European Nitrogen Assessment

Chapter 16: Integrating nitrogen fluxes at the European scale

Supplementary Material: Section A **-** National integrated nitrogen budgets

Lead author: Adrian Leip
Contributing authors: Nevečeřal Rostislav, Pavel Čermák, Anne-Christine LeGall, Markus Geupel, Till Spranger, Albert Bleeker, Beat Achermann, Jürg Heldstab, Penny Johnes, Ulli Dragosits, Dave Fernall, Mark Sutton

16.S1. Introduction

Adrian Leip (adrian.leip@jrc.ec.europa.eu)

EC-Joint Research Centre, Institute for Environment and Sustainability, Ispra (Va), Italy

Integrated nitrogen budgets are defined here as the quantification of all major nitrogen fluxes across sectors and media on an annual basis within given boundaries. In the case of National integrated Nitrogen Budgets (NiNBs), these boundaries are the borders of a country. Considered nitrogen fluxes include those that enter of leave the country. National integrated nitrogen budgets (NiNBs) are a very efficient policy instrument, as they are an optimal tool for visualisation of the main elements of the N cascade within a country into a figure that might transmit its main messages at a quick glance, but which nevertheless contains sufficient detailed information for further analysis. Therefore, a national nitrogen budget is an important tool to help prioritize policies. In particular, NiNBs can serve five objectives:

(i) NiNBs are an efficient instrument for visualizing the N cascade and its potential impact. All main N fluxes are shown in one figure. They thus help to raise awareness about the relations between human activities and N-related problems of the environment and human health.

(ii) NiNBs provide policy makers with information for developing efficient emission reduction measures and instruments;

(iii) NiNBs constructed for different points in time can provide an efficient tool for monitoring the impact and environmental integrity of implemented policies. They can be used to check whether regulations are taking effect or should be reinforced.

(iv) NiNBs are useful for comparisons across countries and with modelling approaches.

(v) NiNBs can help pinpoint to knowledge gaps and thus contribute to improving our scientific understanding of the N cascade.

Often, NiNBs have to rely on information of different origin and quality, and therefore it may not be possible to 'close' the budget for one or several sectors. N fluxes presented in NiNBs are ideally based on a sufficiently dense network of observational data or on detailed models which are calibrated and validated on national conditions; however, often data gaps have to be filled from simpler models and of a broader scope such as the models used for the European Nitrogen Budget.

To build a NiNB is thus a challenging task and many elements of a budget will only be quantifiable within a very high uncertainty range, for example the amount of nitrogen denitrified and released as the stable and harmless N_2 gas; or sedimented and stored for potential future release in the oceans. The magnitude of the uncertainty itself is usually unquantified.

Despite these difficulties, national integrated N-budgets have been developed for some countries or are in the process of being developed. Each of these NiNB is constructed from nationally available information and thus, the budgets are not directly comparable. For example, river import has not been estimated in Germany, while it constitutes a significant flux in the Netherlands and Switzerland. Indeed, river export of nitrogen is the largest individual flux in Switzerland exporting more nitrogen than is applied to agricultural soils as mineral fertilizer.

Several of the NiNBs currently available are of a very recent development, partly being kicked-off during the meetings hold in the preparation of the European Nitrogen Assessment or in the frame of the Task Force on Reactive Nitrogen, which established parallel to this process an Expert Panel on Nitrogen Budgets (EPNB) with the goal of fostering the development of NiNBs. For the EPNB, an excel-tool has been developed to facilitate the construction of new NiNBs.

The NiNBs available are summarized in Chapter 16 of the European Nitrogen Assessment (Leip *et al.*, 2011, Chapter 16). Here, we present additional details on the data sources used and some specific results.

16.S2. Czech Republic

Nevečeřal Rostislav[1], Pavel Čermák[2]

[1] *Czech Hydrometeorological Institute, Prague, Czech Republic*
[2] *Central Institute for Supervising and Testing in Agriculture, Section of official inspection, Brno, Czech Republic*
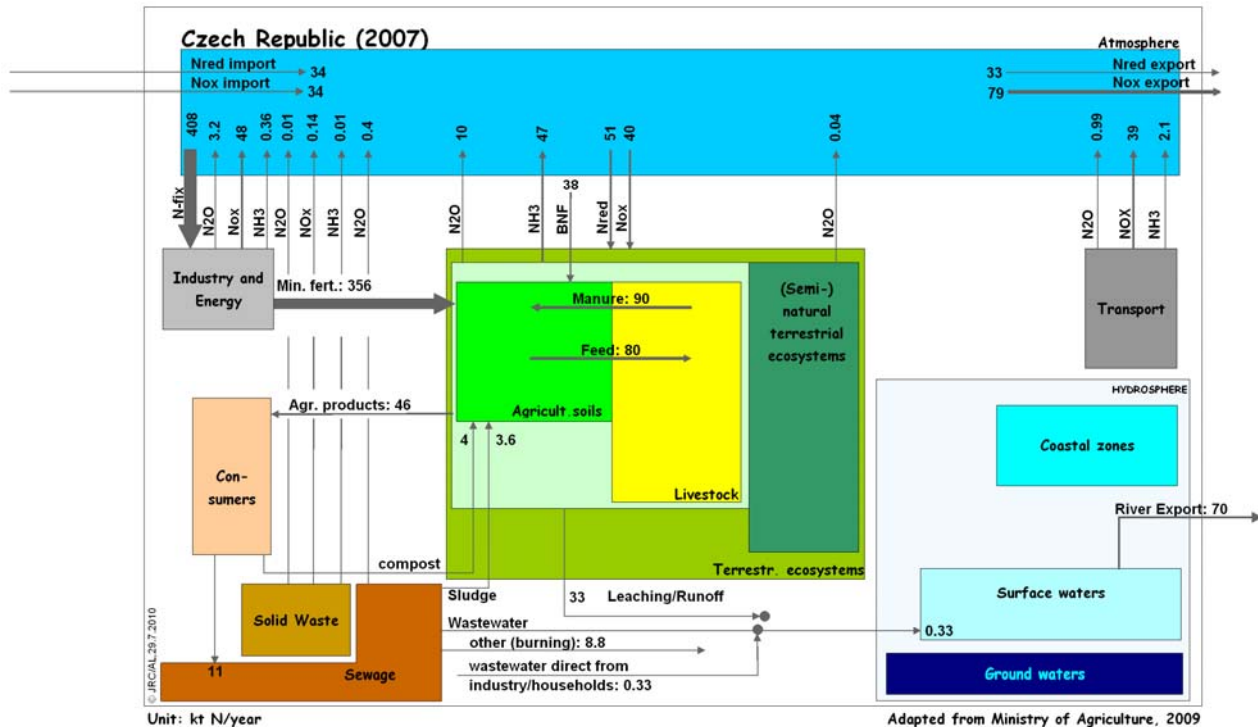
Figure 16.SA1: National nitrogen budget for the Czech Republic for the year 2007. Adapted from Ministry of Agriculture, 2009. Source of data see text.

Agriculture. Data for mineral fertilizer input, manure application and biological N-fixation in agriculture are calculated on the basis of an average N-flux of 83.3, 21.1, and 9 kg N ha^{-1} yr^{-1}, respectively (Klír *et al.*, 2009), and a total area of agricultural land of 42 490 km^2. Atmospheric deposition is obtained from measurements and calculations of wet and dry deposition. Due to a significant increase in mineral fertiliser prices and a decrease in livestock numbers after 1990 in the Czech Republic, the total N input to the soil experienced a dramatic reduction in comparison with values from before 1990.

