Planetary boundaries and the food system in Australia and China: Sustainable futures and mutual benefits

Stuart White & Dana Cordell
Institute for Sustainable Futures, University of Technology Sydney
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1. Introduction

Achieving Net Zero emissions will require decarbonising our food systems. The food and agricultural systems are together responsible for around a third of all global human-made greenhouse gas emissions (Crippa *et al*. 2021).

The food system is also the largest single cause of widespread phosphorus nutrient pollution of our lakes, rivers and oceans, leading to fish kills and 'Dead Zones' (Brownlie *at el*. 2022). Further, while phosphorus is essential to growing food in the form of fertilisers, its global use currently depends on finite risky and increasingly expensive supply chains (Cordell & White 2014).

Transforming the food system towards net zero emissions and phosphorus resilience will require bold initiatives and cooperation across disparate sectors in the food system, from fertiliser producers to supermarkets, from livestock sector to consumers. The good news is that many initiatives are underway which can be scaled-up and out, many of which provide co-benefits for food security, job creation, public health, and biodiversity.

For the first time, the PACSAN project seeks to collaboratively identify and model the most powerful suite of sustainability measures that can simultaneously reduce greenhouse gas emissions to meet the Paris targets, and ensure phosphorus use supports food security and maintains and improves water quality. We are doing this by working together with food system stakeholders across both China and Australia.

This discussion paper is designed to initiate discussion, for the PACSAN workshops and for the establishment of the network.

Phosphorus and Climate Smart Agriculture Network

The Phosphorus and Climate Smart Agriculture Network (PACSAN) initiative aims to identify measures that can support the food chain in Australia and China to operate within planetary boundaries and meet globally agreed targets, while identifying opportunities for mutual benefit between the two countries from implementation of these measures.

The initiative has been funded by the National Foundation for Australia-China Relations, within the Australian Department of Foreign Affairs and Trade, and conducted by the Institute for Sustainable Futures at the University of Technology Sydney in collaboration with the SILC Business School at Shanghai University. The initiative aims to establish and maintain a network to exchange knowledge and to support measures to address the global challenges associated with the impacts of the food system in Australia and China.

The planetary boundaries framework (Richardson *et al*. 2023) defines 'a safe operating space for humanity' for several biophysical parameters (Figure 1). Two of these, climate change and biogeochemical flows (the nutrients phosphorus and nitrogen), are parameters for which humanity has exceeded the level that the scientists who developed this framework have determined is a safe level.

