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Phosphorus flows and balances of the European Union Member States

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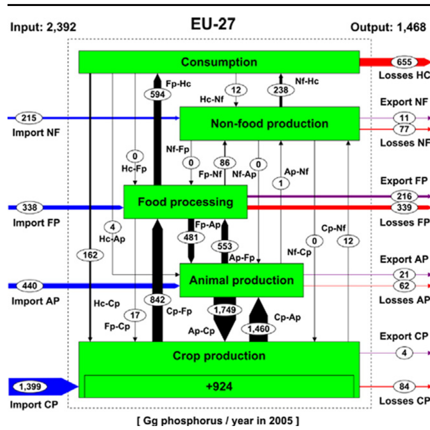
HIGHLIGHTS

- Phosphorus (P) flows were analyzed in detail for EU-27 and its Member States.
- The food consumption–production–waste chain and non-food flows were considered.
- The EU-27 is characterized by large P-rock import and long-term P soil accumulation.
- Large P losses exist, especially emissions to the environment and sequestered waste.
- The relatively low recycling and efficiency provide opportunities for improvement.

GRAPHICAL ABSTRACT



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ABSTRACT

Global society faces serious “phosphorus challenges” given the scarcity, essentiality, unequal global distribution and, at the same time, regional excess of phosphorus (P). Phosphorus flow studies can be used to analyze these challenges, providing insight into how society (re)uses and loses phosphorus, identifying potential solutions.
Phosphorus flows were analyzed in detail for EU-27 and its Member States. To quantify food system and non-food flows, country specific data and historical context were considered. The sectors covered were crop production (CP), animal production (AP), food processing (FP), non-food production (NF) and consumption (HC).
The results show that the EU-27 imported 2392 Gg P in 2005, half of which accumulated in agricultural soils (924 Gg) and half was lost as waste (1217 Gg). Net accumulation was 4.9 kg P/ha/year ranging between +23.2 (Belgium) and −2.8 (Slovakia). From the system losses, 54% was lost from HC in diverse waste flows and 28% from FP, mainly through incinerated slaughter residues. The largest HC losses (655 Gg) were wastewater (55%), food waste (27%), and pet excreta (11%). Phosphorus recycling rates were 73% in AP, 29% in FP, 21% in HC and ~0% in NF. The phosphorus use efficiencies showed that, relative to sector input, about 70% was taken up by crops (CP), 24% was retained in animals (AP), 52% was contained in food products (FP), 76% was stored in non-food materials (NF), and 21% was recycled (HC).
Although wide-ranging variation between countries, generally phosphorus use in EU-27 was characterized by relatively (1) large dependency on (primary) imports, (2) long-term accumulation in agricultural soils, especially in west European countries, (3) leaky losses throughout entire society, especially emissions to the environment and sequestered waste, (4) little recycling with the exception of manure, and (5) low use efficiencies, because of aforementioned issues, providing ample opportunities for improvement.

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Abbreviations

P phosphorus
P2O5 phosphate (P2O5 = 2.29 ∗ P)
CAPRI Common Agricultural Policy Regionalised Impact model
WWTP wastewater treatment plant
MSW municipal solid waste
PUE phosphorus use efficiency

The following sectors were taken into account:
CP crop production
AP animal production
FP food processing
NF non-food production
HC consumption

EU-15 European Union 15 Member States
EU-27 European Union 27 Member States including: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom

1. Introduction

The scarcity, essentiality, unequal global distribution and yet regional excess of phosphorus (P) underlie serious "P challenges" for global society (Childers et al., 2011). Firstly, P is a non-renewable resource on a human time scale and essential for life to function and grow, and thus crucial for our food system and own health (Cordell et al., 2009a). Since the green revolution and the invention of the industrial fixation of nitrogen (N), humans mine P-rock from historical deposits to produce mineral fertilizers (Brown, 2003). This primary P is only renewed on a time scale of millions of years, and the present known reserves are estimated to be exhausted within 50–400 years depending on P supply and demand dynamics (Reijnders, 2014; Sattari et al., 2012; Scholz and Wellmer, 2013). Secondly, the element P is essential for life and cannot be substituted since it is part of crucial biological processes, such as reproduction (DNA), energy supply (ATP) and body structure (bones, teeth) (Oelkers and Valsami-Jones, 2008). Thirdly, primary P sources are spatially concentrated as 77% of the present known global P-rock reserves are located in Morocco and Western Sahara (Cooper et al., 2011). Europe especially is a region with very few P-rock deposits, of which the majority are located in Finland (de Ridder et al., 2012). This imbalanced distribution of P could cause geopolitical problems for European governments and companies, comparable to the geopolitical tension around fossil energy dependency (e.g. gas, oil and coal). Finally, at the same time, there is also excess P in nature, causing eutrophication and thereby reducing water quality and biodiversity (Carpenter, 2008; Carpenter and Bennett, 2011; Steffen et al., 2015). Fortunately, in the scientific (Schröder et al., 2010; Withers et al., 2015a), political (EC, 2014a,b,c,d) and business (Schipper, 2014; Withers et al., 2015b) domains, potential solutions to the P challenge are also proposed. These solutions include sustainable P stewardship that consists of efficient and effective use of P in society including more and better recycling.

