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The nitrogen and phosphorus budget of Flanders: a tool for efficient waste management and nutrient recovery

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Introduction

Nutrients such as nitrogen and phosphorus are key elements for plants and animals and are therefore essential for securing our food supply chain. Today nearly half of the global population is relying on mineral fertilizers for food production (Galloway et al. 2008). The global challenges that face us in the future, such as population growth, the evolution towards a more protein-rich diet and the rise of biofuel production have as a consequence that the demand for agricultural produce continuously rises. This evolution puts pressure on the availability and prices of fertilizers. Sustainable nutrient management, including the recycling of nitrogen and phosphorus from human and agricultural waste streams, is therefore seen as a necessary factor to ensure global food security. The region of Flanders in Belgium has due to its high population density, intensive livestock production and industry a nutrient surplus available in waste streams such as animal manure, organic biological waste and wastewater. It therefore possesses a large potential towards the recovery and reuse of nitrogen and phosphorus. In this study, a substance flow analysis study for nitrogen and phosphorus is presented, in which the fluxes, stocks and hot spots of both nutrients are quantified throughout the economy in Flanders. The relations between the economic and environmental processes are discussed, with particular focus on manure processing, waste management and the nutrient recovery potential of waste streams.

Materials and methods

The quantification of the nitrogen and phosphorus flows and stocks was performed for the reference year 2009 and within the spatial system boundaries of the region of Flanders in Belgium. A substance flow analysis (SFA) model was developed using the software tool STAN, which allows balancing of SFA systems through error propagation and data reconciliation (Cencic and Rechberger 2008) The model is defined by 7 main processes: *Air*, *Water*, *Soil*, *Industry*, *Waste management* and *Consumption, trade and commerce*. *Industry* is further subdivided in the processes *Transport*, *Energy production*, *Food industry*, *Fodder industry* and *Chemical and other industry*. *Agriculture* is subdivided in the processes *Crop production* and *Livestock production*. Further focus is placed on the process *Waste management,* which is defined by the sub processes *Composting*, *Industrial digesters*, *Incineration*, *Landfill*, *Wastewater treatment* and *Manure processing*. For *Wastewater treatment* a subdivision was made in *Activated sludge treatment* and *Sludge digestion*. For *Manure processing* the distinction is also made between the different manure processing technologies applied in Flanders: *Activated sludge treatment*, *Agro-digesters*, *Manure drying* and *Substrate production*. The processes *Air, Water, Soil, Chemical and other industry* and *Landfill* are also assigned with a nutrient stock. The 21 different processes are interlinked by 160 individual nutrient flows of nitrogen and phosphorus. This results in a mathematical model that comprises 517 equations and 937 variables.

Data collection for the different economic and ecological processes was performed with a bottom-up approach through the participation in this study of national and regional sector federations and governmental agencies and consultation of companies. Nutrient fluxes were obtained by multiplying the mass flow of the individual resources, products and waste streams with their specific nitrogen and phosphorus content. Where possible, multiple data sets were used to cross-check results and obtain reliable fluxes. Uncertainties of the different types of collected data were defined according to the data uncertainty interval method of Cooper and Carliell-Marquet (2013). The nutrient flows are expressed in kg N cap^{-1} yr^{-1} and kg $Pcap^{-1}$ yr^{-1} to allow comparison with other regions and processes.

Results and Discussion

In this study the nitrogen and phosphorus balance was quantified for the region of Flanders in Belgium. To our knowledge this study is the first in which both the nitrogen and phosphorus fluxes are quantified on a regional scale level.

The N and P budget of Flanders shows a total import of 136±6% kg N cap^{-1} $yr^{-1}$and 20±4% kg P cap^{-1} yr^{-1} (Figure 1). Resources for the chemical industry (67%), food industry (19%) and fodder industry (12%) are the predominant import flows. The total export is 208±4% kg N cap^{-1} yr^{-1} and 20±4% kg P cap^{-1} $yr^{-1}$and consists mainly of chemicals (82% of N and 60% of P) and food products (12% of N and 18% of P). The chemical, food and fodder industry are thus involved in strong import and export of nutrients. This demonstrates the role of Flanders as a logistic hub within Europe, whereby nitrogen- and phosphorus-rich products are concurrently processed by industry. The interaction with the rest of the economy is also limited and mainly takes place through the use of mineral fertilizers (10±11% kg N cap^{-1} yr^{-1} and 0.22±12 kg P cap^{-1} yr^{-1}), food (9.2±10% kg N cap^{-1} yr^{-1} and 0.67±8% kg P cap^{-1} yr^{-1}) and non-food products (1.4±14% kg N cap^{-1} yr^{-}1 and 0.27±13% kg P cap^{-1} yr^{-1}).

