From Mines to Meals: Assessing the Food Security Impacts of Phosphate Rock Scarcity in a Global CGE Model

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Introduction

Phosphorus, sourced almost entirely from mined phosphate rock, is essential for plant growth. It is a non-substitutable input in agriculture, making it a key determinant of global food security (Cordell et al., 2009). Around 90% of global phosphorus consumption occurs in agriculture, supporting the food needs of a growing world population, projected to exceed 10 billion by 2100 (UN DESA, 2024). However, phosphate rock reserves are scarce, expensive, and located in only a hand full of countries, with over 68% global phosphate rock reserves located in Morocco and Western Sahara (USGS, 2024). This uneven reserve distribution exposes the global food system to geopolitical and market risks. Any future disruption in the continued supply of this important input might significantly affect global food security. Past fertiliser price shocks, for example during the 2008 global economic crisis, show how quickly disruptions in phosphate rock and phosphorus supply can translate into higher food prices and increased food insecurity (Khabarov & Obersteiner, 2017). Therefore, accounting for phosphate rock and phosphorus in economic and food security assessments is important.

However, substantial gaps remain in the assessment of phosphate rock and phosphorus scarcity in economic and food security assessments, both in terms of content and modelling approaches. From a content perspective, most existing studies focus on physical depletion or phosphorus flows, without adequately linking these dynamics to economic and food security outcomes (Fixen & Johnston, 2012; Illakwahhi et al., 2024; Li et al., 2019; Walan et al., 2014). From a modelling perspective, current approaches exhibit clear limitations. Physical depletion and system-based models typically do not capture market feedback or key drivers of phosphate rock and phosphorus demand and supply. These include population growth, extraction costs, technological change, phosphorus recycling and recovery, trade dynamics, and price effects all of which are critical determinants of future phosphate rock and phosphorus availability. Market-based models, treat phosphorus and phosphate rock mining only implicitly within aggregated sectors and as part of natural resource endowments (Beckman et al., 2022; Chepeliev et al.,2025). Even studies that explicitly model phosphorus fertilisers, such as Bartling et al. (2016) and von Lampe et al. (2014), still aggregate phosphate rock extraction within the broader mining sector. Consequently, the integration of the phosphate rock value chain in existing economic modelling frameworks remains limited.

Recent, GTAP extensions have advance the representation of the critical minerals supply chains in the global economic models (Alexeeva-Talebi et al., 2012; Winning et al., 2017), however these efforts have only focused primarily on metals, plastics and cements. We are not aware of an economic modelling framework that captures the entire value chain - from phosphate rock endowments and extraction through fertilizer production to the use of phosphorus in food, feed additives, as well as other industrial and chemical sectors. This omission constrains the ability to systematically evaluate the risks that future phosphate rock and phosphorus scarcity pose to global food security.

Objective and Research Questions

The objective of this study is to contribute to filling this gap by extending a global computable general equilibrium model to explicitly account for phosphate rock mining, phosphorus uses and the key drivers of phosphorus consumption and supply. On this basis we assess the implications of a potential future scarcity of phosphate rock and phosphorus for global food security. Specifically, this study addresses the following research questions:

1. How does an exogenous reduction in the availability of phosphate rock reserves and exports affect global phosphate prices, trade patterns, and sectoral production across regions?

2. What are the implications of phosphate rock and phosphorus scarcity for global food security, in terms of food prices, caloric availability, and regional distributional effects, particularly in import-dependent and low-income countries?
3. Which sectors along the agri-food value chain (crop production, livestock, food processing, feed industries) are most vulnerable to phosphorus constraints, and how do they adjust through substitution, input reallocation, and changes in trade?

