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A Phosphorous Flow Analysis in Spain

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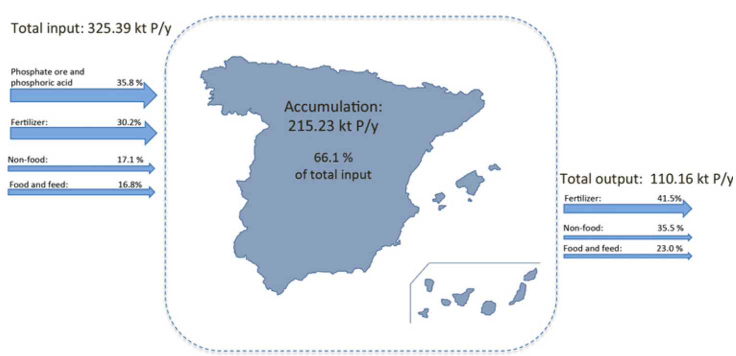
HIGHLIGHTS

- A Phosphorous Flow Analysis (PFA) for Spain was carried out for the year 2012.
- One third of total P imported was lost to the environment.
- The largest proportion of losses is associated to water bodies.
- WWTPs received around 80 kt P within wastewater with 60% removed in sewage sludge.
- Amount of P in the final effluent accounts 71% of the total losses to water bodies.

GRAPHICAL ABSTRACT



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ABSTRACT

Phosphorus (P) is a vital macronutrient required to improve the agricultural yields but its excessive use as a fertilizer has resulted in pollution of water bodies leading to eutrophication. With no reserves of phosphorus source in Spain, increased dependence on phosphorus in agriculture have not only increased dependence on imports but also has raised concerns on its future availability as a resource. A Phosphorous Flow Analysis (PFA) was conducted for Spain for the year 2012 focusing on the food production and consumption systems. The results obtained were finally compared with PFA at both country level and continent level (EU-27). To quantify food and non-food flows systems, country specific data were considered. The sectors covered were crop production (CP), animal production (AP), food processing (FP), non-food production (NF) and consumption (HC). The findings reveal that a total of 325 kt P was imported by Spain in 2012; 66% of which was accumulated in markets stock of food and feed, fertilizers and non-food (91 kt P) while 33% was lost to the environment through land-fill, losses to water bodies, land accumulation and incineration. The largest proportion of losses is associated with water bodies (44.7 kt P) followed by agriculture and land accumulation (42.1 kt P). Wastewater treatment plants (WWTPs) received around 79.5 kt P within wastewater, with 60% being removed in sewage sludge. The 31.7 kt P discharged within final effluent represented the 71% of the total losses to water bodies. Around 69% of the sewage sludge was recycled to agriculture and 27% was sent directly to landfill including the ashes from incineration. Net accumulation was 1.84 kg P/cap which was similar to values reported for the EU-27 average (2.5 kg P/cap).

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1. Introduction

The United Nations growth forecast for world population of about 9.7 billion by 2050 (e.g., an increase of 33% over the next 35 years) will undoubtedly represents an increase in demand for fertilizers. This is also based on the forecast made by Food and Agriculture Organization (FAO) for a 1.8% annual increase in crop production by 2050 (FAO, 2015). Thus, the key to the short- and long-term stability of the food chain is to close the cycles of the main resources, which are necessary to support them (e.g., nutrients as phosphorus (P) and nitrogen (N)). P is an essential element to sustain life since it is part of the crucial biological processes, such as reproduction (e.g., DNA), body structures (e.g., bones) and energy supply in the form of ATP (Oelkers and Valsami-Jones, 2008) and it cannot be substituted. It also plays a vital role in enhancing soil fertility, agricultural productivity and therefore, on the global food security.

Although there is an increase in the global demand, the low diversity of the phosphate rock deposits and the fact that it is considered a non-renewable resource makes P a critical raw material for a nation dependent on agriculture (Sattari et al., 2012). The availability of the phosphate rock reserves is restricted to five major countries (e.g., China, USA, Russia, Morocco and Sahara) and this global imbalance underlies serious challenges at world scale (Childers et al., 2011; Jasinski, 2014; Cooper et al., 2011). Past estimates suggested a time span of 50–100 years for the complete depletion of these primary P reserves (De Haes et al., 2009; Vaccari and Strigul, 2011; Cordell et al., 2010; Cordell et al., 2009a), but current estimates are relying on 300–400 years depending on the dynamics of demand and supply under current extraction rates (Reijnders, 2014; Scholz and Wellmer, 2013; Jasinski, 2014). There is also the probability that the price of P increases in the future with increasing demand and depletion as well as the increase of the cost of production and this may affect the affordability and may also escalate the price of food. This scenario could further create geopolitical tensions which could in turn make it difficult for dependent nations to procure P from the main producers.