The global and regional P challenges and its potential solutions can be identified by P flow analysis (PFA) studies that provide insight into how humans use and reuse P, and how P is lost to the environment on different spatial scales (Chowdhury et al., 2014). As such, PFA can provide knowledge to identify hotspots in society, such as the food system, for more sustainable P use as a roadmap to P use security (Cordell et al., 2012). PFA studies are commonly conducted using methods such as substance/material flow analysis (SFA/MFA) (Brunner and Rechberger, 2004) that can be made qualitative with additional tools (e.g. indicators and LCA) (Brunner, 2010). At the global level P flows have been quantified along the whole P use chain from 'mine to fork' (Cordell et al., 2009a). This quantification was then used (1) for scenario analysis on future P use as a framework for meeting long term P needs for global food demand (Cordell et al., 2009b), (2) to develop a systems framework for P recovery and reuse options as a solution to work on global P security (Cordell et al., 2011), (3) to identify synergies for a sustainable future based on global P scarcity (Neset and Cordell, 2011) and (4) to develop frameworks for assessing the vulnerability of national and regional food systems to the multiple-dimensional stressors of P scarcity (Cordell and Neset, 2014). Other researchers have analyzed P flows at different geographical scales (e.g.Chowdhury et al., 2014; Ma, 2014).

For Europe, several studies on P flows and input–output balances have been published. Historically, the focus has mostly been on agricultural balances, taking primarily agricultural flows related to crop and animal production into account (Csatho and Radimszky, 2009; Csathó and Radimszky, 2012; Eurostat, 2011; Grizzetti et al., 2007; OECD, 2013; Richards and Dawson, 2008; Sibbesen and Runge-Metzger, 1995; Tunney et al., 2003). At regional scales, P balance studies have focused on river basin levels related to the aquatic P losses to surface waters and the identification of eutrophication risks (Buzás, 1999; De Wit and Behrendt, 1999; Delgado and Scalenghe, 2008; Torrent et al., 2007; Ulen et al., 2007). In general, balance studies are limited to quantifying the inputs and outputs of a system, but do not put emphasis on how nutrients flow through the system. In contrast, PFA studies focus on P flows throughout entire society and take different sub-sectors and internal flows into consideration. In Europe, PFA studies have been conducted for the EU-15 (Ott and Rechberger, 2012), and at the national level for several European countries including Austria (Egle et al., 2014; Seyhan, 2006), Belgium (Flanders) (Coppens et al., 2013), Denmark (Klinglmair et al., submitted for publication), Finland (Antikainen et al., 2005, 2008; Saikku et al., 2007), France (Senthilkumar et al., 2012a,b), 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; Seyhan, 2009), and United Kingdom (Cooper and Carliell-Marquet, 2013). Compared to agricultural P balance studies, PFA studies show how P is used, reused and lost across society as a whole. For example, PFA results show that large P quantities are lost outside agriculture in industrial, consumption and waste handling sectors, via wastewater and biodegradable solid waste. These are important output flows from the system, in addition to the unutilized or lost P in the agricultural sector by accumulation in soils, leaching/runoff/erosion and incineration of slaughter waste. National PFA studies specifically show that there are large differences between countries and between regions within countries, this is discussed qualitatively by Schröder et al. (2010) and compared in depth by Jedelhauser and Binder (submitted for publication).

The European PFA studies differ in data, methodology and outcomes. The national PFA studies can be seen as 'bottom up' studies since the researchers from these countries use national parameters and detailed data, knowledge and assumptions to quantify the flows. In this way country specific context, such as agricultural system types, food habits, and waste management policies, is taken into consideration. At the same time, the specific methodologies, data, base years and flow diagrams used, make it difficult to compare European countries or to integrate them into a multiple-country aggregation that include intra and extra trade corrections. In contrast, the study of Ott and Rechberger (2012) for the average base year 2006–2008 was more 'top down' since the P flows were quantified for the EU-15 as a whole, making country comparison impossible. Despite these shortcomings, Ott and Rechberger (2012) concluded that the EU-15 is largely dependent on P import in the form of P-rock and its derivatives, with mineral fertilizer

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