Exploring transformation options in the food-land-water-climate nexus: towards achieving multiple SDGs in China

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Abstract

Food, land, water, and climate are tightly connected and essential to human beings, as indicated by the Sustainable Development Goals (SDGs), especially SDG 2 (zero hunger), SDG 6 (clean water and sanitation), SDG 13 (climate action), and SDG 15 (life on land). Pathways and measures aimed at achieving one or more specific SDGs may cause trade-offs or unexpected changes for other SDGs and/or for other sectors in our society. It remains unclear how solutions to one SDG affect other SDGs in the food-land-water-climate nexus. This study aims to analyse the linkages between food security, sustainable land management, clean water, and climate change (the 'food-land-water-climate nexus') on a global scale. The first step is to establish an integrated environmental-economic framework based on general equilibrium models to represent the interconnections of food, land, water, and climate systems. The second step is to perform illustrative model runs for China and its main food and feed trading partners under the scenarios of improvements in nexus components to assess their impacts on the food-land-water-climate nexus. Our analysis will provide an integrated nexus framework for exploring transformation options in the food-land-water-climate nexus towards achieving multiple Sustainable Development Goals in a global context, with a special focus on China.

Research questions and objectives

The food system is a driver of climate change (Vermeulen, Campbell, & Ingram, 2012), land-use change, and biodiversity loss (Newbold et al., 2015) and an essential factor for realising the Sustainable Development Goals (SDGs), especially SDG 2 (zero hunger), SDG 6 (clean water and sanitation), SDG 13 (climate action), and SDG 15 (life on land) (United Nations (UN), 2015). It, especially in the production phase, has placed tremendous pressure on planetary boundaries (PB, the environmental limits within which humanity can safely operate) regarding climate change, ocean acidification, biogeochemical flows (nitrogen and phosphorus), freshwater use, land-use changes, and biodiversity loss (Springmann et al., 2018). One of the global challenges is how to feed an increasing population with less pollution (Griggs et al., 2013).

Food system transformation is increasingly recognised as critical for achieving multi-dimensional SDGs (Doelman et al., 2022; Newbold et al., 2015). There is a strong interdependency between the use of food, land, water, and climate (Stefan Frank et al., 2021; Fujimori et al., 2022). However, food, land, water, and climate have, in the past, often been approached as individual, disconnected sectors, leading to unsustainable food provisioning and ineffective governance approaches (Johnson et al., 2019). In addition, pathways and measures aimed at achieving one or more specific SDGs may cause trade-offs or unexpected changes for other SDGs and /or for other sectors in our society. For example, land-based mitigation measures, such as large-scale afforestation, can trigger land competition between forest and food production, potentially driving up food prices and undermining food security (Doelman, Stehfest, Tabeau, & van Meijl, 2019; Peña-Lévano, Taheripour, & Tyner, 2019; van Meijl et al., 2018). Further, a carbon tax, recogonised as the most efficient market-based greenhouse gases (GHGs) emission mitigation policy instrument (S. Frank et al., 2018), could potentially raise prices of emission-intensive food products and pose risks to food security, given that the 'polluter pays principle' implies higher carbon taxes for “dirty” producers compared to “clean” producers (Peña-Lévano et al., 2019). Also, enhancing food system efficiency (i.e., allow the food system to produce more with the same inputs) and shifting towards less animal-based diets do not guarantee a reduction in total resource use and economy-wide emissions (Gatto, Kuiper, & van Meijl, 2023; Mason-D'Croz et al., 2022). This is because the saved resources would be reallocated to other sectors across the whole economy, which may mitigate the expected environmental benefits. It remains unclear how solutions to one SDG affect other SDGs in the food-land-water-climate nexus. Hence, it requires a holistic approach that encompasses the nexus to better manage the food-land-water-climate and understand the synergies and trade-offs for alternative solutions.

A nexus approach (implying systems are inextricably linked to form a complex system of interrelations) is needed in the context of achieving multi-dimensional SDGs. A global framework is urgently needed to explore pathways towards achieving multiple SDGs and avoiding the unintended consequences of interventions in food system transformation that could jeopardize sustainability and possibly exacerbate conflicts (Liu et al., 2018; van Vuuren et al., 2015), yet such a framework is still lacking. Although the nexus concept has been mentioned in discussions of sustainable development for a few decades, it has only recently received significant attention from scientific and policy disciplines, especially the interactions between the domains of food, land, water, and climate, which are crucial given the challenges posed by escalating food demand, limited agricultural land, water, and climate change. To analyse the complex linkages among food, land, water, and climate, integrated nexus frameworks have been created either through the expansion of applied general equilibrium (AGE) models or the linking of partial equilibrium (PE) models, which endogenously capture interactions among different global economic sectors (Johnson et al., 2019). Few studies have applied quantitative methods and analysed the linkages in the food-land-water-climate nexus in the context of achieving multi-dimensional SDGs on a global scale.

This study aims to bridge the gap by analysing the linkages between food security, sustainable land management, clean water, and climate change (the 'food-land-water-climate') in a global context, with a special focus on China, given its significant role as one of the world's most important markets for food and feed. A sustainable food system should be able to feed everyone on Earth while also stabilising global land use, providing clean water use, and reducing climate change (Foley et al., 2011). To achieve that, we focused on the improvement of one or more components in the food-land-water-climate nexus. In this study, five scenarios were simulated: four scenarios focusing on improving one nexus component, and one combined scenario focusing on improving all nexus components. Seven sustainability impacts were considered on China and its main food and feed trading partners (MTP, including Brazil, the United States, and Canada): food price, food affordability, food availability, agricultural land (cropland and pasture land) use, emissions of GHGs, emissions of acidification pollutants, emissions of eutrophication pollutants.

