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NUTRIENT BUDGETTING FOR AGRICULTURAL AND ENVIRONMENTAL MANAGEMENT – EXAMPLES FROM CONTRASTING FARM TYPES

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Abstract

This paper evaluates the use of farm nitrogen (N) and phosphorus (P) balances as indicators for the development in resource efficiency and environmental impacts in Denmark and Portugal. In Denmark, over the past decades, a series agro-environmental action plans have facilitated both significant reductions in N and P surpluses and improvements in the use efficiencies. Time-series of the relation between national inputs and outputs are reviewed, as indicators for the development, together with a methodology to map the flows of nutrients between the different compartments of agriculture (crops, livestock etc.), environment (water, air, soil) and the surrounding sectors (energy, fishery etc.). Furthermore, the perspectives for similar analyses to be implemented in other countries are discusses, based on the case of Portugal, and the current Nitro-Portugal project.

Nutrient balances differ significantly between farm types (cash crop, vs. ruminant and granivore livestock farms), and so does the distribution between types of nutrient losses to the environment. An approach to distribute the farm N balance to different types of losses (nitrate to water, ammonia to air etc.) and soil-N changes is demonstrated based on results from the Farm-N model. Results show significant differences in the distribution in types of losses. For instance, cash-crop farms show negative soil-N balances, and relatively high Nitrate losses, while livestock farms show positive soil-N balances, with relatively higher ammonia losses from cattle farms compared to pig farms. Such analyses can be useful to better understand combined livestock and cash crop farming systems, and evaluate effects of potential intensifications, as discussed for the case of the Portuguese Montado System. Finally, we discuss the use of farm type modelling for solution scenarios analyses, based on experience from the www.dNmark.org research alliance and the NitroPortugal EU Horizon 2020 twinning project.

Introduction

The development in Danish nitrogen and phosphorous balances

Figures 1 and 2 show the long term Nitrogen (N) and Phosphorus (P) balances for Danish agriculture. Especially, we note the significant reductions in the surpluses observed over the past 3-4 decades, similar to the large reductions observed during the two world wars! These recent, significant reductions in the surpluses is a result of the series of action plans implemented since the mid 1980'es to reduce nutrient losses to the aquatic environment (Kronvang et al. 2008, 2017; Dalgaard et al. 2014). Empirical studies, like the study of development in nitrate concentrations in oxic groundwater reservoirs (Figure 3, Hansen et al. 2011), have shown a close correlation between the N surplus and environmental pollution, but still there are challenges to achieve further reductions. The present paper exemplifies how farm N balances can be used to target these reductions to specific farming systems, and distinguish between the different types of N losses contributing to the overall N surplus.

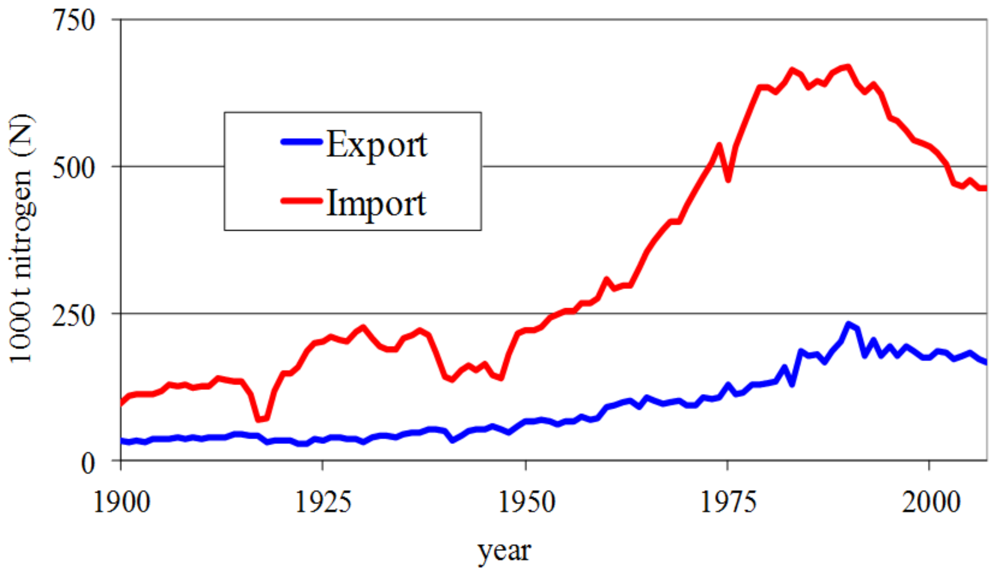

Figure 1: Development in the nitrogen (N) balance in the form of N input (import) and N output (export) from the agricultural sector year 1900-2012 (after Dalgaard et al. 2014).

