FROM ANALYSIS TO DECISION MAKING: THE EXAMPLE OF PHOSPHORUS

Helmut RECHBERGER, Ottavia ZOBOLI, Matthias ZESSNER

Institute for Water Qualty and Resource Management, Technische Universität Wien, Karlsplatz 13/226, 1040 Vienna, Austria

Abstract

Up to now Material Flow Analysis has been mostly applied to depict annual snapshots of the systems under study. Although this approach has delivered a significant body of new information and knowledge, it has offered a limited understanding of the systems in that it has failed to capture essential shifts and trends over time as well as changing relationships between flows and stocks. This chapter highlights the added value of carrying out multiple-year analyses by presenting a time series (1990-2013) of the Austrian phosphorus (P) budget. The degree of change is systematically assessed, showing that even within the relatively short and stable period, the budget recorded extreme changes in individual flows and stocks as well as in efficiency or recycling ratios, with important implications for either resource and waste management or environmental protection.

Once the system has been thoroughly analyzed and understood, it is necessary to move forward and to assess how it can be optimized. Therefore, negative trends are identified, and selected fields of action aimed at optimizing national P management are discussed for their applicability to the Austrian system and their effectiveness. The selected fields of action are grouped into three categories: 1. Reduction of P demand and consumption; 2. Increase of P recovery and recycling; 3. Reduction of emissions to water bodies. For each selected field of action, the potential improvement with respect to the reference year 2013 is quantified, and barriers and opportunities are analyzed. If all selected actions were implemented, emissions to water bodies could be reduced by 23% primarily through abatement of erosion from agricultural soils and by 8% through changes in consumption patterns. Furthermore, domestic use of fossil P fertilizers could be completely replaced (-100%) and import dependency could be reduced by 90%, showing that the current system fulfills environmental protection much better than resource conservation.

Introduction

The need to enhance phosphorus (P) governance in Austria, as in most other countries, is driven by two major objectives: protecting surface waters from eutrophication and ensuring future food and energy security under scenarios of uncertain supply. Furthermore, the management of P rich flows constitutes a key element to achieve the ambitious goal of the European Commission to move towards a circular economy that enables economic growth by minimizing waste, use of raw materials and environmental damage (EC 2015). This case study exemplifies how materials accounting can be performed on a routine base, thereby increasing the power of Material Flow Analysis (MFA) to understand complex systems and to detect fields of action for the optimization of a region's metabolism, i.e., making it more cyclic.

Analysis of a system

If the MFA of a region is periodically repeated (e.g. yearly), a resource accounting scheme is obtained. Zoboli et al. (2016a) established a retrospective accounting scheme for the region of Austria and the resource phosphorus (P) by compiling yearly P-budgets from 1990 to 2013 to demonstrate the feasibility of such a scheme. Their work delivered several important findings.

First, work load and number of budgets (years) are not linearly correlated. Most of the time had to be used to establish the basic system and identify the data sources. Once this is accomplished, the budgets for adjacent years can be produced comparably fast.

