Implications of Russia's War in Ukraine for the Global Agri-Food Sector – An Ex-Ante Assessment using Different Simulation Models

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Abstract

In light of Russia's war in Ukraine, three widely used trade and sector models were applied to assess: i) global food and nutrition security, ii) the effects on the bioeconomy, and iii) the implications for the European Common Agricultural Policy (CAP). Simulation results show that an export stop of agri-food commodities in Ukraine and Russia results in a substantial increase in global agri-food prices under short-term assumptions. However, the longer-term effects are much smaller due to global supply responses. The effects on food security depend on the importance of cereals in countries' diets. Furthermore, due to subsequent Gross Domestic Product declines, there may be further negative long-term implications for food security, especially in Africa. An additional scenario with a 10% increase in the global oil price shows that European Union (EU) biofuel production is heavily affected. The implementation of the initially envisaged CAP requirement of a set-aside of 4% of the farmed area would have little effect on EU cereal production, whereas a 10% reduction in fertiliser availability in the EU would lead to a decline in net production of cereals. A joint reduction in pig herd size and pork consumption could partly mitigate the negative consequences of reduced fertiliser availability, otherwise leakage would occur either through the import of pork into the EU for consumption or the production of EU pork meat for export markets. To mitigate the market effects of the war, EU policymakers should: i) encourage efficient (animal) nutrient use to offset fertiliser shortages and land use choices that increase market availability of food crops, ii) encourage restructuring of animal production in line with consumption developments to prevent leakage effects and ensure that non-food products are used efficiently as feed products, and iii) support vulnerable households to secure short-term food access.

Keywords

Ukraine; food security; biofuels; CGE; GTAP; DART; CAPRI

1 Introduction

The start of Russia's war against Ukraine on 24 February 2022 marked the outbreak of a major military conflict between two countries that both play an important role as exporters of: i) commodities for global agri-food markets, ii) energy-intensive fertilisers and iii) non-renewable energy sources such as crude oil, natural gas and coal (World Bank, 2022). Ukraine is one of the world's main exporters of grain and vegetable oils[1], and the blockade of its Black Sea ports has cut the country off from its main export infrastructure. As a result, large quantities of grain cannot reach the world market. All of this is taking place on top of the

[1] Between 2019 and 2021, an average of 8.1% of global imports of wheat, 12.2% of global imports of maize and other grains, and 5.4% of global imports of vegetable oils came from Ukraine (GTAP nomenclature, own calculations based on UN Comtrade data, 2022).

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since mid-2021 ongoing rising trend in global food prices which started as a result of the Covid-19 pandemic and various climatic events (see e.g. GLAUBEN et al., 2022; VON CRAMON-TAUBADEL 2022).

Responding to Russia's aggressions, some of the world's largest economies such as the European Union (EU), the United States of America (USA), Canada, Japan and other states, have imposed economic sanctions against Russia. These sanctions partly prohibit companies from trading goods and services with Russian companies, and many international firms have divested themselves of their operations in Russia altogether.

In summary, the economic repercussions of this conflict have already revealed global implications and are expected to lead to further disruptions in the near and medium-term future (CHEPELIEV et al., 2022a). For instance, as a potential policy response to Russia's invasion, restrictions on fossil fuel imports were introduced at an early stage. However, an 80-99% reduction in fossil fuel imports[2] from Russia by western and allied countries would have the short-term effect of reducing real incomes in the EU by 0.7-1.7% and increasing energy prices and transport prices by 8-11% and 5-6%, respectively (CHEPELIEV et al., 2022b).

Even without such steps, inflation in the Eurozone is projected to range between 5.5% and 7.7% in 2022, but may fall again to between 2.0% to 2.2% in 2023 (LIADZE et al., 2022; BEHRINGER et al., 2022). This is below the expected global inflation rate of 7.9 to 9.9% in 2022 and 4.9 to 6.5% in 2023, and far below the expected Russian inflation rate of 12.3-12.7% in 2022[3] (BEHRINGER et al., 2022).

Rising prices can have a wide range of distributional effects: poorer households (globally) tend to be more greatly affected by rising food prices due to their relatively high proportion of expenditure on food. Richer households (or households in wealthier countries) tend to be more negatively affected by rising energy prices. In particular, the immediate shortage of grain on the world market along with rising prices are a serious threat for the food security of households that spend a relatively large proportion of their income on food. The FAO Global Food Price Index reached a higher level in early 2022 than it did in the early 1970s when climatic events, a global recession and oil price shocks also converged. As a consequence, fears are growing that food security will deteriorate in many countries over the months and years to come, intensifying the rise in hunger seen in recent years, especially in Africa (FAO, 2021).

The looming food price crisis will affect countries in the Global South and North differently and via multiple channels. While soaring prices for grain commodities may increase farmers' income, especially in highly productive regions such as Europe and North America, the agri-food sector in these regions will also be negatively affected by rising input prices for fertiliser, fuel and feed (POLANSEK and MANO, 2022). Households in Sub-Saharan Africa (SSA) spend up to 40% of their income on food. In addition, local food production in Africa is also hampered by increased input prices. This is a potential trigger for political instability (KOHNERT, 2022). Food security in the MENA region (Middle East and North Africa), the South Caucasus and Turkey is potentially also under threat as Russia and Ukraine are major suppliers of wheat (GLAUBEN et al., 2022). However, some studies have also indicated that a major crisis may still be largely averted if other major cereal exporters refrain from imposing export restrictions (beggar-thy-neighbour policies) and instead even manage to increase their exports (BERKHOUT et al., 2022; GLAUBEN et al., 2022).

Nevertheless, the urgency for a response to this looming crisis has revived several decade-old policy debates: to what extent should natural resources be devoted to the production of bioenergy, if at all? How should the conservation of biodiversity and ecosystems be prioritised over food production? And how can climate change be mitigated in the light of short-term challenges that seem to suggest an intensification of food and bioenergy production in global agriculture?

At EU and member state level (e.g. in Germany), discussions are therefore ongoing as to how short-term policy reforms can help calm global food markets. One of the options being discussed is the use of fallow land in the EU for grain production. The Common Agricultural Policy (CAP) targets 4% of agricultural land to be fallow land in order to support biodiversity. If the EU were to abandon this target, the amount of cereals, wheat and maize produced globally could be increased, yet it remains open to debate as to whether the achieved increase in production would be worth the corresponding sacrifice in

[2] This refers to the EU, USA, Canada, Japan, Australia, New Zealand, South Korea, Hongkong, Taiwan, Singapore, Switzerland, Norway, Iceland and Liechtenstein (CHEPELIEV et al., 2022b).

[3] For 2023, BEHRINGER et al. (2022) expect inflation in Russia to rise to 14.3-15.9%.

biodiversity (LUCKMANN et al., 2022). Alternatively, some policymakers and Non-governmental Organisations (NGOs) are openly requesting a reduction in EU livestock production in order to free more cereals for human consumption or the removal of policies that support the production of biofuels (VON CRAMON-TAUBADEL, 2022).

For these reasons, the short-term and long-term effects of Russia's invasion of Ukraine are already subject to a growing body of economic literature. However, simulations and forecasts typically require assumptions to be made and may not allow straightforward comparisons due to differing underlying databases, modelling structures and assumptions.

This paper aims to add to the ongoing debate about what the most appropriate policy responses might be to the unfolding global crises in agri-food markets and the general economy. For this purpose, the effects of Russia's invasion of Ukraine are examined using three widely used equilibrium models. Rather than tailoring one specific model to the present situation within global agricultural markets, the approach taken in this article synthesises three distinct perspectives: i) GTAP, a comparative-static multi-region, multi-sector computable general equilibrium (CGE) model that has been extended to assess food and nutrition security effects, ii) DART-BIO, a dynamic-recursive multi-regional and multi-sectoral CGE model that features a detailed representation of the bioeconomy, both in terms of the production of agricultural and other biological resources, as well as the processing of these goods into food, fodder, bioenergy and other products made from biomass, and iii) CAPRI, a comparative-static multi-regional partial equilibrium model that represents the agricultural sector of the EU-27 at a very disaggregated level. CAPRI was developed for an analysis of the European Common Agricultural Policy (CAP) and consists of two separate modules: the global market module and the supply module.

