(Note: This is the extended abstract. A full paper will be uploaded soon)

Assessing sectoral impacts of agrifood emission targets under alternative SSPs with improved substantiation of food demand and globalization patterns

Introduction

The targets under the Paris Agreement are not expected to be achieved without significant increases in climate mitigation actions (Chan et al. 2022). The expected increases in global food demand alone could lead to a 0.5°C increase in global temperature by 2050 (Ivanovich et al. 2023), while at the same time it is mandatory for the agrifood sector to adopt measures to mitigate climate change. This need for mitigation efforts across countries generates uncertainties with respect to the developments of the global and regional agrifood systems. Future changes in socioeconomic and technological conditions will create further challenges and opportunities for agrifood sectors. In order to capture these potential future developments, model-based scenario-analysis is used in climate and economic research. To increase comparability across studies, researchers have built the Shared Socioeconomic Pathway (SSP) framework, which defines five scenarios that describe a large set of different potential socioeconomic futures (O'Neill et al. 2017; Riahi et al. 2017).

Most SSP-based analyses have focused on the global and economic climate systems. However, several researchers have studied SSPs in the context of agrifood systems. Some literature has developed SSP narratives for European (Mitter et al. 2019; 2020) or national (Lehtonen et al. 2021) agrifood systems. Multiple modeling teams have quantified the global and macro-regional developments of land use (Doelman et al. 2018), of food security (van Meijl et al. 2020) and of agricultural yields (van Zeist et al. 2020), under the five different SSPs. The vast majority of the literature simulating emission abatement scenarios compares these scenarios to one baseline often based on business-as-usual developments, or following the "middle-of-the-road" SSP2 (Frank et al. 2019; 2021; Jansson et al. 2023; Clora et al. 2021; Pérez-Domínguez et al. 2021). A smaller number of papers analyzes mitigation efforts using three different SSP baselines (SSP1-2-3) (Hasegawa et al. 2018; Fujimori et al. 2022), focusing mostly on food security impacts at the macro-regional and global level.

To our knowledge, no research has quantified alternative agrifood emissions abatement scenarios against the five SSP baselines. We improve this literature in four important aspects. First, we make use of a set of demand elasticities recently estimated specifically for each of the SSPs to form the food demand patterns embedded in the baseline of our analysis (Bouyssou, Clora, Jensen, Yu, 2023; Bouyssou, Jensen, and Yu, 2024). This allows us to better substantiate the SSPs beyond the income and population growth drivers. Second, we improve the globalization/trade policy assumptions used by previous literature in characterizing the SSPs, by applying the scenarios developed in Clora and Yu (2023), which can be matched 1-to-1 with the SSP narratives. Third, we introduce endogenous abatement technology adoptions in our model to capture their abatement potentials in responding elevated emission abatement ambitions. Finally, we assess three sets of agricultural emission reduction scenarios, ranging from a business-as-usual scenario without climate policy, a moderately ambitious scenario featuring a "plausible" emission trajectory developed from a bottom-up analysis by Jensbye and Yu (2023), and a more ambitious scenario connected to the Paris Agreement. In total, we assess 15 scenarios (i.e. each of the five SSPs substantiated with the aforementioned demand and globalization patterns interacting with three agricultural emission settings). We do so by using a recursive dynamic computable general equilibrium (CGE) model. We analyze the impacts of the different assumptions in these 15 scenarios on global and regional agrifood production, trade flows and emissions, focusing on aggregate and key agrifood sectors such as livestock and animal food products.

Methods (model and data)

To perform our analysis, we use an extended recursive dynamic version of the GTAP v7 model (Corong et al. 2017). This extension, among other features, allow for the implementation of different sectoral carbon prices (bundling in two separate groups the agrifood sectors and the rest of the economy) (Clora, Yu, and Corong 2023), models marginal abatement technology adoption in the agrifood sectors (Jensbye, Clora, and Yu 2023), and includes mechanisms to capture changes in consumer preferences in each SSP as driven by socioeconomic drivers (Bouyssou et al. 2023). The model is calibrated on a version of the GTAP-AGROFOOD v10 database (Britz 2022), merged with the GTAP-Power v10 database (Peters 2016). Additional key elasticities available in GTAP-AGROFOOD are adjusted using data from recent literature (Tabeau, Helming, and Philippidis 2017; Ivanic, Beckman, and J. Nava 2023; Akin-Olçum et al. 2022). The dataset is aggregated to represent key agrifood commodities, and key producing and consuming countries. The dataset is updated in one-year steps to recreate five SSP-based baselines towards 2050.