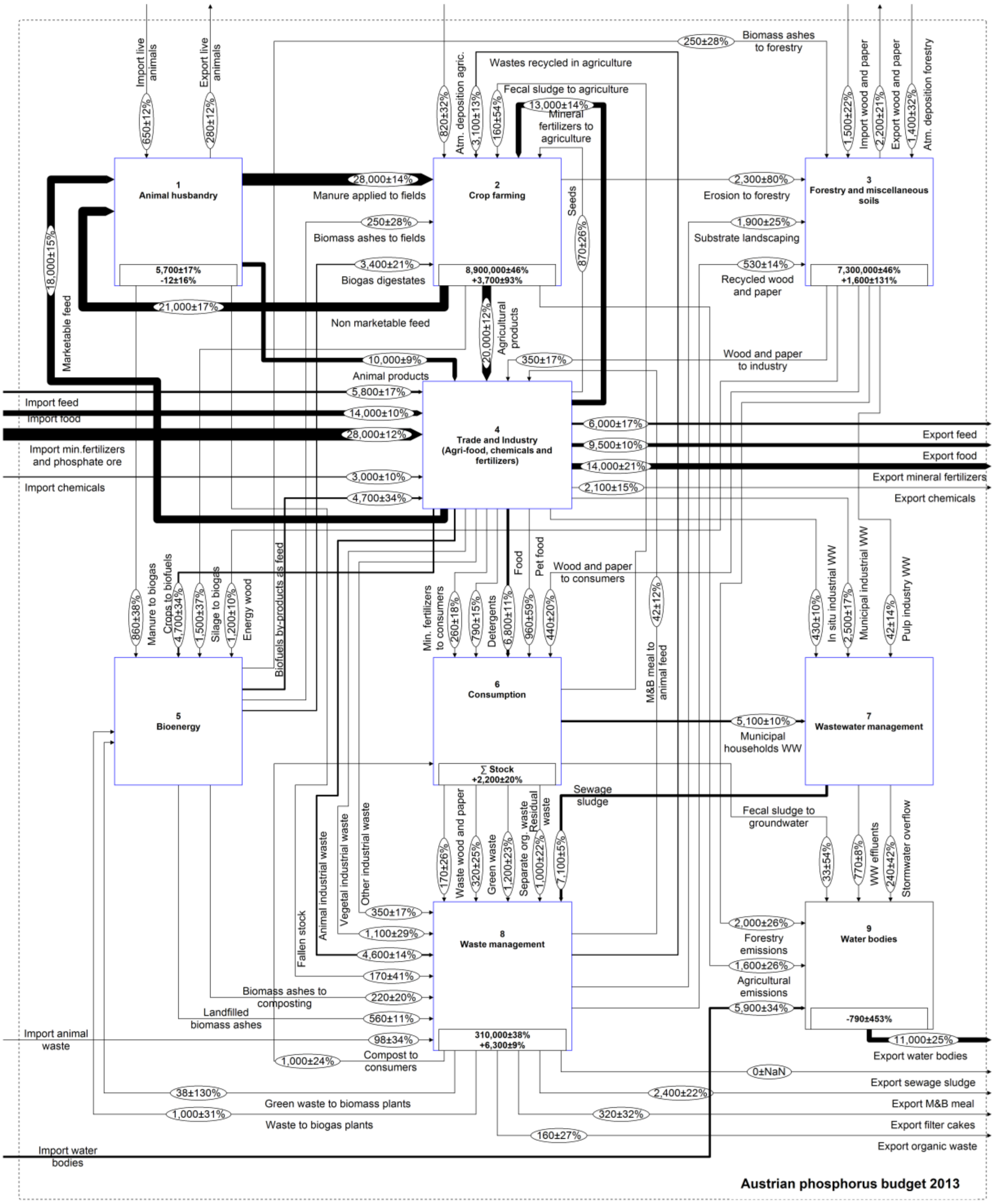

Figure 1: The national Phosphorus budget of Austria for the year 2013 (source: Zoboli et al, 2016b).

Second, even in a relatively short and economically stable period of 24 years, the P budget of Austria (Figure 1), consisting of 122 flows and 8 stocks, has undergone unexpectedly significant and partially abrupt changes. This is illustrated in Figure 2, where the outcomes of the analysis are shown as a function of the degree of change of the budget with respect to the reference year 1990 (left side). Here, flow changes are divided into three categories, namely: constant, moderate, and extreme. Constant means that a flow has not changed since 1990 (rather unrealistic). Extreme means that a flow more than doubled or more than halved compared to 1990. Changes in between are regarded as moderate.

In order to compare uncertain flows of different years, different tolerance levels were applied (see Figure 2). For example, the P-flow via the import of mineral fertilizer to Austria in 1990 was 44.000 t/year ± 8%. In 2003 the same flow amounted to 32.000 t/year ± 8%. Applying tolerance levels of ± 0% to 15% and ± σ (standard deviation) would classify the change as moderate, while ± 20% and ±2*σ would yield no (significant) change as a result. Consequently, the results are partly sensitive to the tolerance levels applied. If tolerance levels between 0% and ±5% are applied, Figure 3 indicates that one third of the flows and stock change rates changed moderately, and two thirds were affected by an extreme variation, whereas with ranges from ±10% to ±20%, the fraction of moderately changing flows and stock rates gradually decreases to 15%.