On the output site, nitrogen leaching have been obtained from long-term lysimeter measurements indicating a N-flux of 7.8 kg N ha^{-1} yr^{-1} for the year 2007 (Čermák & Klement, 2009). River export with the Czech Republic's main watercourses - Labe, Odra, Morava – is estimated to be 70 Gg yr^{-1} (Praha 2007, p. 266).

Industry and consumer. Different sources indicate a wide range for nitrogen in sewage sludge of 2.2% to 4.8% (Černý, 2009). We used the average value of 3.7% of total nitrogen content in dry matter of sludge for the iNB of the Czech Republic. A Czech

legislation imposes that the amount and the quality of sewage sludge, that goes go back to the environment, and waste-water disposal to the water streams is observed. The parameters that must be measured include total N content and its fractionation. From the total N in sewage sludge of 10.6 Gg N yr^{-1}, only 3.6 Gg yr^{-1} are used in agriculture, while the remaining 8.8 Gg N yr^{-1} are used differently (e.g. composting, incineration, …) (CENIA, 2009).

The estimation of N in consumed food is based on recommended rates of foodstuffs in form of a food-pyramid (SZÚ, 2000), giving an average daily consumption of 77 g day^{-1} cap^{-1} of proteins or 46.4 Gg N yr^{-1}.

Atmosphere. Annual average wet deposition is calculated from data of 750 precipitation measuring stations; dry deposition is calculated on the basis of average annual concentrations of NO_x for the Czech Republic and NO_x deposition velocities of 0.4 cm s^{-1} and 0.1 cm s^{-1} for forested and non-forested area, respectively (Statistical Environmental Yearbook of the Czech Republic, Praha, 2007). Data for N imports/exports through atmospheric transport are from EMEP.

Transport and energy. Information on fuels consumption, traffic intensity and vehicle structure are provided every five years on the basis of questionnaires.

16.S3. France

Anne-Christine LeGall

Unité Economie et décision pour l'environnement, Pôle Modélisation environnementale et décision, Direction des Risques Chroniques, INERIS, Verneuil en Halatte, France

In France, the development of the nitrogen budget has been initiated with the aim of developing a global vision of the nitrogen cascade between economic sectors and environmental compartments. To this end, a pluridisciplinary group of experts on nitrogen questions from various research institutes and agencies in France[1] has been established, completed by representatives of French Ministries in charge of Agriculture and of the Environment. It is called GT FAr (Groupe de travail français sur l'azote réactif, or French working group on reactive nitrogen).
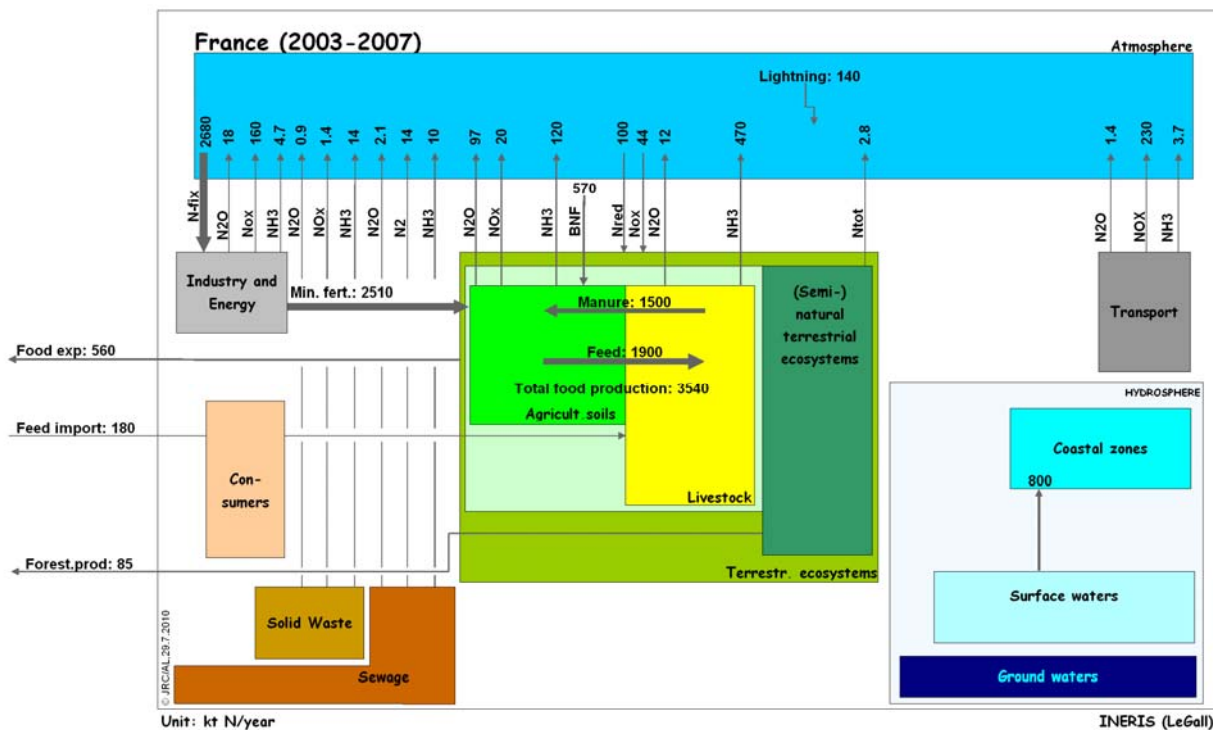

Figure.16.SA2: Integrated nitrogen budget for France calculated with data gathered between 2003 and 2007 (Pers Comm GT FAR). The construction of the French national N-budget is an ongoing process, and the figures are therefore preliminary results and are bound to be modified

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[1] ADEME, Agence de l'environnement et de la maitrise de l'énergie, CEMAGREF (no other name), CITEPA centre interprofessionnel technique d'étude de la qualité de l'air, CNRS, centre national de la recherche scientifique , INERIS, institut national de l'environnement industriel et des risques, INRA, institut national de la recherche agronomique, University of Paris VI.

The development of the French budget has been largely inspired by the German nitrogen budget presented below and has also been discussed with its authors. Some of these suggestions have led to modifications to both French and German budgets.

Experts have estimated data from various sources:

- Emissions to air are either from national inventories prepared by the CITEPA or previsions for 2010 used in the GAINS model;
- Information was extracted from SOLAGRO report on the Nopolu project (SOLAGRO, 2004);
- Deposition on natural ecosystems was assessed according to the methodology and with the data used to calculate critical loads by the French National Focal Centre of the ICP mapping and modelling; This includes data from the monitoring network CATAENAT, from French national statistical services , the French National Forest Inventory, the ICP mapping and modelling manual (Brun *et al.*, 1989; Croisé *et al.*, 2005; IFEN, 2005; Moncoulon *et al.*, 2005; Party, 1999a; Spranger *et al.*, 2004; Ulrich *et al.*, 1998).
- Emissions of N_2O and NH_3 from livestock and crops were estimated from a CEMAGREF study (Gac et al., 2005) and from work synthesized by the CORPEN (Comité d'ORientation pour des Pratiques agricoles respectueuses de l'Environnement, expert groups managed by the French ministries in charge of the environment and in charge of the agriculture).
- Other data were from FAO (http://faostat.fao.org/)
- Other studies that were useful to gather data on nitrogen budget in France include Bouwman *et al.* (2005), Party (1999b), van der Hoek (1998) and chapters of the European Nitrogen Assessment of the European research programme "Nitrogen in Europe" (Billen *et al.*, 2011, Chapter 13; Durand *et al.*, 2011).

All data presented on the budget have been supplemented with complementary information (source, year of validity, known uncertainty on the value...). This helps for interpretation of the data and makes it easier to keep track of its source. The data required to fill in the budget is often not readily available. Compilations and even some calculations may be needed to obtain the level of synthesis required by the chosen presentation of the fluxes. Also, different experts, using different sources, may reach different results. Discussions between experts are required so that the most relevant and accurate values are finally reported in order to be used for the purposes indicated above.

