_{p,i,y} - c_{subs_{p,i,y}}\right)^{\varepsilon\_d\_own_{p,i}} * \prod_{pp}\left(PD_{pp,i,y} - c_{subs_{pp,i,y}}\right)^{\varepsilon\_d\_cross_{p,pp,i}} \quad \perp D_{p,i,y} \geq 0 \qquad \text{(B2)}$$

Ending stocks:

$$EST_{p,i,y} = \alpha_{p,i,y} * PD_{p,i,y}^{\varepsilon\_est_{p,i}} \quad \perp EST_{p,i,y} \geq 0 \qquad \text{(B3)}$$

Market clearing:

$$S_{p,j,y} \geq \sum_{sch,i} X_{sch,p,i,j,y} \quad \perp PS_{p,i,y} \geq 0 \qquad \text{(B4)}$$

$$D_{p,i,y} + EST_{p,i,y} - ost_{p,i,y} \leq \sum_{sch,i} X_{sch,p,j,i,y} \quad \perp PD_{p,i,y} \geq 0 \qquad \text{(B5)}$$

Trade from country-of-origin j to country-of-destination i (spatial arbitrage condition):

$$\begin{aligned} &\left(PS_{p,j,y} + PSH_{sch,p,j,i,y} + exw\_fas_{p,j,y} + loading_{p,j,y} \right. \\ &\quad \left. + freight_{p,j.i,y} + tc_{sch,p,j,i,y}\right) \\ &\quad * \left(1 + tar\_av_{sch,p,j,i,y}\right) + tar\_sp_{sch,p,j,i,y} \\ &\quad + PSH\_MD_{sch,p,j,y} + PSH\_MO_{sch,p,i,y} \\ &\quad + PSH\_MOMD_{sch,p,y} + unloading_{p,i,y} \\ &\quad + inld.\_trans_{p,i,y} \geq PD_{p,i,y} \end{aligned} \quad \perp X_{sch,p,j,i} \geq 0 \qquad \text{(B6)}$$

Tariff Rate Quotas:

$$X_{sch,p,j,i} \leq trq_{sch,p,j,i} \qquad \perp PSH_{sch,p,j,i} \geq 0 \qquad (B7)$$

$$\sum_{i} X_{sch,p,j,i} \leq md\_trq_{sch,p,j} \qquad \perp PSH\_MD_{sch,p,j} \geq 0 \qquad (B8)$$

$$\sum_{j} X_{sch,p,j,i} \leq mo\_trq_{sch,p,i} \qquad \perp PSH\_MO_{sch,p,i} \geq 0 \qquad (B9)$$

$$\sum_{j,i} X_{sch,p,j,i} \leq momd\_trq_{sch,p} \qquad \perp PSH\_MOMD_{sch,p} \geq 0 \qquad (B10)$$

Where:

sch	trade regime (scheme)	tar_av	ad valorem tariff
p	product	tar_sp	specific tariff
j	exporting country	trq	tariff rate quota
i	importing country	md	multi destination
S	supply	mo	multi-origin
D	demand	momd	multi-origin-multi-destination
EST	ending stocks	PSH	quota rent
ost	opening stocks	exw_fas	freight cost from plant to port
X	traded quantity	loading	loading cost
PS	producer price	freight	ocean freight
PD	consumer price	tc	transaction cost
p_subs	producer subsidy	unloadind	unloading costs
c_subs	consumer subsidy	inld_trans	freight cost from port to market
α	intercept	landtrans	cost for trading over land
ε	own- and cross-price elasticity		

B2. Equations of the GHG emission module in AGMEMOD

Green House Gas (GHG) emission per head of animal specie is estimated as;

$$HGG_L = (EFE\_C * CqCHH) + (EFM\_C * CqCHH) + (EFM\_N * CqNOO) \quad \text{(B11)}$$

Where;

HGG_L denote GHG emissions per head of animal species or category in tonnes of CO_2eq; EFE_C is the CH_4 emission factor for enteric fermentation; EFM_C and EFM_N are the CH_4 and N_2O emission factors for manure management; and CqCHH and CqNOO stand for CO_2 equivalent values for CH_4 and N_2O respectively.