In order to reduce the complexity of the model adjustments required, standard model configurations were used to simulate stylised scenarios that are as consistent as possible across the models with respect to their core assumptions. This implementation of stylised standard scenarios facilitated a comparison of simulations across all three models, which is a major strength of our approach. In addition, we are able to simulate other scenarios that exploit the specific features of each model. These additional results were then analysed against the background of the findings from the stylised joint scenarios of all three models. As a caveat, it should be noted that a detailed projection of available base data to the year 2022 was beyond the scope of the present analysis. However, this should barely affect the relative magnitude of the simulated effects (such as percentage price changes) which was the primary focus in our interpretation of the simulation results.

The paper is structured as follows: the results from simulations with each of the three models are presented in Sections 2 to 4, respectively, while Section 5 compares the selected model results and Section 6 discusses the findings. Section 7 concludes with policy recommendations. Additional results are documented in an online supplement (see the Appendix at the end of the paper).

2 Analysis based on GTAP

2.1 Brief Model Description

We applied a comparative-static version of a multi-region, multi-sector computable general equilibrium model that has been widely used for trade policy impact assessments. Specifically, this study used the standard V.7 Global Trade Analysis Project (GTAP) model that is well documented in CORONG et al. (2017) and the internet (www.gtap.agecon.purdue.edu). The standard GTAP model uses an Armington structure (ARMINGTON, 1969) to organise the demand for goods on international market. The GTAP model was initially developed for trade analysis and has recently been extended to facilitate the analysis of food security. For the purpose of this study, we used the GTAP Version 10 database with base year 2014 (AGUIAR et al., 2019), which has been aggregated to 27 sectors by keeping agricultural and food commodities as disaggregated as possible. The countries and regions are aggregated to 26 regions[4], with a focus on the detailed

[4] These regions are: ASIA (rest of Asia), Brazil, Cameroon, China, COMESA (members of the Common Market for Eastern and Southern Africa agreement), EAC (members of the East African Community), ECCAS (members of the Economic Community of Central African States), Egypt, Ethiopia, EU_27 (members of the European Union as of 2020), FORMSOV (rest of the former Soviet Union), India, Kenya, LATAM (Latin America), MEAST (Middle East), Nigeria, OCEANIA (countries of Oceania), REUROPE (rest of Europe), ROW (rest of world), Russia, SADC (members of the Southern African Development Community), South Africa, Ukraine, UMA (members of the Arab Maghreb Union) and USACAN (north American countries). For a complete list of countries, please see the supplementary material.

representation of six African regions and seven African countries.

By simulating a set of scenarios that examine the short to medium-term effects of a 90% export stop of agricultural and food commodities from Ukraine and, to varying degrees, from Russia, this section aims to assess the impact of the war on several food and nutrition security indicators (e.g. food prices, changes in consumer demand, expenditure shares, diets) in the Global South.

2.2 GTAP Scenarios

In order to examine the direct and future effect of Russia's invasion of Ukraine on food security, two short-term scenarios and one long-term scenario were simulated using the GTAP model (Table 1):

Table 1. Scenario description for the analysis with GTAP

Scenario	Scenario description
GTAP_UKR_st	90% reduction in agricultural and food exports from Ukraine, land treated as fixed factors, Armington elasticities halved
GTAP_UKR_RUS_st	90% reduction in agricultural and food exports from Ukraine and Russia, land treated as fixed factors, Armington elasticities halved
GTAP_UKR_RUS_lt	90% reduction in agricultural and food exports from Ukraine and Russia, standard GTAP closure and assumptions

*st = short-term, lt = long-term
Source: own table

The fall in Ukraine's agricultural exports reflects its reduced export capacity due to the blockade of its Black Sea ports. It is assumed that the sanctions imposed on Russia, counter-sanctions by Russia, and the partial exclusion of Russian banks from the SEPA payment settlement procedure are also manifested in the 90% reduction in agricultural and food exports from Russia. The reduction is realised in the model through a variable increase in the export tax, which rises until exports are reduced by 90%. In both short-term scenarios, the use of land is fixed, to consider that short-term land use adjustment are not possible. It is also assumed that in the short term Armington elasticities are halved to account for limited imports substitutability (see e.g., CHEPELIEV at al., 2022b). This is based on a less pronounced ability to adjust trade flows in the short term.

It is assumed that in the longer term, agricultural structures and international trade relations can adapt to reduced exports from Russia and Ukraine. Therefore, land use adjustment is possible and Armington elasticities are no longer halved.

2.3 GTAP Results

The GTAP model used in the present analysis has been extended to include several food security indicators to facilitate the analysis of food security impacts in different countries. For this reason, the focus of the results is on the prices for private households and the quantities they consume of Ukraine's most important agricultural exports under each of the three scenarios, respectively.

Table 2 shows that in the short term, a reduction in agricultural exports from Ukraine (scenario GTAP_UKR_st) and additionally from Russia (scenario GTAP_UKR_RUS_st) leads to expenditure-weighted increases in consumer prices (excluding Ukraine and Russia) by 3.0% and 6.4%, respectively. This effect is less pronounced for all agricultural products since substitution can take place and some products are less dependent on Ukrainian/Russian exports than others. However, Table 2 also shows that the price increases in primary agricultural products (Agri) also induce an almost proportional increase in consumer prices for processed agri-food products (Agri-food).

In the long run, however, the sharp reduction in agricultural exports from Ukraine and Russia will be compensated by both the normalisation of trade[5] flows and land use adjustments, which will level the cereal price increase from 6.4% to 1.8% (scenario GTAP_UKR_RUS_lt).

Table 2. GTAP percentage change deviation of average global consumer prices in the scenarios compared to base year, excluding Russia and Ukraine

Scenario	Product groups		
	"Cereals"	"Agri"	"Agri-food"
GTAP_UKR_st	3.0%	0.5%	0.5%
GTAP_UKR_RUS_st	6.4%	0.9%	1.0%
GTAP_UKR_RUS_lt	1.8%	0.7%	0.6%

Note: **"Cereals"** = rice, wheat, maize, barley, other grains; **"Agri"** = "cereals" + vegetables and fruit, oil seeds, sugar cane and beat, spices and other crops, live cattle, other animal products, raw milk; **"Agri-food"** = "agri" + cattle meat, pork and poultry, vegetable oils and fats, dairy products, processed rice, sugar, other food products. Aggregated consumer prices are weighted by private expenditure of the respective commodities.
Source: Own table, based on GTAP simulation results

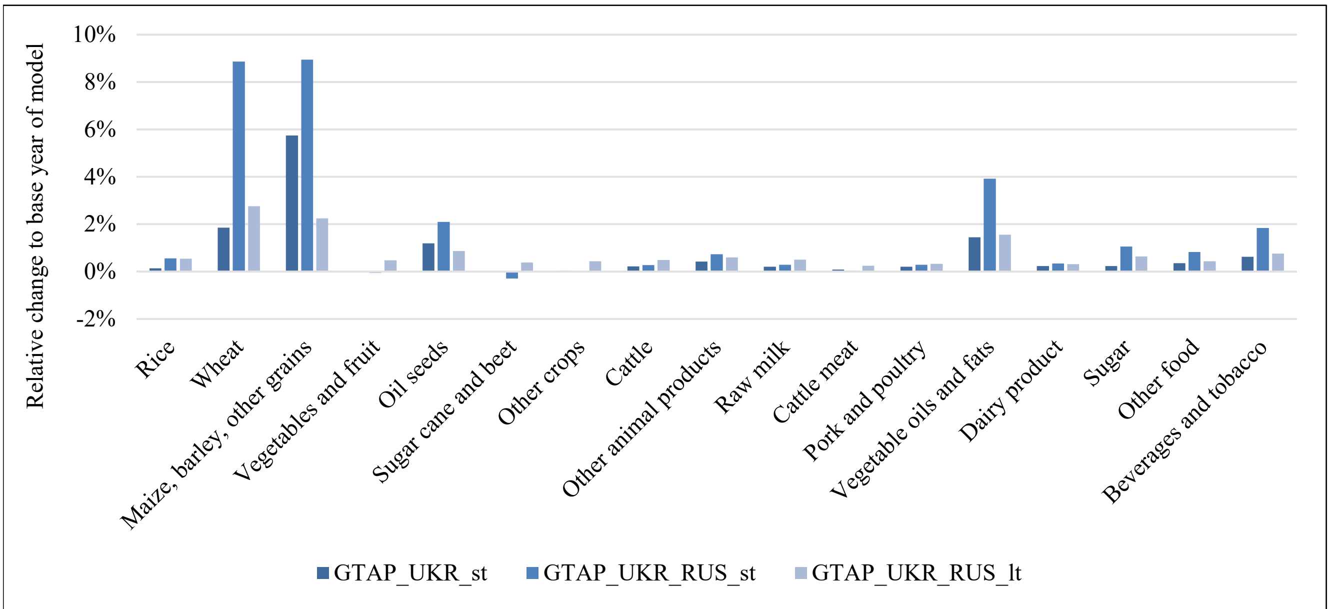
[5] Expressed in original Armington elasticities no longer being halved.