16.S4. Germany

Markus Geupel,Till Spranger[2]

[1]*Federal Environment Agency, Air and Air Pollution Control, Dessau-Roßlau, Germany*
[2]*Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Regional Air Pollution Control, Berlin, Germany*

The formulation of a 'Integrated nitrogen mitigation strategy' for Germany (Umweltbundesamt, 2009b), is based on the realisation that many nitrogen-related environmental goals for Germany were not yet met. These include:

- Progression of the loss of biodiversity, caused by continued eutrophication of terrestrial, marine, and freshwater ecosystems;

- Exceedance of thresholds that were established to reduce health risk with respect to nitrogen concentrations in drinking water, and air pollutants (NO_x, O_3, particulate matter);

- Bisection of nitrogen-emissions to Baltic and North Sea compared to the mid-eighties, which is targeted within Helsinki-Commission (HELCOM) and Oslo-Paris-Commission (PARCOM);

- Difficulties in meeting the targets set by the UNECE Convention on Long-range transboundary air pollution (CLRTAP) and the National Emission Ceilings (NEC)-directive of the EU with regard to NO_x and NH_3;

- The need to strengthen the efforts to mitigate global warming.

The development, evaluation, and selection of measures that allow for reduction of nitrogen emissions while minimizing the risk of unwanted side-effects is based on a detailed quantification of the nitrogen budget for Germany (Umweltbundesamt, 2009a). To achieve this goal, a literature survey was carried out and the elements were put together as shown in Figure 16.SA3. The budget encompasses those N-fluxes for the years 2000-2004 that amount to at least 1 Gg N y^{-1}. As the data compiled are of different origin, some inconsistencies are unavoidable and the budget is therefore not always closed. For example, the atmospheric budget, has a 'gap' of about 260 Gg N y^{-1} with 1420 Gg N y^{-1} accounted sources and 1684 Gg N y^{-1} accounted sinks, each of these elements representing current state-of-the-art (Umweltbundesamt, 2009a).

Total anthropogenic input of reactive nitrogen in Germany amounts to 3200 Gg N and thus is far more than 90% of the total nitrogen input into the biosphere (Geupel et al., 2009). The main contributor is agriculture with the application of mineral fertilizer (1800 Gg N y^{-1}), the import of feed (370 Gg N y^{-1}) and the legume dependent biological N-fixation (230 Gg N y^{-1}). Combustion of fossil fuel adds 520 Gg N y^{-1} and over atmospheric transport, additional 260 Gg N enters Germany. The export of nitrogen is more difficult to quantify. Atmospheric transport exports about 700 Gg N y^{-1} so that Germany is a net source of transboundary pollution. Rivers discharge about 450 Gg N y^{-1} to coastal zones and release furthermore about 230 Gg N y^{-1} as molecular nitrogen following denitrification processes. Additionally waste water treatment and microbial processes in agricultural systems remove about 300 Gg N y^{-1} each as molecular nitrogen.

About 57% of the emissions of reactive nitrogen is of agricultural origin, while the combustion of fossil fuel contributes with 28% (slightly more than 50% of that from the transport sector, the rest from industry and energy generation). 15% of emissions stem from waste and surface waters.
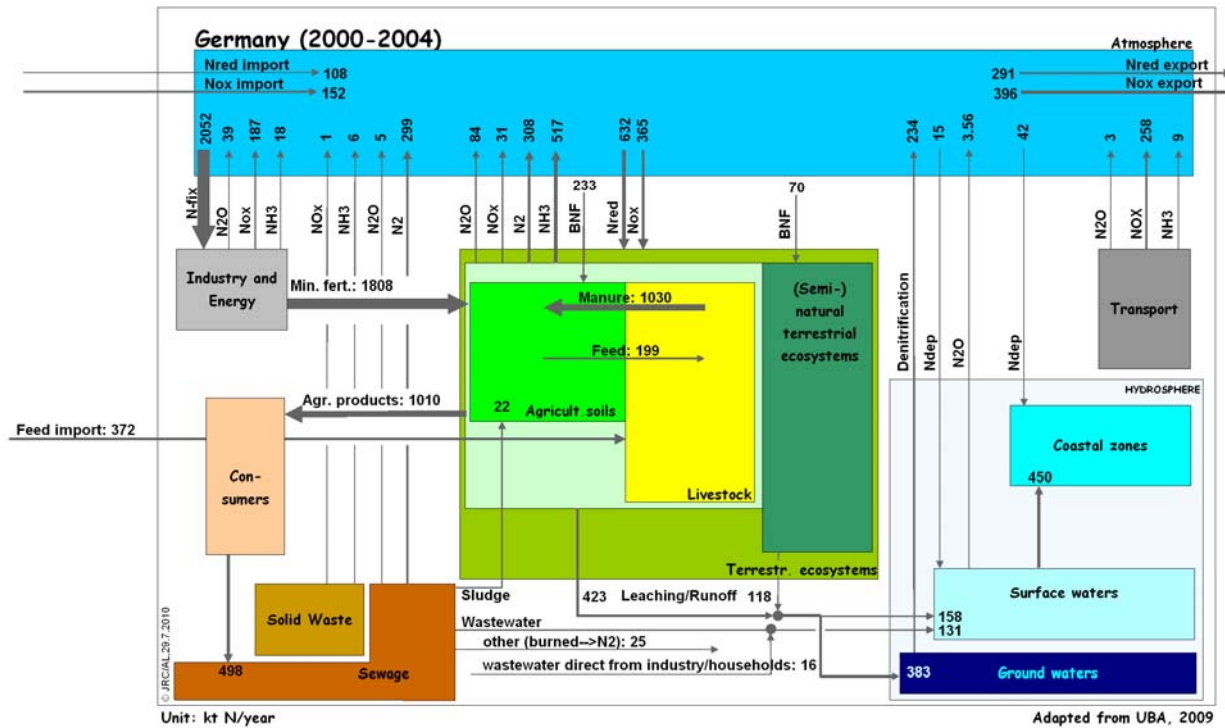

Figure 16.SA3: National nitrogen budget for Germany for the years 2000-2004. Adapted from UBA 2009b. Source of data see text.

Emissions from the Industry & Energy sectors (including households) are estimated from (Umweltbundesamt, 2006b) and amount to 244 Gg N y^{-1} for the year 2004 with the bulk of nitrogen being emitted as NO_x. Also from the 270 Gg N y^{-1} emitted from the transport sector (Umweltbundesamt, 2006b) more than 95% are entering the atmosphere as NO_x. For transport-NO_x, 86% of the emissions stem from the road transport. However, emissions from the aviation sector are included only for national flights and as far as they are emitted during start or landing of the airplanes. Emissions from the transport sector have been substantially reduced since 1990 by about 45%.

