Resources, Conservation and Recycling 105 (2015) 294–310

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Losses and efficiencies of phosphorus on a national level – A comparison of European substance flow analyses

Michael Jedelhauser*, Claudia R. Binder

Chair for Human-Environment Relations, Department of Geography, LMU-University of Munich, Germany

ARTICLE INFO

Article history:
Received 8 April 2015
Received in revised form
29 September 2015
Accepted 29 September 2015
Available online 2 November 2015

Keywords:
Phosphorus
Substance flow analysis
Comparative study
European countries
Losses
Efficiencies
Cluster analysis

ABSTRACT

The sustainable management of phosphorus (P), an essential element for life, is currently discussed intensively in research and policy. In order to provide a data basis for national P strategies, various substance flow analyses (SFA) of P on a national level have been published in recent years. The quantification of flows and stocks helps to identify hot-spots and potentials for sustainable measures within the particular country analysed. However, the national SFAs that have been conducted so far differ with regard to their system definitions, i.e. the processes, flows and stocks identified. This makes comparisons between countries difficult, hinders the transnational transfer of lessons learnt and hampers supranational policy efforts. Therefore, we (i) develop a standardised visualisation format, i.e. a blueprint, which allows for transnational comparability and facilitates future national SFAs of P; (ii) present a systematic comparative analysis of seven European SFAs (Austria, Germany, France, the Netherlands, Sweden, Switzerland and the United Kingdom) using fluxes, indicators and cluster analysis; and (iii) to exemplarily show the added value of a linkage between material flow analysis and social system analysis. Our results show regional disparities with regard to losses and efficiencies of current national P use and to the potential of secondary P to increase national self-sufficiency. The countries analysed can be categorised in three clusters providing a first classification according to selected variables comprising key flows and indicators. By using the current discussion on the application of sewage sludge on agricultural land in Germany as an example, we show the added value of the integration of flow and governance analyses.

1. Introduction

Phosphorus (P) is essential for life and a finite resource for human consumption. Even though alarming studies on the static lifetime of mineral P (Cordell et al., 2009) have recently been put into perspective, in particular regarding methodological issues (Hubbert Curve) and the dynamics of phosphate rock reserves (Scholz and Wellmer, 2013, 2015a), there is a growing awareness of the finiteness of high grade phosphate rock ores. Especially in countries, whose mineral P supply entirely depends on imports, governments, companies and research institutions increasingly claim that efforts for a transition towards a more sustainable P management (increasing the degree of P-cycling) on a national level should be pursued (Ulrich and Schnug, 2013). This can, however, only be reached if there is, on the one hand, a profound quantitative knowledge on national P stocks and flows and their improvement and cycling potential and, on the other hand, an understanding of the agents involved in the system, their perceptions and interests and their options and restrictions towards sustainable P management. That is, a new way of governing the P stocks and flows at a national level has to be developed.

Regarding the quantification of P stocks and flows, substance flow analyses (SFA) at national level have been developed in numerous countries (see Chowdhury et al., 2014 for an overview of SFAs of P on various scales and van Dijk et al., 2015 for an overall analysis of P flows on EU-27 level). They provide useful insights into the key P stocks and flows in each specific country. However, as they differ in their systems definition, the processes analysed and the flows included, it is difficult to compare the quantitative results of the flow analyses and lessons from one country can hardly be transferred to another one. The lack of comparability also hampers the development of supranational nutrient governance efforts at e.g. the EU level. Thus, a standardised material flow format, i.e. a blueprint for national SFAs of P, is needed in order to provide a common procedural approach. Firstly, this increases the transnational comparability with regard to countries' patterns of P flows and to

* Corresponding author.
E-mail addresses: michael.jedelhauser@lmu.de (M. Jedelhauser), claudia.binder@lmu.de (C.R. Binder).

http://dx.doi.org/10.1016/j.resconrec.2015.09.021
0921-3449/

the losses and efficiencies of national P management. Secondly, the blueprint and the comparative analysis allow for classifying and clustering countries according to their P flow structures, which helps to structure efforts for supranational strategies and policies. Thirdly, it provides a basis for future substance flow analyses on a national level.

Regarding the inclusion of agents in the analysis, initial efforts in combining flow analyses and social sciences have been made and methodologies for linking social issues such as governance and actor networks to specific processes or flows have been developed (Binder, 2007a; Broto et al., 2012; Metson et al., 2015). These approaches are based on the observation that the results of material and substance flow analyses do often not find their way to decision-makers and into regional, national and supranational policies. The structural agent analysis (Binder, 2007b) allows for understanding the different roles of stakeholders within a system and the way they interact with the environment and social structures such as rules, traditions and power. It creates a link between the results of the flow analysis and the social system and helps to increase the chances for converting system into action related knowledge. However, so far only very few studies have used structured approaches for combining these two aspects (Binder et al., 2004; Metson et al., 2012; Salmi et al., 2012).

