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Draft Guidance document on National Nitrogen Budgets

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

A. Pre-amble

Nitrogen budgeting at the national level has been proposed as a new provision in the Annex IX of the revised 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. The Expert Panel on Nitrogen Budgets (EPNB) of the Task Force on Reactive Nitrogen has prepared a draft guidance document for establishing these nitrogen budgets at national scale, which is presented here.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 flows* should be considered for the construction of National Nitrogen Budgets (NNBs), and how these pools and flows should be combined. It is important to understand that "budgets" as defined here will not be limited to describe the flows 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 Budgets (NBs) at different scales and also for economic entities.

B. Introduction

Nitrogen Budgets (NBs) respond to the needs of policy makers and national experts to coordinate activities assessing potentially adverse nitrogen flows in and to the environment.

National and international regulations require the collection of relevant information about such flows 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. NBs overcome this problem (Leip et al., 2011):

(i) NBs are an efficient instrument for visualizing the N cascade and its potential impact and thus help to raise awareness;

(ii) NBs provide policy makers with information for identifying intervention points and developing efficient emission reduction measures;

(iii) NBs can provide a tool for monitoring the impact and environmental integrity of implemented policies;

(iv) NBs are useful for comparisons across countries; and

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

The present document provides guidance to build NBs with a focus to the national scale (national NBs or NNBs). The NNBs will support validation of environmental nitrogen flows (by way of identifying inconsistencies) and guide the identification of intervention points to regulate environmental nitrogen emissions or releases and to optimise N use. In order to fulfil these goals, a minimum number of pools and flows considered is needed, which also requires harmonization between countries.

To this purpose, this document (i) provides a clear terminology to be used when constructing NNBs and (ii) gives a description of the elements (pools) that must be included in any NNB taking into account the need to integrate existing structures and available documentation. Once NNBs becomes operative, additional descriptions and details for each of the pools will be developed.

C. 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.

A **Nitrogen budget** (NB) consists of the quantification of all major nitrogen flows across all sectors and media within given boundaries, and flows 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 are elements in a nitrogen budget. They represent “containers” which serve to store quantities of nitrogen (these quantities may be referred to as nitrogen stocks). Exchange of nitrogen occurs between different pools via nitrogen flows. Nitrogen pools can be environmental media (e.g., atmosphere, water), economic sectors (e.g., industry, agriculture) or other societal elements (e.g., humans and settlements). 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 groundwater, lakes, rivers, etc., with additional nitrogen flows across these sub-pools to be quantified.

Stocks represent real-world accumulations. 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 flows (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 variation over time of the respective accumulation, rather than the nitrogen stock itself. Nitrogen stocks can be composed of N in any nitrogen form.

Flow: Nitrogen flows describe the transport of nitrogen over time between the various pools of an NB, or between the sub-pools within a pool. They also link any pool with the pools outside the system boundaries, the 'rest of the world' (RoW), in the form of imports or exports (e.g., trade, atmospheric transport, riverine export). Flows of nitrogen can occur as 'reactive nitrogen' (Nr) or N_2. In addition, flows during which the transformation of nitrogen from reactive nitrogen to molecular N_2 or vice versa need to be considered. These flows 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). Flows 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 (also termed "flux").

Nitrogen forms: Nitrogen can occur in various forms, some of which are irrelevant for NBs. An NB needs to cover reactive forms of nitrogen only.

Reactive nitrogen (Nr): 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.

Inactive nitrogen: Some forms of nitrogen may be considered inactive or inert as they are inaccessible to biosubstrates. This regards primarily molecular nitrogen (N_2), which is the dominant N species but can be excluded from an NB as separated by the considerable amount of energy to become bio-available. This activation process then constitutes a flow bringing Nr from this origin into a nitrogen budget. By way of analogy, other inactive natural forms of N are excluded from the nitrogen budget until being activated (e.g., N contained in mineral oil and its products).

Balance: Ideally, the balance of a pool, a sub-pool, or a full NB is closed, i.e. all nitrogen flows can be explained as input, output or stock changes. The balance equation $N_{output} + N_{stock\_change} - N_{input} = 0$ then. Such a closed N-balance is theoretically possible 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 a value different from 0, with the difference referring to un-accounted nitrogen flows, including any errors. Un-accounted nitrogen flows 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.

Uncertainty: Provides a quantitative estimate on the influence of imperfect information on the quantity of a nitrogen flow 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. Uncertainty quantification typically will not cover bias, as any bias will be corrected as soon as it gets discovered.