The total GHG emissions (tonnes of CO_2eq) per livestock species were then calculated as;

$$GHG_L = HGG_L * CCT_L \quad \text{(B12)}$$

Where GHG_L is the total GHG emissions in tonnes of CO_2eq and CCT_L is the animal population or ending stock of the animal species or category in 1000 heads.

The direct GHG emissions per product (kg of CO2eq) were estimated with the following equation;

$$N_2O_{direct} = (F_{SN} * EF_1 * \text{CqNOO}) * NINO2 \quad \text{(B13)}$$

N2O emissions from atmospheric deposition of N (volatilization) in (kg of CO2eq) were estimated as;

$$N_2O_{vol} = (F_{SN} * Frac_{GASF} * EF_4 * \text{CqNOO}) * NINO2 \quad \text{(B14)}$$

N2O emissions from N leaching (kg of CO2eq) were estimated with the following equation;

$$N_2O_{leach} = (F_{SN} * Frac_{LEACH} * EF_5 * \text{CqNOO}) * NINO2 \quad \text{(B15)}$$

Where;

$N2O_{direct}$ represent emissions from direct sources, N_2O_{vol}, and N_2O_{leach} represent emissions from the indirect sources:- volatilization and leaching; F_{SN} is the annual synthetic nitrogen fertilizer applied per hectare of crop (kgha^{-1}yr^{-1}); $Frac_{GASF}$ is the fraction of N that volatilizes as N_2O, kg N volatilized (kg of N applied)$^{-1}$; $Frac_{LEACH}$ is the fraction of N that is lost through leaching and runoff in kg N leached (kg of N additions)$^{-1}$; EF_1 is the emission factor for N_2O from N fertilizers in kg N_2O–N (kg N volatilized)$^{-1}$; EF_4 is the emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces in kg N_2O–N (kg N input)$^{-1}$; EF_5 is the emission factor for N_2O emissions from N leaching and runoff, kg N_2O–N (kg N leached and runoff)$^{-1}$; NINO2 is the conversion factor of N_2O–N emissions to N_2O emissions for reporting purposes which is equal to 44/28. The IPCC's default values for EF_1 = 0.016, EF_4 = 0.014 (wet climate), and EF_5 = 0.011 were used in the estimations.

The emissions per product in tonnes of CO2eq per 1000 hectares were calculated as;

$$N_2O_{product} = (N_2O_{direct} + N_2O_{vol} + N_2O_{leach})/1000 \quad \text{(B16)}$$

From equation (6), the total GHG emissions per product (tonnes of CO2eq) was estimated as;

$$N_2O_{total} = N_2O_{product} * AHA_{product} \quad \text{(B17)}$$

Where;
$AHA_{product}$ is the total area cultivated per product.

B3. Fallow land per EU member state in AGMEMOD simulations

	fallow land				
	2022	2032			
EU countries	Data	Baseline	F_EU	change 2032 to 2022 in baseline	change scenario to baseline in 2032
	1000 ha	1000 ha	1000 ha	%	%
Spain	2513.3	2513.3	2513.3	0%	0%
France	346.4	664.4	1614.5	92%	143%
Germany	373.1	718.9	1130.4	93%	57%
Poland	187.8	328.8	1096.0	75%	233%
Romania	198.8	338.2	845.4	70%	150%
Italy	322.1	284.2	710.4	-12%	150%
Hungary	129.6	372.7	409.2	188%	10%
Bulgaria	132.8	153.2	347.4	15%	127%
Sweden	166.5	135.0	253.7	-19%	88%
Czech Republic	25.7	109.6	248.0	327%	126%
Denmark	101.2	121.4	237.9	20%	96%
Lithuania	103.5	155.7	231.5	50%	49%
Finland	207.4	207.2	224.5	0%	8%
Portugal	224.4	224.4	224.4	0%	0%
Greece	142.4	296.2	172.1	108%	-42%
Slovakia	45.4	61.4	136.6	35%	123%
Latvia	53.7	54.2	135.6	1%	150%
Austria	49.1	39.9	132.9	-19%	233%
Netherlands	7.8	57.0	100.3	631%	76%
Belgium	18.5	71.9	93.4	289%	30%
Croatia	22.3	34.6	88.6	55%	156%
Estonia	11.2	54.1	70.6	385%	31%
Ireland	2.7	29.8	46.2	1013%	55%
Slovenia	2.5	7.1	17.7	187%	150%
Cyprus	13.4	9.5	9.5	-29%	0%
Malta	0.7	0.7	0.8	-1%	8%