A farm gate nitrogen budget for the German agriculture sector has been performed by Bach (Bach & Frede, 2005; Bach, 2008). For the years 2001-2003, a total input of nitrogen of 2825 Gg N y^{-1} produces an output of nitrogen in crop and animal products of 1010 Gg N y^{-1} giving a nitrogen surplus of 1815 Gg N y^{-1} and an Nitrogen Use Efficiency for both crop- and livestock sector of about 35%. Emissions to the atmosphere are quantified by Umweltbundesamt (2006a) and Dämmget *et al.* (2006) and have been

estimated according to the official procedures described in the EMEP/CORINAIR[2] inventory guidebook and the IPCC guidelines[3]. Agricultural losses of reactive nitrogen to the atmosphere are higher (554 Gg N y^{-1}; most of it as NH_3) than those to the aquatic systems, which have been estimated by Behrendt *et al.* (2003) as 423 Gg N y^{-1} and thus as the most important source for the aquatic nitrogen load. Additionally Dämmgen *et al.* (2006) estimate an N_2-release from agricultural systems of about 310 Gg N y^{-1}. Beside anthropogenic sources of reactive nitrogen the biological nitrogen fixation (BNF) delivers around 300 Gg N y^{-1} to the German nitrogen cycle. In agriculture the cultivation of nitrogen fixing plants like legumes produces 230 Gg N y^{-1} (Bach & Frede, 2005; Bach, 2008) whereas according to Cleveland *et al.* {, 1999 #19} terrestrial ecosystems receive approximately 70 Gg N^{-1} a^{-1} by N-fixing microbial processes.

Emissions from the waste sector depend strongly on the type of waste and management system. NH_3 emissions occur during digestion or compostation of biological waste and have been estimated to 6 Gg N y^{-1} (Cuhls et al., 2008; Statistisches Bundesamt, 2007). NO_x emissions are relevant for the thermic use of solid waste and contributed 1 Gg N y^{-1} (Umweltbundesamt, 2007) to the budget. About 500 Gg N in communal waste water are treated by sewage plants (Statistisches Bundesamt, 2003), which are estimated to emit 5 Gg N y^{-1} as N_2O (Umweltbundesamt, 2006a). With an estimate of the production of about 80 Gg N y^{-1} in sewage sludge (Durth et al., 2005; Umweltbundesamt, 2007) and 115 Gg N y^{-1} being discharged into the river system (Behrendt et al., 2003), the balance could be closed by assuming an emission of 299 Gg N_2-N and hence a total denitrification rate of 60% (Umweltbundesamt, 2009a). About 22 Gg N y^{-1} of sewage sludge was used in agriculture (Umweltbundesamt, 2007) and the remaining was burned, and virtually quantitatively converted to molecular nitrogen with reduction techniques.

Surface freshwaters and groundwater receive next to the quantities from agriculture and sewage water treatment plant about 16 Gg N y^{-1} as point source from industry and about 118 Gg N as diffuse "background" load. This is composed from urban losses and erosion losses from terrestrial systems. 15 Gg N y^{-1} are received through atmospheric deposition (Behrendt et al., 2003). These 688 Gg N y^{-1} are distributed to the watersheds of the North Sea (531 Gg N y^{-1}), the Baltic Sea (34 Gg N y^{-1}) and the Black Sea (123 Gg N y^{-1}) (Behrendt et al., 2003). During the journey to coastal zones denitrification is the most important process of removal of reactive nitrogen (Venterink et al., 2002). Assuming a fraction of 35% being denitrified, 240 Gg N y^{-1} are released as N_2 while - applying the IPCC emission factor for N_2O (IPCC, 1997) - 3-4 Gg N y^{-1} are additionally emitted as N_2O, so that the input into the coastal zones is estimated with about 450 Gg N y^{-1} (Umweltbundesamt, 2009b).

Additionally, German coastal waters receive 9 to 24 kg N ha^{-1} a^{-1} from atmospheric deposition (Tarrasón et al., 2006), which amount to a total of about 42 Gg N y^{-1} over the German Baltic and North Sea, of which about 60 % is reduced nitrogen (Umweltbundesamt, 2009a). Wet and dry deposition over land was 996 Gg N y^{-1} in the year 2004, as estimated by (Gauger et al., 2008), with the deposition of reduced

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[2] EMEP: Cooperative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe; CORINAIR: CO-oRdination d'INformation Environnementale;
[3] see http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/#

compounds dominating (63%). This corresponds to an average of 28 kg N ha^{-1} y^{-1}. Transboundary transport of air pollutants is calculated by (EMEP/MSC-W & Benedictow, 2006) and shows that 260 Gg N y^{-1} are entering and 687 Gg N y^{-1} leaving Germany through this pathway. About 41-42% of N exported from Germany through transboundary transport is in the form of reduced N compounds'.

16.S5. Netherlands

Albert Bleeker

Energy Research Centre of the Netherlands, Air Quality & Climate Change, Petten, The Netherlands

The Netherlands is a very nitrogen intensive country, maybe even the most nitrogen-intensive country of the world. This is due to a combination of high nitrogen inputs in agriculture, an extensive chemical industry and a large traffic volume. This has been causing different problems related to e.g. the emission of NO_x and NH_3 to the air, nitrate in groundwater and nitrogen loading of surface waters.
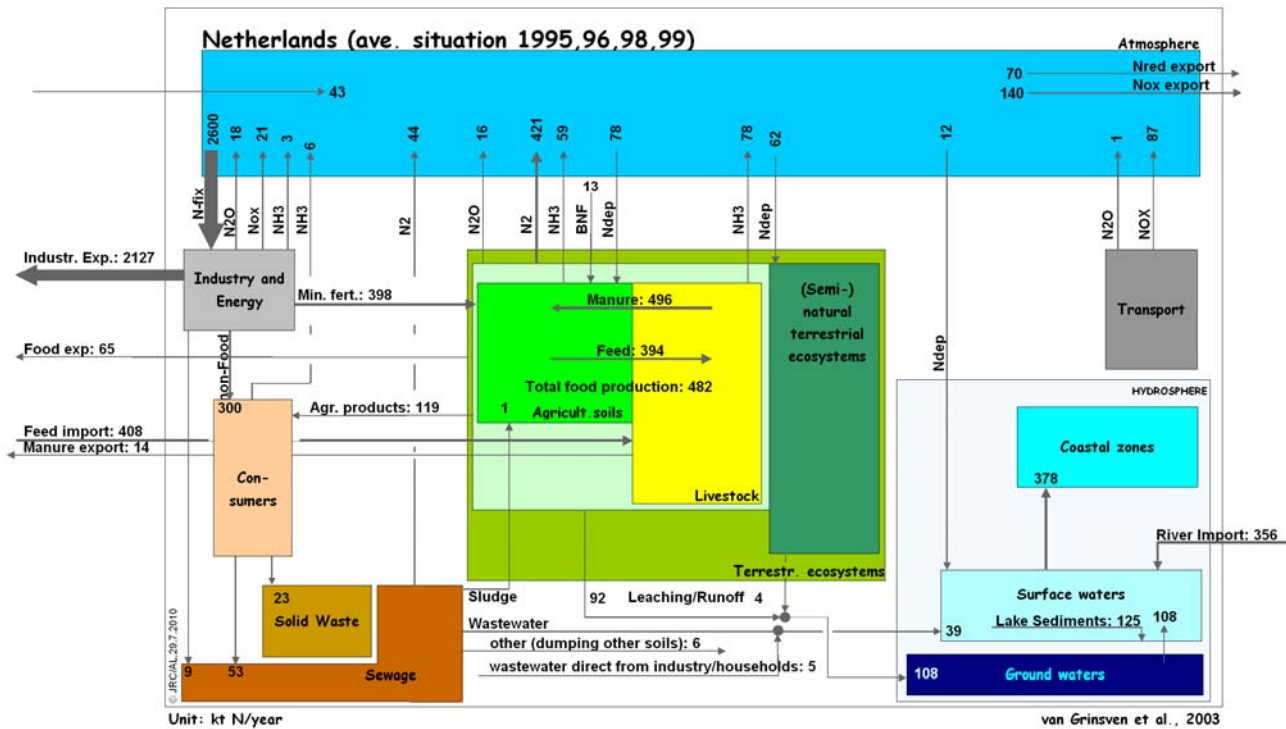

Figure 16.SA4: Integrated nitrogen budget for the Netherlands representing the average situation of 1995, 1997, 1998 and 1999 (van Grinsven et al., 2003). Source of data see text.