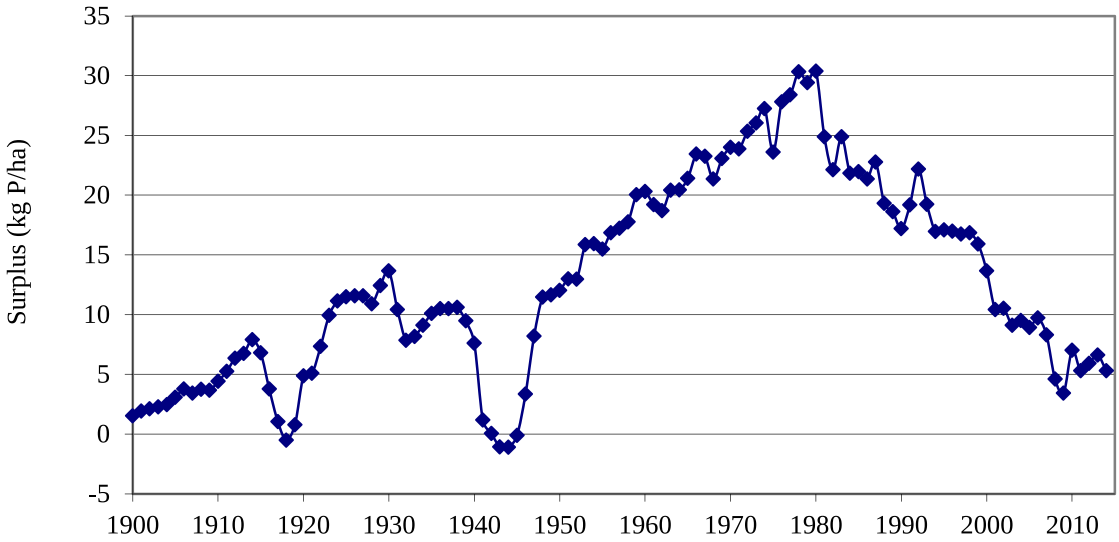

Figure 2: Development in the phosphorus (P) balance the Danish agricultural sector year 1900-2015.

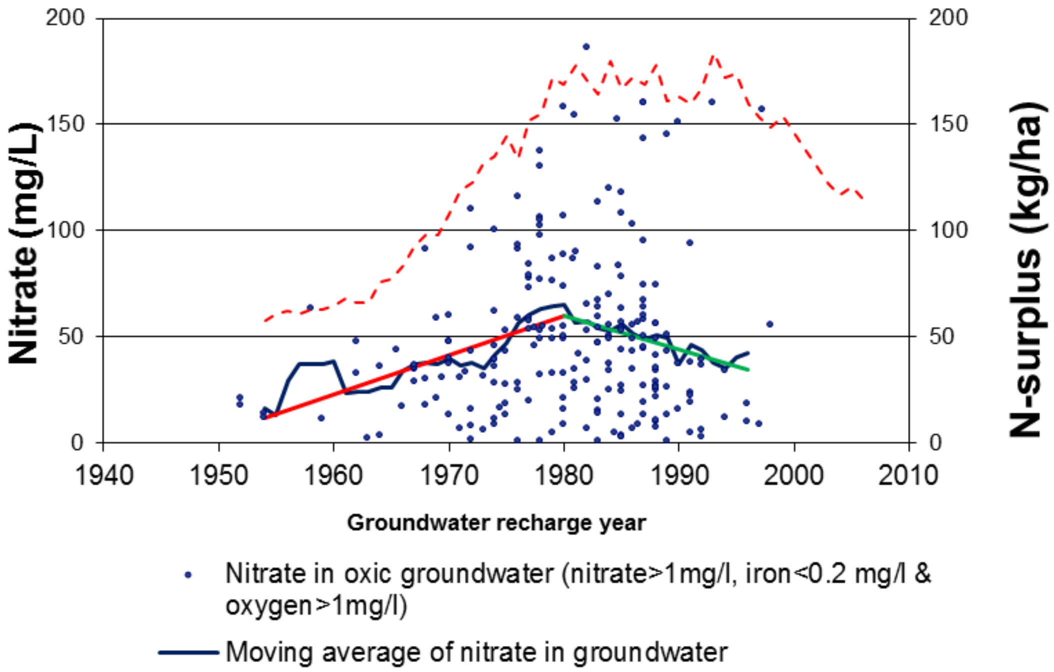

Figure 3: Nitrate trends in oxic Danish groundwater samples and the correlation to the long-term Nitrogen balance of Figure 1, illustrated with the dotted red line (Based on Hansen et al., 2014).

