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Draft Guidance document on Nitrogen Budgets

Submitted by the Co-chairs of the Task Force on Reactive Nitrogen

A. Pre-amble

Nitrogen budgeting at national level has been prosed as a new provision in (the Annex IX of) the revised 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. The Exert Panel on Nitrogen Budgets (EPNB) of the Task Force on Reactive Nitrogen has prepared a draft Guidance Document for establishing these nitrogen budgets at national scale, which is presented here.

The purpose of this “Guidance document on nitrogen budgets” is to provide clear recommendations which *nitrogen pools* and *nitrogen fluxes* should be considered for the construction of National Nitrogen Budgets (NNBs), and how these pools and fluxes should be combined. It is important to understand that “budgets” as defined here will not be limited to describe the fluxes across given system boundaries, but cover also stock changes and internal flows. All concepts are developed to allow guidance also for a broader range of Nitrogen Budges (NBs) at different scales and also for economic entities.

B. Terminology

The following terms are described here in order to provide a better understanding of nitrogen budgets. They are therefore presented in a logical rather than alphabetical order.

Nitrogen budget (NB) describes the quantification of all major nitrogen fluxes across all sectors and media within given boundaries, and fluxes across these boundaries, in a given time frame (typically one year), as well as the changes of nitrogen stocks within the respective sectors and media. NBs can be constructed for any geographic entity, for example at supra-national level (e.g., Europe), sub-national level (regions, districts), for watersheds or even individual households or for economic entities (such as farms). National NBs (NNBs) use the borders of a country including its coastal waters as system boundaries, such that the atmosphere above and the soil below this country are also included.

Pools: Nitrogen pools represent sub-units of a full nitrogen budget in which quantities of nitrogen are stored (nitrogen stocks). Exchange of nitrogen occurs between different pools via nitrogen fluxes. Nitrogen pools can be environmental media (e.g., atmosphere, coastal areas), economic sectors (e.g., industry, agriculture) or other societal elements (e.g., consumers). Selection of pools may differ between budgets, e.g. for a NNB, all relevant pools to describe the nitrogen budget at a country-level shall be included.

Sub-pools: Pools can be further divided into sub-pools if sufficient data are available. For example, the pool “inland water” can be divided into lakes, rivers, etc., with additional nitrogen fluxes across these sub-pools to be quantified.

Stocks: Each pool can store a quantity of nitrogen, for example, as mineral or organic nitrogen in soils (for instance as in agriculture or semi-natural lands/pools). This quantity is the nitrogen stock. Nitrogen stocks may be very large with respect to nitrogen fluxes (e.g., for soil pools), and often N-stocks are difficult to quantify. However, the most relevant parameter for the NB is a potential stock **change**, i.e. a flux to a neighbouring pool or sub-pool, and not so much the nitrogen stock itself.

Flux: Nitrogen fluxes describe the transport of nitrogen between the various pools of an NB, or between the sub-pools within a pool. They also link any pool with the ‘rest of the world’ (RoW) as imports or exports (e.g., trade, atmospheric transport, riverine export). Fluxes of nitrogen can occur as ‘reactive nitrogen’ (Nr), which can be speciated into, e.g., NH_x, NO_x, N_2O, organic nitrogen, nitrate. In addition, fluxes linking reactive nitrogen with molecular N_2 need to be considered. These fluxes include fixation (biological nitrogen fixation by plants and technical fixation by combustion processes or ammonia synthesis) as well as conversion of Nr to N_2 (resulting from denitrification and the anammox processes in soil biology, or from recombination during combustion). All fluxes must be represented in the same unit, e.g. in tons of N per year, or in tons of N per km^2 per year

Reactive nitrogen: Reactive nitrogen (Nr) is any form of nitrogen that is available relatively easily to living organisms via biochemical processes. These compounds include NH_3, NO_x, N_2O, NO_3, organically-bound N in plants, animals, humans and soil − and many other chemical forms. Nitrogen in a state that requires a considerable amount of energy to become bio-available (like molecular nitrogen, N_2 in the atmosphere) is not considered Nr. Also, nitrogen inaccessible to bio-substrates, and which will convert primarily into N_2 is not counted as Nr, but instead is referred to as “locked N”. Specifically, this is N contained in mineral oil and its products.