At first sight, these relative effects may appear modest. However, this is due to the aggregation of product categories used in Table 2. A more nuanced picture emerges in Figure 1, which presents a breakdown of private expenditure-weighted consumer prices for all three GTAP scenarios. In particular, “wheat”, “maize, barley, other grains” and “vegetable oils and fats”, which are Ukraine's most important export products, exhibit more pronounced simulated price changes.

Other differences in price changes can be observed by product and region. Using wheat as an example, Figure 2 breaks down the price increases by the individual regions in the model.

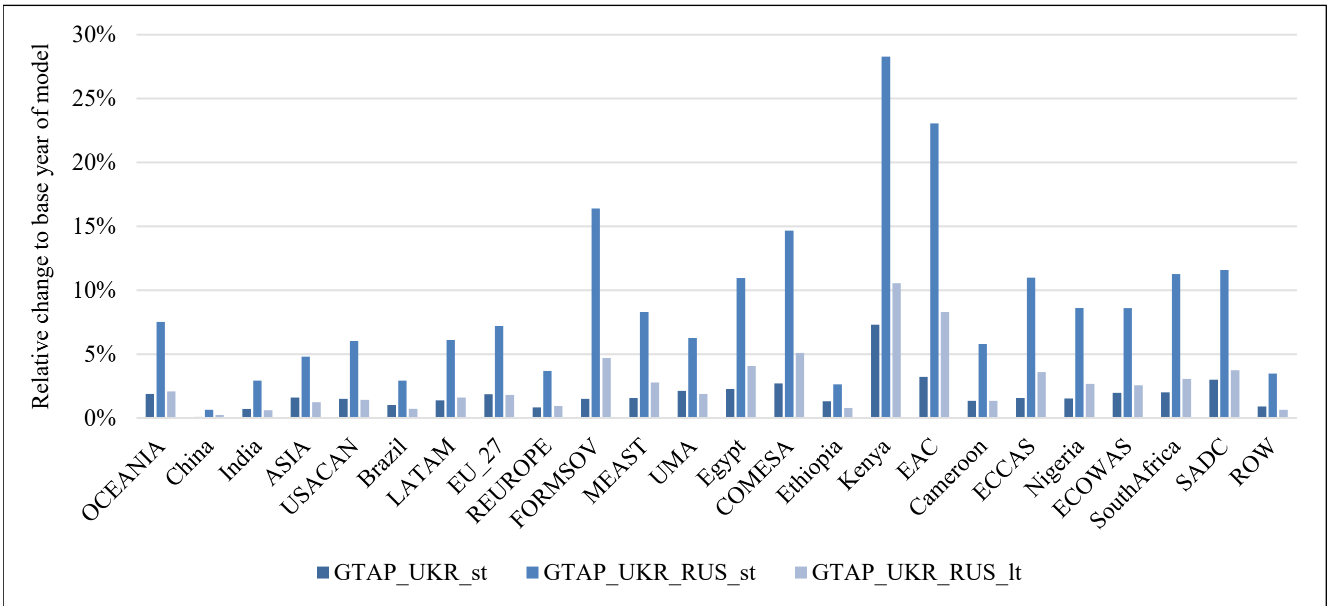
Figure 2 shows that the simulated consumer price increases for wheat in Africa rise by 2.6-28.2% in the event of a short-term decline in agricultural exports from Ukraine and Russia (scenario GTAP_UKR_RUS_st). In industrialised and emerging countries, this price increase amounts to just 0.7-7.2%.

Figure 1. Percentage changes of global consumer prices in the scenarios compared to base year



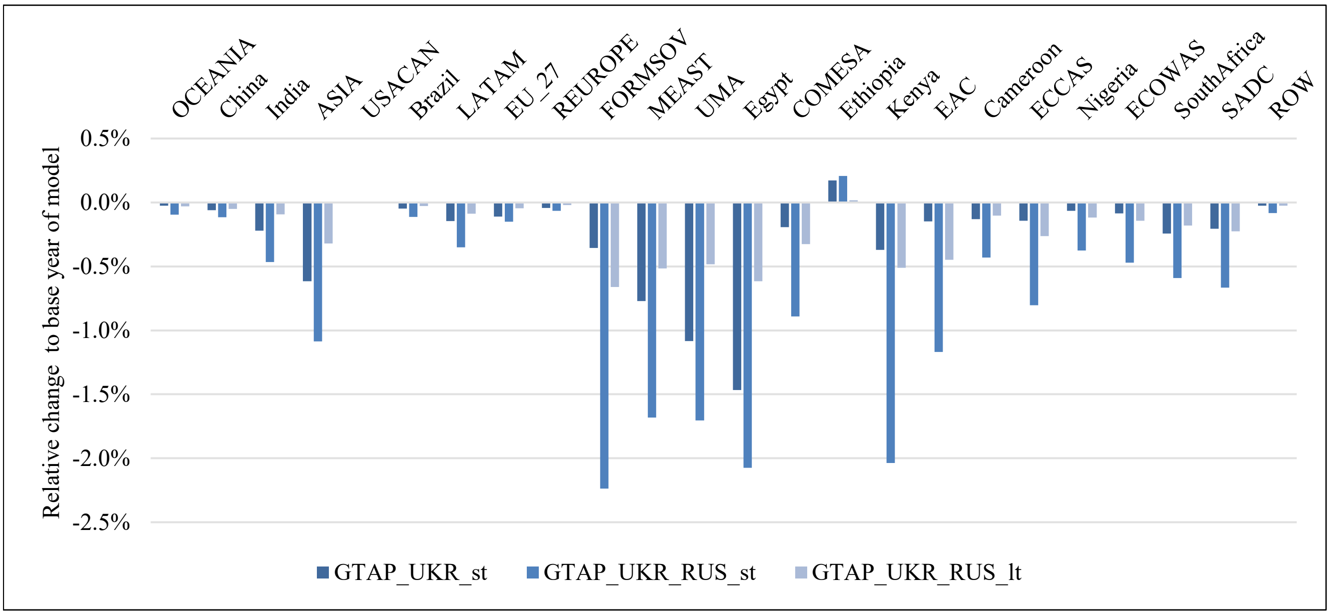
Note: Global private expenditure-weighted change in private consumption prices, excluding Russia and Ukraine.
Source: Own figure, based on GTAP simulation results

Figure 2. Change in consumer prices for wheat under the three GTAP scenarios



Note: Change in private consumption price by region for wheat.
Source: Own figure, based on GTAP simulation results

Figure 3. Regional changes (%) in private household demand for cereals in the three GTAP scenarios



Note: Change in private household demand of cereals (includes "wheat", "rice", "maize, barley, other grains"), unweighted
Source: Own figure, based on GTAP simulation results

Across the scenarios, the expenditure shares for "Cereals" (rice, wheat, maize, barley, other grains) remain constant, and are substantially higher in Africa at an average of 3.3% compared with other regions where the average is 0.5%. The high expenditure shares for cereals in connection with rising prices, falling GDP and falling total expenditure on food lead to a greater decline in private household demand for cereals (see Figure 3). This can be interpreted as representing an increasing threat to food security in the Middle East and African countries, but also in countries of the Former Soviet Union if they were also to experience reduced exports from Ukraine and Russia (as assumed in the model).

The simulations show that a 90% reduction in agricultural exports from Ukraine and Russia would lead to large increases in private consumption prices. The increases occur mainly in "wheat", "maize, barley, other grains" and "vegetable oils and fats", with large regional differences. The relatively high share of expenditure on "cereals" in African countries, as well as large price increases in Africa and the Middle East, lead to additional threats to food security in these regions.

This can be explained by the fact that in regions such as MEAST, North Africa and parts of East Africa, cereals play an important role in the diets of the average consumer. In Ethiopia for instance, consumers spent more than 14% of their income on cereals in the base year. However, Ethiopia has a relatively high self-sufficiency rate with regard to cereals, therefore the effect on the cereal expenditure share and consequently dietary composition is rather modest in the three scenarios (see Table 3).