Materials and methods

The farm nitrogen balance and modelling framework

The farm N balance is calculated on an annual basis as the difference between farm gate inputs and outputs (equation 1). In this study, the Farm-N model (www.farm-N.dk/FarmNTool) is furthermore used to distribute the surplus N into the different types of losses (Figure 3, equation 1).

Equation (1):

Farm N balance = N outputs – N inputs = N surplus =

N products – N feed – N fertiliser – N manure – N fixation – N deposition =

Ammonia emission + N leaching + denitrification – soil N change

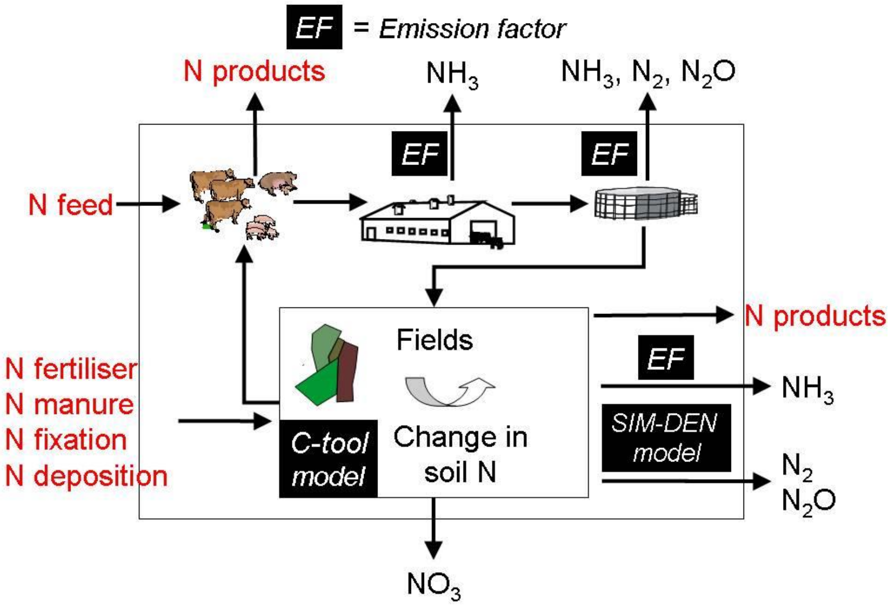

Figure 4. The farm nitrogen balance, and its distribution into types of losses by the Farm-N and FARM-AC models. The N-balance is calculated as the sum of N in products – N feed – N fertiliser – N manure – N fixation – N deposition (see equation 1). In the models, this balance is distributed into different types of losses in the form of ammonia (NH_3) emission, nitrates (NO_3^-) leaching, denitrification to free nitrogen (N_2) or nitrous oxide (N_20), or changes in the soil-N pools. This modeling is based on emission factors (EF) in combination with sub-model components. For instance in Farm-N, C-tool (Pedersen 2007) is used to simulate changes in soil pools and the SIM-DEN (Vinther & Hansen, 2004) component model is used to simulate denitrification (Dalgaard et al., 2010).

Results

Farm nitrogen balance and distribution into types of losses

As an example, the Farm-N model has been used to distribute farm N balances from a set of farms, in Bjerringbro, Denmark, where Figure 5 shows the difference between different types of farms observed. As illustrated, farms with use of livestock manure show a pooling of N in the soil, whereas cash crop farms with no manure mines N from the soil. Moreover, N losses to the air is generally higher from the cattle farming systems (ruminants), compared to the pig farming system (granivores), which show a relatively higher loss to the aquatic environment in the form of nitrates.

Dalgaard et al. (2012) followed the N-surpluses from the same farms over the period 1990-2008, coinciding with the period with the high general reductions in the Danish agricultural N surpluses (Figure 1), and the before mentioned implementation of agro-environmental action plans (see Figure 6).