D. Pools in National Nitrogen Budgets

A NNB must include all relevant pools that store nitrogen in N-stocks and exchange nitrogen with other pools or the RoW. An example has been established by Leip *et al*. (2011) as a contribution to the European Nitrogen Assessment (ENA). It contains a set of national nitrogen budgets, as well as a European budget (Figure 1).

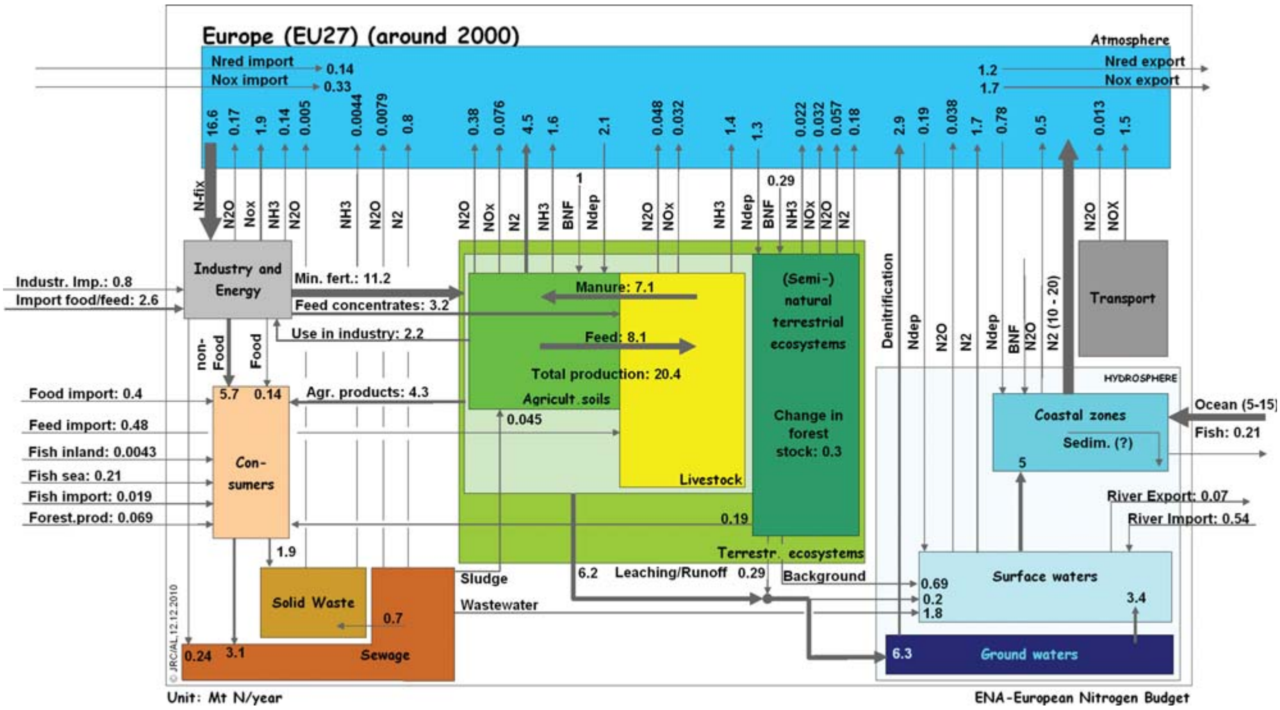

Figure 1: ENA Nitrogen budget (Leip *et al*., 2011)

The European NB provides a comprehensive picture of nitrogen flows in Europe and can thus serve a reference. However, the challenge of this guidance document consists in building upon existing and well-established schemes, which provide appropriate information on a range of scales. 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 a NB. Specifically of interest in the context of NNBs are national balances, as well as reporting obligations for national emissions of Nr for which guidance has already been developed which are successfully applied in many countries:

- The OECD, in cooperation with Eurostat, developed a handbook on *gross nitrogen balances* (OECD, 2007) and is estimating the agricultural gross nitrogen surplus at a regular basis for OECD countries

- The EMEP/EEA air pollutant emission inventory guidebook (EEA, 2009) provides guidance on estimating emissions from both anthropogenic and natural emission sources of NO_x and NH_3.

- The IPCC guidelines for National Greenhouse Gas Inventories (IPCC, 1997, 2006) provide guidance on the quantification of anthropogenic N_2O emissions.

