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Trade scenarios compensating for halted wheat and maize exports from Russia and Ukraine increase carbon emissions without easing food insecurity

Miguel Carriquiry[1], Jerome Dumortier[2]✉ and Amani Elobeid[3]

The Russian invasion of Ukraine has destabilized global agricultural markets, triggering food price increases. We present scenarios of reduced exports and production affecting both countries that increase maize and wheat prices by up to 4.6% and 7.2%, respectively. Production expansion in other regions can partially compensate for export declines but may increase carbon emissions and will exacerbate ongoing global food security challenges.

Disruptions in agricultural markets can be the result of events such as armed conflicts, trade wars, droughts or climate change[1–3]. Agricultural markets are globally integrated and disturbances can trigger changes in price expectations with cascading effects beyond the region(s) in crisis[4]. Higher commodity prices signal to farmers in other regions to expand cropland, which usually occurs at the expense of land allocated to other crops or grassland/grazing land, forest and/or natural vegetation. Land conversion to cropland is associated with carbon emissions that contribute to climate change. In a feedback loop, climate change affects agricultural production, leading to a shift in comparative advantage across countries[5,6]. For example, wheat yields in Russia and Ukraine are expected to increase due to climate change and CO_2 fertilization, and hence unrestricted trade of both countries is important for food security[7,8].

The Russian invasion of Ukraine on 24 February 2022 exacerbated food insecurity alongside high energy costs and supply-chain disruptions arising from the COVID-19 pandemic[9,10]. To shed light on potential medium-term effects of the war between Russia and Ukraine and longer-term effects associated with climate change, a global agricultural trade model coupled with a carbon accounting model is used to assess export and production restrictions in Ukraine and/or Russia as well as changes in biofuel policy in the European Union and the United States. The effects on crop prices, per-capita food consumption and carbon emissions from land-use change are quantified for the following scenarios involving crop production and exports: (A1) no exports from Ukraine; (A2) no exports from Ukraine and 50% export reductions from Russia; (A3) no exports from Ukraine and 50% biofuel reduction in the European Union and the United States; (A4) 50% reduction in Ukrainian crop production but no export restrictions (see Supplementary Information for scenario development, additional scenarios and sensitivity analysis for the scenarios in the main text). The first two scenarios simulate the effects of an inability to export for one or both countries, whereas the third scenario quantifies the effect of a policy option to compensate for the lack of Ukrainian exports. The last scenario can be justified by Ukrainian farmers being unable to produce due, for example, to war-induced destruction of infrastructure and equipment.

The trade model presents results after production adjustments have taken place over a year, and thus does not account for short-term spikes. The results focus on countries other than Russia and Ukraine due to the difficulty of assessing agricultural production in those places given the current situation. In scenario A1, 'no exports from Ukraine', global maize and wheat prices are higher by 3.9% and 3.6%, respectively, compared with the baseline (Table 1). Assuming that Russia reduces its grain exports by 50% (in addition to no Ukrainian exports), price increases of 4.6% and 7.2% for maize and wheat, respectively, are observed. Russia is more important than Ukraine in exporting wheat, which explains the sharper price increase in this scenario. Those increases are lower that the 8–22% price surges estimated by the Food and Agricultural Organization of the United Nations (FAO)[9]. This can be explained in part by the inclusion of higher inputs costs in the FAO analysis as a result of the conflict, and by the reduced capacity of alternative producers to increase output. Our model assumes full adjustment capacity. The increases are on top of the already elevated and rising preconflict levels that were reflecting the difficulty of some countries, such as Pakistan and Egypt, to acquire enough food for a healthy diet[10]. The biofuel reduction policies in the presence of no Ukrainian exports have a price impact that is substantial for the feedstock crops (mostly maize for ethanol and rapeseed for biodiesel) but modest for wheat because the supply gap remains due to no Ukrainian wheat exports. The supply gap caused by the decline in exports is partly closed by an increase in crop production in other countries (Table 1). In the 'no exports' scenario, some of the major wheat-producing countries increase their exports by double-digit percentages; these include India (72.4%), the European Union (36.1%), the United States (24.2%), and Argentina (11.4%). There is also a substantial increase in Australian and Canadian wheat exports of 9.4% and 8.6%, respectively. For maize, which is the other commodity affected by the war in Ukraine, Brazil and the United States increase their exports by 13.8% and 15.6%, respectively.