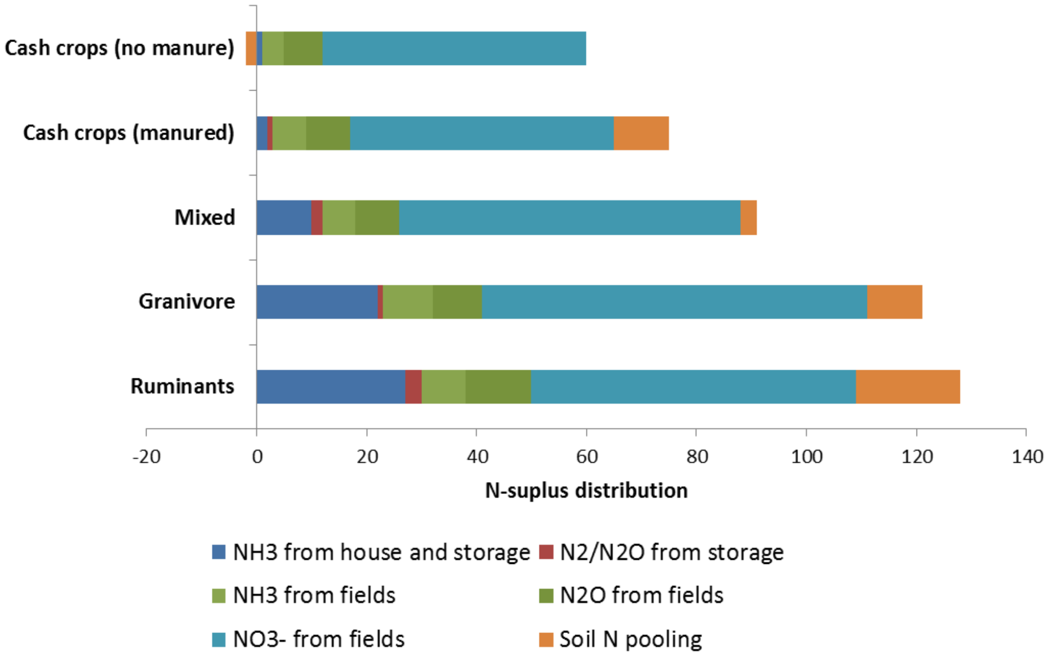

Figure 5. Distribution of the farm nitrogen balance into different types of N losses for the defined farm types (Based on Dalgaard et al., 2011).

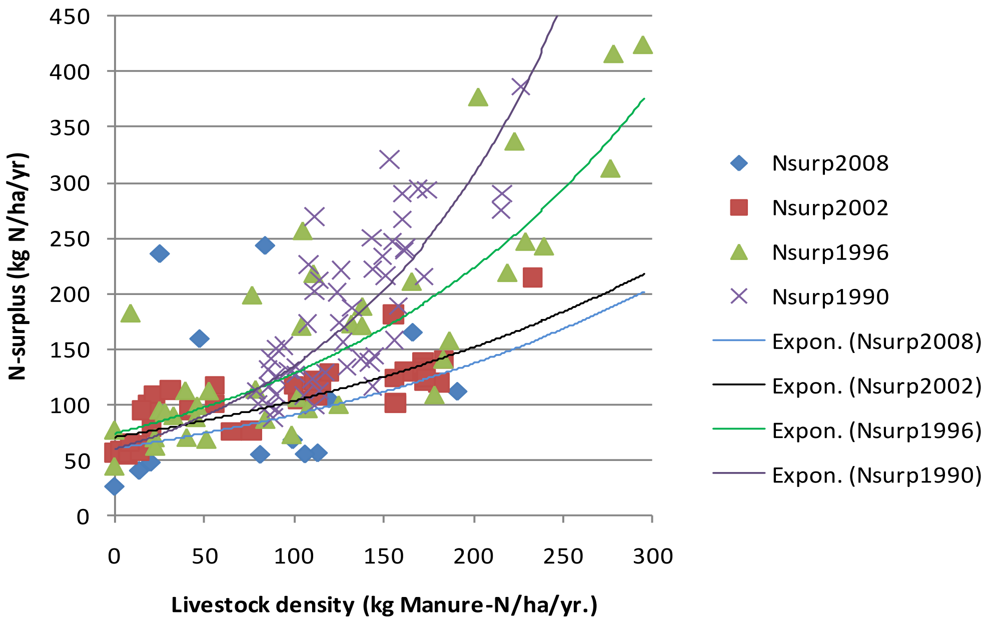

Figure 6. Development in farm N surpluses 1990-2008 for the farms in a study landscape situated south of Bjerringbro, Denmark (Based on Dalgaard et al., 2012).

