Anthropocentric uses of phosphorus: flows quantification and potential for recycling in Ontario

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Abstract

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1. Introduction

Phosphorus is an essential for production of food which has been intensively used for crop and livestock production since the development of synthetic fertilizers in the XIX and XX centuries (Samreen and Kausar, 2019). The combination of synthetic fertilizers with other modern intensive agricultural techniques have increased the productivity of agriculture and farming industries (Pingali, 2012). However, the intensive use of fertilizers in agriculture has resulted in the over-application of phosphorus in many regions worldwide REF, while the run of intensive livestock production facilities, also known as concentrated animal feeding operations (CAFOs) (U.S. Department of Agriculture, 2011), result in important difficulties in the management of the large amounts of manure produced, which is often spread in lands in the vicinity of CAFOs, which also leads to the accumulation of phosphorus in soil. Soil acts as a phosphorus reservoir (Ehlert et al., 2003), building-up a legacy P that can be used for future crops, but also can be transported to waterbodies by erosion and runoff leading to the eutrophication of aquatic ecosystems.

The dual dimension of the anthropogenic use of phosphorus, i.e., its key role in the food production system and the negative environmental impacts associated with the phosphorus used in intensive agricultural techniques, has been stated by the United Nations Environment Assembly in the resolution UNEP/EA.5/Res.2 (United Nations Environment Programme, 2022). An additional

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factor to be considered for addressing the phosphorus challenge is the non-renewable nature of phosphorus, since the phosphorus consumed is not replenished by natural means at human time scale, and there is currently no known synthetic substitute for this material (Cordell et al., 2009). Since the global phosphorus reserves are concentrated in a few number of regions, the supply of phosphorus from a limited number of global supply chains lacks resiliency and it has been proven that it can be globally disrupted by regional events and conflicts, resulting geopolitical tensions (Food and Agriculture Organization of the United Nations, 2022). As a consequence, the recovery and recycling of phosphorus is not just a desirable but also a necessary approach to assure a sustainable, reliable, and sovereign food production system.

Although the main uses of phosphorus are in the agri-food sector, phosphorus is also involved in other industrial activities, including steel, chemical, and forestry industries. Henceforth, phosphorus is a key material for many aspects of human development. As a result, mapping the phosphorus flows involved in human activities to detect opportunities for recovery and recycling is essential for, in a second stage, assess amount of phosphorus that is viable to recover, the economical costs involved, and the enhancement in terms of resiliency of the regional food production system, savings from the reduction of phosphorus imports, and the mitigation of phosphorus pollution on the region implementing strategies for phosphorus recovery and recycling. The quantification of phosphorus flows has been addressed in previous works in the literature for certain sectors such as the agri-food sector (Boh and Clark, 2020; Zhou et al., 2021; Nesme et al., 2018). Additionally, studies on the global phosphorus flows have also been performed (Villalba et al., 2008; Chen and Graedel, 2016), although these studies tend to have a low flow resolution since these are aggregated by major sectors. Additionally, the works quantifying phosphorus often include qualitative recommendations to improve the phosphorus use efficiency and recycling (Van Dijk et al., 2016; Senthilkumar et al., 2012), but often they do not include quantitivae assessments on the amount of phopshorus which recovery is feasible along with the costs involved. Conversely, those works focused on estimating the recoverable phosphorus and the associated recovery cost target specific flows, lacking a holistic perspective of the phosphorus flows in the various human activities (Martín-Hernández et al., 2021; Sampat et al., 2018).

In this work, we have selected the Canadian province of Ontario for mapping the phosphorus flows involved in the agri-food, industrial and urban sectors. This data is used to assess the amount of phosphorus that could be recovered within the province, considering different scenarios regarding the availability of phosphorus recovery technologies, and to estimate the costs associated with the recovery of phosphorus. Finally, we discuss the implications on the use of phosphorus in Ontario that would be derived from implementing active phosphorus recovery and recycling approaches.

2. Methods

2.1. Spatial resolution

2.2. Temporal resolution

2.3. Estimation of phosphorus flows

2.3.1. Agricultural sector

2.3.2. Industrial sector

2.3.3. Urban sector

3. Results and discussion

3.1. Phosphorus flows in Ontario

Showing an overview of the P flows in the province. The use of figures summarizing all the flows of the province in the shape of Sankey or network flow figures could be so great

