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Annexe, updated Version

Detailed Annexes to ECE/EB.AIR/119 – “Guidance document on national nitrogen budgets"

Version No. 4/2025 (update from Version 2.3.2011)

by:

Bettina Schäppi, Judith Reutimann, Sophie Bogler, Anna Ehrler
INFRAS, Zurich Switzerland

Horst Fehrenbach
Ifeu, Heidelberg Germany

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On behalf of the German Environment Agency

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Publisher
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
buergerservice@uba.de
Internet: www.umweltbundesamt.de

Report performed by:
INFRAS AG
Binzstrasse 23
8045 Zurich
Switzerland

ifeu - Institut für Energie- und Umweltforschung gGmbH
Wilckensstr. 3
69120 Heidelberg
Germany

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Abstract: Detailed Annexes to ECE/EB.AIR/119 – "Guidance document on national nitrogen budgets"

The Convention on Long-range Transboundary Air Pollution (CLRTAP) adopted a Guidance Document to assist in the calculation of national nitrogen budgets (NNB) (ECE/EB.AIR/119). NNBs are an efficient instrument for visualizing the N cascade and its potential impact. They provide policy makers with information for identifying intervention points and developing efficient emission reduction measures, they help to monitor the impact of implemented policies and they are useful for comparisons across countries. Last but not least they can help pinpoint knowledge gaps and thus contribute to improve the scientific understanding of the N cascade. Specifically, they support the implementation of the Gothenburg Protocol of the CLRTAP and of the National Emission reduction Commitments Directive of the European Union (EU) and provide knowledge to observe the attainment of nutrient reduction targets as set by the EU Farm-to-Fork-Strategy or by the Global Biodiversity Framework of the Convention on Biological Diversity (CBD). The present annexes describe the detailed methodological approach for the development of a NNB in the framework of the "UNECE Guidance document on national nitrogen budgets".

Nitrogen budgets describe the exchange of quantities of nitrogen between environmental compartments, the economy, and the society within the national borders. National Nitrogen Budgets (NNBs) are established by describing pools, sub-pools and the nitrogen (N) flows between the sub-pools. The NNB includes eight pools, notably "energy and fuels (EF)", "material and products in industry (MP)", "agriculture (AG)", "forests and semi-natural vegetation (FS)", "processing of residues (PR)", "humans and settlements (HS)", "atmosphere (AT)" and "hydrosphere (HY)". Exchanges to and from the outside of national boundaries are considered as flows from/to the "rest of the world (RW)". For each of these pools, specific guidance on how to calculate relevant N flows is provided, including calculation methods and suggestions for possible data sources.

For each (sub-)pool of the NNB a mass balance is set up (i.e. total N inputs minus total N outputs equal stock changes of N within a given (sub-)pool). In the NNB, all relevant flows of reactive N species need to be quantified, but concerning inactive N_2, only N flows that are connected to a transformation of N_2 to a reactive form of nitrogen or vice versa are relevant.

Kurzbeschreibung: Detaillierte Anhänge zu ECE/EB.AIR/119 - „Leitfaden für nationale Stickstoffbilanzen".

Im Rahmen des Übereinkommens über weiträumige grenzüberschreitende Luftverunreinigung (CLRTAP) wurde ein Leitfaden zur Unterstützung der Berechnung nationaler Stickstoffbilanzen (NNB) verabschiedet (ECE/EB.AIR/119). NNBs sind ein effizientes Instrument zur Visualisierung der N-Kaskade und ihrer potenziellen Auswirkungen. Sie liefern politischen Entscheidungsträgern Informationen zu Interventionspunkten und zur Entwicklung effizienter Maßnahmen zur Emissionsreduzierung, sie helfen bei der Überwachung der Erfolge umgesetzter politischer Maßnahmen und sind nützlich für länderübergreifende Vergleiche. Außerdem schließen sie Wissenslücken und tragen somit zur Verbesserung unseres wissenschaftlichen Verständnisses des Stickstoffkreislaufs bei. Insbesondere unterstützen sie die Umsetzung des Göteborg Protokolls des CLRTAP und der Richtlinie der Europäischen Union (EU) über die Reduktion der nationalen Emissionen bestimmter Luftschadstoffe und liefern Erkenntnisse zur Überwachung der Erreichung der Nährstoffreduktionsziele der Farm-to-Fork-Strategie der EU oder des Global Biodiversity Framework des Globalen Übereinkommens über die biologische Vielfalt (CBD). Die vorliegenden Anhänge beschreiben detailliert den

methodischen Ansatz für die Entwicklung einer NNB im Kontext des UNECE Leitfadens zur Berechnung nationaler Stickstoffbilanzen.

Stickstoffbilanzen beschreiben den Austausch von Stickstoffmengen zwischen Umweltkompartimenten, der Wirtschaft und der Gesellschaft innerhalb der nationalen Grenzen. Nationale Stickstoffbilanzen werden durch die Beschreibung von Sektoren, Untersektoren und den Stickstoffflüssen (N) zwischen den Untersektoren erstellt. Die NNB umfasst acht Sektoren, darunter „Energie und Brennstoffe", „Material und Produkte in der Industrie", „Landwirtschaft ", „Wälder und halbnatürliche Vegetation", „Abfälle", „Menschen und Siedlungen", „Atmosphäre" und „Hydrosphäre". Der Austausch von Stickstoff über die nationalen Grenzen wird über N-Flüsse zum bzw. vom „Rest der Welt" berücksichtigt. Für jeden dieser Sektoren wird eine spezifische Anleitung zur Berechnung der relevanten N-Flüsse gegeben, einschließlich Berechnungsmethoden und Vorschläge für mögliche Datenquellen.

Für jeden (Unter-)sektor der NNB wird eine Massenbilanz erstellt (d. h. die gesamten N-Einträge minus die gesamten N-Austräge entsprechen den Lageränderungen von Stickstoff innerhalb eines bestimmten Untersektors). In der NNB werden alle relevanten Flüsse reaktiver N-Spezies quantifiziert. Flüsse von inaktivem N_2 sind nur dann relevant, wenn sie mit einer Umwandlung von N_2 in eine reaktive Form von Stickstoff oder umgekehrt verbunden sind.

Table of content

List of figures

List of tables

List of abbreviations

Abbreviation	Explanation
CBD	Convention on Biological Diversity
CLRTAP	Convention on Long Range Transboundary Air Pollution (Geneva convention)
CRF	Common Reporting Format
EMEP	European Monitoring and Evaluation Programme
EPNB	Expert Panel on Nitrogen Budgets
FAO	Food and Agricultural Organization
g	gram
IPCC	Intergovernmental Panel on Climate Change
kt	kiloton
t	ton
NFR	Nomenclature for reporting
NNB	National Nitrogen Budget
N_r	Reactive nitrogen
N_{mix}	Reactive N species bound to materials (e.g. food, plastic, organic materials) or a mix of different reactive N species (e.g. dissolved forms of nitrogen)
N_{tot}	Total Nitrogen
TFRN	Task Force on Reactive Nitrogen
UN ECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

Summary

The Convention on Long-range Transboundary Air Pollution (CLRTAP) adopted a Guidance Document to assist in the calculation of national nitrogen budgets (NNB) (ECE/EB.AIR/119). NNBs are an efficient instrument for visualizing the N cascade and its potential impact on the environment. They provide policy makers with information for identifying intervention points and developing efficient emission reduction measures, they help to monitor the impact of implemented policies and they are useful for comparisons across countries. Last but not least they can help pinpoint knowledge gaps and thus contribute to improve the scientific understanding of the N cascade. Specifically, they support the implementation of the Gothenburg Protocol of the CLRTAP and of the National Emission reduction Commitments Directive of the European Union (EU) and provide knowledge to observe the attainment of nutrient reduction targets as set by the EU Farm-to-Fork-Strategy or by the Global Biodiversity Framework of the Convention on Biological Diversity (CBD). The present annexes describe the methodological approach for the development of a NNB in the framework of the "UNECE Guidance document on national nitrogen budgets" in detail.

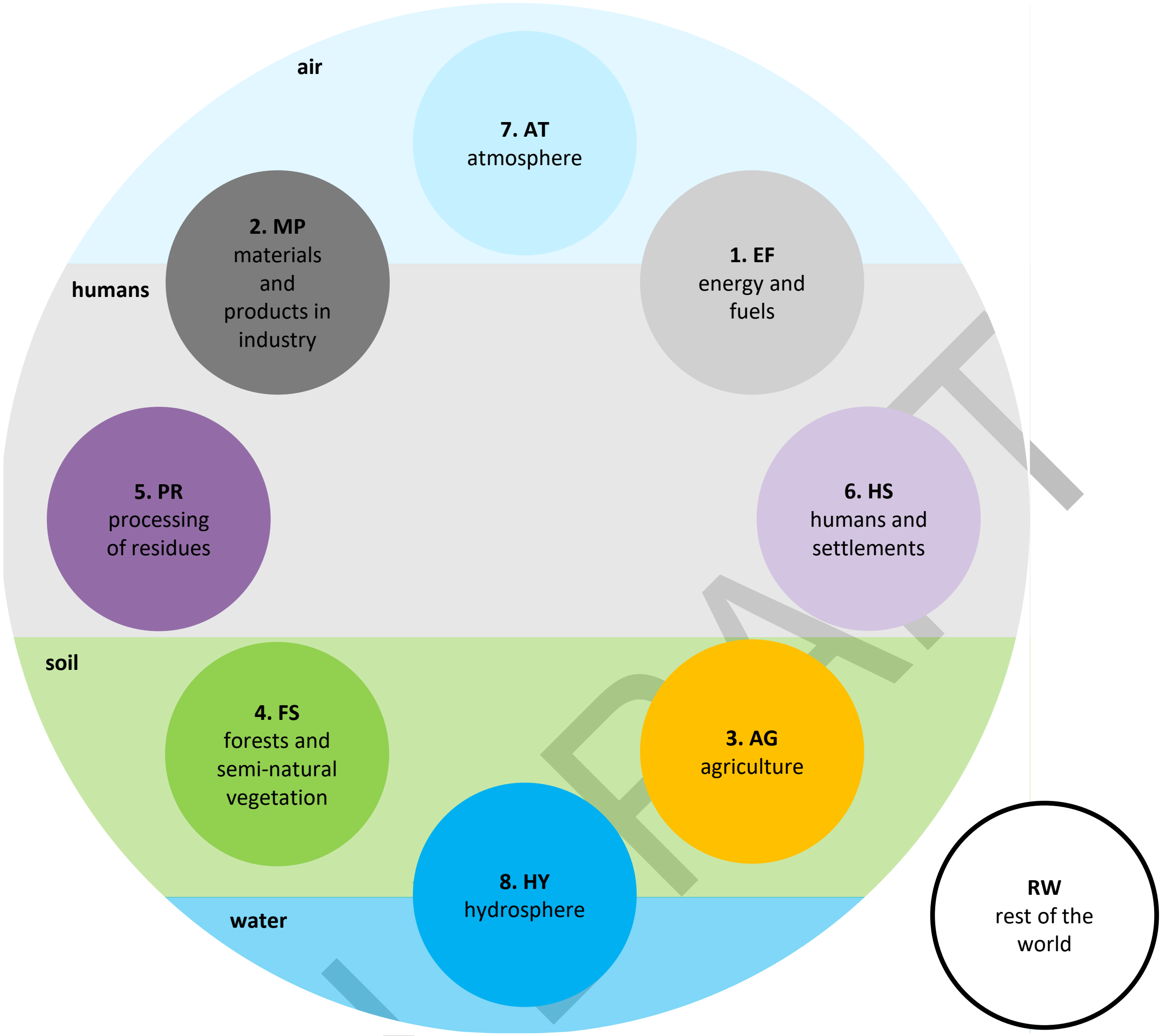
Annex 0 - Introduction, method and conventions for NNBs

Nitrogen budgets describe the exchange of quantities of nitrogen between environmental compartments, the economy, and the society within the national borders. National Nitrogen Budgets (NNBs) are established by describing pools, sub-pools and the nitrogen (N) flows between the sub-pools.

According to the Guidance Document, the NNB includes eight pools (see Figure 1), notably "energy and fuels (EF)", "material and products in industry (MP)", "agriculture (AG)", "forests and semi-natural vegetation (FS)", "processing of residues (PR)", "humans and settlements (HS)", "atmosphere (AT)" and "hydrosphere (HY)". Exchanges to and from the outside of national boundaries are considered as flows from/to the "rest of the world". For each of these pools specific guidance on how to calculate relevant N flows is documented, including calculation methods and suggestions for possible data sources. Some of these pools are further divided into sub-pools.

The present document provides methodological guidance on the development of an NNB in general (Annex 0) as well as for individual pools (Annex 1 – 8).

Figure 1: Overview of pools contained in NNBs



Source: illustration by INFRAS

Nitrogen exists in a large number of different chemical compounds in which it occurs in different oxidative states (see Chapter A.3.2). The different nitrogen species are converted into one another through various natural or industrial processes. We distinguish molecular nitrogen (N_2) and all other forms, subsumed as reactive nitrogen (N_r). In the NNB, all relevant flows of N_r species need to be quantified, but concerning N_2, only flows that are connected to a transformation of N_2 to a reactive form of nitrogen (N_r) or vice versa are relevant (see A.3.1). Note that nitrogen flows can contain more than one N species. These are expressed as N flows of mixed composition (N_{mix}) for simplification. Reporting in kilotons of nitrogen per year (kt N/a) is recommended.