What we observe from Figure 6, is the same magnitude of reductions in farm N surpluses from the farms in landscape investigated south of Bjerringbro, as seen at the national scale (Figure 1) (i.e. a reduction of around 50% at average from 1990 to 2008). However, there are very large variations between farms, and this is especially the case for the livestock farms, which moreover have achieved the largest average reduction in the N-surplus over the period. Similar large variation between farm N surpluses were observed in other European landscapes (Figure 7). This large variation in particular is an important starting point for the further discussion, and identification of potentials for reduction in farm nutrient surpluses and reduced environmental pollution from farming.

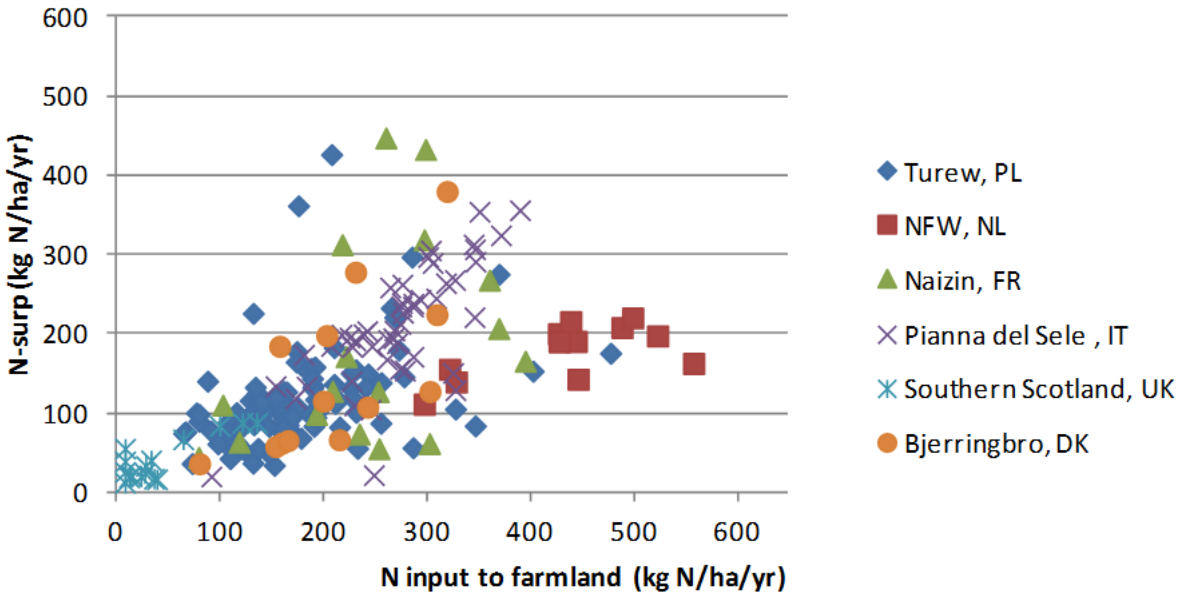

Figure 7. Variation in N surpluses from farms studied in six different European landscapes in 2008. PL= Poland, NL= The Netherlands, FR= France, IT= Italy, UK= United Kingdom, DK= Denmark (Based on Dalgaard et al., 2012).

Discussion and conclusions

The most important take home messages from the present paper are that nitrogen balances are valuable indicators for nitrogen losses, and that understanding the variation in farm level N-balances, and its distribution into different N types of N compound losses, are key to understand the potentials for further reductions in N-losses to the environment.

Especially, livestock farming systems show a high potential for reductions, and a large variations between farms. Therefore, it is also the special focus on reduction in losses from livestock farms, which has been the most important background for the successful reduction in N losses from Danish agriculture from the 1980'es and until today. These lessons are useful to other countries, also focusing on the need to reduce N losses from agriculture. For instance, in the NitroPortugal project this is also the focus. Like all other countries in the European Union, Portugal is challenged to comply with the EU Nitrates and Water Framework Directives, and the related reduction targets for N pollution. Based on the above findings, especially interesting farming systems are identified to illustrate of effective ways to reduce N-losses. This include a study of intensive dairy farming systems, but also potentials for N loss reductions from integrated systems, like the Montado System integrating cattle and forage production with cork oak harvest. To investigate, what an intensification of these systems will mean for the N-loss, integrated farm N-modelling investigations, as illustrated in

Figures 4 and 5, are needed. This also include an assessment of the different types of N losses (Figure 5), and in particular an assessment of the effects on the soil N.

