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Global and Local Policies for Respecting Planetary Boundaries: Tradeoffs and Synergies

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Abstract

In a series of highly cited papers over the period 2009 – 2023, earth system scientists have identified a set of nine planetary boundaries that must not be breached if we wish to avoid catastrophic consequences for nature and humanity. These range from well-mixed, global boundaries such as climate-altering greenhouse gas emissions, to localized limits on freshwater availability and reactive nitrogen entering the environment. Recent estimates by Richardson et al. (2023), suggest that four of the nine planetary boundaries have already been breached. The food system is a key driver of all four exceedances and therefore must play a key role in any solutions. However, the establishment of these boundaries and the analysis of potential solutions has often been devoid of economic considerations. Furthermore, little attention has been given to the economic policies that might allow society to address these critical planetary boundaries, as well as likely synergies and tradeoffs across policies targeted to individual targets. This lecture will bring economic analysis to bear on this question, providing quantitative assessments of global and local policies aimed at respecting these planetary boundaries.

Keywords: Planetary Boundaries, agriculture, environment, tradeoffs, synergies, global trade
JEL code: Q00, Q01

This paper focuses on the food system as a key driver of planetary boundary exceedances. In addition to accounting for more than a quarter of greenhouse gas emissions, land use change that is directly or indirectly driven by food production is the primary cause of tropical deforestation (Busch and Ferretti-Gallon 2017). This is, in turn, the main source of biodiversity loss on the planet (Leclère et al. 2020). Irrigated agriculture is also the most important user of freshwater and is a key driver behind groundwater depletion (Wada and Bierkens 2014). Finally, farming is the largest source of reactive nitrogen and phosphorous entering the environment (Gerten et al. 2020). In short, the food system plays a significant role in the exceedances of five of the six most problematic planetary boundaries identified in the most recent assessment (Richardson et al. 2023). Furthermore, recent estimates suggest that developments in the global food system in the coming decades will only worsen these transgressions (Figure 1).