Balance: The balance of a pool, a sub-pool, or a full NB refers to the following equation: $N_{input} = N_{output} + N_{stock\_change}$. It must theoretically be possible to obtain a closed N-balance for each pool defined and for a full NB. In practice, a closed balance is not a requirement of an NB and the balance becomes: $N_{input} = N_{output} + N_{stock\_change} + \delta$, with δ referring to un-accounted nitrogen fluxes, including any errors. Un-accounted nitrogen fluxes indicate that contradicting/inconsistent data sources are used or that some data are missing. Both cases point to a need of better integration of the scientific understanding. The magnitude of the un-accounted nitrogen fluxes does not necessarily indicate an uncertainty of the accounted nitrogen fluxes.

Uncertainty: Provides a quantitative estimate on the influence of imperfect information on the quantity of a nitrogen flux or stock change. Uncertainty assessment helps to set the priority for improving nitrogen budgets and is an important element of quality assurance in NBs. According to standards set by the IPCC which should be used here, too, a quantitative description of an uncertainty range should cover 95% of the total sample space.

C. Introduction

This document responds to the needs of policy makers and national experts to harmonize activities assessing potentially adverse nitrogen fluxes in and to the environment. National and international regulations require the collection of relevant information about such fluxes or about the resulting environmental state. Often such information is specifically compiled for the agricultural sector, recognizing the importance of Nr as plant nutrient, while not fully reflecting the complete picture of the environmental nitrogen cascade.

The challenge of this guidance document consists in building upon existing and well-established schemes, which provide appropriate information on a range of scales. Specifically of interest in the context of NNBs are national balances, such as the OECD gross nitrogen balances (OECD, 2007), and inventories on the emissions of air pollutants (EEA, 2009) and greenhouse gases (IPCC, 2006), which have been developed at a national level and are successfully applied in many countries. For NNBs it is important to take advantage of existing structures, and to remain fully compatible with each of these activities while minimizing resources to close the remaining gaps towards an nitrogen budget.

The present document provides an outline for a more detailed guide to build NBs with a focus to the national scale (NNBs). It takes into account the need to integrate existing structures and available documentation. Further fine tuning of this document and extended guidance to the individual sections will come as NNBs becomes operative.

D. Pools in National Nitrogen Budgets

In order to benefit, as much as possible, from the detailed data available from the air pollutant and greenhouse gas inventories submitted to EMEP (EEA, 2009) and the UNFCCC (see IPCC, 2006 and 1997), their structure is here as closely as possible. This also entails maintaining IPCC notation for consistency reasons, except that here pools are defined corresponding to the processes as in the IPCC guidelines. The following pools are regarded as essential elements for a (complete) nitrogen budget:

- 0 Atmosphere
- 1 Energy and fuels
  - 1A1 Power plants
  - 1A2 Industry
  - 1A3 Transport
  - 1A4 Other energy and fuels (e.g., residential)
- 2 Material and products in industry (processes)
- 3 Consumer and product use
- 4 Agriculture
  - 4B Animals
  - 4D/E/FCrops & agricultural soils
- 5 Vegetation and non-agricultural soils
- 6 Waste
- 7 Water
  - 7A Groundwater
  - 7B Inland water
  - 7C Coastal marine systems

The aim is for the list of pools to be comprehensive, i.e., any conceivable nitrogen fluxes between pools can be accommodated into this scheme. IPCC definitions will allow a safe attribution in most cases, and practical experience will allow the identification of the remainder.

E. Subsections for guidance document

In a final version, this guidance document will contain specific descriptions for each pool, as defined above. As mentioned before, developing such material is best performed during the development of these budgets, allowing for the best integration of any available information and guidance. Still, compiling such information will be performed on the basis of a general structure, for the benefit of both authors of such subsections, and for potential users who wish to compare between sections.