The present paper has focused on farm level and farming system level studies, but similar methods have been developed to study N flows, and disaggregated N-balances in the national level, into the different types of N losses to air, soil and water (see appendix). A recent review by Hellsten et al. (2017) showed the relevance of these methods in the Nordic countries, both at the farming systems and the national level. It is our hope that these methods will also be useful in other countries throughout the world, including in New Zealand, where the intensification of livestock farming systems and the related environmental pollution and resource use efficiency issues for certain are also an important agenda point for the further development of a sustainable agricultural sector.

Acknowledgements

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Appendix

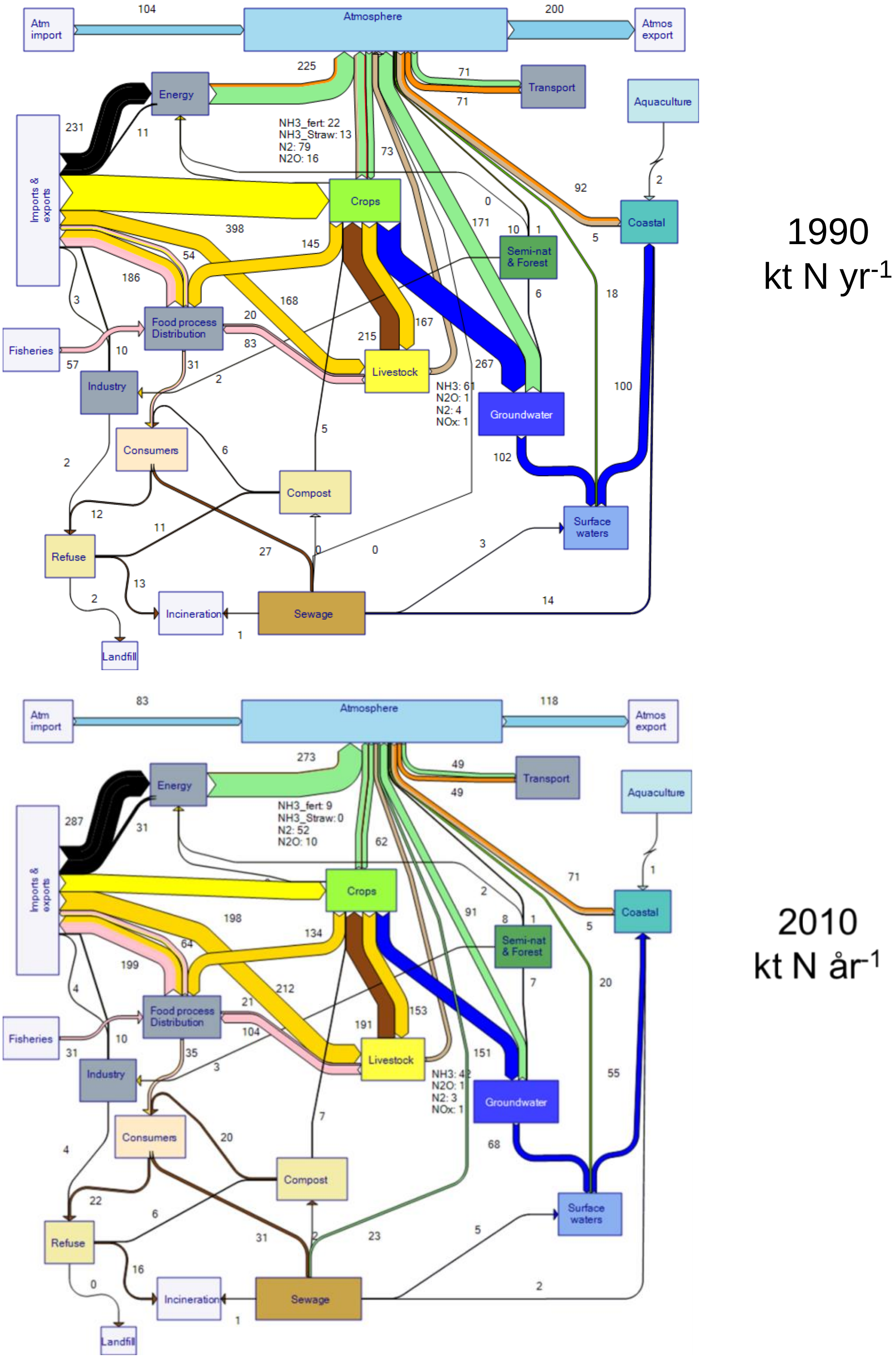

Figure 8. The N balance, N inputs and N flows assessed for Denmark 1990 and 2010 (Hutchings et al. 2014).