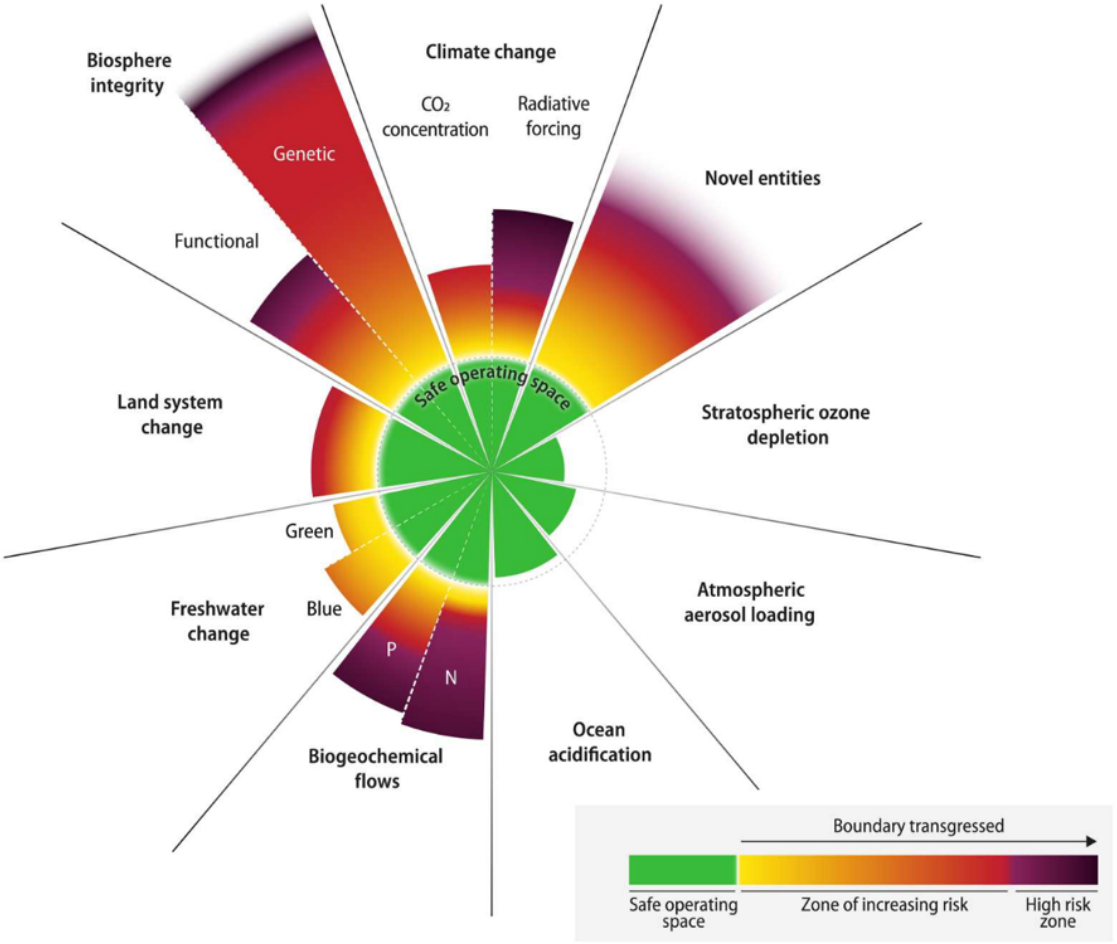

FIGURE 1: Planetary boundaries framework for biophysical parameters (Richardson *et al*. 2023).

Carbon dioxide concentration in the atmosphere is 400 parts per million (ppm) and rising, while the safe limit is considered to be 350 ppm. Similarly, the safe limit for phosphorus mined from phosphate rock and applied as a fertiliser to agricultural soils is considered to be 6.2 million tonnes per year, whereas the current rate of application is around 14 million tonnes per year and rising (Richardson *et al*. 2023: Table 1 p5).

The PACSAN initiative has therefore chosen to analyse greenhouse gas emissions and phosphorus use, as representative and material factors in the impacts of the food system on planetary boundaries. These impacts are described in more detail in the following sections.

2. PACSAN objectives and approach

The PACSAN project aims to support the reduction of the impact of the food system, with a focus on Australia and China and mutual benefits between the two countries.

This will be achieved through the following actions and outcomes:

- Establishing a network of experts, stakeholders, policymakers, industry and NGO representatives that have an interest in identifying and supporting measures to pursue more sustainable pathways for the food system.
- Engaging a number of stakeholders from a range of disciplinary backgrounds, in workshops in both countries, where an in-depth discussion can enable new insights and connections to be formed.
- Developing and testing an interactive web-based model to test and visualise measures that reduce the impact of the food system in the chosen domains, and modelling the extent to which they can meet globally agreed targets.
- Developing accessible outputs from the project, included bi-lingual web-based documents and audio-visual materials that can be used in various setting as information resources, policy briefs and discussion papers for the various stakeholders and their organisations, by researchers, policymakers and members of the community.
- Securing additional and continued support for the network, to enable ongoing collaboration in the form of symposia, short courses, research students and conferences.

3. Climate goals and the food system

There is now global agreement amongst nations that the emission of greenhouse gases must be reduced to ensure that the Earth is not subject to unacceptable global warming. This agreement specifically is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5°C above pre-industrial levels.” (UNFCCC 2015). These results are consistent with a requirement to reduce emissions to net zero by mid-century, and with a 43% reduction by 2030.

Both Australia and China have taken these goals seriously and have stated the following national targets and submitted these to the United Nations Framework Convention on Climate Change (UNFCCC) as part of their respective National Determined Contributions (NDCs). These targets are shown in Table 1.

COUNTRY	NEAR TERM TARGET	LONGER TERM TARGET	REFERENCES
China	Peak emissions before 2030	Net zero emissions by 2060	National Development and Reform Commission of China (2021)
Australia	Reduce emissions by 43% relative to 2005 levels by 2030	Net zero emissions by 2050	Commonwealth of Australia (2022)

TABLE 1: Agreed national greenhouse gas emission targets for China and Australia.

In addition, both China and Australia have signed up to the methane pledge, which was proposed at the Glasgow Conference of the Parties (COP26), and states that "Participants joining the Pledge agree to take voluntary actions to contribute to a collective effort to reduce global methane emissions at least 30 percent from 2020 levels by 2030." (UNEP 2021)

This goal has implications for livestock production due to production of methane from enteric fermentation in ruminant animals (mainly cows, sheep, goats) and also from rice cultivation.