Materials and methods

For this study, we developed a global comparative static AGE model, a modified version of an integrated environmental-economic model (Peña-Lévano et al., 2019; Zhu & Van Ierland, 2004, 2012; Zhu, van Wesenbeeck, & van Ierland, 2006). These modifications focused on enhancing the representation of food-related (detailed crop and livestock) sectors and associated non-food (compound feed, nitrogen fertiliser, phosphorous fertiliser, non-food, and forestry) sectors. We further added three main environmental impacts of food systems into the model: emissions of GHGs, acidification pollutants, and eutrophication pollutants. Through our model, we could present land reallocation patterns and capture the economic and environmental interactions across the whole economy under different scenarios.

Scenario analysis:

i) Food scenario: Shifting towards less meat-intensive diets based on the EAT-Lancet diet recommendation (Willett et al., 2019) in line with SDG 2 (zero hunger).
ii) Land scenario: An afforestation policy based on China's National Forest Management Plan (2016-2050) (Forest Park of National Forestry and Grassland Administration (FPNFGA), 2016) in line with SDG 15 (life on land).
iii) Climate scenario: A carbon tax in line with the Paris Agreement (NDRC, 2018) as well as the PB on climate change and SDG13 (climate action).
iv) Water scenario: Improving crop (Chen et al., 2014; Cui et al., 2018) and livestock (Bai et al., 2018; Du et al., 2018; Wang et al., 2023) production efficiency up to the levels of developed countries in line with SDG 6 (clean water and sanitation).
v) Combined scenario: Combining food, land, water, and climate scenarios.

Data preparation and collaboration

For the integrated environmental-economic framework I am working with, my research group in Wageningen University has bought access to the Global Trade Analysis Project (GTAP) version 10 database (GTAP, 2014). Moreover, I have already collected the relevant environmental and economic data for China and its trading partners and developed my modelling framework by coding in the General Algebraic Modeling System (GAMS) software package (GAMS, 2022). The first application of the framework is to explore pathways towards more sustainable food systems to mitigate negative environmental spillovers from China's trading partners to China, including a partial dietary shift from pork to soy-based food, cleaner cereal production technology, and emission restriction policy. From this paper, we draw the following policy implication: achieving sustainable food production and consumption requires joint efforts from consumers and producers as well as coordinated environmental policy in the world. The second application of the framework is to analyse the possible environmental and economic consequences of upcycling food waste in China's monogastric livestock production in a global context. Our results of this paper highlight the asymmetric impacts of feeding China's monogastric livestock with food waste on food security and environment sustainability, urging complementary measures and policies to mitigate negative spillovers when promoting more circular food systems. My first-author research articles related to these two topics have been submitted to peer-reviewed journals.

The GTAP-BIO-FCS model, which offers a comprehensive representation of various land use patterns, has been extensively employed to assess the interactions between livestock and climate change under various mitigation policies within the global economy (Peña-Lévano et al., 2019). Dr. Luis Peña-Lévano, an Assistant Professor from the University of California, Davis, is one of the main modellers for the GTAP-BIO-FCS model. His research interests are designing solutions to satisfy the future demand in terms of food and climate change mitigation in general, within the limited agricultural land under climate change. If possible, working under his supervision can prepare me to leverage the advantages of the GTAP-BIO-FCS model in enhancing my existing integrated environmental-economic framework.

Innovation

In the recent scientific literature, the linkages between the use of food, land, and water, as well as the relation to climate change, are emphasised as critically important for sustainable development strategies (the 'food-land-water-climate' nexus). However, most of the previous literature does not address the nexus in its entirety and focuses on one or two components. China is one of the leading food supply and demand countries in the world, and its demand is expected to keep increasing in the coming decades, relying on food and feed imports (Food and Agriculture Organization (FAO), 2022). Taking China as an example would be helpful to analyse the synergies and trade-offs in the food-land-water-climate nexus in China to guide policymakers in developing plausible policies towards achieving multiple SDGs. However, an integrated nexus framework simultaneously analysing the linkages between food security, sustainable land management, clean water, and climate change (the 'food-land-water-climate') in the context of achieving multi-dimensional SDGs on a global scale is still lacking. Our analysis will provide an integrated nexus framework to analyse the interlinkages and interdependencies between food security, sustainable land management, clean water, and climate change (the 'food-land-water-climate' nexus) on a global scale, with a special focus on China, In this way, our analysis could provide pathways in the food-land-water-climate nexus towards achieving multiple SDGs in China.

Expected results

It is possible that an effective solution to achieving one or more specific SDGs in the nexus can cause trade-offs or unexpected changes for other SDGs and/or for other sectors in our society. The results will provide insights into minimising the trade-offs and exploiting the synergies in the 'food-land-water-climate nexus' in a global context. While our analysis focuses on China as a case study, its findings hold significant global policy implications, extending beyond China to other densely populated emerging economies. It offers a blueprint for achieving multiple SDGs in the face of escalating food demand, limited agricultural land, water, and climate change.

Timetable and activities

The time plan is presented below:

Year	**Month**			
2024	**10**	**11**	**12**	**1**
1. Collecting data and linking models				
2. Running model and analysing results				
3. Writing first draft				
2025	**10**	**11**	**12**	**1**
4. Revising and finalising draft				

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