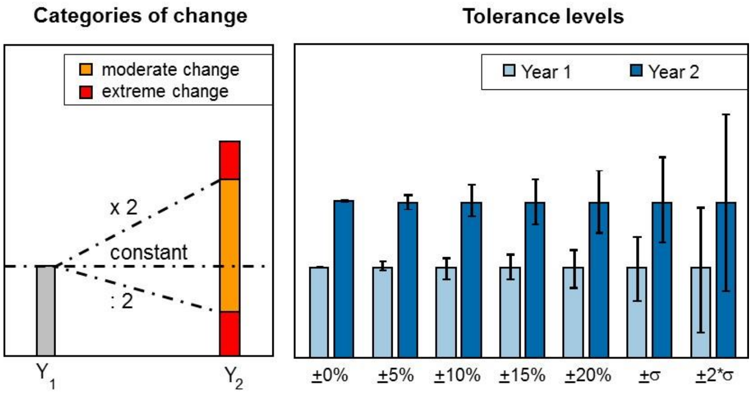

Figure 2: Classification of yearly flow changes (left) and selected tolerance levels (right). The change between Year 1 and Year 2 would be classified as moderate up to a tolerance level of ± 20%, and no change (constant) for tolerance levels ±σ and ±2*σ (adapted from Zoboli et al., 2016a).

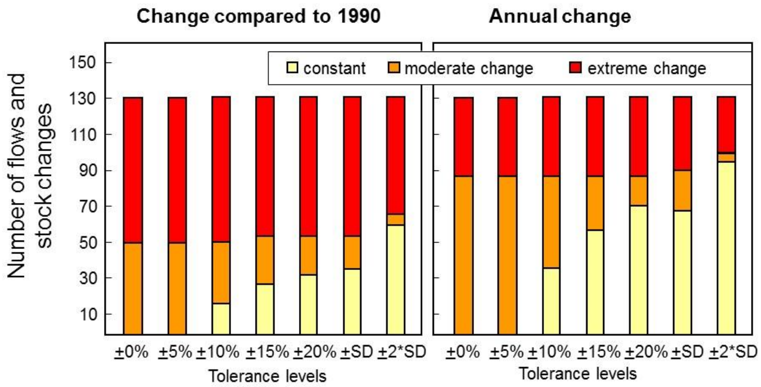

Figure 3: Degree of temporal change of 122 flows and 8 stock change rates. On the left: categorization according to the change with respect to the reference year 1990; on the right: categorization according to annual change. Results are shown for different tolerance levels (uncertainty thresholds used to determine whether temporal changes can actually be detected or not). The y-axis indicates the number of flows and stock change rates in each category (adapted from Zoboli et al., 2016a).

The specific standard deviation shows outcomes very similar to the ±20% range, whereas the level of twice the standard deviation decreases both the extreme and moderate fractions to 50% and 5%, respectively. In conclusion, the analysis reveals that half of the flows and stock change rates changed substantially, with certain flows that appeared or disappeared and others that at least doubled or halved their initial value. The second component of this analysis (Figure 3, on the right), instead explores to what extent the flows and stock change rates changed from a given year to the following one to provide an overview of whether the changes took place gradually or rather abruptly. This analysis reasonably suggests that a large proportion of the flows were affected by gradual and moderate changes, but between 24% and 33% of the flows (depending on the tolerance level considered) recorded at least one extreme variation, indicating the noteworthy presence of substantial and sudden changes. The outcomes also highlight the difficulty of detecting smaller annual changes when uncertainty ranges are applied. However, the main conclusion from this analysis is that national anthropogenic material systems tend not to be stable over time. At least for P, this is the case. This means that classical one-year MFA studies help to acquire a common understanding of a system's metabolism but have to be regularly updated for robust decision-making. Zoboli's work shows that such updating is feasible. Additionally, the multi-year approach also improves the understanding of a system and helps make the model more comprehensive and suitable to form the basis of material accounting and monitoring.