Table 1: Overview of most relevant nitrogen species

Abbreviation	**N species**
Reactive nitrogen N_r	
NO_x	Nitrogen oxides (expressed as mass of NO_2 by definition)
NH_3	Ammonia

Abbreviation	**N species**
NH_4^+	Ammonium
N_2O	Nitrous oxide
NO_3^-	Nitrate
NO_2^-	Nitrite
N_{mix}	Other reactive N-species bound to materials (e.g. food, plastic, organic materials) or a mix of reactive N-species (e.g. dissolved forms of nitrogen)
Inert nitrogen	
N_2	Molecular nitrogen

For each (sub-)pool of the NNB a mass balance is set up (see Eq. 1a). Total N inputs minus total N outputs equal stock changes of N within a given (sub-)pool according to the following equations. In an NNB the mass balance calculated at the annual time scale (see Eq. 1b).

$$\sum N_{input} - \sum N_{output} - \sum N_{stock\ change} = 0 \qquad \text{(Eq. 1a)}$$

$$\sum N_{input,i} - \sum N_{output,i} = \sum N_{stock\ change,i} = \mathit{\Delta}\, N_i \qquad \text{(Eq. 1b)}$$

With:

N_{input}	N flows entering the pool/sub-pool	[kt N]
N_{output}	N flows out of the pool/sub-pool	[kt N]
$N_{stock\ change}$	Changes of nitrogen stocks of the pool/sub-pool	[kt N]
$\mathit{\Delta}^{\circ}N$	Sum of stock changes of the pool / sub-pool	[kt N]
i	year	[-]

Annex 1 - Energy and fuels

The pool "energy and fuels" consists of four sub-pools (Energy conversion, Transportation

Other energy and fuels, Manufacturing industries and construction). It comprises all fuel combustion and energy conversion activities.

- Fuel combustion includes the transport sector, fuel combustion in industrial processes, in the commercial/institutional and in the residential sector.
- Energy conversion processes include heat and electricity production as well as refineries and other fuel production processes apart from biofuel production, which is accounted for in the pools "agriculture" (AG) and "processing of residues" (PR).

The most important flows of reactive nitrogen in the pool "energy and fuels" originate from fuel combustion activities. During fuel combustion, atmospheric nitrogen N_2 is transformed into reactive nitrogen species, such as NO_x, NH_3 and N_2O. Emissions of nitrogen oxides formed by thermal fixation of atmospheric nitrogen are also referred to as "thermal NO_x".

Besides fixation of atmospheric nitrogen, various types of fuels (e.g. coal, wood) contain chemically bound nitrogen. The weight fraction of chemically bound nitrogen varies depending on the fuel type. Also, ammonia itself is becoming relevant as a carbon-free alternative fuel for certain countries and specific vehicle types (e.g. in shipping, heavy-duty vehicles). During combustion processes, chemically bound nitrogen is also converted to NO_x. These NO_x emissions are referred to as “fuel NO_x” (note that thermal NO_x typically dominates the total NO_x emissions). Therefore, each pool that provides fuels is linked to the pool EF by a flow of nitrogen. This includes wood fuel from pool ”forests and semi-natural vegetation”, fossil fuels from the “rest of the world” (RW), waste fuels from pool “materials and products in industry” (MP) and biofuels from the pools “agriculture” and ”processing of residues”. All the flows entering the pool “energy and fuels” consist of reactive nitrogen bound to materials (N_{mix}). Imports and exports of fuels need to be considered for all types of fuels.

Annex 2 - Materials and products in industry

The pool “Materials and products in industry” comprises the sub-pools food processing and other industry. It covers industrial processes following the concepts employed by UNFCCC and UNECE for atmospheric emissions (IPCC, 2006, 2019; EEA, 2013, 2016, 2023). Activities described are those of transformation of goods with the purpose of creating a higher-value product to be made available to general economy. Specifically excluded from this pool is combustion of energy carriers, which are being dealt with in pool “energy and fuels”.

Within the pool MP, the Haber-Bosch ammonia synthesis is by far the most important process for the NNB. The process converts inactive N_2 into reactive NH_3, which is then further processed to mineral fertilizer in the form of ammonium nitrates or urea. Globally, ammonia synthesis is the biggest N flow that is induced by anthropogenic activities. The produced fertilizers are crucial to sustain agricultural productivity on a global level. N_2 fixation by other industrial processes (e.g. synthesis of calcium cyanamides) plays a minor role in comparison to the scale of the Haber-Bosch process; as does the rest of chemical industry involving N.

In addition to Haber-Bosch process, N is exchanged with other pools in the form of organic and inorganic nitrogen bound to materials and products. Nitrogen containing raw materials result in flows from the pools “agriculture” (crops and meat), “forests and semi-natural vegetation” (timber), and “hydrosphere” (fish) to the pool MP, where they are processed and transformed into products of higher value. Inputs may also occur from the pool HS, if residues are collected and transferred to recycling processes in the pool MP.

The products are eventually distributed to consumers (pool HS). Most important N flows in terms of nitrogen content and amount are food for humans and feed for animals. These N flows contain nitrogen mostly in form of protein. Additionally, N flows occur in the form of material goods that contain different N species, from fibers to moldable plastics, from dyes to explosives. The nitrogen bound to these goods is generally less reactive as compared to nitrogen bound to food and feed products. It is however still considered to be a flow of reactive nitrogen (see Chapter A.3.2).

All N flows related to food, feed and materials are relevant beyond a country’s borders, meaning the import and export of food, feed and various goods are to be considered for the NNB as well.

Also note that the flow of materials into pool MP for processing and out of it as higher-value products is not always direct, as several intermediate goods circulate within the pool itself.

Annex 3 - Agriculture

The pool “agriculture” (AG) consists of three sub-pools (Manure management, storage and animal husbandry, Biofuel production and composting, Soil management). It is highly relevant for the National Nitrogen Budgets since the biggest N flows within the whole NNBs are nearly always triggered by agriculture. This includes very big N flows between the AG sub-pools and flows between the pool AG and the pool "atmosphere" (AT) and "hydrosphere" (HY).

The pool AG delivers all agricultural products to the industry (pool "materials and products in industry", MP), where they are further processed and packaged, before they are brought as foodstuff to consumers in the pool "humans and settlements" (HS) or are used as secondary food products, in feed processing or as non-food products. All trade (retail, wholesale) is part of the pool MP, while consumption of food products occurs in the pool HS. Direct marketing of agricultural products (food and non-food) to the pool "humans and settlements" (HS) is therefore not included in the structure of this NNB guidance.

Incoming N flows from the industry (pool MP) are animal compound feed, mineral fertilizer as well as seeds and planting material. Besides the national production, feed is often also imported from other countries (pool "rest of the world", RW). Whether feed is represented in two flows depends on whether the data sources allow for a differentiation of feed production within the (national) borders and import. Other exchanges with the pool RW occur via import and export of live animals and manure.

For biofuel production in the pool AG, only agricultural products are considered as substrate input (organic waste as substrate e.g. from households is treated in pool "processing of residues"). As an exception, aquatic biomass from the pool "hydrosphere" (HY) is considered as an additional substrate source in certain countries. As output from substrate processing, compost produced in the pool AG is transferred back to the pool HS for use in private and public green spaces.; other outputs like digestate are used within the pool AG itself. Finally, sewage sludge from the pool PR is sometimes used as fertilizer in the pool AG, even though this application is associated with various environmental and health problems and may be banned in certain countries, especially without prior treatment.

N losses to the pool "atmosphere" (AT) and pool HY are flows that disperse to the environment. Small fractions of N emitted to pools AT and HY are returned to agriculture by deposition from the atmosphere or with irrigation and animal drinking water. Biological N_2 fixation delivers new reactive N to the pool AG.

Annex 4 - Forests and semi-natural vegetation

The pool FS consists of three sub-pools forests, wetlands and other land. The most significant inflows of nitrogen into the pool FS occur from the atmosphere (Leip et al., 2011). Such nitrogen inputs include atmospheric deposition as well as biological nitrogen fixation (BNF), which is the fixation of elementary nitrogen (N_2) by microbes in association with the roots of higher plants and soil heterotrophic microorganisms. Further, there might be overland flow of nitrogen (lateral transport) from the pool "agriculture" (AG) to the sub-pools of the pool FS.

Nitrogen undergoes various transformation processes in the pool FS (e.g. Butterbach-Bahl et al., 2013). To our current knowledge, the most relevant processes are:

- Ammonification (mineralization): During the decomposition of litter and soil organic matter, different organic nitrogen compounds are mineralized to ammonium (NH_4^+).
- Nitrification: Under aerobic conditions Ammonium (NH_4^+) is oxidized by microbes to nitrite (NO_2^-) and further to nitrate (NO_3^-).

The inorganic N species, ammonium (NH_4^+) and nitrate (NO_3^-) can either be taken up by plants (uptake) or immobilized by soil microorganisms in the form of organic nitrogen compounds (immobilisation). Moreover, ammonium can also be adsorbed on clay minerals and so precluded from further transformation (adsorption). Hence uptake, immobilisation and adsorption ensure for the N retention within the pool.

The most significant outflows from the FS pool are leaching of nitrate (NO_3^-, N_{mix}) into the hydrosphere, nitrogen in harvested biomass and emission of gaseous denitrification products (NO_x, N_2O, N_2) and anammox products (N_2O, N_2) to the atmosphere (AT). Further, wood harvest from the sub-pool “forests” occurs.

Leaching of nitrate (NO_3^-) into water bodies such as streams, lakes, and groundwater occurs when NO_3^- is not completely consumed by plants and microorganisms.

Emissions of N to the atmosphere occurs due to two major processes:

- Denitrification: Under anoxic condition, nitrate (NO_3^-) and nitrite (NO_2^-) are transformed into gaseous compounds such as nitrogen oxide (NO)[1], nitrous oxide (N_2O) and elementary nitrogen (N_2) and are emitted back to the atmosphere.
- Anammox (Anaerobic ammonium oxidation): Also under anoxic condition, nitrite (NO_2) and ammonium (NH_4^+) can be converted into dinitrogen (N_2), which again is emitted.

Biomass losses through tree harvest and wildfires may occur (Peng et al 2020, Theys et al 2020), and natural disturbances such as insect outbreaks, diseases, and windfall typically cause N to move from living biomass to dead biomass and soil. These processes may lead to losses in N stocks. On the other hand, increases in biomass (e.g. tree growth) is resulting in changes in the N stock. Further, stock changes can also be induced by flows related to land use changes.

Annex 5 - Processing of residues

The pool “processing of residues” (PR) includes the sub-pools solid waste and wastewater. This pool is relevant for the National Nitrogen Budgets since almost all other pools produce waste and wastewater and therefore waste-based N flows. Significant shares of the agricultural N flows pass via food waste the pool PR. In addition, big N flows between the PR sub-pools (in particular municipal wastewater sewage sludge) and to the pools “atmosphere” (emissions from waste incineration and wastewater treatment) and “hydrosphere” (discharge of treated wastewater) occur.

The pool PR is also connected to the rest of the world (RW) via imports and exports of waste, which is a relevant mass flow for some countries. Large input flows of N to the pool PR typically originate from HS (municipal solid waste and wastewater), MP (industrial solid waste and wastewater from food industry) and AG (digestate from biofuel, particular biogas production, in countries, where this activity is relevant).

Emissions to the pool “atmosphere” (AT) are caused by the diverse kinds of waste treatment, such as incineration (NO_x, N_2O) as well as landfills and wastewater treatment (NH_3, N_2O, N_2).

N discharge to the pool “hydrosphere” (HY) is predominantly given by all kinds of wastewater treatment (N_{mix}), where the level of technology defines the distribution of N to water (HY) and the atmosphere (AT). In countries where disposal of waste on landfills is usual, leachate can be a

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[1] Note that NO emissions from denitrification are reported in this guidance as part of the species NOx.

relevant flow to hydrosphere. In addition, N flows related to biofuel production and composting of industrial and household wastes are accounted for in the pool "processing of residues".

Annex 6 - Humans and settlements

For the pool HS, exchanges with the pools "agriculture" (AG), "material and products in industry" (MP) and "processing of residues" (PR) are of particular relevance. Domestic inflows into the pool mainly stem from food products as well as from material products from industry. On the other end, N is lost via diffuse release pathways.

The pool HS is dominated by individual human behavior. Important input flows from the pool MP are food and non-food products that are consumed by households. Some of these product flows are characterized by high material heterogeneity and their quantification is therefore affected by uncertainties. On the output side, mainly production of solid waste and wastewater from households are relevant.

The pool HS is not directly connected to the rest of the world (RW), since imports of both food and non-food products are accounted for in the pool MP. Exports from the pool HS are also not considered, as they are also accounted for in the pool MP.

N flows from the pool HS occur mainly in the form of N_{mix} and the N is bound in materials and products (food products, wood and paper products, synthetic polymers for product use, textiles, detergents). This form of nitrogen is less critical regarding its environmental impacts than for instance reactive nitrogen that is formed in combustion processes or agricultural production, when reactive nitrogen species are directly released to the environment. However, nitrogen bound to materials and products is still considered as a reactive form of nitrogen that is potentially harmful for the environment at a later stage and should therefore be included in the NNB. The amount of N embedded in materials and products that are consumed by households can be substantial. According to Leip et al. (2011), more than 50% of the N_{mix} that is available for consumers apparently serves other purposes than nutrition and therefore these flows are highly relevant for the NNB.