Table 3. Change in dietary composition of selected African regions, scenario GTAP_UKR_RUS_st vs. base year

	MEAST	UMA	Egypt	COMESA	Ethiopia	Kenya
Cereals	-1.00%	-1.17%	-0.17%	-0.16%	-0.09%	-0.33%
Vegetables and fruit	0.49%	0.32%	0.71%	0.05%	-0.03%	0.29%
Dairy products	0.31%	-0.10%	-0.67%	0.02%	0.06%	-0.36%
Animal products	0.00%	0.09%	-0.17%	-0.01%	0.07%	-0.01%
Sugar	0.01%	0.13%	0.47%	0.03%	0.07%	0.15%
Other food	-0.39%	0.10%	0.29%	0.04%	0.09%	0.15%
Oilseed/fats	0.35%	-0.05%	-0.13%	-0.11%	0.26%	0.03%
Total food cons.	**-0.75%**	**-0.70%**	**-1.22%**	**-0.31%**	**0.28%**	**-0.99%**

Dark blue = noticeably (< –0.15 %) negative development; light blue = noticeably (> 0.15 %) positive development.
Source: Own table, based on simulation results

By contrast, Middle East, UMA (members of the Arab Maghreb Union), Egypt and Kenya show a comparably low expenditure share on cereals, but due to their low cereal self-sufficiency rate, they greatly depend on cereal imports from the world market, which drives up the expenditure share e.g. by 25% (MEAST) and 15% (Egypt) (see full set of results in the online supplement). Furthermore, Table 3 shows that in most African countries, overall food consumption decreases. An examination of the dietary composition reveals that the share of cereals in the diet is reduced, while in many regions vegetable and fruit consumption increases. We observe that the consumption of dairy and meat products tends to decrease in many regions. This indicates a negative impact on food security, particularly via reduced energy intake and reduced consumption of animal protein (Table 3).

3 Analysis based on DART-BIO

3.1 Brief Model Description

DART-BIO is a dynamic-recursive multi-regional and multi-sectoral model of the world economy and is calibrated to an extended version of the Global Trade Analysis Project (GTAP) 9 database (AGUIAR et al., 2016; DELZEIT et al., 2021). The model includes 21 aggregated regions, with a focus on the EU and major global players in agricultural markets. DART-BIO features a detailed representation of the bioeconomy both in terms of the production of agricultural and other biological resources as well as the processing of these goods into food, fodder, bioenergy and other products made from biomass; in total, 40 out of 51 sectors in the model are involved in bioeconomy activities. The 21 factors of production include 18 different land types based on the GTAP-AEZs (agro-ecological zones) that cover six different growing period lengths and three different climatic zones. In addition, land is divided into cropland, pastureland and forestland (DELZEIT et al., 2021).

3.2 DART Scenarios

In order to investigate the direct effects of the war on the world market for agricultural goods and how these markets adapt in the long term, the following scenarios were examined at different time horizons:

The short-term scenarios are implemented in the base year of the DART-BIO model, 2011. The long-term scenario assumes a shock in 2019, while, in contrast to the short-term scenario, land-use adjustments between sectors are possible again. Unfortunately, the available data do not allow for an explicit consideration of Ukraine in the aggregation of the CGE model. In the DART-BIO aggregation, however, Ukraine is included in "Rest of former Soviet Union" (FSU), which is why FSU is used as a proxy for Ukraine in the scenarios. The war that Russia is waging against Ukraine is associated with far-reaching uncertainties. As Russia is also a major exporter of fossil fuels, these uncertainties also affect the development of the oil price. Therefore, an additional scenario is assumed, which includes a short-term increase of global oil prices by 10% (related to the DART-BIO base year 2011).

Table 4. Scenario description for the analysis with DART-BIO

Scenario	Scenario description
DART-BIO_UKR_st	Reduction in agri-food exports by Ukraine to zero, land use adjustments **are not** possible (compared to baseline_st in 2011)
DART-BIO_UKR_RUS_st	Reduction in agri-food exports by Ukraine and Russia to zero, land use adjustments **are not** possible (compared to baseline_st in 2011)
DART-BIO_UKR_lt	Reduction in agri-food exports by Ukraine to zero, land use adjustments **are** possible (compared to baseline_lt in 2019)
DART-BIO_UKR_RUS_lt	Reduction in agri-food exports by Ukraine and Russia to zero, land use adjustments **are** possible (compared to baseline_lt in 2019)
DART-BIO_UKR_st (oil price +10%)	DART-BIO_UKR_st plus an increase of global oil prices by 10%
DART-BIO_UKR_RUS_st (oil price +10%)	DART-BIO_UKR_RUS_st plus an increase of global oil prices by 10%

*st = short-term, lt = long-term
Source: Own table

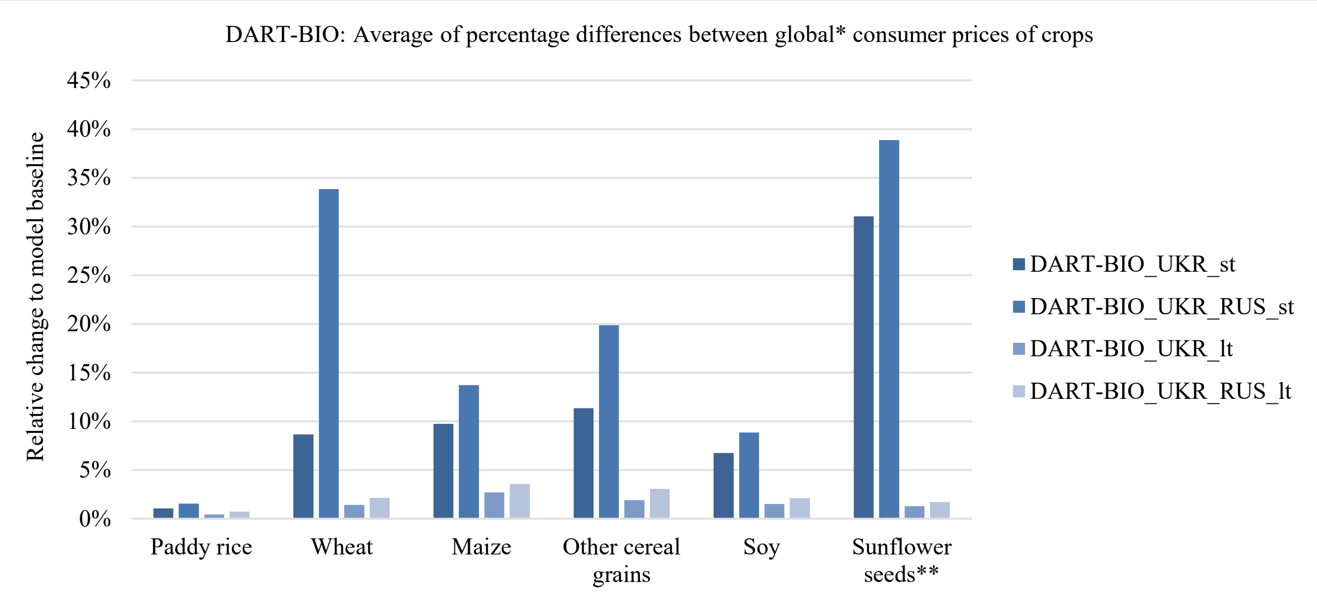
3.3 DART Results

The focus of the results is on vegetable oils and biofuel products as they are part of the main feature of DART-BIO.

3.3.1 Results regarding Crops and processed Agricultural Products

In the short term (scenarios DART-BIO_UKR_st and DART-BIO_UKR_RUS_st), there is no change in agricultural production in the regions (except for FSU and RUS) as this is "not allowed" by the design of the scenarios.

Figure 4. Simulated consumer price changes for selected crops in DART-BIO



*Average (across regions) of price changes excluding FSU and RUS. **The exact product description in DART-BIO is "other oil seeds".
Source: Own figure, based on simulation results

The simulation results (Figure 4) show that in the short term, consumer prices of agricultural crops rise globally (excluding FSU and RUS) on average from 1% (paddy rice) to 31% (sunflower seeds[6]), when the FSU stops exporting agricultural crops (scenario DART-BIO_UKR_st). These effects are amplified when there are also no exports from RUS (scenario DART-BIO_UKR_RUS_st). The increases in the event of an additional export stop by Russia are very high in some cases: in this case, the consumer price for wheat rises globally on average by 34% (from a 9% increase in the DART-BIO_UKR_st scenario), and 39% in the case of "sunflower seeds". In the long run, it is possible for countries to adapt the production structure to the new conditions. With the exception of sunflower oil, the price increase in the long-term scenarios for the remaining vegetable oils is a maximum of 2% compared to the baseline scenario in 2019. The consumer price of "sunflower oil" is still 7-8% higher compared to the baseline.