The five baselines are based on external SSP projections on population and labor force (Kc and Lutz 2017), GDP (Dellink et al. 2017), and saving rates (Fontagné, Perego, and Santoni 2022). Bilateral iceberg trade costs are also varying in each SSP, based on an estimated relation between per capita GDP and the World Bank's Logistic Performance Index (Arvis et al. 2016). Commonly to all SSP baselines, we target exogenously differences in sectoral productivity growth (Bekkers et al. 2019) and non-agrifood emissions consistent with current policies (Keramidas et al. 2021), in addition to changes in energy efficiency. Five alternative globalization scenarios (Clora and Yu 2023), are mapped on the five different SSP storylines. As the focus of our analysis is on the agrifood sectors, crop yields, meat yields and milk yields are exogenously targeted (OECD and Food and Agriculture Organization of the United Nations 2023). Different SSP trajectories for regional food household consumption and for parameters governing the income and price elasticities are included in the same fashion as Bouyssou et al. (2023). Historical changes in agricultural emission intensities not driven by carbon prices are targeted exogenously (Jensbye, Clora, and Yu 2022). In the baselines, agrifood emissions are endogenous.

Two agrifood climate change mitigation scenarios are developed and simulated against each of the baselines, based on recently developed region-specific emission targets (Jensbye and Yu 2023). A first pathway is based on 'moderate' climate action, whereas the second represents more 'aggressive' climate efforts.

Expected results

The analysis will provide results about changing patterns in agrifood consumption and production, across SSPs and regional climate efforts. It will enrich the literature about future demand, trade, technological patterns in the agrifood sectors and the associated emission outcomes, particularly for the livestock and animal food products that are at the center of the debates on climate, trade, and food security.

References

Akin-Olçum, Gökçe, Madanmohan Ghosh, Elisabeth Gilmore, Peter Johnston, Mohammad M. Khabbazan, Ruben Lubowski, Margaret Mccallister, et al. 2022. “A Model Intercomparison of the Welfare Effects of Regional Coalitions for Ambitious Climate Mitigation Targets.” *Climate Change Economics*, August, 2350009. https://doi.org/10.1142/S2010007823500094.

Arvis, Jean-François, Daniel Saslavsky, Lauri Ojala, Ben Shepherd, Christina Busch, Anasuya Raj, and Tapio Naula. 2016. “Connecting to Compete 2016: Trade Logistics in the Global Economy--The Logistics Performance Index and Its Indicators.” Washington, DC: World Bank. https://doi.org/10.1596/24598.

Bekkers, Eddy, Giulia Sabbadini, Robert Koopman, and Robert Teh. 2019. “Long Run Trends in International Trade. The Impact of New Technologies,” 45.

Britz, Wolfgang. 2022. “Disaggregating Agro-Food Sectors in the GTAP Data Base.” *Journal of Global Economic Analysis* 7 (1): 44–75. https://jgea.org/ojs/index.php/jgea/article/view/143.

Chan, Sander, Thomas Hale, Andrew Deneault, Manish Shrivastava, Kennedy Mbeva, Victoria Chengo, and Joanes Atela. 2022. “Assessing the Effectiveness of Orchestrated Climate Action from Five Years of Summits.” *Nature Climate Change* 12 (7): 628–33. https://doi.org/10.1038/s41558-022-01405-6.

Clora, Francesco, and Wusheng Yu. 2023. “Modeling The Impacts of Alternative Globalization Scenarios on International Agricultural And Food Markets.” Presented at the XVII EAAE Congress.

Clora, Francesco, Wusheng Yu, Gino Baudry, and Luís Costa. 2021. “Impacts of Supply-Side Climate Change Mitigation Practices and Trade Policy Regimes under Dietary Transition: The Case of European Agriculture.” *Environmental Research Letters* 16 (12): 124048. https://doi.org/10.1088/1748-9326/ac39bd.

Clora, Francesco, Wusheng Yu, and Erwin Corong. 2023. “Alternative Carbon Border Adjustment Mechanisms in the European Union and International Responses: Aggregate and within-Coalition Results.” *Energy Policy* 174 (March): 113454. https://doi.org/10.1016/j.enpol.2023.113454.

Corong, Erwin, Hertel Thomas, Mcdougall Robert, Marinos Tsigas, and Dominique Van Der Mensbrugghe. 2017. “The Standard GTAP Model, Version 7.” *Journal of Global Economic Analysis* 2 (1): 1–119. https://doi.org/10/gf9zt9.

Dellink, Rob, Jean Chateau, Elisa Lanzi, and Bertrand Magné. 2017. “Long-Term Economic Growth Projections in the Shared Socioeconomic Pathways.” *Global Environmental Change* 42 (January): 200–214. https://doi.org/10.1016/j.gloenvcha.2015.06.004.