In scenario A1, 'no exports from Ukraine', aggregate (on a caloric basis) per-capita consumption of barley, maize, rice, sorghum and wheat changes to between −1.2% and 0.1% across countries due to price increases (Fig. 1). The range increases to −2.0% to 0.4% if Russian

[1]Facultad de Ciencias Económicas y de Administración, Universidad de la República, Montevideo, Uruguay. [2]O'Neill School of Public and Environmental Affairs, IUPUI, Indianapolis, IN, USA. [3]Department of Economics, Iowa State University, Ames, IA, USA. ✉e-mail: jdumorti@iu.edu

Table 1 | Changes in global commodity prices and production (other than from Russia and Ukraine) for the following scenarios: no exports from Ukraine (A1), no exports from Ukraine and 50% export reduction from Russia (A2), no exports from Ukraine and 50% EU and US biofuel reduction (A3), and reduction in total cropland (or arable area) in Ukraine by 50% (A4)

	A1	A2	A3	A4
Price				
Barley	5.7%	9.9%	5.7%	5.3%
Maize	3.9%	4.6%	−0.8%	2.8%
Oilpalm	−0.5%	−1.7%	−2.7%	0.1%
Rapeseed	5.6%	7.2%–	5.4%	4.1%
Rice	0.3%	0.6%	0.2%	0.4%
Sorghum	0.7%	0.7%	0.0%	0.7%
Soybeans	3.3%	4.3%	3.7%	2.1%
Sunflower	35.9%	62.4%	34.7%	21.8%
Wheat	3.6%	7.2%	3.5%	2.9%
Production				
Barley	2.8%	5.2%	3.1%	2.3%
Maize	1.8%	2.3%	−0.2%	1.2%
Oilpalm	0.1%	−0.1%	−0.5%	0.1%
Rapeseed	2.1%	2.8%	−2.0%	1.4%
Rice	0.3%	0.6%	0.3%	0.2%
Sorghum	0.8%	1.3%	0.8%	0.5%
Soybeans	1.8%	2.6%	2.0%	1.1%
Sunflower	15.1%	26.7%	14.7%	9.0%
Wheat	1.1%	2.4%	1.1%	0.8%

exports are reduced by 50% in addition to no Ukrainian exports. At the lower end, the decrease almost doubles because of the importance of Russia as a wheat exporter. In scenario A3, 'no exports from Ukraine and 50% biofuel reduction in the European Union and the United States', the range of per-capita food consumption changes to −1.0% to 0.3%. In the model region 'rest of the world', which contains many low-income countries, per-capita food consumption is least changed (−0.2%) in the scenario in which the European Union and the United States reduce their biofuel use. The reduction in food consumption is more pronounced for the individual crops. Maize and wheat consumption is reduced by up to 1.5% (Argentina) and 1.1% (Brazil), respectively, without Ukrainian exports. This is in stark contrast to the scenario where less biofuel is used in European Union and the United States. Per-capita maize consumption increases between 0.6% and 1.3% in all countries, whereas wheat consumption is still reduced by up to 1.0%. The decrease in the food consumption of wheat and maize in scenario A1, 'no exports from Ukraine', is partially compensated by an increase in the consumption of rice. However, this increase for all countries is below 0.4%. The region 'rest of the world' accounts for approximately 2.5 bn people including the world's poorest. None of the scenarios analysed increases their per-capita food consumption. Many of those countries, especially in Africa, have low baseline per-capita caloric intake, a high number of people in food-insecure situations and a high reliance (as a share of total caloric intake) on grains, roots and tubers. Thus, even a seemingly small decrease in caloric intake can have adverse effects of undernourishment and food security.

To increase production and close the supply gap in scenario A1, 'no exports from Ukraine', major agricultural wheat producers (other than Ukraine and Russia) increase crop area. Australia, China, the European Union and India increase their wheat area by 1.0%, 1.5%, 1.9% and 1.2%, respectively. Across the four scenarios analysed, the total global cropland area (excluding Ukraine and Russia) increases by at least 6.6 Mha (in scenario A3, 'no exports from Ukraine and 50% biofuel reduction in the European Union and the United States') and up to 18.2 Mha (in scenario A2, 'no exports from Ukraine and 50% export reductions from Russia'). The increase in Brazilian area is 1.3 Mha (with maize being responsible for more than half of the increase) in the no-Ukrainian-exports scenario, which is problematic in view of greenhouse gas (GHG) emissions due to the country's biomass and soil carbon stock as well as biodiversity[11].