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 integrated closely. This also entails maintaining IPCC notation for reasons of consistency, except that classification focusses on pools in contrast to the economic sectors used in the IPCC guidelines.

A NNB must be composed of eight essential pools (Table 1). For some pools information on sub-pools must be provided. This concerns the *Energy*, *Agriculture* and the *Waste* pools, for which additional detail is required in order to include important flows occurring to- or from sub-pools and to provide a fully comparable national system. The definition of the sub-pools has been done according to IPCC definitions, thus data will be readily available.

The aim is for the list of pools to be comprehensive, i.e., any conceivable significant nitrogen flow between (sub-)pools can be accommodated into this scheme.

Table 1: Essential pools and sub-pools to be included in a NNB

Pool-ID	Sub-pool	(Sub)Pool-Name
1		**Energy and fuels**
1	A1 + B	Energy conversion (includes flaring and fugitive emissions from fuels)
1	A2	Manufacturing Industries and Construction
1	A3	Transport
1	A4	Other energy and fuels (e.g., residential)
2		**Material and products in industry (processes)**
3		**Humans and settlements**
4		**Agriculture**
4	A	Animals
4	B	Manure / manure management
4	C/D/E/F	Crops & agricultural soils
5		**Forest and semi-natural vegetation including soils**
6		**Waste**
6	A	Solid waste disposal
6	B	Wastewater handling
6	C	Waste incineration
6	D	Other waste
7		**Atmosphere**
8		**Hydrosphere**
8	A	Inland waters (including ground water)
8	B	Coastal and marine waters

E. Description of the pools

1 Energy and fuels

The 'Energy and fuels' pool encompasses the flows of nitrogen of energy conversion sites, industry, transport and other uses of energy and fuels. The flows of nitrogen to be quantified include input flows (N-fixation) and output flows (Nr emissions). Input of nitrogen occurs both by 'activating' nitrogen contained in the fuels and through thermal generation of Nr at high temperatures during the burning process. Distinction between these two flows is difficult, however, and not required.

Emissions of Nr are linked to fuel use the sub-pools, as reflected in national energy statistics and their implementation in UNFCCC/IPCC reporting. This is relevant to nitrogen pollution and emission flows are generally well covered in atmospheric / GHG inventories. Even the questions of international transport and allocation of emissions in cross-boundary transport have been addressed in such 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.

Main input flows are nitrogen fixation processes, such as the Haber-Bosch ammonia synthesis. Industry processes use also nitrogen in agricultural products and imported products. Output flows that need to be quantified are fertilisers, compound feed products, food products, and non-food chemical products (nitric acid, melamine, caprolactam, etc. as used for example in explosives, plasticisers and nylon)

3 Humans and Settlements

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, to subsume "humans" as a pool encompassing various sub-pools:

- the human body with intake of nitrogen in food from agriculture, fishery, industry, and output of nitrogen mainly to sewage systems;
- the 'material world' made of chemical products from industry which accumulate in the 'humans' pool or are disposed of, incinerated or otherwise managed in waste system;
- the 'organic world' with products from agriculture and forestry, including non-consumed food and wood and paper products, but also flowers, package material etc. These products are entering various waste streams, i.e. sewage systems, landfills, waste incinerators, are composted or deposited in other ways.
- non-agricultural animals (pets) that are fed on agricultural products.

The 'humans' pool is linked to the RoW through trade of products. Also the flows to and from the atmosphere (deposition, emissions) may need consideration. Output flows must be quantified to the different sub-pools of the 'waste' pool. Output flows to other pools are usually small, but should be quantified if significant.

4 Agriculture

Agriculture is a key pool for a NNB, and is a key driver for the global nitrogen cycle. Emissions of Nr from agricultural sources are important elements in environmental assessments. Agricultural flows are typically large and associated with high uncertainty. A NNB should differentiate the following sub-pools, defined in analogy to the IPCC source categories of the sector agriculture:

- Animal husbandry (corresponding to category 4A). Input of nitrogen to livestock occurs through grazing, and feeding of crops/fodder and imported feed (concentrates). Output flows of nitrogen from livestock are in products (meat, milk, eggs, wool, etc.), non-carcass retained nitrogen in the animal body, and manure. Also emissions of Nr from animal housing systems might occur.