Source: AGMEMOD simulations.

B4. EU preferential import tariff (AVEs) in AGMEMOD baseline simulation

Table B4a: EU preferential import tariff (AVEs) in AGMEMOD baseline simulation – Crop sectors, 2032

Country/Product	Wheat	Maize	Rice	Other Grains	Soy-bean	Other Oilseeds	Roots& Tuber	Protein Crops
MFN	11%	0%	19%	12%	0%	0%	9%	5%
Argentina	0%	0%	0%	0%	0%	0%	0%	0%
Canada	0%	0%	0%	0%	0%	0%	0%	0%
Switzerland	8%	0%	0%	8%	0%	0%	4%	0%
Chile	8%	0%	0%	9%	0%	0%	8%	3%
China	0%	0%	18%	0%	0%	0%	0%	1%
Colombia	0%	0%	0%	0%	0%	0%	0%	0%
Egypt	8%	0%	0%	9%	0%	0%	8%	3%
Indonesia	0%	0%	0%	0%	0%	0%	8%	3%
India	0%	0%	0%	0%	0%	0%	0%	0%
Iran	0%	0%	0%	0%	0%	0%	0%	0%
Israel	0%	0%	0%	0%	0%	0%	0%	0%
Japan	8%	0%	0%	7%	0%	0%	1%	2%
South Korea	0%	0%	0%	12%	0%	0%	7%	3%
LDC - North Africa	0%	0%	0%	0%	0%	0%	0%	0%
LDC - SSA Africa	0%	0%	0%	0%	0%	0%	0%	0%
LDC - Southern Asia	0%	0%	0%	0%	0%	0%	0%	0%
Mexico	8%	0%	0%	9%	0%	0%	8%	4%
Nigeria	0%	0%	18%	12%	0%	0%	3%	0%
Norway	0%	0%	0%	0%	0%	0%	0%	0%
Pakistan	0%	0%	0%	0%	0%	0%	0%	0%
Peru	0%	0%	0%	9%	0%	0%	8%	3%
Philippines	0%	0%	0%	0%	0%	0%	0%	0%
Paraguay	0%	0%	0%	0%	0%	0%	0%	0%
Russia	0%	0%	0%	0%	0%	0%	0%	0%
Thailand	8%	0%	0%	9%	0%	0%	9%	0%
Turkey	8%	0%	0%	9%	0%	0%	8%	3%
Ukraine	10%	0%	18%	12%	0%	0%	4%	0%
United States	0%	0%	0%	0%	0%	0%	0%	0%
Vietnam	0%	0%	0%	0%	0%	0%	0%	0%
South Africa	0%	0%	0%	9%	0%	0%	8%	3%

Source: Authors' calculations based on ITC (2023), simple average over HS6 codes.