Annex 7 - Atmosphere

The pool "atmosphere" (AT) mainly functions as a transport medium for nitrogen. In addition, various transformation processes take place within the atmosphere. It is however not necessary to quantify these. The formation of reactive nitrogen within the atmosphere can be regarded as a change in the nitrogen stock (e.g. formation of NO_x from N_2 by lightning).

Main input flows are atmospheric import and emissions from all other pools of the National Nitrogen Budget (NNB). Output flows are biological and technical N_2-fixation, export by atmospheric transport and N deposition to land- and water-based pools.

Nitrogen deposition is the term used to describe the process by which atmospheric N-containing trace constituents, such as aerosols, particles and gases, are deposited onto the earth's surface. Most concern has addressed the impacts of nitrogen deposition to terrestrial ecosystems (Bobbink et al., 2022; CLRTAP, 2023), but impacts may also occur in the aquatic environment (Gauss et al., 2021; Rabalais, 2002). The pollutants that contribute to nitrogen deposition derive mainly from nitrogen oxides (NO_x) and ammonia (NH_3) emissions. In the atmosphere NO_x is transformed to a range of secondary pollutants, including nitric acid (HNO_3), nitrates (NO_3^-) and organic compounds, such as peroxyacetyle nitrate (PAN), while NH_3 is transformed to ammonium (NH_4^+). Both the primary and secondary pollutants are removed by wet deposition (scavenging of gases and aerosols by precipitation) and by dry deposition (direct turbulent deposition of gases and aerosols) (Hornung and Williams, 1994). Organic constituents are rarely measured or monitored and are thus often neglected in calculations and inventories. However, their contribution to total nitrogen deposition is crucial varying substantially between 30 and 80% across different ecosystems (Neff et al., 2002; Cornell et al., 2003; Miayazaki et al, 2011; Zhang et al., 2012; Medinets et al., 2012, 2020, 2024).

Transboundary air pollution is an important flow of reactive nitrogen compounds that are not easily removed from the atmosphere, i.e. have considerable residence time in the atmosphere (e.g. NO_3^-, NH_4^+). These are transboundary pollutants that can be generated in one country and transported to other countries. Transboundary air pollutants can remain in the atmosphere sufficiently long to be transported thousands of kilometers and thus to spread over the whole of Europe, across national borders, far from the original sources of polluting emissions, causing eutrophication and acidification.

Annex 8 - Hydrosphere

The pool "hydrosphere" is composed by a number of water bodies connected by the hydrological cycle. It is subdivided into four sub-pools: groundwater, surface water, coastal water and aquaculture.

The division in sub-pools is related to the location of water bodies in the river basin (above/below soil surface) and the salinity (freshwater versus salt water). Within surface waters, sub-pools could be distinguished on the basis of the water residence time into lentic (lakes) and lotic (rivers) water systems. Location, physicochemical characteristics and water residence time have a great influence on the nitrogen's processes in water bodies.

In the river basin, surface water moves from the land to the sea according to the topographic slope, but the direction of exchanges between groundwater and surface waters can vary locally and temporarily. The boundaries of rivers and lakes are defined (although they are subject to seasonal or temporal local variations), while the extent of aquifers and the temporal variation of the water table are not always known. Also, the limits of territorial and international waters are set legally but do not exist physically. Except for the nitrogen load at the river basin outlet, nitrogen flows between sub-pools cannot be measured in practice (unless specific monitoring networks are in place). Therefore, the internal flows do not need to be quantified. However, as the processes related to nitrogen and their intensity vary greatly in the different water bodies, mainly as a consequences of diverse water residence times, the internal nitrogen flows should accounted for if data are available.

In addition, within surface water bodies nitrogen moves continuously through the trophic chain of the aquatic ecosystem, as described by the nutrient spiraling concept (Newbold et al. 1981; Howard-William 1985), cycling through dissolved forms, living organisms and detritus. Due to the complexity of these processes and the lack of data, these internal flows of nitrogen are not computed in the budget.

Zusammenfassung

Im Rahmen des Übereinkommens über weiträumige grenzüberschreitende Luftverunreinigung (CLRTAP) wurde ein Leitfaden zur Unterstützung der Entwicklung nationaler Stickstoffbilanzen (NNB) verabschiedet (ECE/EB.AIR/119). NNBs sind ein effizientes Instrument zur Visualisierung der N-Kaskade und ihrer potenziellen Auswirkungen. Sie liefern politischen Entscheidungsträgern Informationen zu Interventionspunkten und zur Entwicklung effizienter Maßnahmen zur Emissionsreduzierung, sie helfen bei der Überwachung der Erfolge umgesetzter politischer Maßnahmen und sind nützlich für länderübergreifende Vergleiche. Außerdem schließen sie Wissenslücken und tragen somit zur Verbesserung unseres wissenschaftlichen Verständnisses des Stickstoffkreislaufs bei. Insbesondere unterstützen sie die Umsetzung des Göteborg Protokolls des CLRTAP und der Richtlinie der Europäischen Union (EU) über die Reduktion der nationalen Emissionen bestimmter Luftschadstoffe und liefern Erkenntnisse zur Überwachung der Erreichung der Nährstoffreduktionsziele der Farm-to-Fork-Strategie der EU oder des Global Biodiversity Framework des Globalen Übereinkommens über die biologische Vielfalt (CBD). In den vorliegenden Anhängen wird der methodische Ansatz für die Entwicklung eines NNB im Kontext des UNECE Leitfadens zur Berechnung nationaler Stickstoffbilanzen detailliert beschrieben.

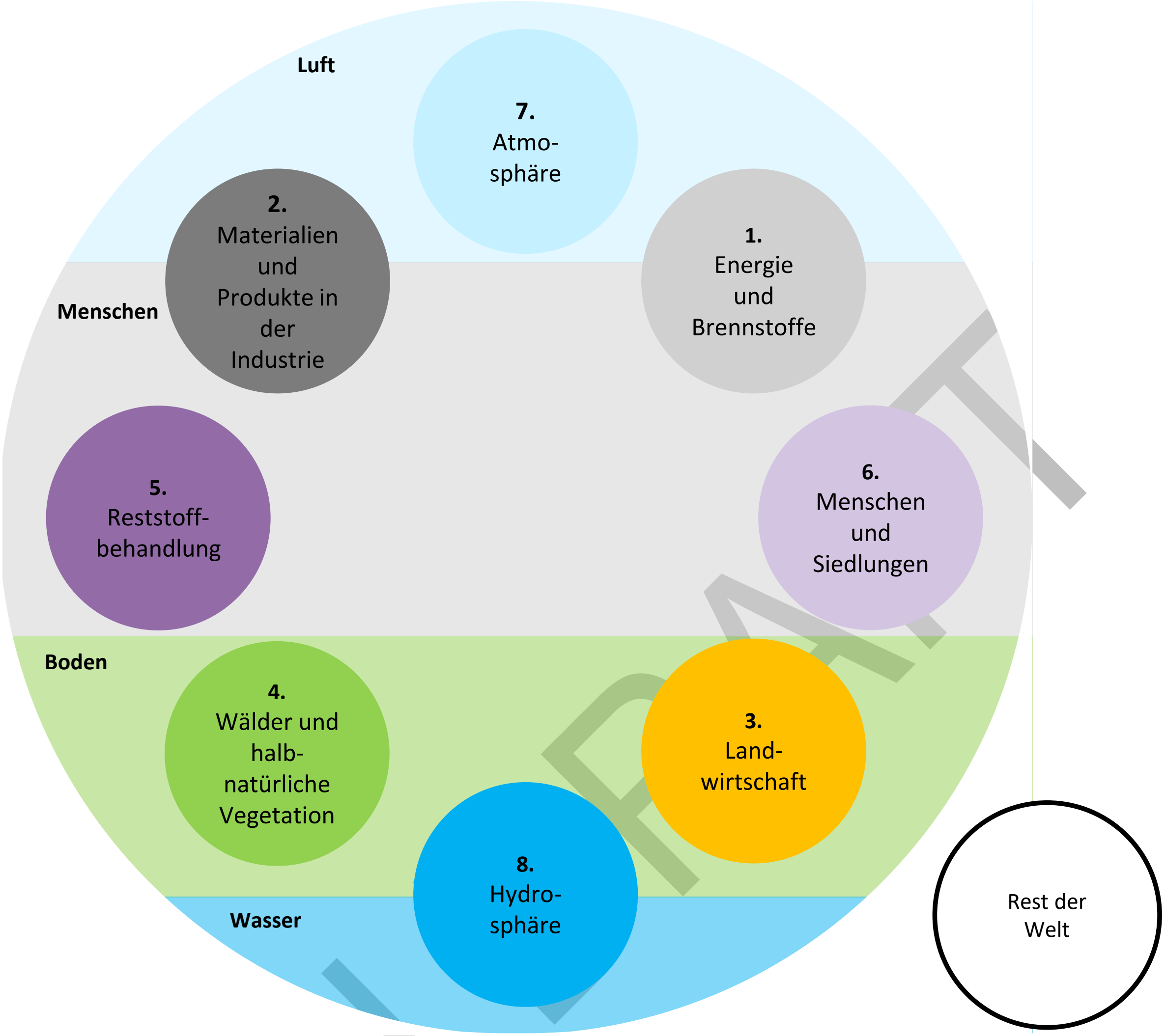
Anhang 0 - Einführung, Methode und Konventionen für NNB.

Nationale Stickstoffbilanzen beschreiben den Austausch von Stickstoff zwischen den Umweltkompartimenten, der Wirtschaft und der Gesellschaft innerhalb der nationalen Grenzen. Sie beinhalten die relevanten Sektoren, Untersektoren und die Stickstoffflüsse zwischen den Untersektoren.

Gemäß dem Leitfaden umfasst die NNB acht Sektoren (siehe Abbildung 1): „Energie und Brennstoffe“, „Materialien und Produkte in der Industrie“, „Landwirtschaft“, „Wälder und halbnatürliche Vegetation“, „Abfall“, „Menschen und Siedlungen“, „Atmosphäre“ und „Hydrosphäre“. Austausch über die nationalen Grenzen hinweg werden als Stickstoffflüsse zum bzw. vom „Rest der Welt“ betrachtet. Für jeden dieser Sektoren sind in den einzelnen Anhängen spezifische Anleitungen zur Berechnung der relevanten Stickstoffflüsse dokumentiert, einschließlich Berechnungsmethoden und Vorschlägen für mögliche Datenquellen. Einige dieser Sektoren sind weiter in Untersektoren unterteilt.

Das vorliegende Dokument enthält methodische Anleitungen für die Entwicklung einer NNB im Allgemeinen (Anhang 0) sowie für einzelne Sektoren (Anhänge 1 - 8).

Abbildung 2: Übersicht der Sektoren der nationalen Stickstoffbilanzen



Quelle: eigene Darstellung, INFRAS

Stickstoff kommt in zahlreichen chemischen Verbindungen vor, in denen er in unterschiedlichen oxidativen Zuständen vorkommt (siehe Kapitel A.3.2). Die verschiedenen Stickstoffspezies werden durch verschiedene natürliche oder industrielle Prozesse ineinander umgewandelt. Es wird zwischen molekularem Stickstoff (N_2) und allen anderen Formen unterschieden. Letztere werden unter dem Begriff reaktiver Stickstoff (N_r) zusammengefasst. In der NNB müssen alle relevanten Flüsse von reaktiven N-Spezies quantifiziert werden. Für inaktiven Stickstoff (N_2) sind nur diejenigen Flüsse relevant, die mit einer Umwandlung von N_2 in eine reaktive Form von Stickstoff (N_r) oder umgekehrt verbunden sind (siehe Kapitel A.3.1). Stickstoffflüsse können mehr als eine N-Spezies umfassen. Zur Vereinfachung werden diese als Stickstoffflüsse mit gemischter Zusammensetzung (N_{mix}) bezeichnet. Für die Stickstoffflüsse wird die Angabe in der Einheit Kilotonnen Stickstoff pro Jahr (kt N/a) empfohlen.

Tabelle 2: Übersicht über relevante Stickstoff-Spezies

Abkürzung	Stickstoff-Spezies
Reaktiver Stickstoff N_r	

Abkürzung	Stickstoff-Spezies
NO_x	Stickstoffoxide (per Definition als Masse von NO_2 ausgewiesen)
NH_3	Ammoniak
NH_4^+	Ammonium
N_2O	Lachgas
NO_3^-	Nitrat
NO_2^-	Nitrit
N_{mix}	Andere reaktive N-Spezies, die in Materialien gebunden sind (z. B. Lebensmittel, Kunststoffe, organische Materialien) oder eine Mischung reaktiver N-Spezies (z. B. gelöste Formen von Stickstoff)
Inaktiver Stickstoff	
N_2	Molekularer Stickstoff

Für jeden (Unter-)Sektor der NNB wird eine Massenbilanz erstellt (siehe Gl. 1a). Die gesamten N-Inputs abzüglich der gesamten N-Outputs entsprechen den Lageränderungen von N innerhalb eines bestimmten (Unter-)Sektors gemäß den folgenden Gleichungen. In einer NNB wird die Massenbilanz auf der jährlichen Zeitskala berechnet (siehe Gl. 1b).

$$\sum N_{input} - \sum N_{output} - \sum N_{Lageränderung} = 0 \qquad \text{(Gl. 1a)}$$

$$\sum N_{input,i} - \sum N_{output,i} = \sum N_{Lageränderung,i} = \Delta N_i \qquad \text{(Gl. 1b)}$$

Mit:

N_{input}	N-Flüsse in den (Unter-)Sektor hinein	**[kt N]**
N_{output}	N-Flüsse aus dem (Unter-)Sektor hinaus	**[kt N]**
$N_{Lageränderung}$	Lageränderung im (Unter-)Sektor	**[kt N]**
Δ N	Summe der Lageränderungen in einem (Unter-)Sektor	**[kt N]**
i	Jahr	**[-]**

Anhang 1 - Energie und Brennstoffe

Der Sektor „Energie und Brennstoffe“ besteht aus vier Untersektoren (Energieumwandlung, Verkehr, Verarbeitende Industrie und Baugewerbe, Sonstiger Energie- und Brennstoffeinsatz). Er umfasst alle Aktivitäten der Brennstoffverbrennung und Energieumwandlung.