Progress on reducing overall emissions

Both Australia and China have made significant efforts to reduce greenhouse gas emissions in key sectors of their respective economies. For example, China has implemented a record investment in clean energy (Carbon Brief 2024) and is likely to peak its emissions in 2025, five years ahead of target. Australia has similarly been rapidly developing renewable energy resources, both large scale wind and solar generation, as well as more than a third of Australian household having rooftop solar (APVI 2023). There is a strong reliance on deploying renewable energy and improving energy efficiency in both countries as principal means of meeting the targets. In both countries, there has been less emphasis on specific steps to reduce emissions in the agriculture and food sectors to meet the 2030 targets (Commonwealth of Australia 2022, Sapkota *et al.* 2024).

As indicated above, the progress on reducing fossil fuel use and decarbonising the electricity and mobility sectors has been a success story that continues. This will place greater emphasis in the next few years on food and agriculture as areas that require attention and action.

Why consider the food system?

It will not be possible to reach the longer-term net zero goals without a similar effort to reduce emissions from the food system. The greenhouse gas emissions from the food system are 40% of the total Australian emissions in 2020, and 18% of the total emissions in China for the same year, as shown in Table 2. The sector breakdown, using the Intergovernmental Panel on Climate Change (IPCC) categories, under-represents the climate impact of the food system, because the emissions are distributed across sectors, including agriculture, energy, transport and waste.

PARAMETER	AUSTRALIA	CHINA
Total greenhouse emissions in 2020 (Mt CO2-e)	473	12,942
Food system greenhouse emissions in 2020 (Mt CO2-e)	191	2,279
Total greenhouse emissions per capita in 2020 (t CO2-e/ capita)	18	9.2
Food system greenhouse emissions per capita in 2020 (t CO2-e/ capita)	7.4	1.6

TABLE 2: Contribution of the food system to total greenhouse gas emissions for China and Australia (FAO 2024, World Bank 2024).

This initiative is focussed on the food system, including agriculture, pre-farm gate and post-farm gate, because a comprehensive and coordinated approach requires that the whole of the food chain is considered. The UN's Food and Agricultural Organisation (FAO) indicates that more than a third of total food-related emissions now come from pre- and post-farm gate sectors (Tubiello *et al.* 2022). For example, if 50% of food is wasted through the value chain, then measures to address food waste must be considered as part of a program of action to reduce emissions from the food chain. Reducing food waste then has the effect of reducing the amount of cropping and the number of livestock, and the amount of fertiliser that needs to be applied.

'Hard to abate' sectors and the use of offsets

The agriculture sector has often been referred to as one of the 'hard to abate' sectors in the context of Australian climate policy (CSIRO 2023). This is likely to be because unlike many industries that rely on burning fossil fuels, agriculture's emissions come from biological processes. These biological sources are considered more difficult to mitigate with technical solutions than, for example, decarbonising the energy sector. As a result of this, there has been a focus on the use of land use measures, including offsets through vegetation as a carbon sink, as a means of meeting greenhouse reduction goals, at least in the Australian context (Meat and Livestock Australia 2024).

4. Phosphorus use and its limits

Phosphorus has no substitute in food production, it is essential for sustaining life and is a critical nutrient for all living things, including plants and animals (Brownlie *et al*. 2022). Unlike nitrogen which is reactive and has a powerful atmospheric phase that contributes to greenhouse gas emissions, phosphorus doesn't have a notable atmospheric phase, cycling naturally between land, plants and animals, and water. However, humans have mobilised four times the natural level of phosphate from bedrock to topsoil as fertilisers, with significant planetary ramifications for water and food security (Elser & Bennett 2011).

While all the world's farmers need access to phosphorus fertiliser to meet growing global food demand, our main source comes from fossil resources that have taken millions of years to form (Cordell & White 2014). While phosphorus is abundant in the Earth's upper crust, high concentration resources of accessible phosphate rock are not widely distributed and, as a result, it is one of the most shipped commodities in the world. Just five countries produce three-quarters of the world's phosphate each year (Jasinski 2024) and prices have fluctuated by as much as 400% in the past two years. Access to global phosphorus sources is therefore a key constraint to food security.

The other constraint, referred to above as one of the planetary boundaries, is the impact of phosphorus fertiliser use on the aquatic environment. This has become a problem of global consequence, and is a twin problem with nitrogen pollution, the causes of which also contribute to the global greenhouse impact.

While there are no global policies for managing phosphorus comparable to the IPPC's Paris Agreement, the world's most prominent phosphorus and environmental scientists have proposed several frameworks and goals (Figure 4). The "50:50:50" aspirational global goal by the Our Phosphorus Future initiative calls for a 50% reduction in phosphorus pollution, a 50% increase in recycling of phosphorus, by 2050 (Brownlie *et al.* 2022).

