Going global to local: achieving agri-food sustainability from a spatially explicit input-output analysis perspective

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Summary

The global agri-food system plays a critical role in food security and environmental issues including land use, biodiversity loss and climate change. Increasing globalization has resulted in a complex international food system where production and consumption along the international supply chain can incorporate many geographically distinct regions. This interconnection means that it is difficult for any single producer or consumer to address these impacts. This thesis represents a step towards mapping the global food system from producers to consumers and offers several policy-relevant insights, especially in the national accounting of environmental footprints. Given that many drivers occur locally, but are traded globally, and that inter-regional differences in consumption are increasingly important, it is a natural next step to find approaches that can connect local impacts (production side) with global consumption (consumption side) through trade. Global spatially explicit multi-regional input-output (SMRIO) analyses can help to identify hotspots of local production and associated social and environmental impacts driven by global consumption. Therefore, this thesis puts forward the following overarching research question:

"*How can spatially explicit multi-regional input-output approaches be used to evaluate sustainability in the global agri-food system?*".

In this thesis, I first assessed the past use of SMRIO to evaluate *what is the current status of spatially explicit input-output analysis (sub-question 1)?*.

To further assess the potential of the technique, I built a variety of SMRIO models for three different case studies. I used SMRIO models to investigate three critical issues (i.e. food security, biodiversity loss, and climate change) in the agri-food system. They address the following questions:

What are the local production hotspots of crops and livestock driven by global consumption and how does this impact food security through trade (sub-question 2)?

How does land use driven by final consumption affect global biodiversity within key biodiversity areas (sub-question 3)?

What are the global interactions between carbon emissions and carbon sequestration driven by diets and diet changes in high-income nations (sub-question 4)?

To answer the first sub-question, Chapter 2 reviews the literature on spatially explicit input-output analysis and assesses the mechanisms proposed for connecting global consumption with local environmental pressures. I define spatially explicit input-output analysis as cases where the spatial resolution of results are greater than the underlying input-output transaction matrix. I assess past attempts at combining these perspectives at varying temporal and spatial scales, and with different environmental stressors. Past studies covered various environmental pressures and impacts, such as GHG emissions, water use, air pollution, and biodiversity loss. Three ways are identified to make input-output analysis spatially explicit based on the structure of environmentally extended input-output databases (i.e. environmental extensions, final demand, and transaction matrix). On the global scale, most studies linked spatial environmental extensions with global multi-regional input-output (GMRIO) tables to estimate local environmental impacts driven by global consumption. In general, it is more challenging to disaggregate the final demand and transaction matrix than the extensions matrix given the limitation of present datasets and computational power. The review proposed a theoretical framework of global SMRIO analysis and provided methodological support to answer the remaining sub-questions.

In the first case study, Chapter 3 identifies hotspots (i.e. the most significant production regions) for primary crops and livestock driven by international consumption, by linking high-resolution production maps of crop and livestock with a GMRIO table (EXIOBASE in Chapter 3). The embodied primary crops and livestock for high-income countries are distributed over larger areas is the case for middle- and low-income countries. This is driven by the higher number and complexity of trade links for high-income countries and higher per-capita consumption volumes, particular of animal products. This means low- and middle-income countries rely for feeding their own population more on their own production and export large amounts of fodder and food for use in high-income countries, that often see overconsumption of food and/or have systems of intensive husbandry. This has clear ramifications on food security for low- and middle-income nations. Therefore, identified hotspots driven by global consumption can facilitate targeted cooperation between consumers and producers to safeguard global food security. In terms of methodology, this chapter moves SMRIO forward by using road density from the Global Roads Inventory Project (GRIP) to distinguish the spatial distribution of production for local consumption and export (i.e. whether local production within a grid cell is used for export or domestic consumption). The comparison between these results and subnational trade data in Brazil shows some agreement. However, global calibration using such a proxy approach is still not possible due to data limitations.