Die Verbrennung von Brennstoffen umfasst den Verkehrssektor, die Verbrennung von Brennstoffen in industriellen Prozessen, im kommerziellen/institutionellen Bereich und in Haushalten.

- Energieumwandlungsprozesse umfassen die Wärme- und Stromerzeugung sowie Raffinerien und andere Kraftstofferzeugungsprozesse mit Ausnahme der Brennstofferzeugung aus Biomasse, die in den Sektoren „Landwirtschaft“ und „Abfall“ erfasst werden.

- Die wichtigsten Stickstoff-Flüsse im Sektor „Energie und Brennstoffe" stammen aus der Verbrennung von Brennstoffen. Bei der Verbrennung von Brennstoffen wird der atmosphärische Stickstoff N_2 in reaktiven Stickstoff wie NO_x, NH_3 und N_2O umgewandelt. Emissionen von Stickstoffoxiden, die durch thermische Fixierung von Luftstickstoff entstehen, werden auch als „thermisches NO_x " bezeichnet.

Neben der Fixierung von Luftstickstoff enthalten verschiedene Arten von Brennstoffen (z. B. Kohle, Holz) chemisch gebundenen Stickstoff. Der Gewichtsanteil des chemisch gebundenen Stickstoffs variiert je nach Brennstoffart. Auch Ammoniak selbst wird zukünftig als kohlenstofffreier Alternativkraftstoff für bestimmte Länder und bestimmte Fahrzeugtypen (z. B. in der Schifffahrt und bei schweren Nutzfahrzeugen) relevanter werden. Bei Verbrennungsprozessen wird chemisch gebundener Stickstoff auch in NO_x umgewandelt. Diese NO_x-Emissionen werden als „Brennstoff-NO_x" bezeichnet (wobei zu beachten ist, dass thermisches NO_x in der Regel die gesamten NO_x-Emissionen dominiert). Daher ist jeder Sektor, der Brennstoffe liefert, durch einen Stickstofffluss mit dem Sektor „Energie und Brennstoffe" verbunden. Dazu gehören Holzbrennstoffe aus dem Sektor „Wälder und halbnatürliche Vegetation", importierte fossile Brennstoffe aus dem „Rest der Welt", Abfallbrennstoffe aus dem Sektor „Materialien und Produkte in der Industrie" und Biobrennstoffe aus den Sektoren „Landwirtschaft" und „Abfall". Alle Stickstoffflüsse, die mit Brennstoffen in den Sektor „Energie und Brennstoffe" fließen, bestehen aus reaktivem, an Stoffe gebundenem Stickstoff (N_{mix}). Für alle Brennstoffe müssen jeweils auch Importe und Exporte berücksichtigt werden.

Anhang 2 - Materialien und Produkte in der Industrie

Der Sektor „Materialien und Produkte in der Industrie" umfasst die Untersektoren Lebensmittelverarbeitung und weitere Industrien. Er berücksichtigt industrielle Prozesse in Anlehnung an die von der UNFCCC und der UNECE für atmosphärische Emissionen verwendete Struktur (IPCC, 2006, 2019; EUA, 2013, 2016, 2023). Beschrieben werden Stickstoffflüsse im Zusammenhang mit der Umwandlung von Gütern in der Industrie mit dem Ziel, höherwertige Produkte für den Endkonsum zu schaffen. In diesem Sektor explizit nicht enthalten sind die Stickstoffflüsse im Zusammenhang mit der Verbrennung von Energieträgern, welche im Sektor „Energie und Brennstoffe" berücksichtigt werden.

Innerhalb des Sektors „Materialien und Produkte in der Industrie" ist die Ammoniaksynthese nach dem Haber-Bosch-Verfahren der bei weitem wichtigste Prozess für die NNB. Der Prozess wandelt inaktives N_2 in reaktives NH_3 um, das dann zu Mineraldünger in Form von Ammoniumnitraten oder Harnstoff weiterverarbeitet wird. Weltweit ist die Ammoniaksynthese der größte Stickstofffluss, der durch anthropogene Aktivitäten ausgelöst wird. Die produzierten Düngemittel sind entscheidend für die Aufrechterhaltung der landwirtschaftlichen Produktivität auf globaler Ebene. Die N_2-Fixierung durch andere industrielle Prozesse (z. B. die Synthese von Calciumcyanamiden) spielt im Vergleich zur Größenordnung des Haber-Bosch-Prozesses eine untergeordnete Rolle, ebenso wie die übrige chemische Industrie.

Neben den Stickstoffflüssen im Zusammenhang mit dem Haber-Bosch-Verfahren wird organischer und anorganischer Stickstoff, der in Stoffen und Produkten gebunden ist, mit anderen Sektoren ausgetauscht. Stickstoffhaltige Rohstoffe fließen aus den Sektoren „Landwirtschaft" (Getreide und Fleisch), „Wald und halbnatürliche Vegetation" (Holz) und „Hydrosphäre" (Fische) in den Sektor „Materialien und Produkte in der Industrie", wo sie verarbeitet und in höherwertige Produkte umgewandelt werden. Inputs können auch aus dem Sektor «Menschen und Siedlungen» erfolgen, wenn Abfälle gesammelt und den Recyclingprozessen des Sektors „Materialien und Produkte in der Industrie" zugeführt werden.

Die Produkte werden schließlich an die Verbraucher verteilt (Sektor «Menschen und Siedlungen»). Die wichtigsten Stickstoffflüsse in Bezug auf Stickstoffgehalt und absolute Mengen sind Nahrungsmittel für Menschen und Futtermittel für Tiere. Diese Stickstoffflüsse enthalten Stickstoff hauptsächlich in Form von Eiweiß. Darüber hinaus verursachen weitere Konsumgüter Stickstoffflüsse unterschiedlicher Zusammensetzung (Fasern, Kunststoffe, Farbstoffe, Sprengstoffe). Der an diese Güter gebundene Stickstoff ist im Allgemeinen weniger reaktiv als der an Lebens- und Futtermittel gebundene Stickstoff. Er wird jedoch ebenfalls als reaktiver Stickstoff betrachtet (siehe Kapitel A.3.2).

Alle Stickstoffflüsse im Zusammenhang mit Produktion von Lebens- und Futtermitteln sowie Materialien sind über die Grenzen eines Landes hinaus relevant, was bedeutet, dass die Ein- und Ausfuhr von Lebens- und Futtermitteln sowie von verschiedenen Waren ebenfalls in der NNB zu berücksichtigen ist.

Außerdem ist zu beachten, dass Zwischenprodukte der Industrie innerhalb des Sektors «Materialien und Produkte in der Industrie» zirkulieren können.

Anhang 3 - Landwirtschaft

Der Sektor „Landwirtschaft“ besteht aus drei Untersektoren (1. Düngermanagement, Lagerung und Tierhaltung, 2. Bodenmanagement, 3. Produktion von Biobrennstoffen und Kompostierung). Er ist für die nationalen Stickstoffbilanzen von großer Bedeutung, da die größten Stickstoffflüsse innerhalb der gesamten NNB fast immer durch die Landwirtschaft ausgelöst werden. Dazu gehören sehr große Stickstoffflüsse zwischen den Untersektoren innerhalb der Landwirtschaft und zwischen dem Sektor Landwirtschaft und den Sektoren „Atmosphäre“ und „Hydrosphäre“.

Der Sektor Landwirtschaft liefert alle landwirtschaftlichen Produkte an die Industrie, wo sie weiterverarbeitet und verpackt werden, bevor sie als Lebensmittel zu den Verbrauchern im Sektor „Menschen und Siedlungen“ gelangen oder als sekundäre Lebensmittelprodukte, in der Futtermittelverarbeitung oder als Non-Food-Produkte verwendet werden. Der gesamte Handel (Einzelhandel, Großhandel) ist Teil des Sektors „Materialien und Produkte in der Industrie“, während der Konsum von Lebensmitteln im Sektor „Menschen und Siedlungen“ erfolgt. Die Direktvermarktung von landwirtschaftlichen Erzeugnissen (Lebensmittel und Nicht-Lebensmittel) an den Sektor „Menschen und Siedlungen“ wird nicht separat ausgewiesen.

Eingehende Stickstoffflüsse aus der Industrie (Sektor „Materialien und Produkte in der Industrie“) sind Futtermittel, Mineraldünger sowie Saat- und Pflanzgut. Neben der nationalen Produktion werden Futtermittel häufig auch aus anderen Ländern importiert (Sektor „Rest der Welt“). Ob für Futtermittel zwei separate Flüsse ausgewiesen werden, hängt davon ab, ob die Datenquellen eine Unterscheidung zwischen der Futtermittelproduktion innerhalb der (nationalen) Grenzen und den Importen erlauben. Weitere Stickstoffflüsse über die Landesgrenzen erfolgen über die Ein- und Ausfuhr von lebenden Tieren und Dünger.

Für die Produktion von Biobrennstoffen werden nur Substrate aus der Landwirtschaft betrachtet (organische Abfälle z.B. aus Haushalten werden im Sektor „Abfall“ behandelt). Eine Ausnahme bildet die aquatische Biomasse aus dem Sektor „Hydrosphäre“, die in einigen Ländern als Substrat genutzt wird. Als Output wird der erzeugte Kompost in den Sektor „Menschen und Abfälle“ zurückgeführt, wo er in privaten und öffentlichen Grünanlagen eingesetzt wird. Andere Outputs wie Gärreste werden innerhalb des Sektors «Landwirtschaft» eingesetzt. Schließlich wird Klärschlamm aus dem Sektor «Abfall» in manchen Ländern in der Landwirtschaft als Düngemittel verwendet, obwohl diese Anwendung mit verschiedenen Umwelt- und Gesundheitsproblemen verbunden ist und in bestimmten Ländern verboten ist, insbesondere ohne vorherige Behandlung.

Bei den N-Verlusten in die Atmosphäre und in die Hydrosphäre handelt es sich um Flüsse, die in die Umwelt abgegeben werden. Ein kleiner Teil des emittierten Stickstoffs wird durch Ablagerung aus der Atmosphäre oder durch Bewässerung und Tränkewasser in die Landwirtschaft zurückgeführt. Die biologische N_2-Fixierung liefert neuen reaktiven Stickstoff an den Sektor «Landwirtschaft».

Anhang 4 - Wälder und halbnatürliche Vegetation

Der Sektor «Wälder und halbnatürliche Vegetation» besteht aus den drei Untersektoren (Wälder, Feuchtgebiete und sonstige Flächen). Die wichtigsten Stickstoffeinträge in den Sektor «Wälder und halbnatürliche Vegetation» erfolgen aus der Atmosphäre (Leip et al., 2011). Zu diesen Stickstoffeinträgen gehören die atmosphärische Deposition sowie die biologische Stickstofffixierung, d. h. die Fixierung von elementarem Stickstoff (N_2) durch Mikroben in Verbindung mit den Wurzeln höherer Pflanzen und heterotrophen Mikroorganismen im Boden. Außerdem wird Stickstoff über oberflächlichen Abfluss aus dem Sektor „Landwirtschaft" eingetragen.

Stickstoff durchläuft im Sektor «Wälder und halbnatürliche Vegetation» verschiedene Umwandlungsprozesse (z. B. Butterbach-Bahl et al., 2013). Nach derzeitigem Kenntnisstand sind hauptsächlich folgende Prozesse relevant:

- Ammonifikation (Mineralisierung): Bei der Zersetzung von pflanzlichem Material und organischer Bodensubstanz werden verschiedene organische Stickstoffverbindungen zu Ammonium mineralisiert.
- Nitrifikation: Unter aeroben Bedingungen wird Ammonium von Mikroben zu Nitrit und weiter zu Nitrat oxidiert.

Die anorganischen N-Spezies Ammonium und Nitrat können entweder von Pflanzen aufgenommen oder von Bodenmikroorganismen in Form von organischen Stickstoffverbindungen immobilisiert werden. Darüber hinaus kann Ammonium auch an Tonmineralien adsorbiert werden und so einer weiteren Umwandlung entzogen werden. Somit sorgen Aufnahme, Immobilisierung und Adsorption für die N-Retention innerhalb des Sektors «Wälder und halbnatürliche Vegetation».

Die wichtigsten Outputs sind die Auswaschung von Nitrat in die Hydrosphäre, Stickstoff in geernteter Biomasse und die Emission von gasförmigen Denitrifikationsprodukten (NO_x, N_2O, N_2) und Emissionen aus dem Anamox-Prozess (N_2O, N_2) in die Atmosphäre (AT). Außerdem wird Holz aus dem Untersektor „Wald" geerntet.