Similarly, the stated goal of the planetary boundaries framework is to more than halve the amount of phosphorus applied to agricultural land (Richardson *et al.* 2023).

SCALE	PHOSPHORUS GOAL	TARGET	REFERENCES
Global	50% reduction in phosphorus pollution	2050	Our Phosphorus Future (Brownlie *et al*. 2022)
Global	Reduce the flow of phosphorus from fresh water to ocean (sustain 11 million tonnes of P annually, down from 22.6 million tonnes of P)	N/A	Planetary Boundaries (Richardson *et al.* 2023)
Global	65% reduction in phosphorus mined and applied to agriculture soils as fertiliser (from 17.5 to 6.2 million tonnes of P per year)	N/A	Planetary Boundaries (Richardson *et al.* 2023)
Global	50% increase in recycling of phosphorus	2050	Our Phosphorus Future (Brownlie *et al*. 2022)
China	Cap the use of P fertilisers	2020	Council of China (2015)
Australia	N/A	N/A	N/A

TABLE 3: Proposed global goals for phosphorus pollution and recycling.

Sustainable supply and management of phosphorus is of great importance to both China and Australia. For example, China is the world's largest producer and consumer of phosphorus, supporting both domestic and global food security (FAO 2024), while Australia is the world's 5th largest phosphate importer (despite its smaller population) to produce food for the region (Cordell & White 2014). At the same time, nutrient pollution of rivers and ocean from phosphorus mismanagement in agriculture and sewage treatment is an issue for both countries (Jiang *et al*. 2019; Liu *et al*. 2016). There are significant opportunities for both China and Australia to secure sustainable sources of phosphorus from renewable domestic sources via a circular nutrient economy, and to simultaneously mitigate eutrophication to improve water quality.

5. Measures to meet planetary goals

The PACSAN initiative has identified several measures that will, in combination, enable the greenhouse and phosphorus targets to be met. The selection of these categories of measures has been based on an extensive review of the literature and previous work by the authors (Cordell, Drangert and White 2009, Cordell & White 2014). These measures will be tested and refined by experts through the workshops and network meetings associated with this project.

Measure	Description
1. Renewable fertiliser	• Ammonia produced with renewable hydrogen • Recovery and recycling of phosphorus from manures, crop waste and sewage
2. Nutrient productivity	• On farm efficiency of fertiliser • Smart agriculture • Tapping legacy phosphorus, soil testing and mapping
3. Soil carbon sequestration	• Lock-up carbon in soils
4. Crop type	• Rice varieties to reduce greenhouse emissions • Crop varieties that maximise nutrient use efficiency
5. Livestock feed additives	• Feed additives for ruminants to reduce methanogenesis • Phytase additives to maximise phosphorus uptake
6. Energy productivity across food value chain	• Improving energy productivity along the food chain, • Electrification incl mobility, food processing • increased renewables in the grid
7. Sustainable food choices	• Shifting food consumption from livestock to plant-based
8. Food waste avoidance	• Reducing avoidable food waste across the food chain

TABLE 4: Measures to meet planetary goals for greenhouse gas emissions and phosphorus use across the food system in China and Australia.

Each of these measures involve many actions or interventions. A number of these are being progressed at present, and a great deal of research, policy making, education and investment is happening. The purpose of this PACSAN initiative is to do three things that represent new contributions to the field.

1. To consider the climate and the phosphorus domains together, and explore the mutual benefits associated with this combined view. While this approach is also incomplete, in that it does not consider other planetary boundaries, such as biodiversity loss, or impacts on global fisheries, it provides a template for taking more than a singular view.

2. To analyse measures using a systems perspective, including technical, environmental, social and policy aspects. Often measures are considered from a singular perspective, for example, only fertiliser productivity, or only reducing food waste. In this case, a full range of measures are being considered.

3. The measures interact with each other, and that is being considered in this PACSAN initiative. For example, if food waste is reduced, then this reduces the need for fertiliser upstream.

6. Next steps for this initiative

This project aims to create a network of researchers, practitioners and stakeholders who can investigate, share, discuss, analyse and develop solutions regarding the impact of the food system on greenhouse gas emissions and phosphorus cycling on planetary systems.

The next steps in this initiative include two stakeholder workshops, one in China in May 2024 and one in Australia in August 2024 and following up with on-line meetings of an ongoing network. The workshops have the aim of reviewing the eight (8) measures above and using and reviewing an interactive model developed by the project team which aims to demonstrate, in an accessible way, the combined impact of implementing several measures at once.

It is through the power of dialogue, collaboration and shared endeavour between members of the network that we hope to influence the outcomes for the benefit of the planet and its people, and for mutual benefit between Australia and China.

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