Like global consumer prices, global producer prices for agricultural goods increase under the scenarios (not shown in the figures; see detailed simulation results in the online supplement). The products that are among the most important agricultural exports from Ukraine and Russia obviously show the greatest increases. Global producer prices for "sunflower seeds" jump in the short term by 27% in the DART-BIO_UKR_st scenario, and by up to 31% in the DART-BIO_UKR_RUS_st scenario. When FSU stops exporting agricultural products (scenario DART-BIO_UKR_st), producer prices for wheat rise by 6% in the short term. However, an additional export stop by Russia (scenario DART-BIO_UKR_RUS_st) leads to a huge 24% price increase for wheat in the short term. Nevertheless, the long-term changes in global producer prices are quite small as countries can adapt their production structure (scenarios DART-BIO_UKR_lt and DART-BIO_UKR_RUS_lt).

Overall, the scenarios show that in the short term (scenarios DART-BIO_UKR_st and DART-BIO_UKR_RUS_st), export bans by Ukraine (i.e. FSU) and Russia are associated with sharply rising global prices for consumers. In the longer term, these drastic price increases dwindle to an increase of 1-3% compared to the baseline of the DART-BIO model, as the crop composition in countries adjusts to the new situation due to the land use adjustments. Like consumer prices, in the long term producer prices virtually fall back to pre-war levels.

3.3.2 Results regarding Biofuels

The production of biofuels is also affected by Russia's invasion of Ukraine and the associated export ban on agricultural goods from Russia and Ukraine (or FSU).

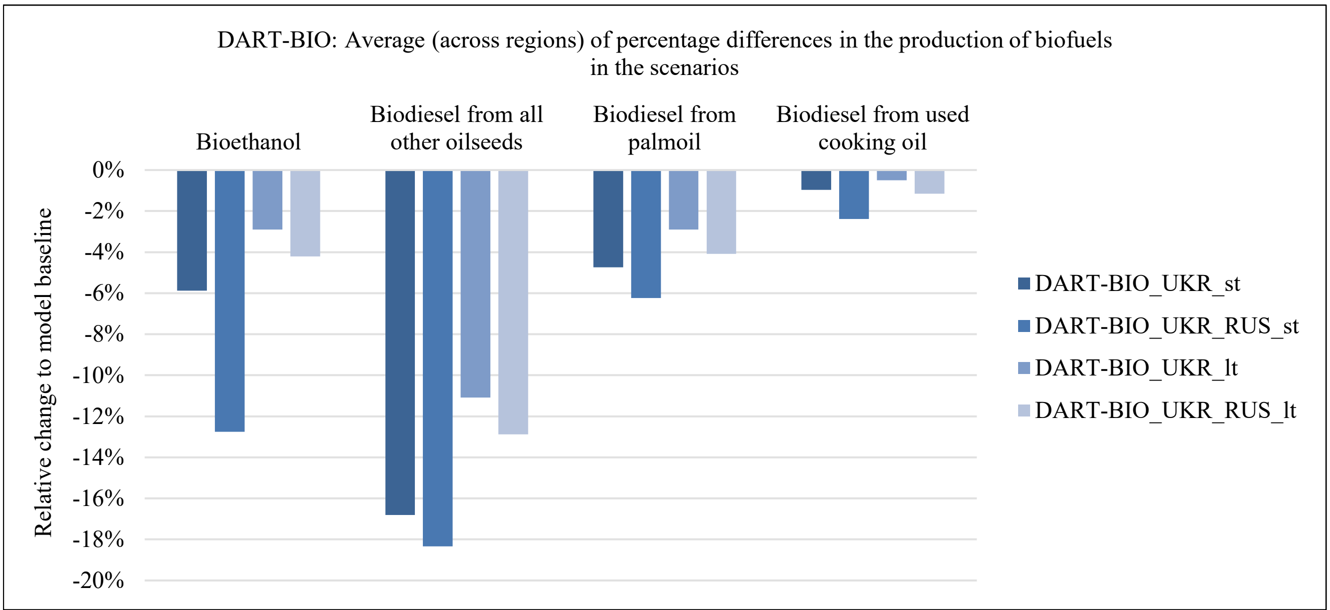
In addition, the war-related effects on international agricultural commodity markets are accompanied by national production restrictions in the biofuel

6 Whenever "sunflower seeds" are mentioned in chapter 4, it refers to the product group "Other oil seeds" in DART-BIO.

sector. Figure 5 shows that, under all scenarios, global biofuel production decreases across regions.

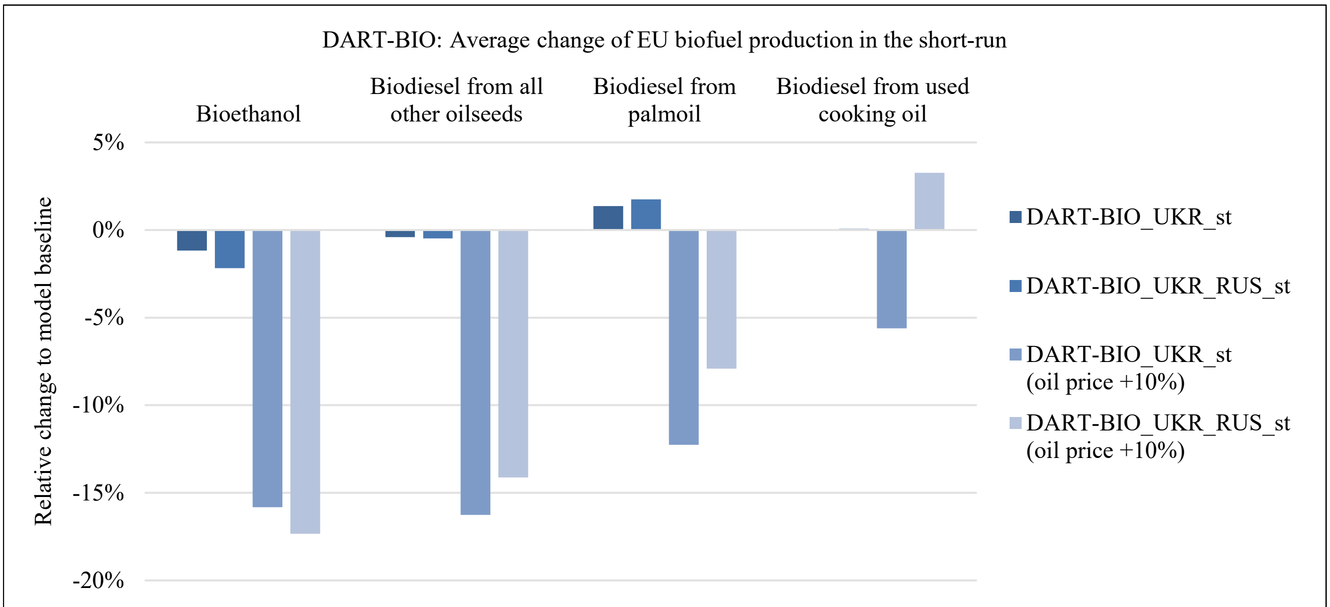
One of the reasons for this reduction in biofuel production is the rise in feed cost: the change in "biodiesel from all other oilseeds" in the short run (Figure 5) is mainly due to an 88-90% reduction in production (and exports of vegetable oils) in the FSU (which includes Ukraine) and also due to an increase in global consumer prices. Compared with the global average, it is striking that the changes in biofuels produced in the EU are only minimal in the short term (see Figure 6). This is because the EU biofuel mandate according to the Renewable Energy Directive sets a fixed percentage share of energy consumption in the transport sector that has to be fulfilled by biofuels. Therefore, the size of the transport sector determines the amount of biofuels consumed in the EU regardless of price changes for biofuels. Practically, mineral oil companies are required to blend biofuels with fossil fuels to a certain percentage and have to pay a penalty otherwise. However, EU biofuel production is more greatly affected when an oil price increase is also

Figure 5. Simulated changes in biofuel production under DART-BIO



Source: Own figure, based on simulation results

Figure 6. Simulated change in EU biofuel production under DART-BIO scenarios



Source: Own figure, based on simulation results

simulated: in the short-term scenarios, there is a 0.4-0.5% decrease in the production of "biodiesel from all other oilseeds", but an additional 10% increase in oil prices leads to a decrease in production of 14.0-16.5%. The reason for this lies in the impact of increasing oil prices on the size of the transport sector. As oil prices increase, total energy consumption in the transport sector decreases. While the percentage biofuel quota remains the same, the absolute amount of biofuels needed to fulfil the mandate is reduced, resulting in a lower demand for biofuels by mineral oil companies and a lower production of biofuels.