Die Auswaschung von Nitrat in Gewässer wie Flüsse, Seen und Grundwasser erfolgt, wenn Nitrat nicht vollständig von Pflanzen und Mikroorganismen verbraucht wird.

Die Emission von Stickstoff in die Atmosphäre erfolgt durch zwei Hauptprozesse:

- Denitrifikation: Unter anoxischen Bedingungen werden Nitrat und Nitrit in gasförmige Verbindungen wie Stickstoffoxid, Lachgas und elementaren Stickstoff umgewandelt und wieder in die Atmosphäre emittiert.
- Anammox (Anaerobe Ammoniumoxidation): Auch unter anoxischen Bedingungen können Nitrit und Ammonium in elementaren Stickstoff umgewandelt werden, der wiederum emittiert wird.

Es kann zu Biomasseverlusten durch Rodungen und Waldbrände kommen (Peng et al. 2020, Theys et al. 2020), und natürliche Störungen wie Insektenbefall, Krankheiten und Windwurf führen in der Regel dazu, dass Stickstoff von der lebenden Biomasse in die tote Biomasse und den Boden übergeht. Diese Prozesse können zu Stickstoffverlusten führen. Andererseits erhöht das Biomassewachstum den im Wald und in der halbnatürlichen Vegetation gespeicherten Stickstoff. Darüber hinaus können Lageränderungen auch durch Stickstoffflüsse im Zusammenhang mit Landnutzungsänderungen hervorgerufen werden.

Anhang 5 - Reststoffbehandlung

Der Sektor „Reststoffbehandlung" umfasst die Untersektoren feste Abfälle und Abwässer. Dieser Sektor ist für die nationalen Stickstoffbilanzen relevant, da fast alle anderen Sektoren Abfälle und Abwässer und somit entsprechende Stickstoffflüsse verursachen. Ein erheblicher Teil der landwirtschaftlichen Stickstoffflüsse fließt über Lebensmittelabfälle in den Sektor «Reststoffbehandlung». Darüber hinaus gibt es große Stickstoffflüsse zwischen den Untersektoren des Sektors «Reststoffbehandlung» (insbesondere Klärschlamm aus kommunalen Abwässern), sowie in den Sektor „Atmosphäre" (Emissionen aus der Abfallverbrennung und der Abwasserbehandlung) und in den Sektor „Hydrosphäre" (Einleitung von gereinigten Abwässern).

Der Sektor «Reststoffbehandlung» ist über die Ein- und Ausfuhr von Abfällen auch mit dem Rest der Welt verbunden, was für einige Länder einen relevanten Stickstofffluss darstellt. Große Stickstoffflüsse stammen in der Regel aus dem Sektor «Menschen und Siedlungen» (feste Siedlungsabfälle und Abwässer), aus dem Sektor «Materialien und Produkte in der Industrie» (feste Industrieabfälle und Abwässer aus der Lebensmittelindustrie) und aus dem Sektor «Landwirtschaft» (Gärreste aus der Biobrennstoff-, insbesondere der Biogasproduktion).

Emissionen in den Sektor „Atmosphäre" werden durch die verschiedenen Arten der Abfallbehandlung verursacht, wie Verbrennung (NO_x, N_2O) sowie Deponien und Abwasserbehandlung (NH_3, N_2O, N_2).

Der Stickstoffeintrag in den Sektor „Hydrosphäre" erfolgt in erster Linie durch die Abwasserbehandlung (N_{mix}), wobei der Stand der Technik die Verteilung des Stickstoffs auf die Hydrosphäre und die Atmosphäre bestimmt. In Ländern, in denen die Entsorgung von Abfällen auf Deponien üblich ist, kann Sickerwasser ein relevanter Stickstofffluss in die Hydrosphäre sein. Darüber hinaus werden Stickstoffflüsse im Zusammenhang mit der Biobrennstoffproduktion und der Kompostierung von Industrie- und Haushaltsabfällen im Sektor „Reststoffbehandlung" berücksichtigt.

Anhang 6 - Menschen und Siedlungen

Für den Sektor «Menschen und Siedlungen» ist vor allem der Austausch mit den Sektoren „Landwirtschaft", „Materialien und Produkte in der Industrie" und „Abfall" von Bedeutung. Die Stickstoffflüsse in den Sektor stammen hauptsächlich aus Nahrungsmitteln sowie aus weiteren industriellen Produkten. Auf der anderen Seite wird Stickstoff über verschiedene diffuse Pfade in die Umwelt freigesetzt.

Der Sektor «Menschen und Siedlungen» wird durch das individuelle menschliche Verhalten dominiert. Wichtige Inputflüsse aus dem Sektor „Materialien und Produkte in der Industrie" sind Nahrungsmittel und Non-Food-Produkte, die von den Haushalten konsumiert werden. Einige dieser Produktströme sind durch eine hohe Materialheterogenität gekennzeichnet und ihre Quantifizierung ist daher mit Unsicherheiten behaftet. Auf der Outputseite sind vor allem die festen Siedlungsabfälle und Abwässer aus Haushalten relevant.

Der Sektor «Menschen und Siedlungen» ist nicht direkt mit dem «Rest der Welt» verbunden, da die Importe sowohl von Nahrungsmitteln als auch von Non-Food-Produkten im Sektor «Materialien und Produkte in der Industrie» erfasst werden. Die Ausfuhren aus dem Sektor werden ebenfalls nicht berücksichtigt, da sie ebenfalls im Sektor „Materialien und Produkte in der Industrie" erfasst werden.

Die Stickstoffflüsse aus dem Sektor «Menschen und Siedlungen» erfolgen hauptsächlich in Form von in Materialien und Produkten (Lebensmittel, Holz- und Papierprodukte, synthetische Polymere für die Produktnutzung, Textilien, Waschmittel) gebundenem Stickstoff (N_{mix}). Diese Form des Stickstoffs ist hinsichtlich seiner Umweltauswirkungen weniger kritisch als reaktiver Stickstoff, der beispielsweise bei Verbrennungsprozessen oder in der landwirtschaftlichen Produktion entsteht und direkt in die Umwelt freigesetzt wird. An Materialien und Produkte gebundener Stickstoff wird jedoch ebenfalls als reaktive Form von Stickstoff betrachtet, da er rasch in umweltschädliche Formen umgewandelt werden kann und daher werden die gebundenen Formen ebenfalls in die NNB aufgenommen. Die in den von Haushalten konsumierten Materialien und Produkten gebundene Stickstoffmenge, kann erheblich sein. Gemäss Leip et al. (2011) entfällt die Hälfte des Stickstoffs auf Non-food-Produkte, weshalb diese Stickstoffflüsse für die NNB von großer Bedeutung sind.

Anhang 7 - Atmosphäre

Der Sektor „Atmosphäre" (AT) fungiert hauptsächlich als Transportmedium für Stickstoff. Zudem wird finden innerhalb der Atmosphäre verschiedene Umwandlungsprozesse statt. Deren Quantifizierung ist nicht erforderlich. Die Neubildung von reaktivem Stickstoff innerhalb der Atmosphäre kann als eine Veränderung des Stickstofflagers betrachtet werden (z.B. Bildung von NO_x aus N_2 durch Blitze).

Die wichtigsten Inputflüsse sind der atmosphärische Import reaktiver Stickstoffverbindungen und Emissionen aus allen anderen Sektoren der NNB. Outputflüsse sind die biologische und technische Stickstofffixierung, der Export reaktiver Stickstoffverbindungen durch atmosphärischen Transport und die Stickstoffdeposition in auf Land- und Wasserflächen.

Als Stickstoffdeposition wird der Prozess bezeichnet, durch den stickstoffhaltige Verbindungen aus der Atmosphäre, wie Aerosole, Partikel und Gase, auf der Erdoberfläche abgelagert werden. Die Deposition von Stickstoff schädigt insbesondere terrestrische Ökosysteme (Bobbink et al., 2022; CLRTAP, 2023), aber auch in den aquatischen Ökosystemen können schädliche Umweltauswirkungen auftreten (Gauss et al., 2021; Rabalais, 2002). Die Schadstoffe, die zur Deposition beitragen, stammen hauptsächlich aus Emissionen von Stickstoffoxiden und Ammoniak. In der Atmosphäre wird Stickstoffoxid in eine Reihe von Sekundärschadstoffen umgewandelt, darunter Salpetersäure, Nitrat und organische Verbindungen wie Peroxyacetylnitrat, während Ammoniak in Ammonium umgewandelt wird. Sowohl die primären als auch die sekundären Schadstoffe werden durch nasse Deposition (Aufnahme von Gasen und Aerosolen durch Niederschlag) und durch trockene Deposition (direkte turbulente Deposition von Gasen und Aerosolen) aus der Atmosphäre entfernt (Hornung und Williams, 1994). Die organisch gebundenen Formen der Deposition werden nur selten gemessen oder überwacht und daher bei Berechnungen und Bilanzierungen oft vernachlässigt. Ihr Beitrag zur Gesamtstickstoffdeposition ist jedoch von entscheidender Bedeutung und schwankt in verschiedenen Ökosystemen erheblich zwischen 30 und 80 % (Neff et al., 2002; Cornell et al., 2003; Miayazaki et al, 2011; Zhang et al., 2012; Medinets et al., 2012, 2020, 2024).

Ein wesentlicher Stickstofffluss ist zudem die grenzüberschreitende Verfrachtung von stickstoffhaltigen Luftschadstoffen, die nicht leicht aus der Atmosphäre entfernt werden können, d. h. eine beträchtliche Verweilzeit in der Atmosphäre haben (z. B. Nitrat, Ammonium). Dabei handelt es sich um grenzüberschreitende Schadstoffe, die in einem Land erzeugt und in andere Länder transportiert werden können. Sie können über Tausende von Kilometern transportiert werden und weit entfernt von der ursprünglichen Quelle der Schadstoffemissionen Eutrophierung und Versauerung verursachen.

Anhang 8 - Hydrosphäre

Der Sektor „Hydrosphäre" umfasst die Wasserkörper, die durch den Wasserkreislauf miteinander verbunden sind. Er ist in vier Untersektoren unterteilt: Grundwasser, Oberflächengewässer, Küstengewässer und Aquakulturen.

Die Unterteilung in Untersektoren unterscheidet nach Lage der Wasserkörper im Einzugsgebiet (oberhalb der Bodenoberfläche: Oberflächengewässer, unterhalb der Bodenoberfläche: Grundwasser) und nach Salzgehalt (Süßwasser versus Salzwasser). Innerhalb der Oberflächengewässer können auf der Grundlage der Wasserverweilzeit lentische (Seen) und lotische (Flüsse) Wassersysteme unterschieden werden. Standort, physikalisch-chemische Eigenschaften und Wasserverweilzeit haben einen großen Einfluss auf die Stickstoffprozesse in Gewässern.

In einem Einzugsgebiet bewegt sich das Wasser entsprechend dem topografischen Gefälle vom Land zum Meer, aber die Richtung des Austauschs zwischen Grundwasser und Oberflächengewässern kann örtlich und zeitlich variieren. Die Grenzen von Flüssen und Seen sind festgelegt (auch wenn sie saisonalen oder zeitlichen lokalen Schwankungen unterliegen), während die Ausdehnung von Grundwasserleitern und die zeitliche Veränderung des Grundwasserspiegels nicht immer bekannt sind. Auch die Grenzen der Hoheitsgewässer und der internationalen Gewässer sind zwar rechtlich festgelegt, aber physisch nicht vorhanden. Abgesehen von der Stickstoffbelastung an der Mündung eines Einzugsgebiets können die Stickstoffflüsse zwischen den Teilgebieten in der Praxis nicht gemessen werden (es sei denn, es sind spezielle Überwachungsnetze vorhanden). Daher kann auf eine Quantifizierung der internen Flüsse zwischen diesen Untersektoren verzichtet werden. Da jedoch die mit Stickstoff verbundenen Prozesse und ihre Intensität in den verschiedenen Wasserkörpern sehr unterschiedlich sind, hauptsächlich als Folge der unterschiedlichen Wasserverweilzeiten, sollten auch die internen Stickstoffflüsse berücksichtigt werden, falls entsprechende Daten verfügbar sind.

Darüber hinaus bewegt sich Stickstoff in Oberflächengewässern kontinuierlich durch die trophische Kette des aquatischen Ökosystems, wie im Konzept der Nährstoffspirale beschrieben (Newbold et al. 1981; Howard-William 1985), und durchläuft dabei den Kreislauf von gelösten Formen, lebenden Organismen und Detritus. Aufgrund der Komplexität dieser Prozesse und des Mangels an Daten werden diese internen Stickstoffflüsse in der NNB nicht berechnet.

A Annex 0 – Introduction, method and conventions for NNBs

A.1 Introduction

The Convention on Long-range Transboundary Air Pollution (CLRTAP) adopted a Guidance Document to assist in the calculation of national nitrogen budgets (NNB) (ECE/EB.AIR/119).

Nitrogen budgets describe the exchange of quantities of nitrogen between environmental compartments, the economy, and the society within the national borders. National Nitrogen Budgets (NNB) are established by describing pools, sub-pools and the nitrogen (N) flows between the sub-pools. The elements of the NNB in general are described in the Guidance Document in Chapter III. Terminology.