- Manure management and manure storage systems (corresponding to category 4B). Input to manure management and storage systems is, first of all, from animal husbandry. The concept extends to N input to biogas plants even when limiting to material from energy crops (consistent with approaches taken by EEA, 2009). Main output flows are emissions to the atmosphere and hydrosphere and application of manure on soils. If import/export of manure is a significant flow in a country, it should be quantified as well. Manure management and storage systems are important for emission mitigation measures.

- Soil-based agricultural pools. This includes rice cultivation (category 4C), cultivation of upland crops (category 4D) including grazing by ruminants (category 4D2), and prescribed burning of savannas and field burning of agricultural residues (categories 4E and 4F). Input flows are the application of mineral fertilisers, nitrogen in manure that has been applied to fields (i.e., following spreading or from grazing livestock), nitrogen in other organic fertilisers (including crop residues), seeds, and N in atmospheric deposition and biological fixation. Output flows are harvested crop products, crop residues, and emissions of N to the atmosphere or hydrosphere.

In addition to IPCC's definition of agriculture, NNBs consider not only soil processes, but also stock changes in animal husbandry, manure management and storage systems, and cropland and grassland soils.

In contrast to IPCC methodology, *indirect* emissions from agricultural sources are not included here, as they are no output flow from the agricultural pool. Instead, emissions of N following volatilisation and deposition of Nr are quantified for the pool where the atmospheric deposition happens (forests and other non-agricultural vegetation and soils, settlements, or inland or coastal/marine waters). Equally, emissions of agricultural N towards the hydrosphere are 'followed' along its path. This constitutes a deviation from IPCC's approach but maintains consistency in the NNB.

The "Gross Nitrogen Balances" of the OECD (2007) have been used successfully to describe the nitrogen flows 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 fulfil 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 EUROSTAT's activities to align the methodology for estimating Gross Nitrogen Balances with other international reporting obligations. Guidance provided here takes account of these existing activities and strives to harmonize, as much as possible, the different needs while taking advantage of existing activities. This will allow for a reassessment of data needs at all levels with respect to not only present nitrogen flows, but also potential flows under conditions of emission abatement. Integrating such options is important for the use of NBs to study intervention points.

5 Forest and semi-natural vegetation including 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, according to the CORINE land cover class 3 "Forests and semi-natural areas" (EEA, 2007). Input flows are atmospheric deposition, biological N-fixation, and application of mineral or organic fertiliser. Output flows are harvesting of products to industry, to the humans, or as a fuel to 'energy', as well as emissions to the atmosphere and the hydrosphere.

6 Waste

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

7 Atmosphere

Atmosphere is used mainly as a transport medium, as the atmosphere serves to collect, to deposit and to transport reactive nitrogen under various chemical forms. Even though most of the available nitrogen is stored here in the form of inert molecular N_2, only the fraction present as Nr or being converted to or from Nr must be quantified. The quantification of conversions between compounds different possible atmospheric sub-pools (e.g., oxidised or reduces Nr-species) is not required, except for N_2 fixation to NO_x due to lightning, which is considered as an input flow. Other input flows are atmospheric import of Nr, as well as emissions from all other pools in a NNB. Also fluxes of N_2 from pools to the atmosphere are regarded as input flow. Output flows are biological and technical N-fixation, export of Nr by atmospheric transport and Nr-deposition to land-based pools.

8 Hydrosphere

The hydrosphere 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 flows, most of which bear prime responsibility for water pollution, are specifically relevant for NNBs, as is the split into the individual pools describing inland waters (groundwater and surface water) and marine waters (such as coastal lagoons and estuaries). 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.

F. Specific guidance on each nitrogen pools of a NNB

This guidance document contains the framework under which specific guidance to each of the 8 pools listed including the required sub-pools can be developed (to be added as Annexes to the document). 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/flows encompassed by the pool; clear definition of boundaries, separate description for all potential nitrogen species involved
3. Internal structure: possible reference to sub-pools and their structure.
4. Pool description: flows of Nr into and out of the pool; flows of N_2 formed or used when undergoing conversion (e.g., fixation or denitrification); stock changes within the pool; "unlocking" (of other relevant fixed nitrogen) into Nr, if relevant; conversion of Nr species, if needed. The pool definition requires keeping the balance of the pool conceptually 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 flow (and stock change) information, labelling of flows that are determined as residual from closing balance equations
7. Uncertainties, data quality issues and other items critically affecting results; indication of potentially missing flows
8. References, bibliography, further reading
9. Document version, author contact information

G. References

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