4 Analysis based on CAPRI

4.1 Brief Model Description

The CAPRI model represents the agricultural sector of the EU-27 at a very disaggregated level. It was developed with a view to policy analysis of the CAP and consists of two separate modules: the global market module and the supply module. A total of 60 agricultural commodities are considered in both modules (GOCHT et al., 2017; BLANCO et al., 2019). The world market module comprises a total of 40 trade blocs and country aggregates, whereby trade flows are modelled within this module using an Armington structure (ARMINGTON, 1969). The supply module covers the EU-27 at a subnational level with a total of 244 NUTS-2 regions, and is thus much more disaggregated than the global market module. The production activities of the 60 agricultural goods are split into an intensive and an extensive variant. Each of the 244 NUTS-2 regions can be regarded as a representative region farm supply model, whereby the output of crops and animal products is modelled using the maximisation of a profit function. Markets in CAPRI clear in physical units (in 1000 metric tonnes) using behavioural demand and supply functions. The base year of the CAPRI model used here is 2017 (BRITZ and WITZKE, 2014; GOCHT et al., 2017; BLANCO et al., 2019).

The global market module and supply module are solved sequentially until both modules converge. Commodity prices from the global market module are fed into the supply module, which in turn determines supply and feed demand on the global market in the market module. The consistent determination of agricultural demand, production, trade and market-clearing prices at the global and disaggregated level is one of CAPRI's key strengths, which is particularly advantageous for the ex-ante analysis of policies and economic shocks (BRITZ and WITZKE, 2014; GOCHT et al., 2017; BLANCO et al., 2019).

4.2 CAPRI Scenarios

The EU is one of the world's largest cereal exporters and thus has a certain leverage to physically offset the reductions in cereal exports from Russia and Ukraine. With the aim of boosting cereal production and exports, one possible policy at EU level is to (temporarily) suspend the requirement to leave 4% of arable land fallow for reasons of biodiversity conservation. Additional uncertainty on the world and EU markets is due to the reduced availability of fertiliser owing to rising energy prices and lower exports from major suppliers. Taking pork production as an example of animal production activities that are intensive in cereal consumption (at least prior to the market price increases), different additional scenarios were also calculated. The possibilities of reducing the production and consumption of pork were investigated, since a substantial part of the grain produced serves as input for this production sector, but the interaction of synthetic fertiliser availability with impacts of manure availability from pork production are also of interest. In this context, the following scenarios were considered (Table 5):

Table 5. Scenario description for the analysis with CAPRI

Scenario	Scenario description
Baseline	Implementation of the CAP of 2014-2020.
CAPRI_UKR_RUS	Baseline + no cereal exports from Ukraine and Russia
Other scenarios	
CAPRI_NewCAP	No cereal exports from Ukraine and Russia + 4% of cultivated agricultural land reserved as fallow land
CAPRI_Fertiliser	No cereal exports from Ukraine and Russia + a 10% reduction in fertiliser use in the EU
CAPRI_HerdSize	CAPRI_Fertiliser + a reduction in the original pig herd size to 70%
CAPRI_Cons	CAPRI_Fertiliser + a reduction in pork meat consumption to 70%
CAPRI_Cons_HerdSize	CAPRI_HerdSize + CAPRI_Cons

Source: Own table

4.3 CAPRI Results

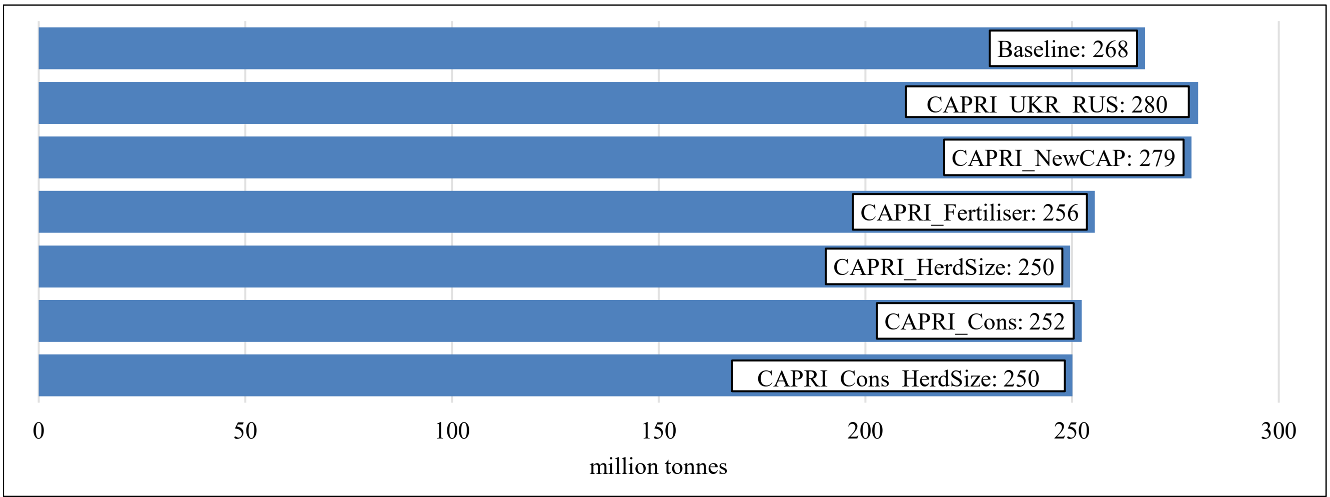
In the CAPRI_UKR_RUS scenario, Ukraine and Russia do not export any cereals. Since both countries are among the world's largest exporters of cereals, increases in the world market price incentivise European producers to expand their production. As a result, EU net cereal production increases by 12 million tonnes from 268 million to 280 million tonnes (see Figure 7). The increase in world market prices makes it relatively more attractive for European producers to export to the world market. Therefore, net cereal exports increase by 16 million tonnes to a total of 35 million tonnes. This corresponds to almost a doubling of net exports of cereals.

Figure 7 shows that the full implementation of the 4% target (scenario CAPRI_NewCAP) would only lead to a minimal reduction in the EU's net production by 1 million tonnes (-0.6%) and net exports by just 1 million tonnes (-2.6%) relative to the CAPRI_UKR_RUS scenario.

Thus, the availability of fertilisers has a much greater effect on the production and export of cereals than the implementation of the 4% fallow target. If the availability of fertiliser in the EU is reduced by 10% (see Figure 7, CAPRI_Fertiliser scenario), net production in the EU will fall by 24 million tonnes (-8.9%) compared with the CAPRI_UKR_RUS scenario, and by 12 million tonnes relative to the baseline scenario before the war. However, net exports will fall by 19 million tonnes, which is slightly more than half the exports under the CAPRI_UKR_RUS scenario (-52.9%). Relative to the pre-war baseline, net exports would still fall by 3 million tonnes under the CAPRI_Fertiliser scenario.

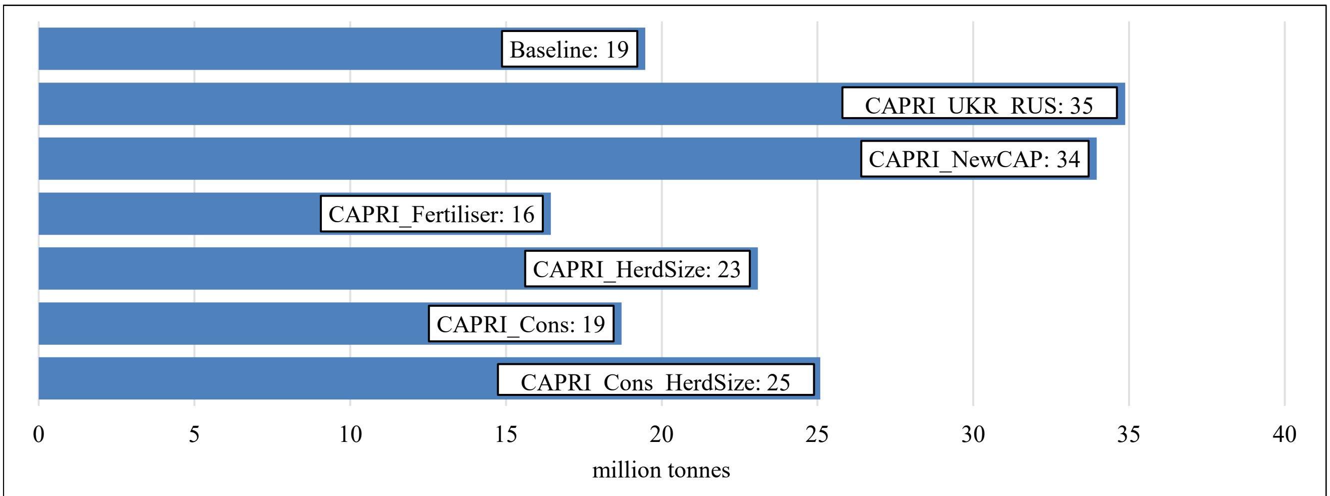
Reducing the herd size of pigs and pork consumption can mitigate some of the negative consequences of reduced fertiliser availability in terms of net exports of cereals (see Figure 8). The greatest effect comes from a joint reduction in herd sizes and