According to the Guidance Document, the NNB includes eight pools, notably "energy and fuels", "material and products in industry", "agriculture", "forests and semi-natural vegetation", "processing of residues", "humans and settlements", "atmosphere" and "hydrosphere". Exchanges to/from the outside of national boundaries are considered as flows from/to the "rest of the world".

The following Annexes to the Guidance Document on National Nitrogen Budgets (NNBs) provide detailed descriptions for each individual pool. Items common to the overall system and to all pools are dealt within this Annex 0. It describes the principles, methods and definitions to be generally used when establishing an NNB, covering the following topics:

- General method of the NNB (A.2)
- Nitrogen compounds (A.3)
- Pools and sub-pools and their systematic nomenclature (A.4)
- N flows and their nomenclature for unambiguous identification (A.5), detail levels to be assessed (A.5.1), and general approach for quantification (A.5.2)
- How to deal with stocks and stock changes (A.6)
- Concept of uncertainty treatment (A.7)
- Quality controls and calculations of the mass balances (A.8)
- Nitrogen indicators and reduction targets (A.9)
- Guidance on how to start and technical support with the NNB (A.10)

This guidance document relates to existing national nitrogen budgets (NNB) such as the Nitrogen Budget of Switzerland (Heldstab et al. 2010, Reutimann et al. 2022), Germany (Umweltbundesamt 2009), Scottland (Centre for Ecology and Hydrology 2019), Austria (Broneder et al. 2024), Sweden (IVL Swedish Environmental Research Institute 2019), Japan (National Institute for Environmental Studies) as well as the European N budget (Leip et al. 2011). The Annexes are adopting structure and data from existing inventories and databases (e.g. IPCC guideline for National Greenhouse Gas Inventories (2006, 2019), Eurostat[2], Statistics of the Food and Agricultural Organization (FAO)[3]).

A.2 Method of the National Nitrogen Balances (NNB)

The NNBs are based on the method of material flow analysis (MFA). The material flow analyses use the system approach and the principle of mass conservancy to establish mass balances of (sub-)pools for checking, reconciling, and calculating flows. The physical entity that is measured and for which the mass balance holds is the chemical element nitrogen N reported in tonnes (t) or kilotonnes (kt) over a period of one year. The focus is thereby on nitrogen in its “reactive” form (N_r), and molecular N_2 flows are only considered in connection with a process that converts the N_2 to N_r or vice versa (see also A.3).

A.2.1 System definition

The system definition is the starting point of every MFA.

System boundary of the NNB

The system boundary is defined by the territorial principle: All nitrogen flows occurring within the territory of a country are inside the boundary of the NNB, irrespective of e.g., the citizenship of the person responsible for it. Regarding the time scale, NNB are typically calculated at an annual time scale.

Structure of the NNB

The structure of NNBs results from a schematic representation of the nitrogen processes and flows according to the MFA methodology. It is defined by pools, which are further divided into sub-pools[4]. Looking at pools allows us to consider sub-pools and flows between those sub-pools. In the (sub-)pools, nitrogen is present in various forms. They represent “containers” which store or transform nitrogen. The stored quantities are referred to as nitrogen stocks.

Sub-pools are the smallest unit between which the N flows are allocated: N flows move nitrogen between (sub-)pools. According to the method of the MFA, nitrogen species are considered not to change its form during transportation with a flow[5], but it might be converted from one species to another in the sub-pools. In addition, nitrogen stored in a (sub-)pool (i.e. the nitrogen stock) can be activated from the stock and become ready to be moved with a flow to another (sub-)pool, or nitrogen can be stockpiled into the (sub-)pool’s existing stock. This particular type of flow is referred to as a stock change.

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[2] https://ec.europa.eu/eurostat/de/home (accessed on 9.12.2024)

[3] https://www.fao.org/faostat/en/#data (accessed on 9.12.2024)

[4] In MFAs the more general term “process” is normally used for the smallest units where materials are transformed or stored that can or should be modelled. These processes are connected by flows.

[5] The method depicts the system in a schematic way. In nature, relations are more fluent and complex, for example, N-containing compounds can change their chemical composition while being transported in the atmosphere, or while being distributed on soils.

A.2.2 Mass balance

For each (sub-)pool of a material flow system in general and the NNB in particular two equations (mass balances) can be set up.

Mass balance equation (conservation of mass):

$$\sum N_{input,i} - \sum N_{output,i} - \sum N_{stock\ change,i} = 0 \qquad \text{(Eq. 1a)}$$

$$\sum N_{input,i} - \sum N_{output,i} = \sum N_{stock\ change,i} = \mathit{\Delta}\, N_i \qquad \text{(Eq. 1b)}$$

With:

N_{input}	N flows entering the pool/sub-pool	[kt N]
N_{output}	N flows out of the pool/sub-pool	[kt N]
$N_{stock\ change}$	Changes of nitrogen stocks of the pool/sub-pool	[kt N]
$\mathit{\Delta}$ N	Sum of stock changes of the pool / sub-pool	[kt N]
i	year	[-]

Stock equation, describing stock changes over time:

$$N\ stock_{i+1} = N\ stock_i + \Delta\ N_i \qquad \text{(Eq. 2)}$$

With:

N $stock_{i+1}$	N stock in year i+1 (including stock change in year i)	[kt N]
N $stock_{i}$	N stock in year i	[kt N]
$\Delta\ N_{i}$	Stock change in the pool or sub-pool in year i	[kt N]

A nitrogen budget thus is determined by its N flows and stock changes. The total NNB of a country as well as the NNB of each individual pool or sub-pool must comply with the equations above. Usually, the mass balance (Eq. 1a) is calculated on sub-pool level. The quantification of N stocks in pools and sub-pools (Eq. 2) is not part of NNBs. N stocks are often difficult to quantify and not necessary for calculation of NNBs. Quantification of (potential) stock changes, however, are a basic element of MFAs and can be used to check the plausibility of a Nitrogen Budget (see Chapter A.6).

A.3 Nitrogen compounds

Nitrogen exists in a large number of different chemical compounds in which it occurs in different oxidative states (see Chapter A.3.2). The different nitrogen species are converted into one another through various natural or industrial processes. We distinguish molecular nitrogen (N_2) and all other forms, subsumed as reactive nitrogen (N_r).

In the NNB, all relevant flows of N_r species need to be quantified, but concerning N_2, only flows that are connected to a transformation of N_2 to a reactive form of nitrogen (N_r) or vice versa are relevant (see Chapter A.3.1). The mass balance equation (Eq. 1a) applies to the quantified N_r and N_2 flows.

A.3.1 Handling of molecular nitrogen N_2

While for reactive nitrogen N_r all flows and stock changes are relevant for the NNB, the handling of N_2 is special: N_2 flows are only considered in an NNB as far as they are connected to a transformation of N_2 to N_r or vice versa. Only such flows are relevant for the mass balance, and also of interest in considerations of nitrogen efficiency and the concept of "N wasted" (see Chapter A.9). Note that where such transformation flows appear they need to be registered as an input or output in the balance equation (Eq. 1a or 1b). However, the majority of N_2 flows that represent exchanges of inert N_2 between (sub-)pools, do not fulfil this condition, and are hence excluded. N_2 is inert in its gaseous molecular form, and part of the air that it exchanged between the atmosphere and other pools, for as long as it is not converted to any form of N_r by use of energy. As N_2 is environmentally neutral, but its flows easily exceed N_r flows, it needs to be excluded from the balance equation except for N_2 flows linked to a transformation as mentioned above. Examples of such irrelevant N_2 flows are N_2 exchange with air masses, N_2 exchange between atmosphere and interstitial air in soil, N_2 inhaled and exhaled by animals and humans, N_2 dissolved in water bodies.

Quantification of the relevant N_2 flows linked to transformations (such as fixation, especially biological nitrogen fixation, or denitrification) is often a challenge, given that little information is available in literature because N_2 measurements are often difficult and out of focus of most studies. For the NNBs, the calculation of N_2 flows linked to transformations as difference values is therefore an option, if no data can be obtained (see also Chapter A.6.2). However, this approach makes it difficult to detect gross errors because these flows simply take the missing parts of the mass balance. If possible, direct quantification of N_2 flows linked to transformations should therefore be preferred, even if only rough estimations for N_2 emissions are available.

A.3.2 Nitrogen species

Reactive nitrogen (N_r) is understood as all chemical species of the element nitrogen other than the elemental gaseous form (N_2). Most compounds can be readily assimilated by biosubstrates. Reactive nitrogen is contained in chemical compounds, which also may be considered part of materials. Flows of reactive nitrogen thus depend on the quantity of material to be exchanged, and on the nitrogen content of the material. For the NNBs, each nitrogen form is identified by an abbreviation (see Table 3).

Note that nitrogen flows can contain more than one N species. These are expressed as N flows of mixed composition (N_{mix}) for simplification.

Table 3: Nitrogen contents of selected nitrogen species as derived by stoichiometry

Abbreviation	N species	Chemical formula	N content (%)	State
Reactive nitrogen N_r				
NO_x	Nitrogen oxides	NO_x (expressed as mass of NO_2 by definition)	30.43	gaseous
NH_3	Ammonia	NH_3	82.35	gaseous
NH_4^+	Ammonium	NH_4^+	77.8	in aqueous solution
N_2O	Nitrous oxide	N_2O	63.64	gaseous
NO_3^-	Nitrate	NO_3^-	22.58	in aqueous solution
NO_2	Nitrite	NO_2^-	30.43	in aqueous solution
N_{mix}	Other reactive N-species bound to materials (e.g. food, plastic, organic materials) or a mix of reactive N-species (e.g. dissolved forms of nitrogen)	-	-	Solid, gaseous or in aqueous solution
Inert nitrogen				
N_2	Molecular nitrogen	N_2	100	gaseous

Table 4: Definitions for aggregations of N species

Abbreviation	Definition
N_r	Sum of reactive N species such as NO_x, NH_3, N_2O, NH_4^+, etc.
RDN	Sum of wet and dry deposition and atmospheric transport of reduced N-species (gaseous: NH_3, solid/liquid aerosols: NH_4^+)
OXN	Sum of wet and dry deposition and atmospheric transport of oxidized N-species (gaseous: NO, NO_2, HNO_3, N_2O, PAN, solid/liquid aerosols: NO_2^- , NO_3^-)
N_{tot}	Total nitrogen flow between two sub-pools (sum over all N-species)
$N_{r\ tot}$	Total flow of reactive nitrogen between two sub-pools (sum over all N-species)

A.4 Pools and sub-pools and their nomenclature

According to the Guidance Document, for a NNB, all relevant pools to describe the nitrogen budget at country-level shall be included. Potentially relevant pools and sub-pools are defined in the following chapters. Additional pools or sub-pools should only be added if a countries' specific characteristics of nitrogen flows cannot be covered with the elements defined herein.

For the purpose of numerical handling a unique (alphanumeric) ID is to be given to each pool and sub-pool. Further, a unique (textual) code can be given to each (sub-)pool.

A.4.1 Pools

All pools have a two-letter code and a unique pool-ID, which conceptually follows the guidance used for reporting of greenhouse gases under the UNFCCC (see IPCC Guidelines (2006, 2019)) and the Nomenclature for Reporting (NFR) for air pollutants under the CLRTAP (EMEP/EEA Guidebook (2013, 2016, 2023)) for pools 1 to 5.

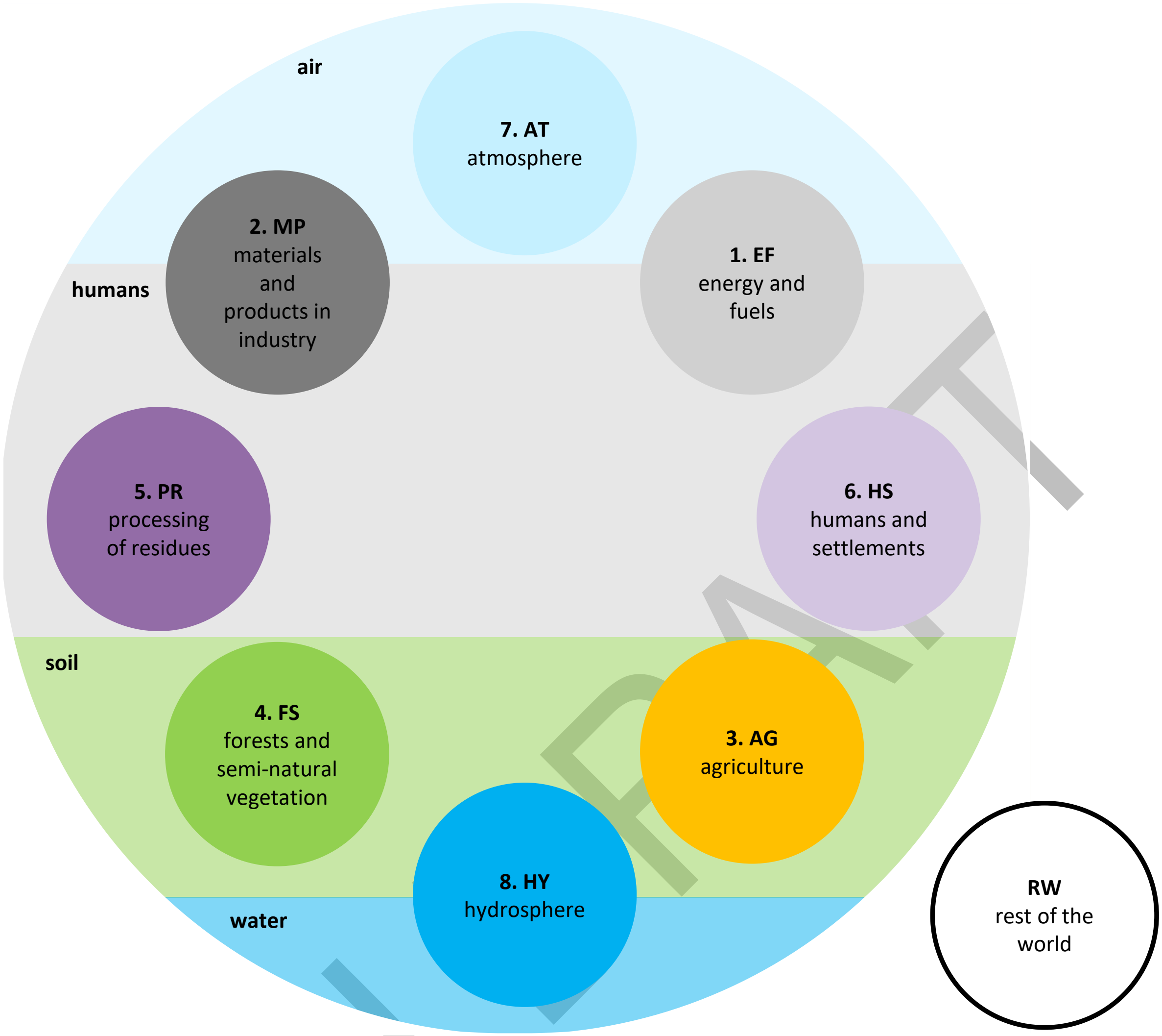
The pool "rest of the world" forms the start or endpoint of flows that enter or exit the national boundaries. For "rest of the world," no Annex is provided. The relevant information on quantification of import and export flows is provided in the Annexes of the pools to which N is imported, or from which N is exported.