The predominant nutrient fluxes within the Flemish economy are found within the food supply chain, which connects the chemical, food and fodder industry with crop and livestock production. Here the intensive livestock production in Flanders is notable as 71% of the crops produced are used as fodder. Also 21±8% kg N cap^{-1} yr^{-1} and 4.7±7% kg P cap^{-1} yr^{-1} of animal manure is produced, which makes it the most important fertilizer source (55% of N and 87% of P demand). At the end of the production and consumption chain a total of 17.1 kg N cap^{-1} yr^{-1} and 8.3 kg P cap^{-1} yr^{-1} of nutrients end up in waste streams. Excess manure for manure processing (20% of N and 11% of P), industrial organic waste (14% of N and 17% of P) and domestic wastewater (19% of N and 6% of P) are the predominant waste streams. The largest nutrient recovery potential is situated at manure processing, where activated sludge treatment (42% of N), manure drying (35% of N, 81% of P) and organic substrate production (14% of N and P) technologies are applied (Figure 2). Here nutrient recovery, instead of nutrient removal through denitrification, is technologically and economically feasible. Through partial nitrification of the liquid manure fraction to ammonium nitrate the use of synthetic Haber-Bosch nitrogen fertilizers can be reduced by 18%. A further implementation of agro-digesters for energy recovery can further stimulate the production of P-rich fertilizers from the solid manure fraction through bio-thermic drying.

Additionally, the P-rich fluxes of waste from the food industry and domestic wastewater can be recovered through the employment of mono-incineration of animal waste and activated sludge. This can result in an additional recovery of 1.6 kg P cap^{-1} yr^{-1}.