Figure 7. Simulated effects on EU net production of cereals under CAPRI scenarios



Note: Cereals in CAPRI include wheat, barley, maize, paddy rice, rye, oats, other cereals (excl. rice).
Source: Own figure, based on simulation results

Figure 8. Simulated effect on EU net exports of cereals under CAPRI scenarios



Note: Cereals in CAPRI include wheat, barley, maize, paddy rice, rye, oats, other cereals (excl. rice).
Source: Own figure, based on simulation results

consumption, which leads to an increase in European net exports of 9 million tonnes compared with the scenario featuring a 10% reduction in fertiliser use. A simultaneous reduction in the consumption and production of pork is important in this case, otherwise leakage by additional exports or imports of pork meat will occur.

Overall, each policy entry point has different advantages and disadvantages ("There is no such thing as a free lunch"). Increased prices for cereals (viewed in isolation) provide an incentive for European farmers to expand production, resulting in higher net production and higher net exports (Figure 7, Figure 8). However, abandoning the 4% fallow land target as a potential policy reaction to the CAPRI_UKR_RUS scenario will lead to very little change in net production and net exports but would potentially harm the objective of biodiversity (insect/bird) protection. Nevertheless, the reduction in fertiliser availability more than offsets these price-induced increases in cereal production compared to the baseline (Figure 7). It seems obvious to counteract these production declines by reducing the production and consumption of pork, as cereals are an essential ingredient in animal feed. However, the manure contribution of animals in crop production should not be underestimated. A reduction only in either the size of the pig herd or in pork consumption is detrimental, as it encourages leakage via trade: either more pork is produced for export or additional pork is imported into the EU for human consumption which means that cereals are used for pig meat production elsewhere. Only a joint reduction in pig herd size and pork consumption will really free up grain for global food markets. However, in this scenario (CAPRI_Cons_HerdSize), the EU's net exports of cereals would still fall short of the CAPRI_UKR_RUS scenario by about 10 million tonnes.

5 Model Comparison

Due to the different model assumptions, data years, and units and restrictions on available sectoral and regional aggregations, a comparison of different results between models can only be carried out to a limited extent, even though the stylised standard scenarios were chosen for being as similar to each other as is allowed by each of the three models in their standard versions.

Nevertheless, Table 6 presents an overview of the simulated price changes for wheat and maize in the scenarios GTAP_UKR_RUS_lt, DART-BIO_UKR_RUS_lt and CAPRI_UKR_RUS.

Table 6. Relative change in average global* consumer prices for wheat and maize

Model	Scenario	Wheat	Maize
GTAP	GTAP_UKR_RUS_lt	2.8%	2.3%**
DART-BIO	DART-BIO_UKR_RUS_lt	2.2%	3.6%
CAPRI	CAPRI_UKR_RUS	0.9%	0.5%

*Without Ukraine and Russia, **Due to the available data and product aggregation, barley and rye are included for GTAP in addition to maize.
Source: Own table, based on simulation results

GTAP and DART-BIO show that in the long term ("long term" due to the non-fixed production factor land), an export stop by Russia and Ukraine will increase consumer prices for maize and wheat by 2.2-3.6% compared with the respective baseline. The changes in CAPRI, however, are lower and in the range of 0.5% to 0.9%.

Considering the wheat prices in the scenarios of the individual models (see Figure 9), it is noticeable that the price developments show regional differences: in Africa, the change in wheat price for consumers is between 2.3 to 2.6 percentage points higher than in Europe, depending on the model. This highlights the additional threat to food security in Africa posed by Russia's war in Ukraine.

With the exception of the GTAP model, these patterns are observed for consumer prices for maize in DART-BIO and CAPRI, where the relative price changes in Africa/Middle East in DART-BIO and in Africa in CAPRI are higher than the respective simulated relative price changes in Europe.

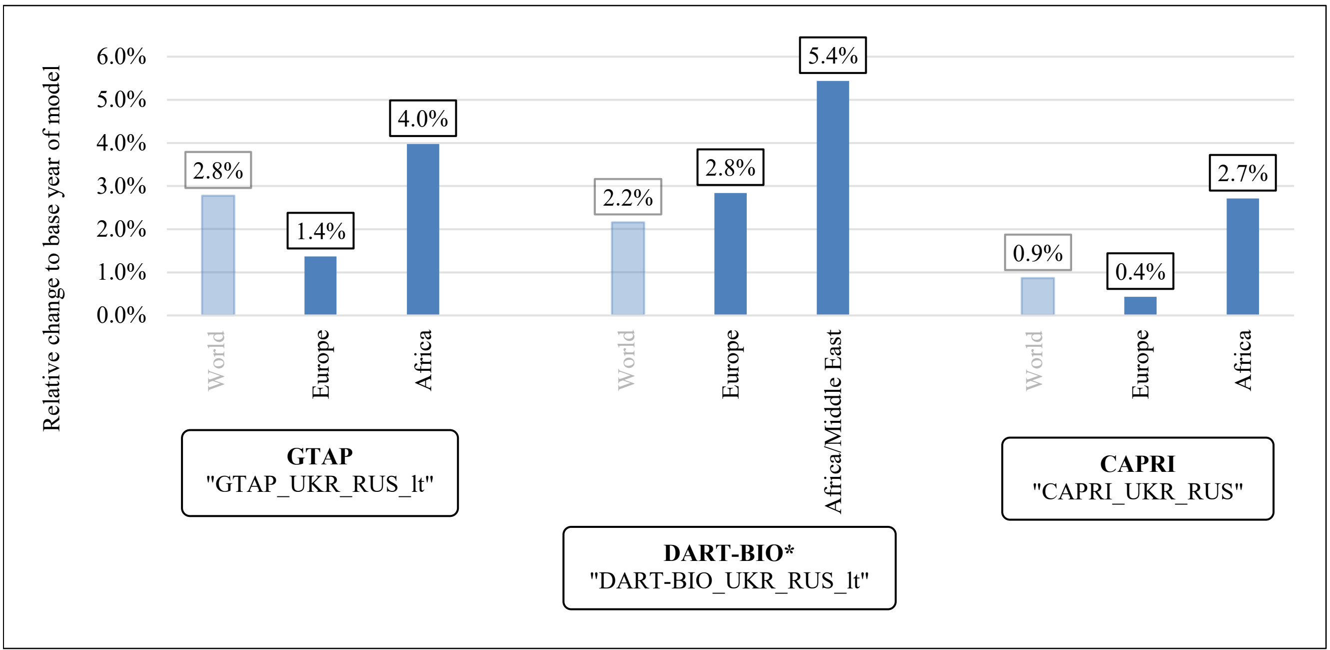
Table 7 compares relative changes in the EU's net exports of cereals. Even before the war, the EU was a net exporter of cereals. Overall, the three models show that the EU's net exports of cereals increase sharply due to Russia's war in Ukraine, including in the long term, namely by 21.7-85.4%. This indicates that some of the long-term production adjustments from a longer-lasting export stop from Ukraine and Russia would, according to the models, rely on an expansion of production in the EU.

6 Discussion

The simulation results from the three different models suggest that future policy responses to Russia's invasion of Ukraine as a major threat to global supplies of food, fertiliser and energy should take into account the fact that these three issues are interlinked and cannot be viewed separately from each other in any future policy design.