Due to the facts and projections as stated above, the EU has included, in 2014, the P-rock in the critical materials list (EC, 2014a). Thus, nations and regions having no P reserves or having low deposits (e.g., EU with only very few P-deposits in Finland (de Ridder et al., 2012; Reijnders, 2014)) need to initiate a change in the cycle of this critical resource to reduce their dependence on primary sources. The probable solution to the P-challenge has been directed to its sustainable management consisting of its efficient use including higher and better recycling. Such potential solutions can be identified by P flow analysis (PFA) studies that provide an insight into how humans have used P, and how P has been transfer to the environment on different spatial scales (Chowdhury et al., 2014). The PFA can also provide knowledge to identify in-sustainable uses for more sustainable P use (Cordell et al., 2012). Various PFA's have been conducted at a global level (Smil, 2000; Liu et al., 2008; Cordell et al., 2009a) and also at a continent level like the EU (Richards and Dawson, 2008; Ott and Rechberger, 2012) and Africa (Cordell et al., 2009a). PFA's were also conducted on specific countries like Australia (Cordell et al., 2010), China (Li et al., 2012), Japan (Matsubae et al., 2011; Mishima et al., 2009), Austria (Egle et al., 2014; Seyhan, 2009), Belgium (Coppens et al., 2013), Denmark (Klinglmair et al., 2015), Finland (Antikainen et al., 2005, 2008; Saikku et al., 2007), France (Senthilkumar et al., 2012a, 2012b), Germany (Gethke, 2012), Netherlands (de Buck et al., 2012; Smit et al., 2010), Norway (Hamilton et al., 2015), Sweden (Linderholm et al., 2012a), Switzerland (Binder et al., 2009; Lamprecht et al., 2011), Turkey (Seyhan, 2006, 2009), and United Kingdom (Cooper and Carliell-Marquet, 2013). Such studies have given a qualitative as well as a quantitative description of P flows which in turn have been used to forecast future P requirement and usage, recovery and reuse options so as to secure both food as well as P availability.

The results of these analyses have some common findings despite the differences in terms of the territory covered or the purpose of the study. It can be highlighted that some of these countries are net phosphorous importers even those that are net food exporter (e.g., Australia). Substantial losses and inefficiencies have been identified in the P cycles due to the low recycling rates for several P flows with the largest losses within the systems to water and soil accumulations. Some studies highlighted a considerable unexploited potential for improvement. Those efforts should be focused on P removal and recovery at WWTP, as well as the developing more effective methods for recycling bulky wastes such as animal manure, food waste and especially municipal sewage sludge, which could potentially substitute a significant part of the total applied mineral P fertilizers. However, resource recycling and, thereby, reducing P fertilizer use appeared to be less promising than scenarios based on reduced food waste or redesigned agricultural systems.

Spain, like other European countries, has no P-rock mineral deposits and therefore depends on imported mineral phosphate fertilizers to support Spanish fertilizer industries and agriculture. Therefore, the food security in Spain is at present highly dependent on a secure and affordable supply of mineral fertilizers derived from imported phosphate rock. Based on this context, a PFA analysis of Spain has been conducted focusing mainly on the agriculture, food and fertilizers production and consumption system. Since these are the flows where most of the phosphorus transfer occurs, but including flows from industrial processes and waste management processes which interact with P system. The flow diagram and system boundaries used in the PFA analysis were based on a global perspective, which includes the food system (food consumption–production–waste chain), as well as non-food flows (detergent, fertilizer and forestry industries), in addition to obtaining quantitative information on imports, exports, major areas of loss or accumulation. The objective behind the PFA analysis is to identify the areas requiring the primary resources of P and simultaneously to identify available secondary resources. An analysis of the potential contribution of secondary P resources associated with urban wastewaters, identified by the EU as one of the target contribution against the P scarcity, was carried out and results compared to other PFAs as reported worldwide. The study has extracted data on P cycles, industrial and agricultural uses to develop the mass flow analysis using databases available for public consultation. For data not available, published data from mass flow analysis on other country or region was taken into account. This PFA on a global perspective will be especially relevant for the proposed EU approaches: circular economy (EC, 2011, 2014d) and bio-based economy (EC, 2012).

2. Methodology

Material Flow Analysis (MFA), has been used to examine resources such as minerals, water or energy at a wide range of geographical scales (from global to local) (Cordell and Neset, 2014). The method was established in the field of Industrial Ecology to aid environmental management for assessing the 'metabolism' of human (anthroposphere) or technical (technosphere) systems. The method is based on two scientific approaches: i) mass balance, which enables a systematic assessment and tracking of the flow of materials (e.g., P) between various processes, as well as the imports to and exports from the system (Cooper and Carliell-Marquet, 2013) and finally ii) the system analysis. An important concept regarding mass balance under the MFA is related to the conservation of mass in which a material is transformed during its flow but cannot be destroyed (Baccini and Brunner, 2012).

At the global level P flows have been quantified along the whole P use chain (Cordell et al., 2009a). This quantification was then used for: i) predicting the future P use so as to ensure long term global food demand (Cordell et al., 2009b), ii) developing a system so as to recover and reuse P in order to ensure global P security (Cordell et al., 2011, 2013) iii) identifying synergies for a sustainable future based on global P scarcity (Neset et al., 2013) and finally, iv) developing a framework to assess the vulnerability of national and regional food systems