Table 5: List of pools contained in NNBs

Annex	Code	Pool name
1	EF	Energy and fuels
2	MP	Materials and products in industry
3	AG	Agriculture
4	FS	Forests and semi-natural vegetation
5	PR	Processing of residues
6	HS	Humans and settlements
7	AT	Atmosphere
8	HY	Hydrosphere
*)	RW	Rest of the world

*) RW is start and endpoint for transboundary nitrogen flows (imports/exports). No specific Annex is provided.

Figure 3: **Overview of pools contained in NNBs**



Overview over the eight pools of the NNB and the pool „rest of the world“ that is defined as outside of national boundaries.
Source: illustration by INFRAS

A.4.2 Sub-pools

All sub-pools have a two-letter code to be combined with the two-letter code of their parent pool. For example, the pool “agriculture” (AG) has three sub-pools: “manure management, storage and animal husbandry” (MM) and “soil management” (SM) as well as “biofuel production and composting” (BC). Note that in cases where one level is sufficient, for the sake of simplicity, sub-pools can be referred to also as “pools,” as long as they are clearly defined.

Table 6: **List of all sub-pools**

Chapter	Code	Sub-Pool name
1, Annex 1	EF.EC	Energy and fuels – Energy conversion
	EF.TR	Energy and fuels – Transportation
	EF.OE	Energy and fuels – Other energy and fuels

Chapter	Code	Sub-Pool name
	EF.IC	Energy and fuels – Manufacturing industries and construction
2, Annex 2	MP.FP	Materials and products in industry – Food processing
	MP.OP	Materials and products in industry – Other producing industry
3, Annex 3	AG.MM	Agriculture – Manure management, storage and animal husbandry
	AG.BC	Agriculture – Biofuel production and composting
	AG.SM	Agriculture – Soil management
4, Annex 4	FS.FO	Forests and semi-natural area – Forests
	FS.OL	Forests and semi-natural area – Other Land
	FS.WL	Forests and semi-natural area – Wetland
5, Annex 5	PR.SO	Processing of residues – Solid waste
	PR.WW	Processing of residues – Wastewater
6, Annex 6	HS*	Humans and settlements (no sub-pool)
7, Annex 7	AT*	Atmosphere (no sub-pool)
8, Annex 8	HY.GW	Hydrosphere – Groundwater
	HY.SW	Hydrosphere – Surface water
	HY.CW	Hydrosphere – Coastal water
	HY.AC	Hydrosphere – Aquaculture

*) For the pool HS and AT, no sub-pools are defined.

A.5 Flows

A nitrogen budget covers flows of reactive nitrogen (N_r) as well as flows of molecular nitrogen (N_2). During transportation within flows, nitrogen species are considered not to change its form according to the MFA method (see also Chapter A.2.1), although in nature, relations are more fluent and complex, for example, N-containing compounds can change their chemical composition while being transported in the atmosphere, or while being distributed on soils.

The definition of flows adheres to the following principles:

- Flows are usually defined between sub-pools. If no sub-pools are defined, pools are suitable start and endpoints.
- A flow usually bears the name of the good in which the nitrogen is contained (e.g. raw materials, wastewater, food).
- Flows are given in tons N per year; expressed in 1000 t N per year or kt N per year.

For a unique identification of a flow the following information should be given:

1. The sub-pools the flow is flowing out of ($\text{sub-pool}_{\text{out}}$)
2. The sub-pool the flow is flowing into ($\text{sub-pool}_{\text{in}}$)
3. A short name of the flow

4. The nitrogen species in which the nitrogen is transported between sub-pool$_{out}$ and the sub-pool$_{in}$ (if no information is given, this is by default total N_r)

Information on the sub-pool$_{out}$, sub-pool$_{in}$ and the species is required for every flow (see examples in Table 7). Start and end points should be indicated at the highest level of detail the flow has been quantified (usually this is the sub-pool). Based on this information, each flow is defined by a unique flow code consisting of the starting and endpoint (sub-pools), a short flow name as well as the N species, separated by dashes (e.g. AG.SM-AT-emissions-NH_3).

Sometimes, a transformation process in one (sub-)pool can lead to several flows of N with different N species into another pool (e.g. denitrification leads to flows of N_2 as well as of the side products N_2O and NO into the atmosphere). Because the flows arise from the same process, they are grouped in graphs and tables and indicated only by their flow name. For example, emissions to the atmosphere from agricultural soils contain the N-species NH_3, NO_x, N_2O and N_2. These three flows are grouped as one emission flow (AG.SM – AT; see Table 7 or Figure 9). However, in the corresponding Excel reporting template[6] for NNBs (see Chapter A.10), the complete list of flows is provided. Further information on specific N flows is given in the description (see examples in Table 7).

The flow names given in the descriptive tables of this guidance correspond exactly to the flow names given in the Excel-Template for NNBs (see Chapter A.10) and are part of the unique flow code. In the graphs (e.g. Figure 5) however, the flow names may contain additional details for clear identification, such as an indication of the source or destination sub-pool. In the graphs, the identification of the flow is further facilitated by colours that indicate from which pool the flows originate (the colours assigned to the pools can be seen in the overview graphics "n flows between pools").

Table 7: Examples of flows in NNBs

Sub-pool$_{out}$	Sub-pool$_{in}$	Flow code	Flow Name	Flow name in graph	Description	Species
MP.FP	AG.MM	MP.FP-AG.MM-Farm animal feed-N_{mix}	Farm animal feed	Farm animal feed	Animal feed used in animal husbandry	N_{mix}
AG.SM	HY.SW	AG.SM-HY.SW-Overland flow-N_{mix}	Overland flow	Overland flow to surface water	Input from agricultural land via runoff, erosion, drainage	N_{mix}
AG.SM	AT	AG.SM-AT-Emissions-NH_3[7]	Emissions	Agricultural soil emissions	Emissions from application of mineral and organic fertilizers and soil cultivation	NH_3 NO_x N_2O N_2

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[6] Excel reporting template: https://www.clrtap-tfrn.org/sites/default/files/2025-05/Reporting-Template-NNB_V1.0.xlsx

[7] The example given is for NH_3, the flow code for the other species follows the same nomenclature.

Sub-pool$_{out}$	Sub-pool$_{in}$	Flow code	Flow Name	Flow name in graph	Description	Species
AG.MM	AT	AG.MM-AT-Emissions-NH_3[7]	Emissions	Manure and animal husbandry emissions	Emissions from livestock production (incl. manure management)	NH_3 NO_x N_2O

A.5.1 Level of detail

In a national nitrogen budget, not all flows need to be covered in detail. Some are dealt with as agglomerates, and others may even be neglected. Relevance and negligibility of each N flow are discussed for each pool in the individual chapters (Annexes 1 to 8), guided by the following principles:

- *Level of detail:* In general, calculations for N flows are based on default values from international sources. However, if more specific data from national sources is available, this should preferably be used, depending on the ambition level of national nitrogen budget. The following Annexes provide guidance to a simple approach, and only in few cases reference is made to potentially available national data sources.
- *N flow thresholds*: To use resources efficiently, no efforts should be spent on nitrogen flows that are considered negligible. Instead, small N flows can be neglected or subsumed in other N flows, where appropriate and applicable. Based on experience obtained for Switzerland (Heldstab et al. 2005) and for Germany (Umweltbundesamt 2009), the N flow threshold was set at 100 g N per person and year (equivalent to 100 t per million inhabitants and year). It is recommended that this threshold (i.e. 100 g N per person and year) is applied to determine which N flows need not be accounted for separately, but could be merged into related flows. However, regionally important streams may additionally be considered, e.g. coastal and wetland delta streams, even if they fall below the threshold and would be negligible at a national level (when divided by population), especially if these flows have been identified as important within regional studies and data from previous research are available.
- *N flows within and between pools*: Some flows occur between sub-pools within the boundaries of a pool and are covered in the description of the corresponding pool. Many of the N flows occur between sub-pools of different pools. They are described in the Annexes of the pool from which the flow originates.

While the individual Annexes have been established to accommodate for the requirements as outlined above, there may be specific country cases where a more stringent coverage is advisable. For gaseous N flows (and some others) data is usually given directly as N containig compounds, without the need for activity data (hard to quantify). Compilers of NNBs should consider splitting flows that exceed the minimum detail level by a factor of 10, i.e. 1 kg N per person and year. In splitting, care should be taken that more different elements are separated into different sections of the split flow (e.g., those partial flows that are available from separate statistics, or that can be distinguished by very different N contents etc.). Moreover, if the uncertainty margins of the sum of flows into and out of a pool (or sub-pool) do not overlap, compilers may consider adding relevant flows or stock changes that have been left out (even if guidance is not provided for in this document).

A.5.2 Quantification of flows

Depending on the information and data available, there are various ways of quantifying a N flow. In general, nitrogen in flows is calculated by multiplying activity data (A) with a corresponding N content (f_N) according to the following general equation:

$$F = A \cdot f_N \qquad \text{(Eq. 3)}$$

With:

F	Flow of nitrogen between (sub-)pools.	[kt N]
A	Activity data refers to statistical information of numbers, volumes, quantities etc. of a certain activity that results in a nitrogen flow between (sub)-pools. Examples are quantity of agricultural products, volume of fuel use or production volumes of fertilizer, etc.	[kt] or [m^3]
f_N	Nitrogen content of respective activity data (ranging between 0 at 100%): Depending on the units of the activity data, additional conversion factors need to be applied (such as densities, net calorific values, etc.). See Annexes 1-8 for more details on calculation of individual N flows).	[% N]

For gaseous N flows (and some others) the data are usually given directly as N, so that quantification with activity data and N content is not necessary.

Nitrogen flows can be quantified at different time scales. For NNBs N flows are quantified at an annual time scale. All equations provided for quantification of N flows in the following Annexes refer to the annual time scale, but could equally be applied at any other time scale.

For the calculation of how much nitrogen is flowing, the following sources of information can be used:

- *Nitrogen species and nitrogen contents* (see also A.3 and Guidance Document): There are thousands of individual chemical compounds containing nitrogen that are listed by Chemical Abstract Services (CAS). Nitrogen contents can be assessed from the chemical formulae by stoichiometry using the respective atomic and molecular weights (see e.g. Supplementary Information to Pelletier & Leip, 2014). Nitrogen is also present in complex chemical compounds such as organic material (food, wood products, waste). For those materials, N contents are provided (i.e. percentage of nitrogen contained in the material). Overview of the relevant nitrogen species are given in Table 3.
- *Activity data:* refers to statistical information of numbers, volumes, quantities etc. of a certain activity that results in a nitrogen flow between (sub)pools. Examples are quantity of agricultural products, volume of fuel use or production volumes of fertilizer, etc. Data can be found in national and international statistics and databases. Examples of national databases are inventories for greenhouse gases and air pollutants and trade statistics. Important international statistics are provided by FAO and Eurostat, e.g. agricultural nutrient balances and energy balances.

Many nitrogen flows are calculated based on the same principles as emission flows to the atmosphere, which are anyways assessed and reported for the UNFCCC or UNECE. Tables with most commonly used activity data and their nitrogen content are given in the Annexes. The Annexes also provide further information on quantification of N flows.

A.6 N stocks and stock changes

A.6.1 N stocks

The pools and sub-pools of the NNB store large quantities of nitrogen, e.g. in biomass, in soils, fuels, landfills, water bodies or – in the case of the pool "atmosphere" – as inert nitrogen in the air. However, the sizes of N stocks in pools and sub-pools are often not necessary to understand the processes involving nitrogen. Furthermore, N stocks are often difficult to quantify. Therefore, the quantification of N stocks in pools and sub-pools is not part of NNBs and for that reason, it is not specified in the Annexes.