Doelman, Jonathan C., Elke Stehfest, Andrzej Tabeau, Hans van Meijl, Luis Lassaletta, David E. H. J. Gernaat, Kathleen Hermans, et al. 2018. “Exploring SSP Land-Use Dynamics Using the IMAGE Model: Regional and Gridded Scenarios of Land-Use Change and Land-Based Climate Change Mitigation.” *Global Environmental Change* 48 (January): 119–35. https://doi.org/10/gf6cj9.

Fontagné, Lionel, Erica Perego, and Gianluca Santoni. 2022. “MaGE 3.1: Long-Term Macroeconomic Projections of the World Economy.” *International Economics* 172 (December): 168–89. https://doi.org/10.1016/j.inteco.2022.08.002.

Frank, Stefan, Petr Havlík, Elke Stehfest, Hans van Meijl, Peter Witzke, Ignacio Pérez-Domínguez, Michiel van Dijk, et al. 2019. “Agricultural Non-CO2 Emission Reduction Potential in the Context of the 1.5 °C Target.” *Nature Climate Change* 9 (1): 66–72. https://doi.org/10.1038/s41558-018-0358-8.

Frank, Stefan, Petr Havlík, Andrzej Tabeau, Peter Witzke, Esther Boere, Mariia Bogonos, Andre Deppermann, et al. 2021. “How Much Multilateralism Do We Need? Effectiveness of Unilateral Agricultural Mitigation Efforts in the Global Context.”

Environmental Research Letters 16 (10): 104038. https://doi.org/10.1088/1748-9326/ac2967.
Fujimori, Shinichiro, Wenchao Wu, Jonathan Doelman, Stefan Frank, Jordan Hristov, Page Kyle, Ronald Sands, et al. 2022. "Land-Based Climate Change Mitigation Measures Can Affect Agricultural Markets and Food Security." *Nature Food* 3 (2): 110–21. https://doi.org/10.1038/s43016-022-00464-4.
Bouyssou CG, Jensen JD, Yu W. Food for thought: A meta-analysis of animal food demand elasticities across world regions. Food Policy. 2024 Jan;122. 102581. https://doi.org/10.1016/j.foodpol.2023.102581
Bouyssou, Clara Garcia, Francesco Clora, Jørgen D. Jensen, and Wusheng Yu. 2023. "Projecting Demand Elasticities for Disaggregated Animal Food Products under Alternative Shared Socioeconomic Pathways." Presented during the 26th Annual Conference on Global Economic Analysis (Bordeaux, France). Department of Agricultural Economics, Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=6810.

Hasegawa, Tomoko, Shinichiro Fujimori, Petr Havlík, Hugo Valin, Benjamin Leon Bodirsky, Jonathan C. Doelman, Thomas Fellmann, et al. 2018. "Risk of Increased Food Insecurity under Stringent Global Climate Change Mitigation Policy." *Nature Climate Change* 8 (8): 699–703. https://doi.org/10.1038/s41558-018-0230-x.
Ivanic, Maros, Jayson Beckman, and Noe J. Nava. 2023. "Estimation of the Value-Added/Intermediate Input Substitution Elasticities Consistent with the GTAP Data." *Journal of Global Economic Analysis* 8 (2): 136–61. https://doi.org/10.21642/JGEA.080204AF.
Ivanovich, Catherine C., Tianyi Sun, Doria R. Gordon, and Ilissa B. Ocko. 2023. "Future Warming from Global Food Consumption." *Nature Climate Change* 13 (3): 297–302. https://doi.org/10.1038/s41558-023-01605-8.
Jansson, Torbjörn, Nils Malmström, Helena Johansson, and Hyungsik Choi. 2023. "Carbon Taxes and Agriculture: The Benefit of a Multilateral Agreement." *Climate Policy*, 1–13. https://doi.org/10.1080/14693062.2023.2171355.
Jensbye, Laerke, Francesco Clora, and Wusheng Yu. 2022. "Nationally Determined Contributions and Scenarios of Agricultural Emission Reductions at Country Level." Presented during the 25th Annual Conference on Global Economic Analysis (Virtual Conference). Department of Agricultural Economics, Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=6533.
———. 2023. "Modelling the Potential to Abate Greenhouse Gases from Agriculture Using Detailed Abatement Technologies in a CGE Model." Presented during the 26th Annual Conference on Global Economic Analysis (Bordeaux, France). Department of Agricultural Economics, Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=6811.
Jensbye, Lærke Godsk, and Wusheng Yu. 2023. "Agricultural Emission Reduction Targets at Country and Global Levels: A Bottom-up Analysis." *Climate Policy* 0 (0): 1–17. https://doi.org/10.1080/14693062.2023.2267021.
Kc, Samir, and Wolfgang Lutz. 2017. "The Human Core of the Shared Socioeconomic Pathways: Population Scenarios by Age, Sex and Level of Education for All Countries to 2100." *Global Environmental Change* 42 (January): 181–92. https://doi.org/10.1016/j.gloenvcha.2014.06.004.
Keramidas, Kimon, Florian Fosse, Ana Diaz Vazquez, Paul Dowling, Rafael Garaffa, Jacques Després, Hans Peter Russ, Burkhard Schade, Andreas Schmitz, and Antonio Soria Ramirez. 2021. *Global Energy and Climate Outlook 2021: Advancing towards Climate Neutrality*. Publications Office of the European Union.
Lehtonen, Heikki S., Jyrki Aakkula, Stefan Fronzek, Janne Helin, Mikael Hildén, Suvi Huttunen, Minna Kaljonen, et al. 2021. "Shared Socioeconomic Pathways for Climate