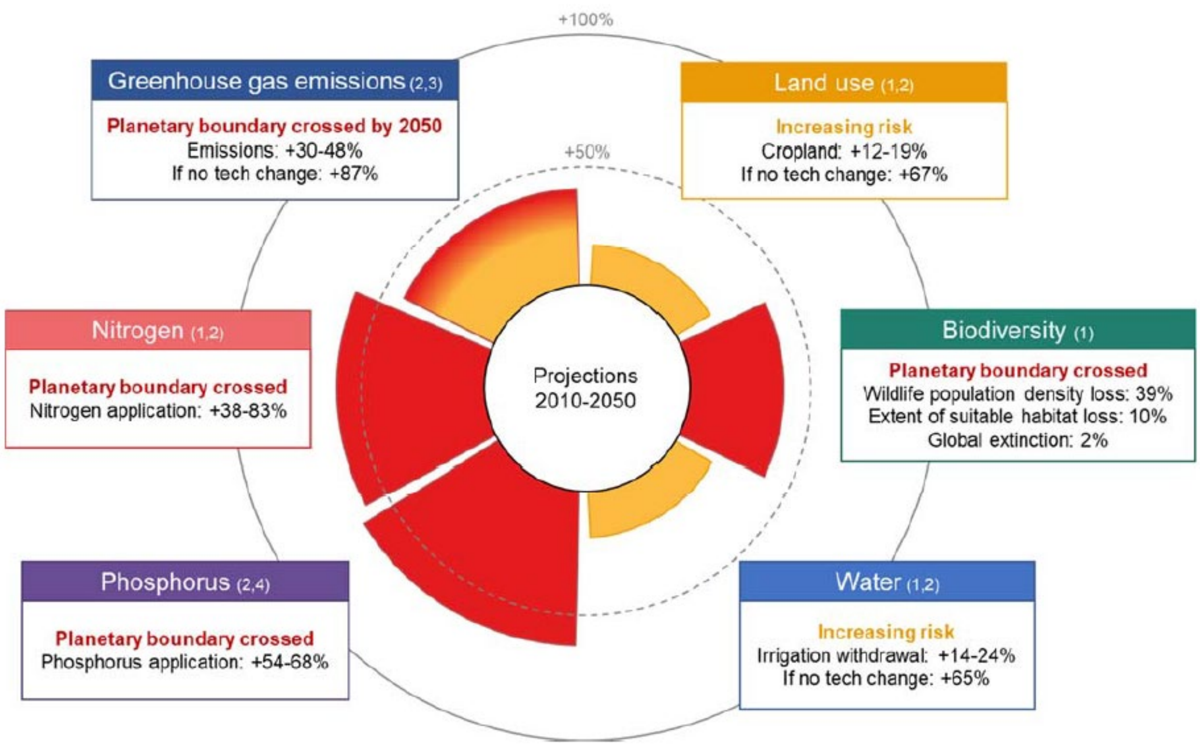

Figure 1. Colors of the sectors indicate the status for each planetary boundary: green = no risk (none); orange = at risk of crossing by 2050; red = boundary crossed (plain if crossed already in 2010, gradient if crossed by 2050). Sector size corresponds to the range of values covered by the sources. Source: Valin et al. In Revision.

While local consumption of locally produced foods is a popular concept, today’s food system is increasingly globalized. Supply chains now span national and continental boundaries, as retailers seek to provide consumers with low cost, healthy, environmentally sustainable products. Global change drivers, including income, population, biofuels and technological change over the 2010-2050 period are projected to boost GHG emissions from the food system by more than one-third, increase nitrogen and phosphorous applications by as much as 50% and boost cropland and irrigation significantly as well (Valin et al., 2023). This translates into additional stress on the planetary boundaries in absence of new and reformed policies. This paper will explore the impact of four different types of sustainability policies, each aimed at correcting the failure to price non-market externalities. In so doing, it identifies synergies, as well as tradeoffs across the different planetary boundaries.

The first policy considered is a climate policy which places a price on fossil fuel-based CO2 emissions in the United States (Zuidema et al. 2023). The impact of this policy on GHG emissions has been widely explored in the literature, so we focus here on the synergistic impact on nitrate pollution. Using a combination of four models: ENVISAGE (global CGE), SIMPLE-G-CS (gridded partial equilibrium model), Agro-IBIS (agroecological model) and WBM (hydrological model), we find that implementing a carbon price at $152/ton CO2, boosts fertilizer prices by nearly 100%, reducing the fertilizer intensity of corn production as well as the total area cultivated. This, in turn, cuts the amount of nitrate pollution reaching the Gulf of Mexico by more than 8%, as well as reducing groundwater pollution in the Mississippi Basin (Figure 2). In short, addressing the climate planetary boundary has positive synergies with the biogeochemical planetary boundaries.