For each pool, the following subsections should be considered:

1. Introduction, main known features of the pool (compared to other pools)
2. Definition: detailed description of activities/fluxes encompassed by the pool; clear definition of boundaries, separate description for all potential nitrogen species involved
3. Internal structure: possible reference to sub-pools; “unlocking” (of other relevant fixed nitrogen) into Nr, if relevant; conversion of Nr species, if needed.
4. External structure: fluxes of Nr into and out of the pool; fluxes of N2 formed or used when undergoing conversion (e.g., fixation or denitrification). The external structure must be defined in a way that the balance of the pool is conceptionally closed.
5. Underlying data: suggestions of data sources to be used (e.g., reference to other guidelines).
6. Factors and models: detailed descriptions of calculation algorithms for quantitative flux (and stock change) information, labeling of fluxes that are determined as residual from closing balance equations
7. Uncertainties, data quality issues and other items critically affecting results; indication of potentially missing fluxes
8. References, bibliography, further reading
9. Document version, author contact information

F. Level of detail

The NNBs will support validation of environmental nitrogen fluxes (by way of identifying inconsistencies) and guide the identification of intervention points to regulate environmental nitrogen emissions or releases. In order to fulfill these goals, a minimum resolution of the fluxes considered is needed, which also requires harmonization between countries.

As part of the European Nitrogen Assessment (ENA), Leip *et al*. (2011) established a set of national nitrogen budgets, as well as a European budget. These budgets provide a reasonable resolution that has been proven to be workable. The individual fluxes presented (Fig. 1) can thus serve as a minimum level of detail.

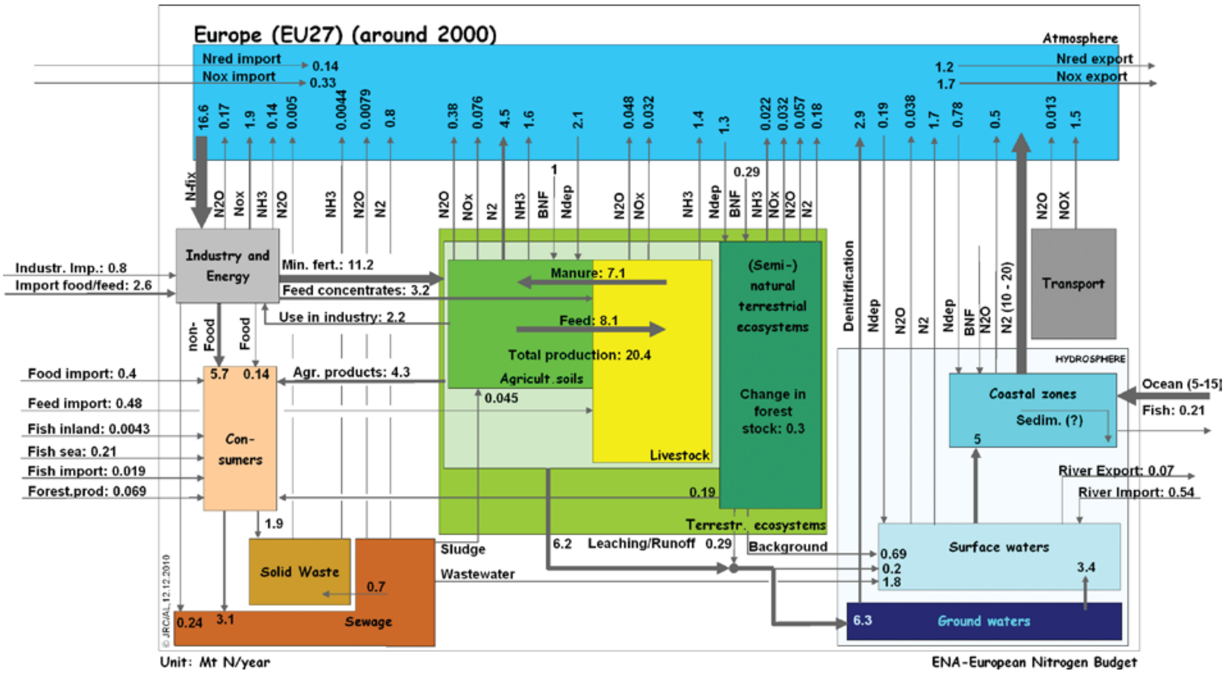

Fig. 1: ENA Nitrogen budget (Leip *et al.*, 2011)

G. Specific considerations for pools

0 Atmosphere

Atmosphere is used mainly as a reservoir pool. Most of the available nitrogen is stored here in the form of unreactive molecular N_2. It also serves to collect, to deposit and to transport reactive nitrogen under various chemical forms. Conversions between compounds in the atmosphere are not normally covered, except for N_2 fixation to NO_x due to lightning, which is included in the guidance to derive air pollutant emissions.