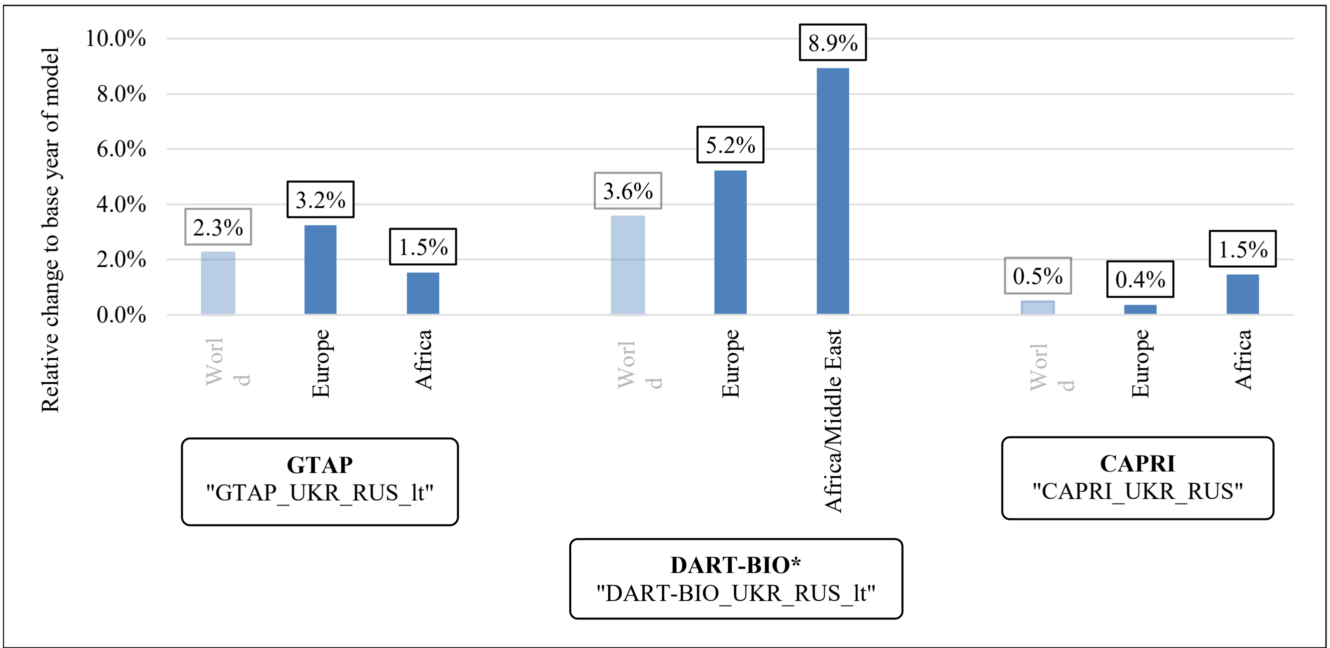
All three models confirm what markets have partly shown during the first half of 2022: Russia's invasion of Ukraine reduces the global export supply of cereals and oilseeds, which leads to substantial short-term price increases. Furthermore, this means that private household expenditure for cereal consumption needs to increase in many developing countries. However, even if Ukrainian (and Russian) exports continued to be blocked for a longer period, global land use

Figure 9. Comparison of simulated long-term global consumer prices for wheat



Note: Product aggregations of the models are similar but not identical due to data restrictions, which limits the comparability of the results. *In the DART-BIO aggregation, North Africa and the Middle East are combined into one region.
Source: Own figure, based on simulation results

Figure 10. Comparison of simulated long-term global consumer prices for maize



Note: Product aggregations of the models are similar but not identical due to data restrictions, which limits the comparability of the results. *In the DART-BIO aggregation, North Africa and the Middle East are combined into one region.
Source: Own figure, based on simulation results

Table 7. Relative change in EU net exports of cereals compared with the base situation of the respective models

Model	Scenario	Relative increase in net exports of cereals
GTAP	GTAP_UKR_RUS_lt	85.4%
DART-BIO	DART-BIO_UKR_RUS_lt	21.7%
CAPRI*	CAPRI_UKR_RUS	66.3%

*Calculations of relative change in net exports of cereals are based on Euro values.
Source: Own table, based on simulation results

change would adjust to the price signals such that price levels prior to the invasion could eventually be restored.

In this respect, it should be noted that none of the three models is designed to take potential sustainability effects of land use changes into account. While global food production in combination with global agri-food trade seem to be capable of compensating for the losses in export supplies under the simulated scenarios, future analyses would have to take into account the potential effects on deforestation, biodiversity, water footprints and climate-related emissions (e.g. due to agricultural expansion in wetlands). In addition, a certain share of the 'globally missing' cereals would, according to the simulation results, come from increased production in the EU, which highlights the importance of EU agricultural production for global agri-food markets.

The CAPRI model scenarios on fertiliser reduction (CAPRI_fertiliser) and fallow land (CAPRI_NewCAP) highlighted in this context the importance and dependence on fertilizer for high yields in relation to land use changes. Beyond the actual context of Russia's invasion of Ukraine, these scenarios could also be interpreted with respect to general political targets under the EU's Green Deal. If an increasing share of organic agriculture is targeted, the simulation results suggest that the implied general reduction in fertiliser use due to this measure would cut agricultural output in the EU significantly. This is also confirmed by recent assessments of the EU's Green Deal (BARREIRO-HURLE et al., 2021; HENNING et al., 2021; ISERMEYER et al., 2020; KÜHL et al., 2021).

A comparison of the fertiliser reduction versus fallow land scenarios also suggests that policymakers should explore more efficient ways of trading biodiversity preservation against production of agri-food products in a way that protects as much biodiversity as possible with the smallest reduction in agri-food production as necessary.

Simulations with the DART-BIO model suggest that due to the current EU biofuel mandates that require biofuel blending as a fixed share of energy consumption in the transport sector, rising biofuel-related feedstock prices do not influence the demand for biofuels in the EU, but may exacerbate competition with food production. Rather the implications of the war for global oil prices affect demand and production on biofuels in the EU as the size of the transport sector shrinks. Therefore, the debate should focus on the fact that any lifestyle with higher shares of meat and energy consumption per capita has a high opportunity cost in terms of plant-based food products, let alone potentially adverse effects on ecological sustainability.

Finally, the CAPRI scenarios of a 30% reduction in pig herd size and/or 30% reduction in pork consumption in the EU show that the two combined would compensate for slightly less than half of the foregone net exports of EU cereals from a 10% general reduction in fertiliser use. Thus, the simulation results put important arguments about future policy directions into a quantitative perspective. According to this perspective, EU policymakers could best contribute to the global food supply through efficient nutrient management in soils in combination with effective use of fertiliser geared to maximum yields.

Redirecting similar quantities of cereals towards global export markets under a policy framework that limits fertiliser use in the EU would require rather drastic changes in both meat consumption patterns and the structure of European animal production. In turn, the combined simulation results from the three models suggest that the EU as a major agricultural player could perhaps make not only a contribution to the global food supply, but also make a major contribution to the preservation of natural resources if private households in the EU greatly reduced their meat and energy consumption.

7 Conclusions

The three models offer several joint conclusions. The effect of reduced exports from Ukraine and potentially also from Russia will have severe short-term effects, especially on low-income net food-importing countries and on biofuel production. However, supply response will largely be able to remedy these effects over a number of years, while the type and direction of global land use changes would have to be monitored closely in this respect, and the EU's supply response would in principle have an important role to play in relation to available export quantities. Potential shortages of fertiliser appear to be a major risk factor in all scenarios, which could severely amplify the most adverse effects of the war.

Policymakers should therefore: i) prioritise short-term responses to famines and food shortages in the form of food aid and financial transfer to food insecure individuals, bearing in mind however that the current crisis will probably also have negative long-term economic consequences for many regions, ii) promote efficient use of organic fertilisers and nutrient management in soils, and iii) encourage a gradual restructuring of the EU pork and poultry sector towards less per capita consumption in combination with a reduction in the number of animals.

The simulation results from the three models show that an ambitious implementation of recent policy proposals e.g. around efficient nutrient management and restructuring of animal production in light of farm animal welfare, would probably be appropriate responses to the current crises in the medium term, while also being in line with other overarching goals such as a reduction in carbon emissions. However, the results also indicate that it would indeed be counterproductive to focus on the production side alone; instead, these policy measures would only become effective mitigation tools if they were combined with a gradual change in EU demand towards less consumption of animal products.

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Appendix

An online supplement with other model results, including the absolute figures underlying the percentage changes that are mentioned in the manuscript, are available at: https://drive.google.com/file/d/1mRiV0jEZuaYj0Kruqkh3Iswzkd7EN147/view?usp=sharing.