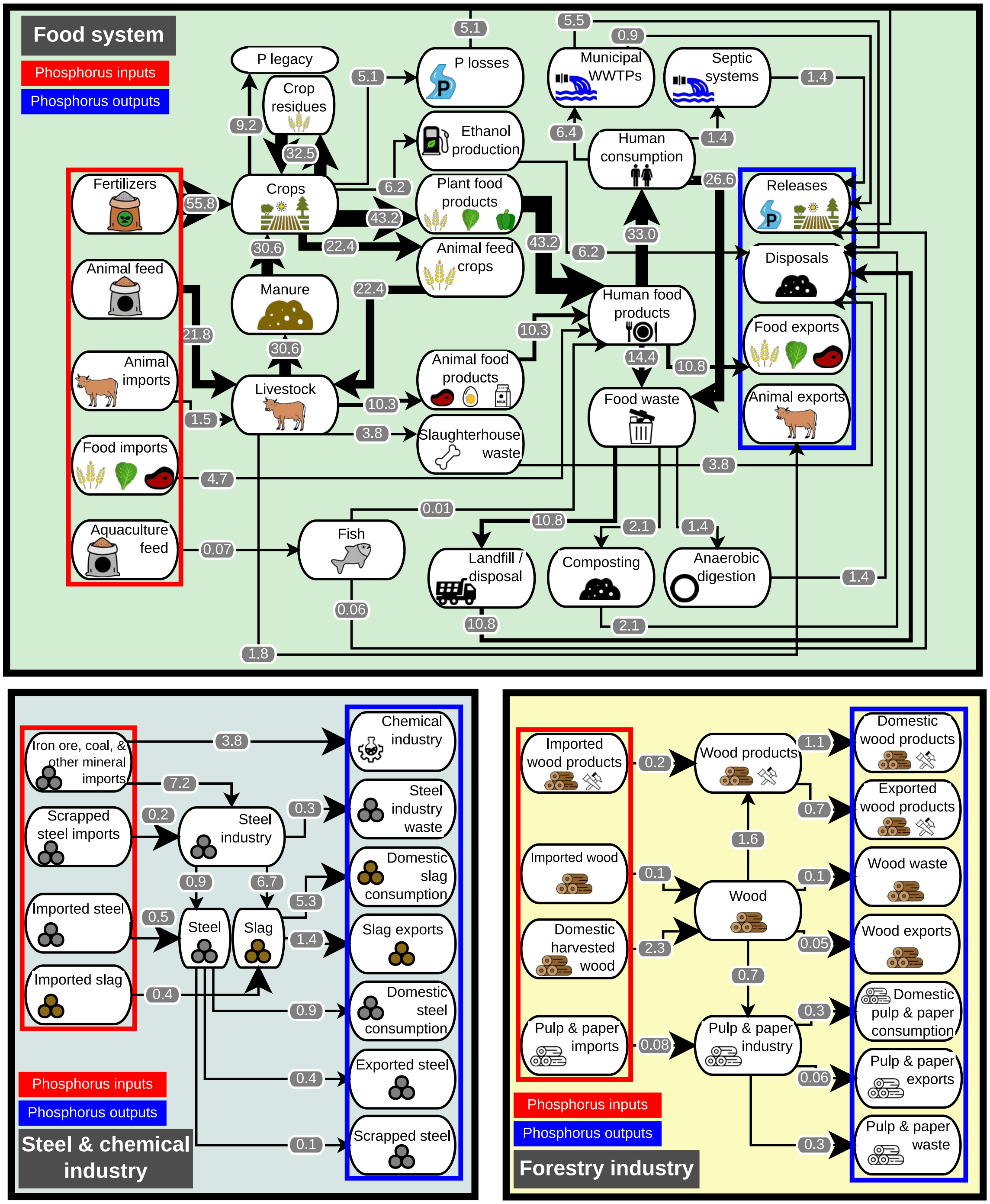

Figure 1: Phosphorus flows in the province of Ontario. The streams within red rectangles denote phosphorus inflows into the province, while those streams within blue rectangles denote phosphorus outflows out of the province.

Figure 1 summarizes the phosphorus flows in the province of Ontario. It can be observed that the flow of of phosphorus through the anthropogenic activities are divided into 3 independent networks, i.e., the flow of phosphorus involved the production and processing of food (including the treatment of wastewater), the flow of phosphorus used in the steel and chemical industries, and the phosphorus involved in the forestry industry.

The production of animal food products exhibits a lower phosphorus use efficiency than the production of plant base products, similarly to the use effciciency of other resources such as water CITE HERE, CALCULAR ENTRA VS SALE!

3.2. Phosphorus recovery techniques ***(This section could be Supplementary Material)***

Brief overview of potential P recovery techniques for each sector

3.2.1. Agricultural sector

3.2.2. Industrial sector

3.2.3. Urban sector

3.3. Potential of phosphorus recovery in Ontario

Assessment of different scenarios of P recovery in Ontario, P imports that would be saved, reduction of P dependency of the province, etc (all implications related with mass-balances)

3.4. Economic implications of phosphorus recovery in Ontario

Economic costs or saving derived from the recovery of P in the province and all implications related with economy

3.5. Implications on food sovereignty of phosphorus recovery in Ontario

Implications on food production self-sufficiency derived from the (partial) recycling of P. Discussion on the improvement of the food production system resiliency against disruptions of the global supply supply chains (e.g., current context derived from the COVID-19 pandemia and the war in Ukraine)

3.6. Gaps of knowledge

4. Conclusions

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