Van Grinsven et al. (2003) presented an overview of the nitrogen balance for the Netherlands, showing the different flows of nitrogen through the economic and environmental system in the Netherlands. Overall, the Netherlands had a net import of about 1200 kt reactive nitrogen yearly between 1995 and 2000 in the form of products and raw materials, an input of 400 kt via air and rivers and a net production of about 2700 kt N. Of this gross input of 4300 kt reactive nitrogen, approximately 2700 kt is exported in the form of products and raw material, while 600 kt leaves the country by air and rivers and some 1000 kt reactive nitrogen leaks into the environment. The surplus (reflecting the difference between input and output of nitrogen into/from the Netherlands) of reactive

nitrogen, which is the source for potential effect, is 1200 kt, of which about half can be attributed to agriculture.

The national nitrogen budget is based on information from different publications, mainly originating from the National Bureau of Statistics. They produce different balances and publish them in different ways (also digitally). A very complete overview for 1995, giving the total nitrogen cycle for the Netherlands (Fong, 1999; Olsthoorn & Fong, 1998) together with information about nitrogen in agriculture in 1995, 1997, 1998 and 1999 was used as a basis for the numbers presented in Figure.16.SA4. Combining all this information gives an overview of the average national nitrogen budget for these years (Fong, 1999; Fong, 2000). Using the average is also done to level out the effects of economical and meteorological year to year variations, which can both have an impact on the annual situation.

A few overall remarks can be made when looking at the integrated nitrogen budget for the Netherlands:

- the industrial nitrogen fixation is mainly occurring during the production of artificial fertilizer (about 70%). The other 30% is for the production of chemicals like ammonia, melamine and caprolactam, that are mainly for the export market

- the import of inorganic nitrogen compounds is mainly through artificial fertilizer

- the import and export via big rivers (Rhine and Meuse) is strongly dependent on the precipitation amounts in the watersheds. Because of this, the net contribution of the Netherlands to the nitrogen flux to the North Sea varies between +126 and -19 kt per year

- denitrification from agricultural soils and waste water treatment plants is very uncertain and therefore not taken into account as a loss term.

In the following paragraphs some more general descriptions for three different sectors (agriculture, food, fertilizer) that are important for the Netherlands are given. More detailed description for the other sectors can be found in Van Grinsven et al. (2003).

Agriculture. The Netherlands is a net exporter of agricultural products for human consumption (i.e. excluding feed). Almost half of the Dutch land surface is used for agriculture. The Dutch agriculture produces about 147 kt N as animal product and 50 kt N as crop products. About 70 out of 197 kt N that is produced annually by the agricultural sector is exported. Nitrogen input by artificial fertilizers (398 kt yr^{-1}) and feed (about 400 kt yr^{-1}) are important inputs of the Dutch agriculture. Therefore, the nitrogen surplus in agriculture, the difference between N-input (fertilizer and feed) and N-output (products) is about 600 kt yr^{-1}.

This nitrogen is then being emitted to the Dutch environment and dispersed via air and water. Eventually the major part of the surplus is converted in the soil and water to inert N_2 (about 500 kt), while a smaller part is exported abroad (mainly in the form of NH_3 – about 50 kt) by air or in the form of N in river water to the North Sea (about 10-20 kt). A small part is stored in the soil or sediment.

Food. The Dutch consumed about 95 kt of protein nitrogen per year, or near 6 kg N per capita via food. The recommended protein-N intake is approximately 3.4 kg. Some 35%

of the protein is taken out of dairy products, 30% out of vegetable products and the rest out of meat products. The amount of N necessary for this protein consumption is dependent on the diet. For a kg of beef protein about 3 times more N is needed compared to a kg of poultry protein and 15 times more compared to a kg of vegetable protein. For the annual consumption of 6 kg N per capita about 90 kg N is needed from agricultural production. Part of the loss from the animal protein production of is in the form of manure and meat waste and can be recycled for the food production for man and pets.

The Netherlands has also an important food processing function. 465 kt N is imported as food product and about 530 kt is exported on a yearly basis. With an agricultural production of about 197 kt and a consumption of 95 kt, this sector is losing 37 kt in total.

Artificial fertilizer. The Netherlands is a fertilizer producing and exporting country. The production is based on the Haber-Bosch process, where inert N_2 from the air and natural gas is converted to NH_3. About 1500 kt N is produced annually as fertilizer. This makes around 1.5% of the world production. About 90% of this production is exported as fertilizer or base material for the further processing to fertilizer. The use of fertilizer in the Netherlands is about 398 kt with a net import of more than 200 kt.

The most important conclusions that were drawn from the integrated analyses of sources, flows and effects of nitrogen are:

- agriculture is contributing to the Dutch nitrogen surplus at about half and therefore largely contributes to the potential effects of nitrogen in the environment and nature;

- consumers contribute to the nitrogen surplus by 10 or 35%, depending on whether 'accumulation in finished products' is taken into account. In terms of effects, this contribution is less important than the one from agriculture, since the reactive nitrogen of this contribution can lead to effects on environment and nature only to a small extent. However, since knowledge on this contribution is still inadequate, further research is needed.;

- the nitrate problem in ground waters is mainly an agricultural problem: 80% of the net load to the soil originates from agriculture. The distribution of this surplus over pooling in the soil phase, denitrification and run-off/leaching is still uncertain. Extrapolation of empirical knowledge about this topics by means of models shows a large variation: the increase of N-storage in the soil vary between -130 and +115 kt N yr^{-1}, denitrification contributes with 200-500 kt N yr^{-1}, and run-off/leaching range from 80 to 100 kt N yr^{-1};

- fresh surface waters are polluted by direct discharges of waste water, run-off from agricultural soils and atmospheric deposition. Looking at different water types, dominance of different sources can be recognised. It needs to be noted that eutrophication of fresh surface waters is primarily caused by phosphate making the pollution by nitrogen often playing a secondary role;

- the above mentioned is also true for salt surface waters, with the difference concerning nitrogen that is also primarily causing the effects of eutrophication.

- the average Dutch contribution to the North Sea is 22 kt yr^{-1} (varying between +126 and -19 kt) . As an export flow of the Dutch N-surplus this comprises 2% and as a

contribution to the export via big rivers 5%. However, the contribution of the Netherlands to the overall load of the North Sea is still very uncertain. This is mainly caused by the large year to year variations (i.e. the relatively large variation in the annual loads mentioned above, due to e.g. variation in precipitation amounts), dominant contribution of foreign import and the uncertainty concerning the size of nitrogen contribution via e.g. small river systems;

- 14% of the national N-surplus (or about 170 kt N yr^{-1}) is exported over the Dutch borders through the air. It is expected that the Dutch contribution to nitrogen deposition in the border areas of Germany and Belgium is considerable, and contributing to direct and indirect effects of NH_3 and NO_x on nature and humans.

16.S6. Switzerland

Beat Achermann[1], Juerg Heldstab[2]

[1]*Federal Office for the Environment, Department of the Environment, Transport, Energy and Communications, Bern, Switzerland*
[2]*INFRAS consulting, policy analysis and research, Zuerich, Switzerland*

The first detailed analysis of the nitrogen fluxes in Switzerland was carried out between 1994 and 1996 based on a mandate of the Departments of Economic Affairs and Home Affairs of the Swiss government. The project aimed at identifying the most important N fluxes between the compartments anthroposphere, pedosphere, atmosphere and hydrosphere, at assessing the fluxes with respect to the exceedance of effects-based environmental and health quality criteria and at elaborating a strategy for a stepwise reduction of emissions of reactive nitrogen compounds from the source categories traffic, large- and small-scale industry, households and agriculture, considering national and international developments. The results of the work of the project group are summarized in the report „Strategy for the Reduction of Nitrogen Emissions" (BUWAL, 1996).