Methodology

Our modelling framework extends the Global Trade Analysis Project (GTAP) model version 7 (Corong et al., 2017). The GTAP model is a multi-region, multi-sector computable general equilibrium model based upon standard general equilibrium assumptions such as market clearance, zero profits, and utility maximisation and cost minimisation of representative agents. All industries are modelled through a representative firm that maximises its profits in a perfectly competitive market. The production functions of each economic sector are specified using a series of nested constant elasticity of substitution (CES) functions. Domestic and foreign inputs are not perfect substitutes and are modelled using the Armington assumption, which accounts for product heterogeneity between different world regions. A representative consumer in each region receives household income, defined as the service value of national primary factors. National income is allocated between aggregate household consumption, public consumption and savings.

The underlying database for our study is the GTAP Circular Economy (GTAP-CE) database (Chepeliev, 2023), which builds upon the standard GTAP social accounting matrices. The base year for our analysis is 2017. The database currently includes 99 disaggregated sectors across 160 regions. However, despite the database accounting for multiple extraction, mining and other users' sectors, phosphate rock mining and important users of phosphorus remain in aggregated sectors thus making detailed phosphate rock depletion policy analyses impossible.

According to this backdrop, we extend the circular economy database to explicitly account for phosphate rock mining and use of phosphorus in animal feed, food additives, fertilizer, and other industrial and chemical sectors. We introduce a dedicated phosphate rock extraction sector and corresponding commodity into the input–output and trade structures. We disaggregated the existing non-metallic mineral mining (nmn) sector using physical and monetary data on phosphate rock production, consumption, and trade from the International Fertilizer Association (IFA), USGS, UN COMTRADE database and specialized market research reports and update the GTAP version 7 model accordingly. On the use side, phosphorus flows are allocated across animal feed, food additives, mineral fertilizers, and other industrial and chemical applications by splitting the corresponding GTAP sectors based on detailed use shares, cost shares and price information from the literature. These additional sectoral splits allow the construction of a phosphorus-specific supply use structure that is consistent with national accounts and GTAP's value flows, while also tracing the physical phosphorus content.

Methodologically, the extension follows standard GTAP disaggregation procedures: we identify candidate composite sectors, we define new subsectors and commodities, and then we used external data to derive split shares for the new sector output, intermediate use, final demand, and bilateral trade, and reconcile the new accounts with the original GTAP totals to preserve macroeconomic consistency. The resulting extended GTAP modelling framework provides a consistent basis to assess economy wide impacts of phosphorus related policies and possible future resource constraints on global food security. The database disaggregation was implemented using the SplitCom utility (Horridge, 2008). A detailed explanation of the split process to introduce the new sectors and data used are presented in the appendix section of this paper.

For the modelling part of this study, we aggregated the extended GTAP-CE database to include 27 regions and 24 sectors that are relevant for modelling the effects of phosphate rock scarcity on agrifood markets. The regional aggregation preserves countries that are key players in phosphate rock production (China, United States, and Morocco), fertilizer, feed and cereal producers and consumers, (Russia, Germany, Canada, Spain, EU, Mexico, Brazil, Argentina, Japan, South Korea, and India) as separate countries. We also separate sectors along the phosphate rock value chain, such as phosphate mining, cereals, paddy, wheat, other crop sectors, feed, cattle, fish, other animals, and the three different fertilizers (nitrogen, potassium, and phosphorus), and other downstream phosphate rock users. This regional and sectoral aggregation provides a robust framework for analysing the economy-wide effects of phosphate rock scarcity, capturing both the direct and indirect effects on agricultural production, trade flows, and food security.

Scenario description

1. **Baseline**

To develop a future baseline equilibrium, we adopt the methodology describe by (Dixon & Rimmer, 2025). Base on this methodology we derived a reference general equilibrium benchmark for the two time periods (2030 and 2050) by using projected growth data on key macroeconomic variables in the model. In the baseline we update regional endowment, other factors specific and productivity changes, population and regional economic growth. It is consistent with the middle-of-the-road pathway of the Shared Socioeconomic Pathways (SSP2) described by O'Neill et al. (2017). Population projections are based on those of the International Institute for Applied Systems Analysis (IIASA) (Kc et al., 2024), while growth in GDP, capital stock, and labour is based on Organization for Economic Cooperation and Development (OECD) projection (OECD, 2026).