Determination of actions to optimize the system

The analysis of MFA time series directly leads to relevant actions in decision making. This is demonstrated in Figure 4 for Phosphorus and Austria. In the upper left diagram one can see that the total P inputs into the Austrian waste management sector have increased considerably since 1990. One of the major tasks of waste management is to collect materials, therefore, such a development can be regarded as positive or, in any case, as showing the growing importance (and responsibility) of the sector. On the other hand, the upper right time series of Figure 4 reveals that large amounts of the waste P are lost in landfills and in concrete. The latter is due to the co-combustion of sewage sludge and meat and bone meal (slaughter waste) in cement kilns. Comparing the two time series reveals that the ratio of losses versus input has rather increased over the years, a clear negative trend that requires counteraction(s).

The two other time series of Figure 4 provide information on emissions of P to the hydrosphere. While emissions from point sources (here: wastewater treatment plants) could be substantially reduced, diffuse emissions, which mostly stem from agricultural soils, have remained rather constant and are now even becoming dominant. A general conclusion is that point sources are easier to control than diffuse emissions: a finding that has been made several times before, e.g. by Bergbäck (1992), for some heavy metals. The specific conclusion for P is that effective water protection means putting more emphasis on the agricultural sector. This is another clue for decision makers as to where action (adequate policy) is required.

Zoboli and colleagues (Zoboli et al., 2016b) determined how and to what extent the management of P in Austria could be optimized. They used a detailed national model, obtained for the year 2013, as a reference system (Figure 1). Then they selected a range of measures (fields of action) aimed at reducing consumption, increasing recycling and lowering emissions of P and discussed them with regard to applicability and limitations. The potential effect of each field of action on the reference system was quantified and compared using three indicators: import dependency, mineral fertilizers consumption and emissions to water bodies. Table 1 gives an overview of the diverse actions that were identified to optimize the system.

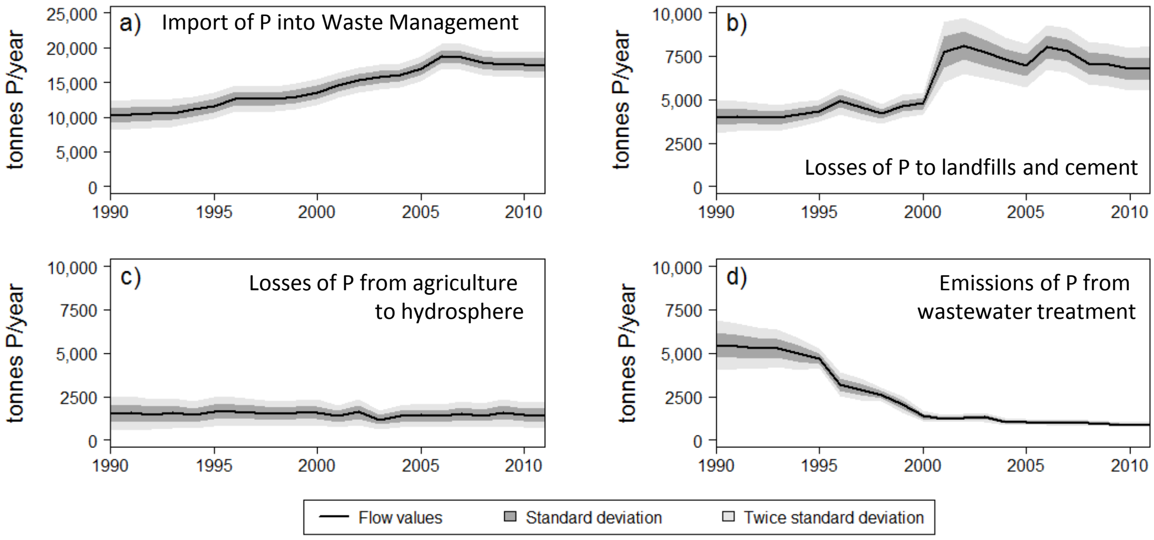

Figure 4: While the import of P into waste management increased constantly over the past years (a) the losses of P to landfills and cement increased even more (b), indicating a clear field for required action. The losses of P from agriculture to the hydrosphere remained rather constant (c), indicating that efforts to optimize fertilizing and farming practice have been rather inefficient. In contrast, the emissions of P from wastewater treatment works could be reduced significantly (d), showing the effectiveness of technical solutions (modified from Zoboli et al., 2016a).