Table B4b: EU preferential import tariff (AVEs) in AGMEMOD baseline simulation – Processed crop sectors, 2032

Country/Product	Protein Meals	Veg. Oils	Sugar	HFCS
MFN	0%	7%	50%	37%
Argentina	0%	0%	44%	0%
Canada	0%	0%	0%	0%
Switzerland	0%	0%	43%	0%
Chile	0%	3%	43%	32%
China	0%	0%	0%	0%
Colombia	0%	0%	43%	22%
Egypt	0%	3%	0%	32%
Indonesia	0%	3%	43%	32%
India	0%	0%	44%	0%
Iran	0%	0%	0%	0%
Israel	0%	0%	0%	0%
Japan	0%	0%	43%	33%
South Korea	0%	3%	0%	0%
LDC - North Africa	0%	0%	0%	0%
LDC - SSA Africa	0%	0%	0%	0%
LDC - Southern Asia	0%	0%	0%	0%
Mexico	0%	1%	0%	0%
Nigeria	0%	0%	44%	0%
Norway	0%	0%	44%	0%
Pakistan	0%	0%	0%	0%
Peru	0%	3%	43%	0%
Philippines	0%	0%	44%	0%
Paraguay	0%	0%	0%	0%
Russia	0%	0%	0%	0%
Thailand	0%	6%	43%	0%
Turkey	0%	3%	43%	32%
Ukraine	0%	0%	44%	21%
United States	0%	0%	0%	0%
Vietnam	0%	0%	44%	0%
South Africa	0%	3%	0%	0%

Note: For sugar and HFCS EU TRQs and specific tariffs are modelled explicitly.

Source: Authors' calculations based on ITC (2023), simple average over HS6 codes.

Table B4c EU preferential import tariffs (AVEs) in AGMEMOD baseline simulation – Meat and Dairy products, 2032

Country/Product	Beef	Pork	Poultry	Lamb	Fresh Dairy	Cheese	SMP	WMP
MFN	38%	14%	13%	35%	30%	32%	19%	11%
Argentina	0%	0%	0%	0%	0%	0%	0%	0%
Canada	0%	7%	8%	1%	0%	0%	0%	0%
Switzerland	0%	12%	0%	0%	0%	32%	0%	0%
Chile	0%	13%	0%	0%	0%	0%	0%	0%
China	37%	9%	13%	7%	12%	10%	0%	0%
Colombia	0%	0%	0%	0%	0%	0%	0%	0%
Egypt	0%	13%	0%	0%	0%	0%	0%	0%
Indonesia	0%	13%	0%	0%	0%	0%	0%	0%
India	0%	0%	0%	0%	0%	0%	0%	0%
Iran	0%	0%	5%	0%	11%	0%	0%	0%
Israel	0%	0%	0%	0%	0%	0%	0%	0%
Japan	0%	11%	11%	1%	0%	0%	0%	0%
South Korea	38%	14%	13%	34%	30%	0%	0%	0%
LDC - North Africa	0%	0%	0%	0%	0%	0%	0%	0%
LDC - SSA Africa	0%	0%	0%	0%	0%	0%	0%	0%
LDC - Southern Asia	0%	0%	0%	0%	0%	0%	0%	0%
Mexico	0%	13%	0%	0%	0%	0%	0%	0%
Nigeria	38%	0%	13%	34%	30%	0%	0%	0%
Norway	0%	0%	0%	0%	0%	0%	0%	0%
Pakistan	0%	1%	0%	1%	0%	0%	0%	0%
Peru	0%	13%	0%	0%	0%	0%	0%	0%
Philippines	0%	0%	0%	0%	0%	0%	0%	0%
Paraguay	0%	1%	1%	1%	3%	0%	0%	0%
Russia	0%	0%	0%	0%	0%	0%	0%	0%
Thailand	0%	13%	0%	0%	0%	0%	0%	0%
Turkey	0%	13%	0%	0%	0%	0%	0%	0%
Ukraine	28%	0%	12%	24%	30%	32%	0%	0%
United States	0%	0%	0%	0%	0%	0%	0%	0%
Vietnam	0%	0%	0%	0%	0%	0%	0%	0%
South Africa	0%	13%	0%	0%	0%	0%	0%	0%

Source: Authors' calculations based on ITC (2023), simple average over HS6 codes.