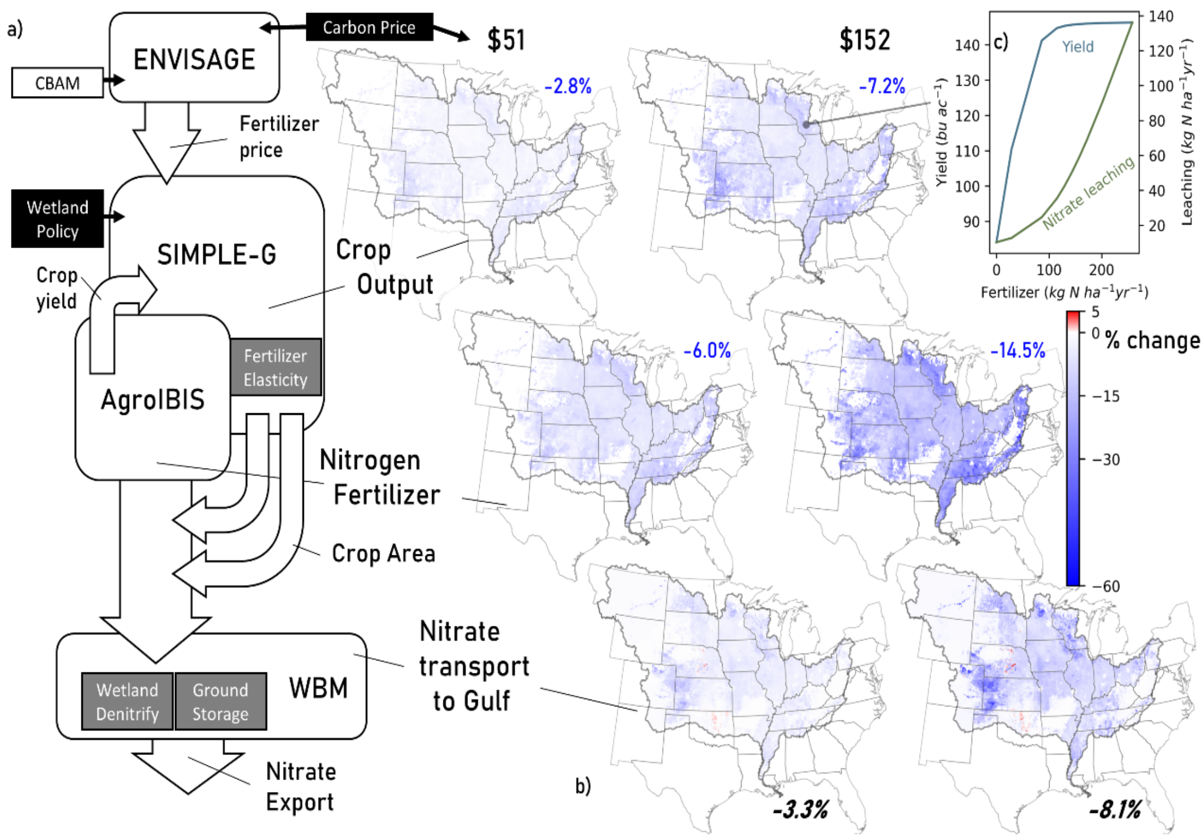

Figure 2. Impact of carbon pricing on water quality in the Mississippi River Basin and the deliverty of nitrates to the Gulf of Mexico. Source: Zuidema et al., PNAS, 2023

The second policy considered is a direct intervention into the nitrogen cascade, in the form of a tax on nitrogen used in agriculture. Here, we build on prior work by (Schulte-Uebbing et al. 2022) which quantifies local planetary boundaries associated with nitrate pollution from agriculture. Instead of using a biophysical modeling approach and dictating *a priori* how the nitrogen should be applied globally in order to return to a safe operating space (Gerten et al. 2020), we instead embed these biophysical relationships – derived from the LPJmL ecological model -- in an economic model (SIMPLE-G) and consider the impact of an economic policy aimed at achieving these targets. Specifically, we apply a location-specific tax aimed at curbing excess nitrogen applications (Haqiqi et al. 2024). This approach yields some important insights about tradeoffs and synergies. Firstly, the reduction in fertilizer demand in locations where nitrate leaching is stressing the local environment, such as Northeast China, Northern Europe and the US Corn Belt, reduces the price of nitrogen fertilizer. This makes fertilizer more affordable for producers in other regions where application rates are currently very low, such as Africa and parts of South America. This boosts local food production and enhances food security in those regions. It is also the case that higher fertilizer prices in Northeast China, Northern India and parts of the US create incentives to move production elsewhere. Overall, global cropland increases to compensate for the lower level of intensification. This is a planetary boundary tradeoff. However, the coincidence of excess nitrogen applications with groundwater mining in some regions (e.g., Northern India), generates some positive synergies, as production and hence groundwater withdrawals in those locations declines.

The third policy examined in this paper is targeted at excessive groundwater withdrawals across the planet (Haqiqi, Perry, and Hertel 2022). In this case, we implement a local regulation on groundwater withdrawals in those locations where they are in excess of recharge rates. This policy has spillover effects into land use, as those areas currently exceeding planetary boundaries via excessive withdrawals account for more than 12% of global crop production. When production declines, prices rise, and there is an incentive to expand cropland globally as well as to intensify production and boost fertilizer applications. In short, this is an example of the kind of tradeoff that arises when seeking to remain within a given planetary boundary.