Table 1: Fields of action to optimize the Austrian Phosphorus system

Fields of action
Increase of P recovery and recycling
1. Increase of P recycling from meat and bone meal
2. Increase of P recycling from sewage sludge
3. Increase of P recycling from compost
4. Increase of P recycling from digestates
5. Increase of P recycling from biomass ashes
6. Increase of P recycling from manure
7. Improvement of municipal and industrial organic waste management
Reduction of P demand and consumption
8. Achievement of a balanced and healthy diet
9. Increase in the use efficiency in crop farming
10. Optimization of P content in feedstuff
11. Reduction of P use in detergents
12. Reduction of P use in other industrial processes
13. Reduction of surplus accumulation in private and public green areas
Reduction of emissions to water bodies
14. Reduction of point discharges
15. Reduction of erosion from agricultural soils

In a second step, all the gains that could be obtained through the measures (fields of action) were integrated in the reference system to generate an ideal target system. The fact that this optimization results in an extremely low import dependency of 0.23 kgP/cap.y (instead of 2.2 kgP/cap.y in 2013), zero consumption of mineral fertilizer for domestic use, and a 23% decline of emissions to water bodies indicates that governance in Austria offers a large scope for P stewardship (see Figure 5).

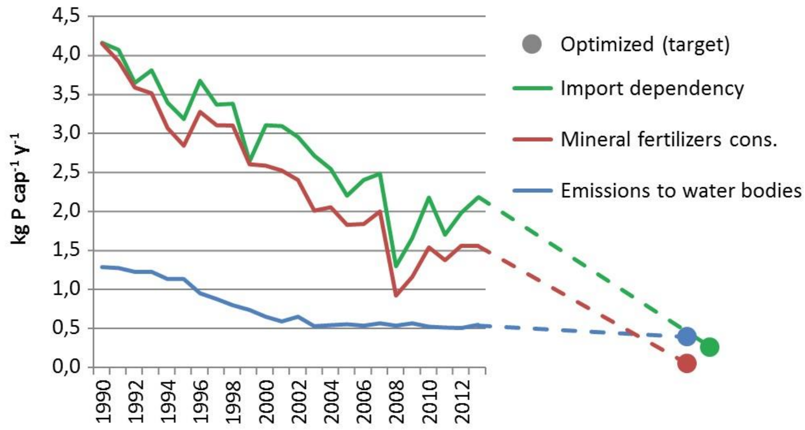

Figure 5: Development of the Austrian Phosphorus system over time with respect to selected indicators.

The systemic approach of MFA in this study allowed the relative effect of each field of action on the national performance measured to be quantified by means of different indicators, thereby facilitating a proper comparative assessment. Furthermore, it has made possible the generation and visualization of a target system, obtained through the integration of all potential gains in the reference model. The resulting concise though exhaustive overview can be very useful to support decision makers in designing national governance strategies and setting priorities, as well as to assist domain experts in fitting their work into a broader context. As a next step, such studies need to be complemented with an analysis of the different costs involved in implementing each field of action.

Conclusions

Based on the results of the case study, the following conclusions can be drawn:

► Materials accounting is feasible and delivers better understanding of the system and data situation.

► The time-series created are instrumental for decision making. They directly point to fields of action (problem spots) and therefore support and guide decision making.

Recommendations

► Routine materials accounting should be introduced at a national and EU level. This should be performed by statistical offices or other administrative bodies such as EPAs. There should be national and EU level experts for each set of commodities exchanging data and knowledge about their respective systems.

References

Bergbäck, B. Industrial Metabolism: The Emerging Landscape of Heavy Metal Emission in Sweden, PhD thesis, Linköping University, Sweden, 1992.

EC, 2015. Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the loop - an EU action plan for the circular economy COM(2015)614 final http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614.

Zoboli, O., Laner, D., Zessner, M. & Rechberger, H. (2016a): Added Values of Time Series in Material Flow Analysis - The Austrian Phosphorus Budget 1990-2011, *Journal of Industrial Ecology*, 20, 6, 1334-1348.

Zoboli, O., Zessner, M. & Rechberger (2016b): H. Supporting phosphorus management in Austria: Potential, priorities and limitations, *Science of the Total Environment*, 565, 313-323.