The present paper aims at filling the gaps mentioned above and contributing to a more qualified discussion on sustainable management of P flows. Our goals are (i) to develop a blueprint for national P stocks and flows, which allows for a standardised procedure for future substance flow analyses and facilitates comparability of existing substance flow analyses; (ii) to present a systematic comparative analysis of national substance flow analyses of P in Europe; and (iii) to exemplarily show the added value of a linkage between material flow and social system analysis.

One crucial challenge in material and substance flow analyses is the reliability of the sources and data used for the quantitative analysis. Doubts about the trustworthiness of results reduce the strengths of the arguments and policy recommendations and weaken flow analyses as a valuable method for sustainable resource management per se. As a consequence, the issue of data uncertainties in flow analyses has been increasingly discussed in recent publications and several approaches for dealing with this issue have been developed (Fischer-Kowalski et al., 2011; Hedbrandt and Sörme, 2001; Laner et al., 2014; Rechberger et al., 2014). Therefore, uncertainties will be explicitly taken into account and discussed in the present paper.

2. Methodology

2.1. Material flow analysis

Material flow analysis (MFA) is a method for “a systematic assessment of the flows and stocks of materials within a system defined in space and time” (Brunner and Rechberger, 2004). It is based on the principle of mass conservation using a systems approach. Main elements of MFA are processes, flows and stocks as well as clearly defined system boundaries. The transfer coefficient shows the partitioning of input flows into processes. By providing quantitative information on flows and stocks within a system, MFA can inform policymakers and serve as a basis for both the improvement of sustainable regional material management and for the development of monitoring programmes and scenarios (Binder, 2007a). MFA comprises the quantification of both goods and substances, whereas SFA focus on substances only. Substances are either chemical compounds or elements (Baccini and Brunner, 2012). Since the present study focuses exclusively on P as a substance, we used the term SFA throughout the paper.

2.2. Blueprint

To develop the blueprint for national P-stocks and flows, we extracted the individual processes, flows and stocks from the national SFAs. The extracted components of the system were then aggregated to standardised processes, flows and stocks. The focus was set on making losses and efficiencies of P within the national systems comparable to each other. The aggregated flows and stocks were used for assessing the potential of different measures to reduce losses and improving efficiencies. Furthermore, the blueprint provides a common visualisation format, which allows for better comparability of specific flows and for recognizing general patterns of national P systems. For reasons of visual clarity, we did not include flows, which only occurred in one or two of the SFAs analysed, in the final blueprint.[1]

2.3. Selection of the countries

For the comparative analysis, we selected countries according to the following criteria:

(i) We exclusively selected European countries due to their comparable political, economic, cultural and natural context the P flows are embedded in. Since six of the seven countries are members of the European Union, the results could contribute to policy efforts on a supranational level.
(ii) The domestic supply of P for mineral fertiliser use is entirely dependent on imports.
(iii) SFAs of P on a national level have been conducted and published for the countries.

Thus, the countries and their corresponding SFAs selected comprise Austria (Egle et al., 2014a,b), France (Senthilkumar et al., 2012, 2014), Germany (Gethke-Albinus, 2012), the Netherlands (Smit et al., 2010), Sweden (Linderholm et al., 2012), Switzerland (Binder et al., 2009) and the United Kingdom (UK) (Cooper and Carliell-Marquet, 2013). Due to its domestic phosphate rock reserves, we did not include the SFA of Finland in the comparative study (Antikainen, 2007).

2.4. Comparative analysis

We used the blueprint and the data of the seven SFAs to compare national P systems. In order to provide comparability between countries, we used fluxes, i.e. we standardised all flows and stocks by calculating annual values per capita or hectare of agricultural land (Brunner and Rechberger, 2004). For flows and stocks per capita, we used the population numbers of the specific year the national SFA refers to. In case the SFAs show average values of several years, we calculated the average population and hectare of the respective time period. The population numbers are 82,002,000 for Germany (German Federal Bureau of Statistics, 2015), 62,275,400 for France (National Institute of Statistics and Economic Studies, 2015), 61,800,000 for the UK (Cooper and Carliell-Marquet, 2013), 16,300,000 for the Netherlands (Statistics Netherlands, 2006), 9,337,533 for Sweden (Statistics Sweden, 2014), 8,255,800 for Austria (Statistics Austria, 2015) and 7,508,739 for Switzerland (Swiss Federal Statistical Office, 2015). The area of agricultural land comprises 29.6 million ha in France (65.8% crop land; 34.2% grass land), 16.9 million ha in Germany (71.7% crop land; 28.3%

[1] Except the flows related to losses (“Mono-Incineration” and “Other Losses”), which were included due to the focus of the paper. However, other flows that appeared in only one or two SFAs were depicted in the specific national SFAs in Section 3.2.