The final policy examined relates to public investments in research and development (R&D) aimed at boosting agricultural productivity. These investments generate knowledge capital which raise productivity, not only in the country making the investment, but the gains have also been shown to spillover to other regions (Fuglie, 2018). There is a long tradition of studying the relationship between R&D and productivity in agricultural economics (Alston et al. 2010) and the evidence is that these investments yield a high economic return. However, less attention has been given to the environmental impacts of such investments. In a recent review paper, Fuglie et al. (forthcoming) assess the potential for R&D to mitigate greenhouse gas emissions. They conclude that the associated cost of abatement is quite favorable (e.g., \$37-\$56/ton CO2 abated, based on findings in Fuglie et al., 2022), when compared to the social cost of carbon. They also note that such investments can alleviate the pressure to expand cropland, thereby lowering the cost of policies aimed at setting aside land for other ecosystem services (Fuglie et al., 2022).

Furthermore, recent research (Baldos et al., in Review) has shown that, by sparing cropland in biodiversity hotspots, the adoption of modern crop varieties has served to limit the extent of agriculture-driven biodiversity degradation (Figure 3).

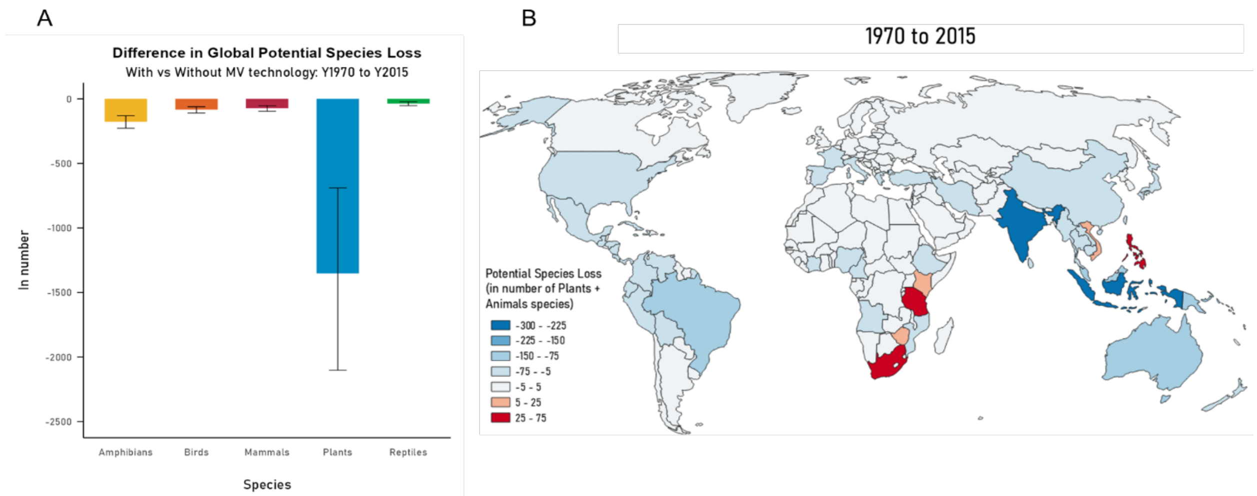

Figure 3. Changes in potential species loss due to adoption of improved crop varieties. (A) Global changes in potential species loss by species type. (B) Map of average changes in potential species loss for both plants and animals by country. Blue areas are where potential species loss was lower. Red areas are where potential species loss was higher due to varietal adoption. Source: Baldos et al. (in Review).

Each of these studies is based on the idea that understanding the drivers of planetary boundary exceedances, as well as potential solutions, requires a multiscale approach. While local analysis is essential to assessing the impact of agriculture on greenhouse gas emissions, water quality, water availability and biodiversity, it is not possible to understand the synergies and tradeoffs associated with such interventions without adopting a multiscale framework. Such a framework must account for the market-mediated, spillover effects associated with targeted interventions aimed a dealing with local environmental externalities. One such framework is SIMPLE-G: A Simplified International Model of Prices Land use and the Environment – Gridded version. All of the results reported in this paper have been produced using variants of the SIMPLE-G model which is publicly available, and which is documented the forthcoming book by Haqiqi and Hertel, due to be published by Springer in summer, 2024.

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