In the second case study, Chapter 4 presents a comprehensive assessment of the potential global loss of terrestrial species driven by domestic and teleconnected land use within key biodiversity areas (KBAs). For this, I build an SMRIO model from physical and monetary input-output databases, spatially-explicit land use maps, and characterization factors of biodiversity loss. Human land use is dominated by agriculture sectors. Traditional GMRIO databases have highly aggregated agricultural sectors or regions. This limitation is addressed by using the Food and Agriculture Biomass Input-Output (FABIO) table, a consistent, balanced, physical input-output database based on FAOSTAT data, covering 191 countries and 130 agriculture, food, and forestry products. However, FABIO only has a partial coverage of the global economy does not include production and trade of non-agricultural products. In order to cover non-agricultural sectors, this chapter uses an integrated model framework linking FABIO and EXIOBASE. EXIOBASE is a highly detailed GMRIO database, including 200 products and 49 countries or regions. The chapter finds that land use within KBAs only accounts for 7% of total land use, while it causes 16% of global plant loss and 12% of global vertebrate loss compared to total land use. Animal product consumption accounted for more than half of biodiversity loss within KBAs. Bovine meat consumption alone contributed to about 40% of biodiversity loss within KBAs. In terms of land use, lightly grazed pastureland contributes to around half of all species loss. International trade is an important driver of loss, accounting for 25-33% of plant and vertebrate loss. The comprehensive assessment can provide guidance for maintaining the integrity of KBAs and global biodiversity.

In the third case study, Chapter 5 assesses the potential for a ‘double dividend’ for climate change mitigation via the dietary change in high-income countries from both (1) reduced direct agricultural production emissions and (2) carbon sequestration via land sparing whereby agricultural lands can revert to other uses. I employ the SMRIO approach by linking FABIO with spatially explicit maps agricultural GHG emissions and of storage of harmonized aboveground biomass carbon (AGBC), belowground biomass carbon (BGBC) and soil organic carbon (SOC), in the case of use of land for agriculture and agricultural land reverted to other uses (most notably rewilding). The dividend is estimated for a scenario in which national average diets in 54 high-income nations representing 68% of global GDP and 17% of population shift to a planetary health diet as proposed by the EAT-Lancet Commission, which is committed to co-development of healthy diets and sustainable food production. I find that dietary changes in high-income nations could result in an increased carbon sequestration potential of 115.57 Pg CO_2e over the long term (~2.3 years of global CO_2e yr^{-1} emissions in 2010), and a decrease in food system emissions of 0.61 Pg CO_2e yr^{-1}. Animal protein consumption reduction contributes the largest benefit. Including often-overlooked food and beverage items outside the EAT-Lancet diet could offer another potential carbon benefit. For example, about 1.8 Pg CO_2e carbon sequestration would benefit from cutting out beer consumption in high-income nations. The carbon sequestration from land sparing due to dietary change represents potentially a significant contribution to limiting GHG atmospheric concentrations. Linking land, food, climate, and public health policy will be vital to harnessing the opportunities of this double dividend.

Finally, Chapter 6 concludes that SMRIO analysis is capable of contributing novel insights into the sustainability of the agri-food system. The results based on SMRIO analysis can help to identify local impact hotspots, set effective impact reduction priorities, and facilitate targeted cooperation between producers and consumers. Chapter 6 also gives a general discussion on SMRIO analysis and presents three potential lines for their improvement, including the improvement of spatial data and the potential for further applications not explored in this thesis. The latest high-resolution satellite data in combination with machine learning approaches may include greater amounts of natural science data in SMRIO analysis. Improving the accuracy of the transaction matrix is very challenging, and a key opportunity for future research is the use of greater amounts of subnational trade information to map a more precise relationship between producers and consumers. This can lead particularly to better estimate in which sub-national regions food produced is mainly used for regional consumption (including e.g. subsistence farming), and in which regions mainly for exports. If data on subnational trade is not available then the use of a proxy may be considered, like e.g. road density as used in Chapter 3. However, better validation of proxy approaches would be beneficial.

Overall, each study found results with scientific and policy relevance. The consumption of animal products played a prominent role in every case study of this thesis. As these studies and others highlight, there is an urgent need for different forms of protein production and dietary change. These sorts of assessments can help provide insights into how we might avoid catastrophic environmental problems in a globalized world. However, any of the benefits highlighted in these studies will require significant international action and collaboration. They will also have to be sensitive to local conditions and the economic ramifications at both global and local level of rapid food transitions.