1 Energy and fuels

Pools covering the nitrogen contained in fuels (used in combustion processes in industry, power plants, transport, residential use) reflect national energy statistics and their implementation in UNFCCC / IPCC reporting. This is relevant to nitrogen pollution, emission fluxes are generally well covered in atmospheric / GHG inventories.

2 Material and products in industry

Typically, statistical information (energy statistics) differentiates between fuel combustion and feedstock use of fuels. IPCC deals with the latter case under “industrial processes”, a convention that is mimicked in NNBs. Processes that are especially important with regard to nitrogen are fixation processes, such as the Haber-Bosch ammonia synthesis, and nitric acid production.

3 Consumer and product use

A separate sector in the IPCC guidance covers the use of compounds that are subsequently released into the atmosphere. For NNBs, this concept needs to be extended slightly, to subsume “consumers” as a pool and to consider releases to other media than atmosphere.

This pool then also includes nitrogen compounds physically consumed or excreted by humans, such as the stock change of body mass N. These coefficients are included in UNFCCC inventories even now, albeit only in the "waste" category.

4 Agriculture

As a key category relevant for the environmental nitrogen cycle, agricultural N balances have been an important element in environmental assessments. Agricultural fluxes are typically large and associated with high uncertainty. Following the IPCC guidelines, nitrogen fluxes occur in animal husbandry (sector 4B) and in plant production (sector 4D-4F; sectors 4A and 4C are not relevant for nitrogen). This differentiation is also critical in NNBs. In line with other guidelines, processes in animal houses and distributing manure, up to the manure application process itself, are activities directly related to animal husbandry, while manure that has been applied to fields (i.e., following spreading or from grazing livestock) and its related emissions are to be regarded as elements of plant production.

The "Gross Nitrogen Balances" of the OECD (2007) have been used successfully to describe the nitrogen fluxes in the agriculture pool. More detailed information, supporting the development of some of the national coefficients used in the OECD approach, is being compiled by national authorities to fulfill the requirements of national GHG or air pollutant inventories. The DireDate project (Oenema *et al*., 2011) discusses the respective reporting requirements and data on agricultural nitrogen in detail and serves as an input to the EUROSTAT Task Force meeting scheduled for November 2011. The results of this project also allow for a reassessment of data needs with respect to not only present nitrogen fluxes, but also potential fluxes under conditions of emission abatement. Integrating such options is important for the use of NBs to study intervention points.

In addition to IPCC's definition of agriculture, NNBs consider not only soil processes, but also stock changes in agricultural and grassland soils accounted for by plant production.

5 Vegetation and non-agricultural soils

While the IPCC sector "Land use, land use change and forestry" focuses on carbon stock changes, the corresponding NNB pool assesses the related change in nitrogen stocks in biomass and non-agricultural soils. This comprises all natural and semi-natural terrestrial ecosystems, and provides an appropriate pool for one of IPCC's elements of "indirect" emissions, the Nr re-released from deposited material following atmospheric transport and deposition. This constitutes a deviation from IPCC's approach but maintains consistency in the NNB.

6 Waste

This sector is another major contributor of environmental nitrogen. By separation specifically between waste disposal and wastewater treatment, NNBs follow the same concept as IPCC. Due to coverage of multiple environmental media, several fluxes additional to the ones covered by IPCC need consideration. These include, specifically, waste and sewage produced by consumers, application of sludge to fields and release of wastewater to surface waters.

7 Water

The water pool needs to be considered in addition to the existing IPCC categories. Water bodies not only provide a major environmental transport pathway but are also an important element in the nitrogen cascade. Some transformation processes, e.g. aqueous formation of the greenhouse gas N_2O actually take place here. Thus it is consistent to assign the “indirect” emissions due to leaching of agricultural nitrogen (in IPCC terminology) to the water pool, together with similar transformation of other water-available Nr. Again this difference to the IPCC approach is needed for consistency. Several other fluxes, most of which bear prime responsibility for water pollution, are specifically relevant for NNBs, as is the split into the individual pools describing groundwater, surface waters and coastal zones, respectively. The quantification of imports and exports via surface and ground waters is of special importance for NNBs. These processes may play a dominant role for closing balance equations of the water pools.

H. References

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