Total increase in global crop area (not including Russia and Ukraine) is 11.1 Mha, an increase of 1.4% relative to the baseline in scenario A1, 'no exports from Ukraine'. This crop area expansion due to the invasion of Ukraine by Russia can lead to significant carbon emissions from land-use change. Using mean carbon coefficients, land-use change emissions are 1,011.2 MtCO_2e (Extended Data Fig. 1). Land-use change and emissions from Russia and Ukraine are excluded in this number because it is difficult to quantify area changes at this point. Thus, the emission numbers mentioned represent upper bounds. Compared to other estimates in GHG emissions from different macroeconomic developments or policy scenarios, the land-use change emissions from the Russian invasion into Ukraine are significant. For example, analysing the emissions from a 30% reduction in biofuels in the United States and the European Union from an increase in fuel efficiency and vehicle electrification results in a decrease in emission of between 188.8 and 468.1 MtCO_2e for minimum and maximum carbon coefficients, respectively[12]. The land-use-change-induced emissions are reduced to 527.2 MtCO_2e if EU and US biofuel use is cut in half.

The increase in maize production in Brazil represents an important contribution to the aforementioned carbon emissions. Scenario A3, 'no exports from Ukraine and 50% biofuel reduction in the European Union and the United States', leads to an increase in the exports of US maize at the expense of exports from other countries. For example, maize exports from Brazil decrease compared to the baseline if the United States reduces its biofuel production by 50%. This changes the emission profile in Brazil notably (Extended Data Fig. 1). There are important reductions in terms of lower GHG from land use, although those are not all net gains as less biofuels will lead to an increase in fossil fuel use.

While the Russia–Ukraine grain agreement from July 2022 is a positive development, the situation in Ukraine and the status of agricultural exports remains uncertain. The attack on the port of Odesa or, potentially, mines in the Black Sea have made grain shipments expensive and far below normal (so far, less than 0.4 Mt). Our analysis presents plausible ranges from no exports to some production shortfall from Ukraine to give a sense of impacts given the unknown outcome and end of this war. However, it assumes that countries are able to respond to price signals by increasing production and trade. Yet, drought conditions in South America, the decision by major producing countries (for example, Argentina and Indonesia) to curb exports of agricultural commodities, and high fertilizer costs are exacerbating food insecurity in many poor communities. Policy for aiding vulnerable populations could include domestic food subsidies and the reduction or elimination of trade restrictions. The effect of future climate change can be mitigated by unrestricted trade, allowing a shift of comparative advantage across countries. These and other multifaceted approaches will be needed in the near and long term[13]. Although price increases are dampened by area and production expansions in other countries, this may come at the expense of potentially large carbon emissions—highlighting how trade and production disruptions in Russia and Ukraine have the double impact of compromising global food security and efforts to mitigate climate change.