The national nitrogen budget study included the import of nitrogen containing air pollutants over the atmosphere, the import of nitrogen bound in animal feed, mineral fertilizer and agricultural consumer products, the import of nitrogen compounds in water systems, as well as the export of air pollutants and the export of nitrogen containing agricultural products. The transformation of nitrogen compounds and the N transfer between different environmental compartments within Switzerland were as much as possible differentiated to get the fluxes for single reactive nitrogen compounds like nitrogen oxides, ammonia, nitrous oxide and nitrate. The resulting fluxes for the year 1994 are summarized in Figure.16.SA5. The figure contains the middle values of the ranges for all fluxes given in the original report to indicate quite substantial uncertainties that sometimes appear (BUWAL, 1996).

The data for the elaboration of the national nitrogen budget and for the assessment of the single fluxes of nitrogen compounds were taken or derived i.a. from agricultural statistics (Schweizerischer Bauernverband, 1994; Schweizerischer Bauernverband, 1995), from studies carried out at agricultural research stations (Stadelmann et al., 1996), from studies relating to water protection (BUWAL, 1993), from national air pollutant emission inventories (BUWAL, 1995), from import/export statistics relating to consumer goods, from the modelling of transboundary air pollution (EMEP, 1995), from national and harmonized international effects assessments (EKL, 1989; PARCOM, 1988; SAEFL, 1996; UN-ECE, 1993; UN-ECE, 1995).

The evaluation of the national nitrogen budget for 1994 showed that the most important emissions of reactive nitrogen compounds were those from the anthroposphere and pedosphere to the atmosphere and the hydrosphere. These fluxes are summarized in Table 16.SA1.
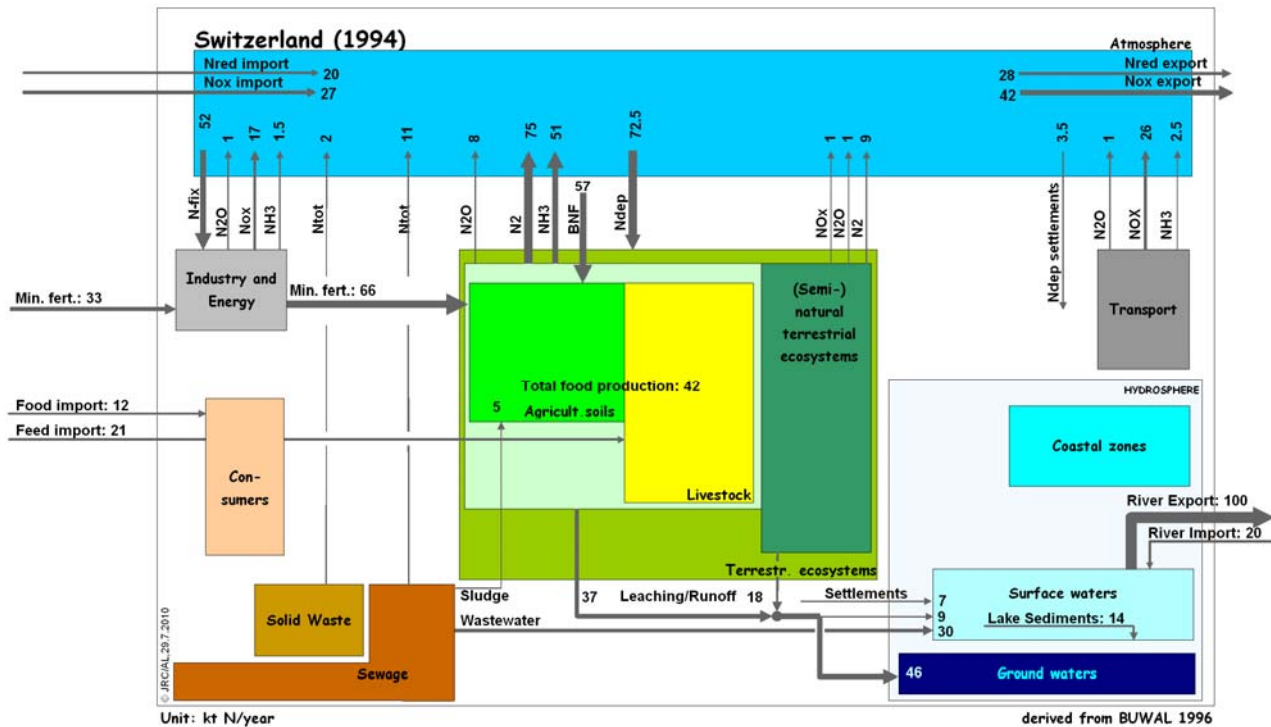
Figure 16.SA5: *National nitrogen budget for Switzerland for 1994 (derived from BUWAL, 1996)*

Table 16.SA1. Emissions of important reactive nitrogen compounds in Switzerland in the year 1994 from the most relevant source categories traffic, industry, households and agriculture

Emissions 1994 (kt N)	Total	From traffic, house-holds, industry		From agriculture		From „natural sources"	
		to air	to water	to air	to water	to air	to water
NO_x	43	43				1	
NH_3	55	4		51			
N_2O	11	2		8		1	
N in surface waters	46		37		3		6
NO_3^- in groundwater	46				34		12
Total	201	49	37	59	37	2	18

The results show that about 48% of the emissions have agricultural origin, 43% are emitted from the traffic, industry and households sectors, and 9% were allocated to „natural sources". The emissions from „natural sources" like e.g. nitrate leaching from forest soils and from soils of other (semi-)natural ecosystems are considered to be to a large extent anthropogenically induced by high nitrogen deposition from the air. Thus a substantial proportion of these emissions should be allocated to traffic, industry, households and agriculture source categories.

The emissions of reactive nitrogen compounds and their fluxes in 1994 were also compared with fluxes and emissions resulting from the requirement to have no exceedances of critical loads for nitrogen (protection of sensitive natural ecosystems), critical levels and health-oriented air quality standards for ozone (with NO_x as a precursor), health-oriented water quality standards (relating to nitrate) and long-term sustainable nitrogen inputs to water systems to prevent eutrophication of e.g coastal marine ecosystems. This assessment resulted in a quantification of the further emission reductions needed to achieve effects-based ecological and health-oriented goals. It is shown in Table 16.SA2.

Table 16.SA2. N fluxes in Switzerland: Situation in 1994, estimates of maximum tolerable emission levels to achieve non-exceedance of ecological and health-oriented standards and emission reductions needed to reach these goals

Emissions (kt N/a)	Situation in 1994	Tolerable emission levels to achieve ecological and health-oriented goals	Emission reductions needed compared with 1994
NO_x to the air	43 *	11 – 16	27 – 32
NH_3 to the air	55 *	25 – 30	25 – 30
N_2O to the air	10 *	**	-
Nitrate in groundwater	34 *	15 – 20	14 – 19
N input to the catchment of the Rhine downstream from the lakes	46	25 - 35	11 - 21

* corresponds to the total emissions minus those from „natural sources" (see Table 16.SA1 above)
** to be determined as part of an overall strategy to abate greenhouse gases

This assessment clearly showed that action has to be taken in all sectors contributing to the emissions of reactive nitrogen compounds. Consequently the strategy study contains a substantial part on the evaluation of appropriate measures to further reduce emissions.

Following measures were proposed for agriculture:

- Direct payments on the basis of the fulfillment of specific criteria relating to ecological farming;
- Incentive strategy to encourage production forms considering environmental criteria and animal welfare;
- Establish specific programs to adjust production in areas with elevated nitrate leaching;
- Abatement of ammonia emissions by optimizing animal feeding, by using low-emission manure application techniques, low-emission manure storage and low-emission housing systems and by adjusting the number of animals in areas with high densities.