References

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Figures

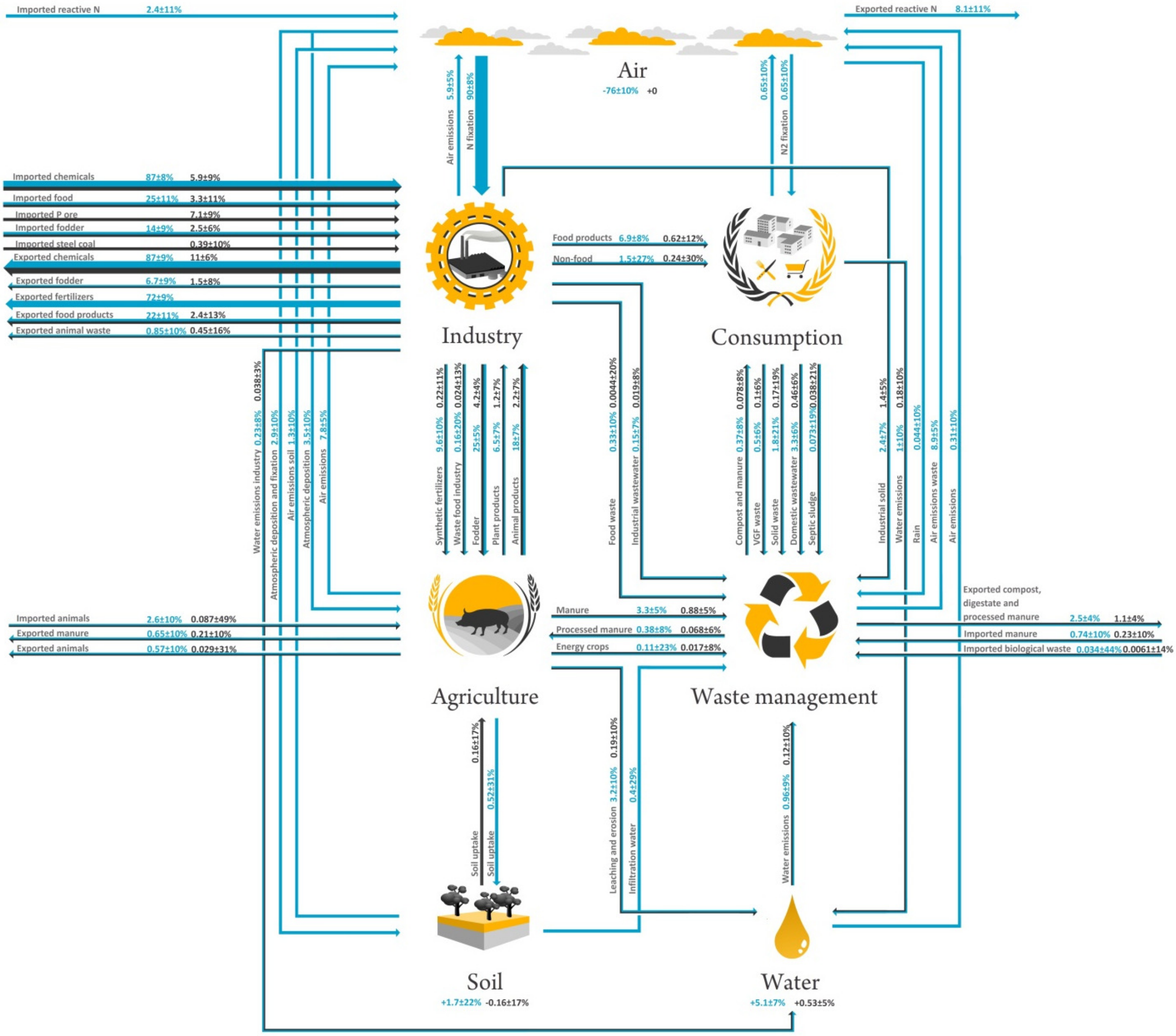

Figure 1. The nitrogen and phosphorus budget in Flanders

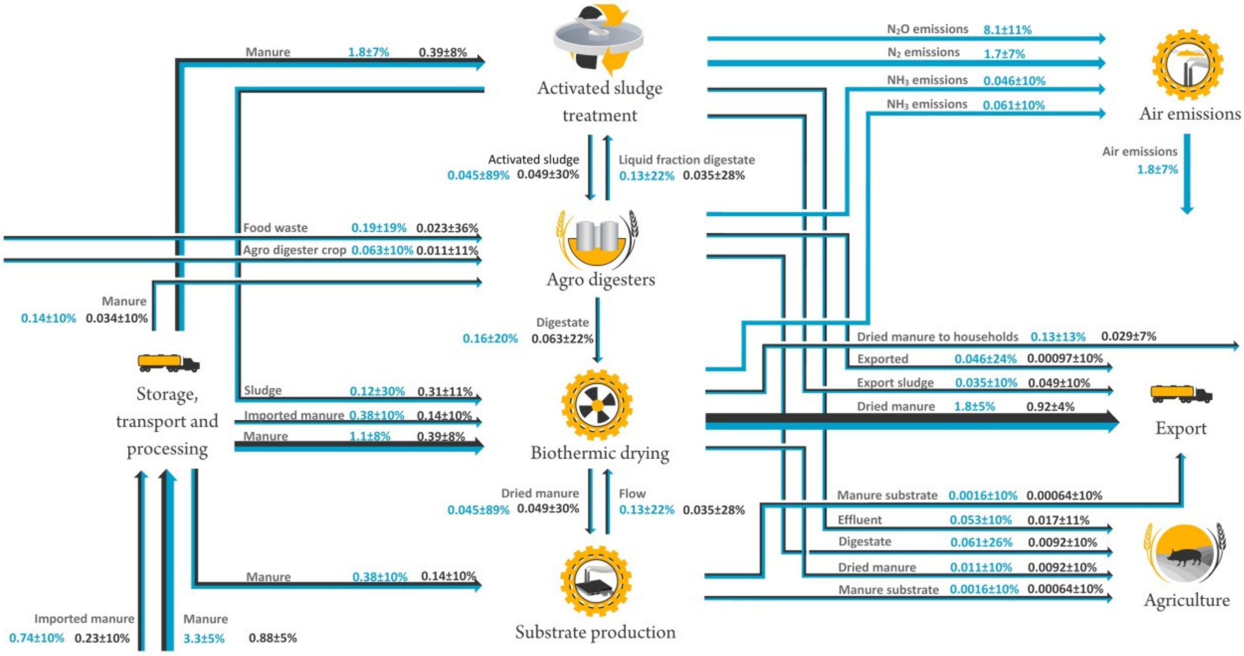

Figure 2. The nitrogen and phosphorus flows within manure processing, which contains the process technologies activated sludge treatment, agro digesters, (bio)thermic drying and substrate production