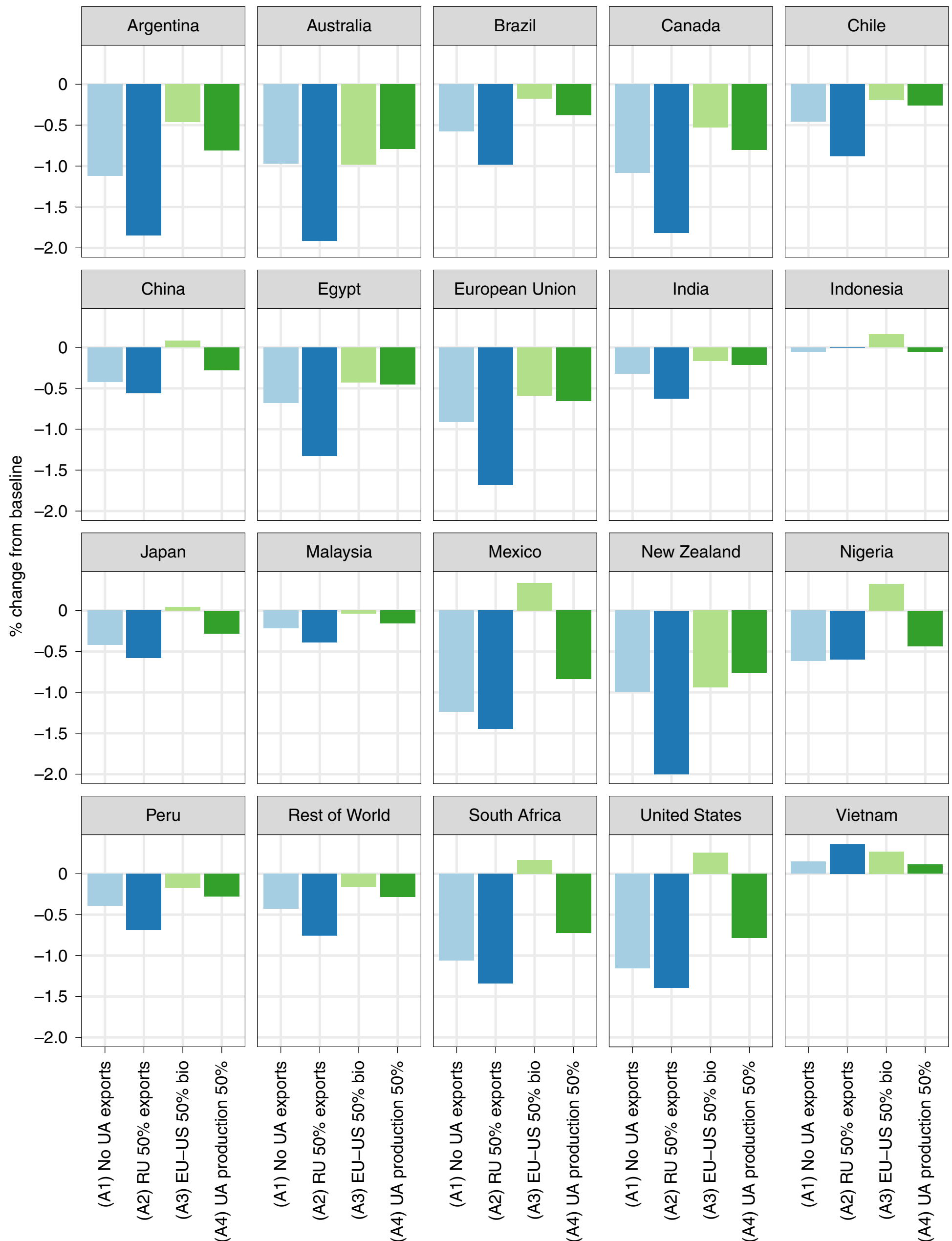

Fig. 1 | Changes in per-capita food consumption. Aggregated changes in per-capita food consumption on a caloric basis for barley, maize, rice, sorghum and wheat for scenarios A1–A4. RU, Russia, UA, Ukraine.

Reporting summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

All data required to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Information. The output of the agricultural trade model is available at www.github.com/foodclimate. The repository also includes the codes to generate all results, figures and GHG calculations based on the agricultural trade model output. Source data are provided with this paper.

Code availability

Details and code for the agricultural trade model are available from the corresponding author upon request.

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Author contributions

M.C. and J.D. conceived and designed the experiments. M.C. performed the experiments. J.D. analysed the data. M.C. and A.E. contributed materials/analysis tools. M.C., J.D. and A.E. wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

Extended data is available for this paper at https://doi.org/10.1038/s43016-022-00600-0.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s43016-022-00600-0.

Correspondence and requests for materials should be addressed to Jerome Dumortier.