With respect to combustion processes a further tightening of motor vehicle exhaust regulations was requested for passenger cars and heavy duty vehicles, stationary engines and utility vehicles in agriculture. In addition, economic instruments like a mileage dependent heavy duty vehicles tax taking into account the level of emission control and a CO_2 tax were proposed.

For waste water optimization, improved performance of sewage treatment is proposed by introduction of N elimination stages (nitrification, denitrification) in particular in new or substantially reconstructed plants.

A further national nitrogen budget study was carried out for the year 2005. The results of this study will be available by the end of 2010 and published by the Federal Office for the Environment (BAFU, 2010). The results of the study are summarised in the following Figure.16.SA6. Due to some methodological changes (e.g. aggregation of sub-flows) and due to updated emission factors (e.g. N_2O emissions from agricultural soils), some flows in Figure.16.SA6 cannot directly be compared with the flows in Figure.16.SA5.
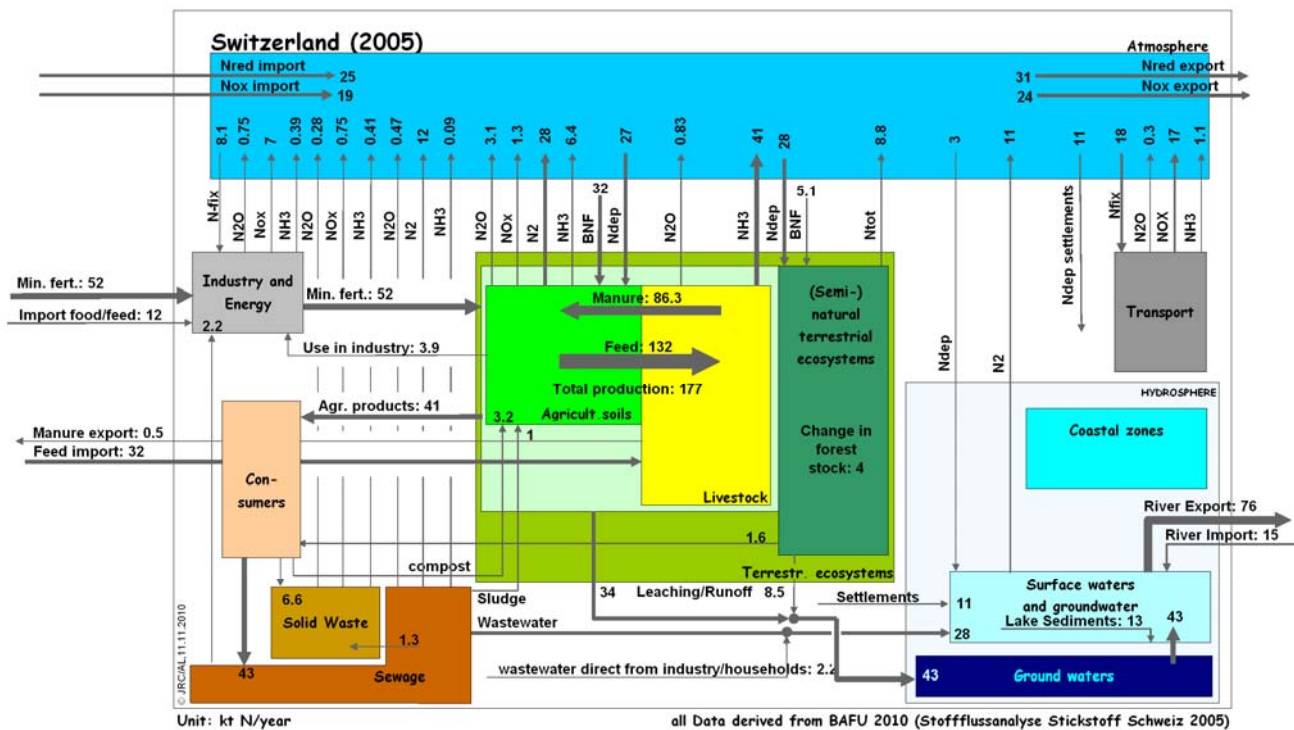

Figure 16.SA6: *National nitrogen budget for Switzerland in 2005 derived from BAFU, 2010. Note that the system definition for Consumers and Industry+Energy is different from BAFU, 2010, where N flows from Industry and Energy to Solid Waste and to Sewage are shown explicitly. In the above figure these flows are contained in the corresponding out-flows from the box Consumers.*

The updated N budget 2005 allows a comparison with the situation in 1994 as well as an assessment of the progress realized in the abatement of emissions of reactive nitrogen

compounds during the last 10 years. The changes of important N flows since 1994 are shown in Table 16.SA3.

Table 16.SA3. Emissions of important reactive nitrogen compounds into atmosphere and hydrosphere in Switzerland in the years 1994 and 2005. The last column shows the changes in percent (1994 equals 100%). The new numbers for 1994 are taken from BAFU, 2010, which result from recalculations of the first N budget (previous numbers are shown in brackets and may also be found in Table 16.SA2).

Emissions (kt N/a)	1994	2005	1994 - 2005
NO_x	38 (43)	26	-32%
NH_3	55 (55)	49	-12%
N_2O	7.3 (10)	6.7	-9%
N in surface waters	49 (46)	39	-20%
NO_3^- in groundwater	55 (55)	54	-2%
Total	204 (209)	175	-14%

16.S7. United Kingdom

Penny Johnes[1], Ulli Dragosits[2], Dave Fernall[3], Mark Sutton[2], Adrian Leip[4]

[1] *University of Reading, Aquatic Environments Research Centre, Reading, UK*
[2] *Atmospheric Sciences Centre for Ecology and Hydrology (CEH), Edinburgh, UK*
[3] *Defra, Food and Farming Group, Agri-environment Workstream, Economics & Statistics Programme, York, UK*
[4] *EC-Joint Research Centre, Institute for Environment and Sustainability, Ispra (Va), Italy*

Previously, partial UK nitrogen budgets have been constructed separately for, e.g., atmospheric N_r (import, emission, deposition, export) (Fowler et al., 1998; NEGTAP, 2001; RoTAP, 2011), surface waters, waste water, agricultural food and feed production (Fernall and Murray, 2009), import and export of materials. The budget constructed here brings together these elements for the first time, to create a complete nitrogen budget for the UK (excluding denitrification emissions of N_2, except for emissions from coastal waters).

Atmospheric emissions of ammonia (NH_3), nitrogen dioxide (NO_2) and nitrous oxide (N_2O) are calculated annually as part of the UK government's National Atmospheric Emissions Inventory (NAEI, 2010) and Greenhouse Gas Inventory (GHGI, 2010). Detailed emission estimates are prepared for agriculture, industry, transport, waste, nature etc. by national experts from different organisations (e.g. AEA, North Wyke Research, CEH) and mapped at a high resolution. These emission inventory maps are used as input for atmospheric transport modelling (Dore et al., 2007), which allows estimation of the transboundary import and export of nitrogen in air to and from the UK. The UK wet deposition budget is calculated for oxidised and reduced N by interpolation of measurements of wet deposition from the UK national monitoring networks (Smith et al., 2000). For the dry deposition budget, maps of gas and aerosol concentrations are obtained using both interpolation of measurements and national scale modelling combined with application of appropriate vegetation specific deposition velocities (RoTAP, 2011).