Estimates of population and labour supply shows continued global growth with significant regional heterogeneity. Population is projected to increase most rapidly in developing regions, particularly in Sub-Saharan Africa, where total population rises by approximately 35% by 2030 and 94% by 2050 relative to the base year. In contrast, population growth stagnates or declines in several advanced and emerging economies, with China's population at 0% in 2030 and decreasing by around -8% by 2050 and European Union experiencing a reduction of approximately -2% and -3% in 2030 and 2050 respectively. Labour supply evolves in line with these demographic trends, with strong expansion in Sub-Saharan Africa of approximately 47% and 139% by 2030 and 2050 respectively, while declining in ageing economies such as the European Union (2% and 12% by 2030 and 2050 respectively) and China (2% and −16% by 2030 and 2050 respectively).

Macroeconomic growth projections show sustained global economic expansion driven primarily by developing regions. By 2030, GDP will increase by approximately 23% in Northern America, 15% in Latin America, and 84% in China. By 2050, growth becomes more pronounced in emerging economies, with China's GDP rising by around 184%, Southern Asia by 247%, and Sub-Saharan Africa by 64%, while developed regions such as the European Union grow more moderately, by approximately 59%. Capital accumulation follows these growth trajectories, with strong capital deepening in developing regions, particularly in Sub-Saharan Africa (68% and 356% by 2030 and 2050 respectively) and Southern Asia (129% and 452% by 2030 and 2050 respectively), and more moderate increases in advanced economies.

In addition to these standard drivers, the baseline incorporates assumptions relevant to phosphorus use, including continued growth in agricultural demand, fertilizer use, and structural transformation of agri-food systems. Growth in agricultural production and crop yields is derived from the IMAGE 3.0 implementation (Mogollón et al., 2018)[1], with linear interpolation to align with the 2017 base year of the GTAP-CE database. Global crop production increases by 24% by 2030 and 42% by 2050. Yield improvements account for approximately 16% and 27% of global crop production growth by 2030 and 2050, with the remainder coming from cropland expansion. Crop phosphorus uptake, a key driver of fertilizer demand, follows a similar pattern, with global uptake increasing by 21% and 38% by 2030 and 2050 respectively. Significant regional heterogeneity exists, industrialized regions experience modest crop phosphorus uptake growth (9% and 14% by 2030 and 2050 respectively), while the rest of

[1] Mogollón et al. (2018) project up to 2050 with 2010 as the base year. For the years 2017-2030 and 2017-2050, we interpolate the trends of the period 2010-2050.

the world sees rapid expansion (39% and 71% by 2030 and 2050 respectively. The baseline scenario assumes no additional constraints on phosphate rock availability or trade, and no major policy shifts affecting fertilizer markets.

2. Experiment

On top of this reference baseline, we design a set of counterfactual scenarios that vary the long-term availability and accessibility of phosphate rock. Drawing on alternative phosphorus supply models and resource assessments from the literature, we construct contrasting futures that differ in terms of ultimately recoverable reserves, extraction costs, and export capacities of key producing regions. In the model, these scenarios are implemented as exogenous constraints and cost shocks on phosphate rock extraction and trade, which propagate through fertilizer markets, agri-food value chains, and international trade.

Results and Discussion

Next on this paper is the simulation face which is currently underway. Once completed, we will compare the reference baseline to progressively tighter scarcity scenarios to quantify how exogenous constraints on phosphate rock supply propagate through the global economy. By tracking changes in phosphate rock and fertilizer prices, trade patterns, and regional production, we will identify the effects of reduced phosphate rock reserves, higher extraction costs, and export limitations on global phosphorus use and sectoral output. Linking these outcomes to food prices, caloric availability, and regional distributional effects allows us to assess implications for global food security, with a focus on vulnerable, import-dependent, and low-income countries. The findings will contribute to the limited literature on economy-wide impacts of phosphate rock scarcity.

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