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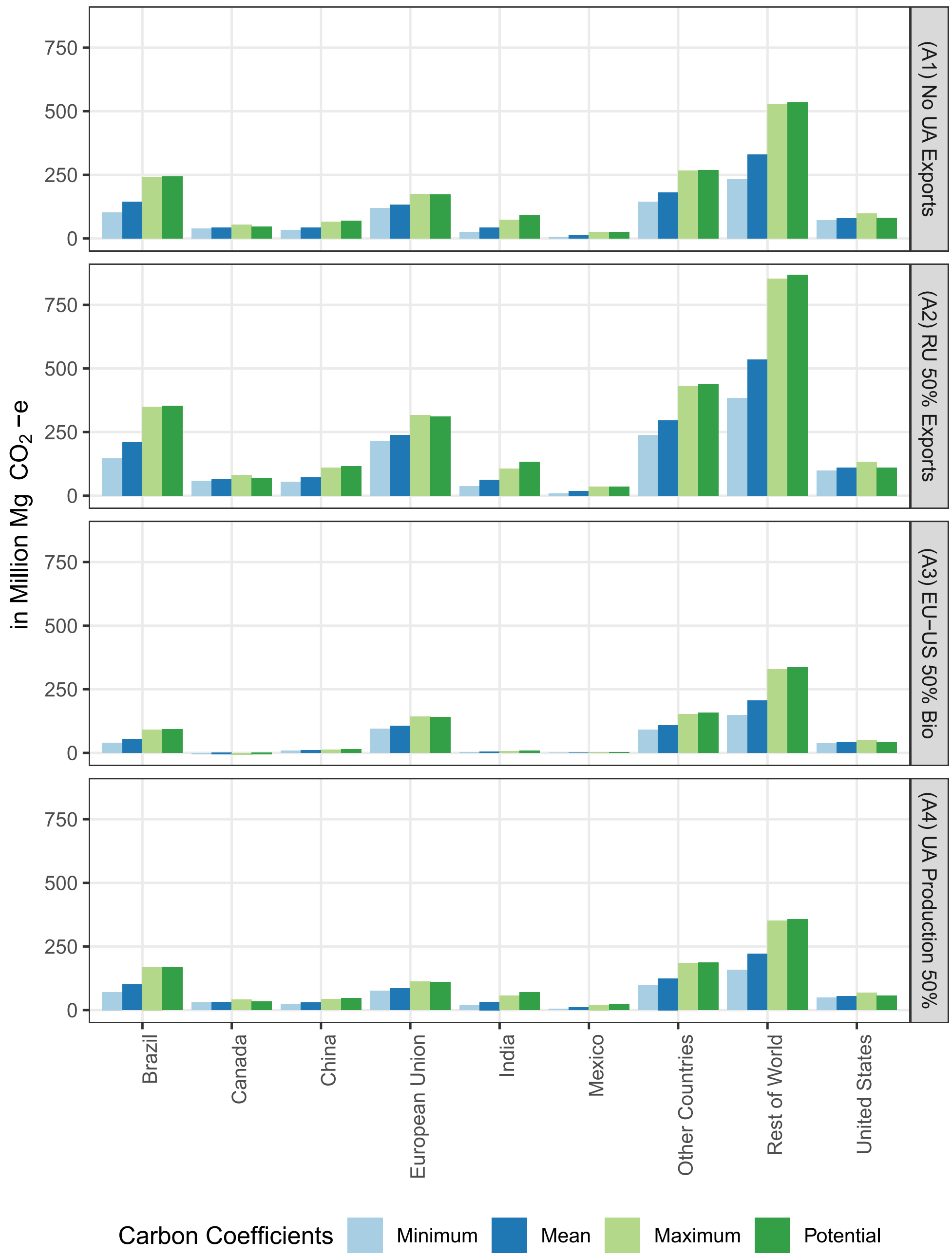

Extended Data Fig. 1 | Carbon emissions in MMT CO_2-e for minimum, mean, and maximum and potential biomass carbon coefficients. The land-use change emissions calculations are based on previous research[14,15].

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Corresponding author(s): JEROME DUMORTIER

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Reporting Summary

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Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	The agricultural trade and GHG emission models contributing to this study are written in Microsoft Excel and R, respectively. Details and code for each model can be requested from the corresponding author or downloaded from www.github.com/foodclimate.
Data analysis	All data analyses and preparation of figures were done in Microsoft Excel and using R version 4.1.2 (2021-11-01) "Bird Hippie" Copyright (C) 2021 The R Foundation for Statistical Computing Platform: x86_64-w64-mingw32/x64 (64-bit).

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All data required to evaluate the conclusions in the paper are present in the paper and/or the Online Material. The output of the agricultural trade model is available at www.github.com/foodclimate. The repository also includes the codes to generate all results, figures, and GHG calculations based on the agricultural trade model output.

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Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Simulation of the economic and environmental effects on global agricultural trade and land use of no crop exports from Russia and Ukraine due to the Russian invasion on February 24, 2022.
Research sample	Not applicable
Sampling strategy	Not applicable.
Data collection	Not applicable.
Timing	Not applicable.
Data exclusions	No data were excluded.
Non-participation	The analysis is based on an economic simulation model and no participants/human subjects were involved in the study.
Randomization	Not applicable.

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