Change Research in Finland: Co-Developing Extended SSP Narratives for Agriculture.” *Regional Environmental Change* 21 (1). https://doi.org/10.1007/s10113-020-01734-2.
Meijl, Hans van, Andrzej Tabeau, Elke Stehfest, Jonathan Doelman, and Paul Lucas. 2020. “How Food Secure Are the Green, Rocky and Middle Roads: Food Security Effects in Different World Development Paths.” *Environmental Research Communications* 2 (3): 031002. https://doi.org/10.1088/2515-7620/ab7aba.
Mitter, Hermine, Anja-K. Techen, Franz Sinabell, Katharina Helming, Kasper Kok, Jörg A. Priess, Erwin Schmid, et al. 2019. “A Protocol to Develop Shared Socio-Economic Pathways for European Agriculture.” *Journal of Environmental Management* 252 (December): 109701. https://doi.org/10.1016/j.jenvman.2019.109701.
Mitter, Hermine, Anja-K. Techen, Franz Sinabell, Katharina Helming, Erwin Schmid, Benjamin L. Bodirsky, Ian Holman, et al. 2020. “Shared Socio-Economic Pathways for European Agriculture and Food Systems: The Eur-Agri-SSPs.” *Global Environmental Change* 65 (November): 102159. https://doi.org/10.1016/j.gloenvcha.2020.102159.
OECD and Food and Agriculture Organization of the United Nations. 2023. *OECD-FAO Agricultural Outlook 2023-2032*. OECD-FAO Agricultural Outlook. OECD. https://doi.org/10.1787/08801ab7-en.
O’Neill, Brian C., Elmar Kriegler, Kristie L. Ebi, Eric Kemp-Benedict, Keywan Riahi, Dale S. Rothman, Bas J. van Ruijven, et al. 2017. “The Roads Ahead: Narratives for Shared Socioeconomic Pathways Describing World Futures in the 21st Century.” *Global Environmental Change* 42 (January): 169–80. https://doi.org/10.1016/j.gloenvcha.2015.01.004.
Pérez-Domínguez, Ignacio, Agustin Del Prado, Klaus Mittenzwei, Jordan Hristov, Stefan Frank, Andrzej Tabeau, Peter Witzke, et al. 2021. “Short- and Long-Term Warming Effects of Methane May Affect the Cost-Effectiveness of Mitigation Policies and Benefits of Low-Meat Diets.” *Nature Food* 2 (12): 970–80. https://doi.org/10.1038/s43016-021-00385-8.
Peters, Jeffrey C. 2016. “The GTAP-Power Data Base: Disaggregating the Electricity Sector in the GTAP Data Base.” *Journal of Global Economic Analysis* 1 (1): 209–50. https://doi.org/10.21642/JGEA.010104AF.
Riahi, Keywan, Detlef P. van Vuuren, Elmar Kriegler, Jae Edmonds, Brian C. O’Neill, Shinichiro Fujimori, Nico Bauer, et al. 2017. “The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview.” *Global Environmental Change* 42 (January): 153–68. https://doi.org/10.1016/j.gloenvcha.2016.05.009.
Tabeau, Andrzej, John Helming, and George Philippidis. 2017. *Land Supply Elasticities: Overview of Available Estimates and Recommended Values for MAGNET*. LU: Publications Office. https://data.europa.eu/doi/10.2760/852141.
Zeist, Willem-Jan van, Elke Stehfest, Jonathan C. Doelman, Hugo Valin, Katherine Calvin, Shinichiro Fujimori, Tomoko Hasegawa, et al. 2020. “Are Scenario Projections Overly Optimistic about Future Yield Progress?” *Global Environmental Change* 64 (September): 102120. https://doi.org/10.1016/j.gloenvcha.2020.102120.