The nitrogen balance for agricultural soils of the UK is derived from the UK TAPAS (Technical Action Plan for improving Agricultural Statistics) modelling, using the OECD system (Fernall and Murray, 2009). The approach provides data on mineral fertilizer application rates and manure management. In addition, national food and feed balance modelling (DEFRA, 2008) provides data on food and feed import as well as feed production. Net nitrogen import in food and feed is calculated from these data, together with nitrogen export from agriculture for human consumption using the NANI approach (Boyer et al. 2002, Net Anthropogenic Nitrogen Input, see Billen et al. (2011, Chapter 13). The NANI approach is applied to the whole of the UK using the Defra Food and feed import/export data, together with statistics from FAOSTAT on dietary N intake by food type and DEFRA summary statistics from the June 2008 Agricultural Census for the UK.

Industrial discharge to surface waters is based on a publication on the P budget of the UK (White & Hammond, 2009) which suggests that 3% of P export to waters is from industrial discharges. We assume that this rate is also applicable for N export, in the absence of observed data and recognised that this is a limitation of this estimate. We note

that this estimate is comparable to the estimate of the German budget which gives a figure of 2.4% for Germany.

United Kingdom (1995-2008)

Atmosphere

Nred import 40
Nox import 50

105 → Nred export
301 → Nox export

N-fix 1306
N2O 5
Nox 218
NH3 7
NH3 1
NOx 1
NH3 6
N2O 1
NH3 5
N2O 26
NOx 0.2
NH3 (*) 205
Nred 175
Nox 161
NH3 6
N2O 0.3
Denitrification 116
Ndep 6
N2O 2
NOX 209
NH3 10

Industry and Energy

Min. fert.: 1076

Manure: 1014

(Semi-) natural terrestrial ecosystems

Transport

Food&Feed (net): 312

Feed: 1223

HYDROSPHERE

Agr. products: 728

Agricult. soils
60

Coastal zones
603

Con-sumers

Livestock

Terrestr. ecosystems

Surface waters

490

Solid Waste
42

Sludge
Wastewater

489 Leaching/Runoff 66

270
153

291

242

Sewage

wastewater direct industry/households: 18

septic tanks

288
2.7

Ground waters

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Unit: kt N/year

Situation around 1995-2008
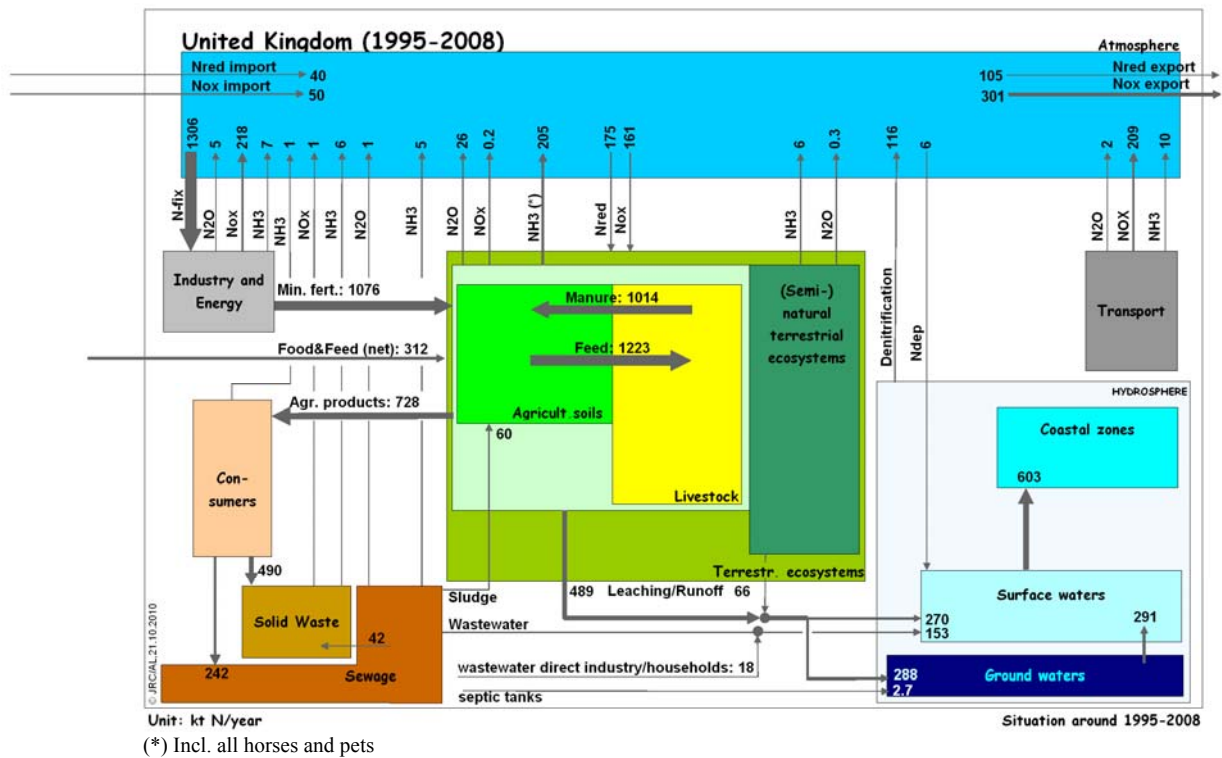
(*) Incl. all horses and pets

Figure 16.SA7: National nitrogen budget for the United Kingdom describing the situation around 1995-2008.

Nitrogen fixation to the industry and energy sector is calculated from the available data on mineral fertilizer application and atmospheric emissions from this sector. It does not include any Nr fixation in products not considered in this budget.

Public wastewater emissions are based on a per capita excretion rate and average national N removal rates through primary, secondary and tertiary treatment (Johnes, 1996; Johnes & Butterfield, 2002). Additionally, a retention of 2.7 kt N of assumed to be retained in septic tanks and never removed through pumping. This nitrogen is assumed to leach eventually to groundwater and adds to the diffuse leaching to groundwater from agricultural sources. Sewage sludge application data to agricultural land are obtained from the UK TAPAS modelling (Fernall and Murray, 2009).

The figures for diffuse emissions (to water) from agriculture are based on best available national estimates, derived using the export coefficient modelling approach (Johnes, 1996; Johnes & Butterfield, 2002; Johnes et al., 2007). However, as the data for North Ireland and Scotland (Dunn et al., 2004a; Dunn et al., 2004b) are for nitrate only and not for total nitrogen, they were increased based on the assumption that nitrate is typically 60% of the total nitrogen load in intensively monitored catchments in the UK. Since these are data for the 1990s, they should be updated on the basis of observed and modelled

total nitrogen load. Furthermore, the split between diffuse emissions to groundwater as opposed to surface water is done based on national base flow rate, derived from hydrograph separation of data of the national monitoring network and cross-referenced against the Baseflow Index data derived from the HOST (Hydrology of Soil Types) system. Background emissions to water of nitrogen from woodland, rough grazing and moorland are estimated as 10 kg ha^{-1}yr^{-1}. This seems to be a robust estimate for agricultural catchments, but may be less reliable in Northern and Western parts of the UK. For direct atmospheric deposition to surface waters an average deposition rate of 20 kg N ha^{-1} yr^{-1} is used (Johnes & Butterfield, 2002).

Exports of nitrogen from the UK to its coastal waters are split into discharges to the North Sea, the North Atlantic and the English Channel (Johnes and Butterfield, 2002; MLURI – Bob Ferrier, pers. comm.). Finally, a denitrification rate of 16% of the N exported to coastal waters (including emissions of both N_2 and N_2O) is applied, based on the East Coast estuaries (Trimmer *et al.*, 2000). This figure will be appropriate for muddy east coast estuaries with moderately high nitrate loading, but may be inappropriate for sandy or rocky systems, or for the wetter, marginally colder systems of the west coast of the UK for which no observational data are available.

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