For other research questions, awareness of stocks in different pools may however be of interest.

A.6.2 Stock changes

Nitrogen stocks in pools or sub-pools may change over time for various reasons. For example, if accumulation of N in forest biomass or soil occurs, the stock of the pool FS changes. Similarly, the conversion of inert N_2 to NO_x in the troposphere due to lightning represents a stock change in reactive N in the pool "atmosphere".

Stock changes are an integral part of the material flow analysis of the NNB (see Eq. 1a and Eq. 2). Hence, knowledge of stock changes provides information that can help to validate the mass balances of the pools and sub-pools.

The following Annexes contain further information about the stock changes that may possibly occur in the respective pools and sub-pools and how they can be identified and/or quantified.

In general, there are two approaches to quantify stock changes:

a) Identification of stock changes based on mass balance analyses and qualitative interpretation

According to the mass balancing equation (Eq. 1), the stock change of a pool/sub-pool is the difference between the sum of the inputs and the sum of the outputs. When outputs exceed inputs, the N stock of the pool/sub-pool decreases, and there is a depletion of N; when inputs exceed outputs, the N stock increases, and the pool accumulates nitrogen.

With this approach, the focus lies on explaining the calculated N stock changes qualitatively: reasons for the stock changes must be at hand that support the calculated stock change. For this reason, qualitative information from literature or other NNBs should be gathered. If no realistic explanations for the occurrence of the calculated stock changes and no supportive information in literature can be found, alternative explanations for the differences in inputs vs. outputs must be considered, such as high uncertainties in in- or output flows, incorrectly quantified flows or even missing flows (see Chapter A.8).

This approach entails the difficulty, that besides stock changes, there are also certain flows that are rather calculated than quantified, e.g. the N_2 formation due to denitrification or biological nitrogen fixation. If not quantified but calculated by mass balancing, flows and stock changes act as mechanisms to "even out" the budgets. To avoid wrong assumptions, such calculations should be applied to a reasonable extent only.

b) Direct quantification of stock changes

Stock changes can be quantified by e.g. repeated direct measurements of stock sizes, such as e.g. repeated measurements of standing biomass in forests, and identification of the changes therein.

With this approach, stock changes are quantified based on (sub-)pool-specific methods (see Annex FS for examples). However, prior to the calculation, a qualitative check should be carried out to determine whether a corresponding stock change is likely or not; if not, a calculation is not recommended. It must be considered that the quantification of stock changes is often based on complex methods, the data availability is often poor and, correspondingly, the uncertainties can be considerably high.

Land use changes

Land use change can be regarded as a shift of land from one stock to another. This shift of land between two pools does not only transfer nitrogen but at the same time increases resp. decreases the size (area) of the pool. For the NNB, we do not recommend to account for this N shift of stocks, as that would require quantification of stocks first, and stocks are out of focus for the NNBs. However, there are subsequent effects that need to be considered: Over time, land use changes (e.g. afforestation of agricultural land) induce N flows (e.g. emissions to the atmosphere) in pools affected by those changes (i.e. "agriculture", "forests and semi-natural vegetation", "hydrosphere", "humans and settlements"). N flows that are induced by land use changes are as far as possible included in the NNB (see respective Annexes).

If such land use change induced flows exist, a corresponding stock change is likely and it can most probably be interpreted as being caused by that land use change. While doing so, any other causes for stock changes should be ruled out (by quantification or qualitative considerations).

A.7 Quantification of uncertainties of N flows

This section specifies a general approach to assess uncertainties in the utilized data sets. The proposed method corresponds to the approach recommended for air pollutant and greenhouse gas inventories, as documented in the EMEP/EEA Guidebook (EEA 2013) and IPCC Guidelines (IPCC 2006).

In general, all data (for nitrogen) are associated with uncertainty. The range of uncertainty should be indicated with the quantified N flows, because considering uncertainties can have consequences for the results and interpretation of the mass balance analysis. To indicate the range of uncertainty is of particular importance because NNBs often rely on data that lack established and reliable data sources. Some N flows have to be determined as residuals from other flows within the pool, and quantifications are frequently based on assumptions.

Information on uncertainty of the input and output flows can then be used for the interpretation of the resulting N balances per pool or sub-pool. Uncertainty estimates allow to interpret inconsistencies between input and output flows. For example, a difference between total input and total output flows may be explained when accounting for the uncertainties in the data. I.e. an overlap of the uncertainty interval of inputs (i.e. total inputs including their uncertainty range) with the uncertainty interval of outputs (i.e. total outputs including their uncertainty range) indicates that the N balance of a sub-pool is complete and consistent. On the other hand, if uncertainty ranges do not overlap, the N balance should be further investigated (e.g. check for missing N flows or relevant stock changes, see also Chapter A.6).

Definition

The uncertainties to be provided per N flows are defined as follows. The term uncertainty defines the 95% interval of the likely values of a N flow. It is quantified by a relative uncertainty value (in percent), which indicates half of the 95% interval. For instance, if an N flow of 1 kt of nitrogen has an uncertainty value of 30%, the 95% interval of the likely value corresponds to 0.7-1.3 kt of nitrogen.

Data availability

In some cases, data sources used for an NNB indicate also the underlying uncertainties in the data. For example, the emission data from the national inventories reported under the UNFCCC[8] or the CLRTAP[9] provide also information on the respective uncertainties. Those data can directly be assigned to the corresponding N flows of the NNB. However, in many cases no information on underlying uncertainties will be available. In this case, uncertainties need to be estimated. It is suggested to assign an uncertainty level based on the type of data source and assessing respective uncertainties as indicated in Table 8. These values are compatible with the ratings and typical error ranges from the EMEP/EEA air pollutant emission inventory guidebook (EEA 2013).

Uncertainty levels can be assigned to both N contents and corresponding activity data or directly to N flows. When calculating N flows by multiplying N contents with corresponding activity data, the uncertainty levels of those values may differ (e.g. 10% uncertainty for activity data and 30% for N content). For the resulting N flow the higher uncertainty value can be assumed as a simplification, since the value with a higher uncertainty dominates also total uncertainty (thus in the example mentioned above, an uncertainty of 30% can be assumed for the resulting N flow). If data on uncertainties are available for both N contents and activity data, the error propagation may also be applied at the level of individual N flows. As it is expected that such detailed uncertainty data will rarely be available, the method proposed in general is limited to the assessment of a total uncertainty per N flow.

Table 8: Levels of uncertainty (based on Egle et al. 2014, Thaler et al. 2011, Laner et al. 2015)

Level	Uncertainty	Criteria
1	10%	Current official statistics, measurement data, data from appropriate literature
2	30%	Expert estimates, outdated official statistics, unofficial statistics, presentations, industry reports
3	50%	Assumptions for which neither official statistics nor expert estimates were available often based on on-line data sources or publications without accurate literature reference
4	100%	An estimate based on a calculation derived from assumptions only

Aggregation of uncertainties

When adding up uncertain quantities (e.g. total uncertainty of all input or output flows of a sub-pool), the absolute uncertainty of the sum of all N flows equals the square root of the sum of the

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[8] https://unfccc.int/ghg-inventories-annex-i-parties/2024

[9] https://www.ceip.at/

squares of the absolute uncertainties of each flow that is added[10]. The relative uncertainty of the sum (U_{Total}) can be derived from the following equation (EEA 2013, IPCC 2006):

$$U_{Total} = \frac{\sqrt{(U_1\,F_1)^2 \; + \; (U_2\,F_2)^2 + \cdots + (U_n\,F_n)^2}}{F_1 + F_2 + \cdots + F_n} \qquad \text{(Eq. 4)}$$

With:

F_i	N flow	[kt N]
U_i	Relative uncertainty (half the 95% confidence interval)	[%]
U_{Total}	Total relative uncertainty	[%]

For the total N flow, F_{Total} (e.g. total of N inputs into a pool), the *total uncertainty interval* of the likely values ranges from *"$F_{Total} - U_{Total}$" to "$F_{Total} + U_{Total}$"*.

A.8 Quality controls and mass balances

Once the flows have been quantified for an NNB, the mass balance (Eq. 1a) should, under consideration of uncertainties (quantification of uncertainties, see Chapter A.7), add up for every pool and sub-pool. It is recommended to calculate the mass balances for every pool and sub-pool. Further it can be calculated for the whole country, by looking at the flows that enter or exit the system boundaries from or to the rest of the world.

Interpretation should always concern the whole budget of every (sub-)pool, including inputs, outputs and stock changes likewise, and should be done irrespective of what method for quantification of flows and stock changes is used. Based on the results, the quality and plausibility of the underlying data can be assessed. The mass balance per pool allows to identify differences between total inputs and outputs, which may be due to accumulation or depletion within the pool but may also due to missing flows or inaccurate data for the input and output flows. If balances do not add up while taking into account uncertainties, the following reasons should be taken into consideration:

- Some flows have not been identified or quantified and are missing in the NNB,
- Flows are not correctly quantified or have higher uncertainties than assumed,
- Stock changes exist.

As mentioned in Chapter A.3.2, to add flows or stock changes should be taken into consideration if the uncertainty margins of the total N flow into and out of a pool (or sub-pool) do not overlap (e.g. if the total inputs including its uncertainty range are between 5 and 10 kt N and the total outputs including its uncertainty range lies between 20 and 40 kt N it is likely that there are missing N flows or stock changes (accumulations in the stock) that need to be considered). To

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[10] This rule is valid only for uncorrelated variables. In case of correlated data, uncertainties should be assessed by a Monte Carlo procedure. Information on application of uncertainty assessments accounting for correlated values can be found in EEA 2013 and IPCC 2006. The method described in Annex 0 can be used as a first approximation.

identify such missing flows or stock changes, the NNBs of other countries or scientific literature can be consulted.

Besides serving as quality controls, mass balance calculations can also be used specifically to indirectly calculate flows or stock changes that cannot be calculated directly (see also Chapter A.6.2).

A.9 Nitrogen indicators and reduction targets

Nitrogen use efficiency and nitrogen waste

Nitrogen compounds are vital building blocks of life, needed a.o. for food and bio-energy production. At the same time, the massively increasing supply of nitrogen in the last decades goes along with substantial transgression of the “planetary boundaries” with impacts way beyond the direct environmental consequences. Therefore, N_r has to be considered a precious and limited commodity that should be used efficiently and not be wasted. This is further underpinned by the fact that nitrogen in the form of atmospheric N_2 is abundant, but substantial energy is needed to create reactive nitrogen species – whether by lightning, fertilizer manufacture, or biological nitrogen fixation. N_r species on the other hand naturally tend to revert to N_2, while producing environmentally harmful N_r gases as side products, such as nitric oxide (NO), and nitrous oxide (N_2O). Therefore, an efficient use is required.

Furthermore, nitrogen flows can be differentiated between useful outputs (e.g. intended products such as food, feed, etc.), recycling outputs (e.g. manure used as fertilizer) and losses to the environment (e.g. leaching, emissions). The Excel reporting template[11] for NNBs provides a definition of each N flow.

Nitrogen use efficiency (NUE) is a possible measure for target setting, defined in general as follows:

$$NUE = \frac{\sum N_{outputs}}{\sum N_{inputs}} * 100 = \frac{\sum N_{useful\ outputs} + \sum N_{recycling\ outputs}}{\sum N_{inputs}} * 100 \qquad \text{(Eq. 5)}$$

With:

NUE	Nitrogen Use Efficiency	[%]
$N_{outputs}$	N in outputs (= useful outputs + recycling outputs)	[kt N]
N_{inputs}	N in inputs (e.g. feed and fertilizer)	[kt N]
$N_{useful\ outputs}$	N in useful outputs (e.g. agricultural products)	[kt N]
$N_{recycling\ outputs}$	N in recycling outputs (e.g. manure for biogas production)	[kt N]

The NUE of a country’s crop production for example can be calculated as the division of total N outputs with harvested food and fodder crops etc. by the total N inputs to arable land with mineral fertilizers, manure, atmospheric N deposition, biological N_2 fixation etc. (Scottish

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[11] Excel reporting template: https://www.clrtap-tfrn.org/sites/default/files/2025-05/Reporting-Template-NNB_V1.0.xlsx

Government 2021, EU Nitrogen Expert Panel 2016). Crop production NUE ranged from 40-77% for EU countries (Lassaletta et al. 2014, Ludemann et al. 2024).

A low N surplus indicates that the potential for N loss and impacts on the environment is low, with a large part of the N input recovered in N in output products (e.g. harvested products).

Another approach, focused on reducing overall environmental impact, considers nitrogen that is not being used for plant growth (agricultural products) and therefore wasted (N wasted) (Sutton et al. 2021). It can be used as an indicator and target. N wasted is defined as the sum of all losses of N_r to the environment plus denitrification to N_2, which is equally a waste of N_r resources (UNECE 2022).

Reduction in total N wasted in percent is calculated as follows:

$$Reduction\ in\ total\ N_{wasted} = \frac{N_{wasted,t1} - N_{wasted,t2}}{N_{wasted,t1}} * 100 \qquad \text{(Eq. 6)}$$

With:

$Reduction\ in\ total\ N_{wasted}$	Reduction in N wasted between year t1 and year t2	[%]
$N_{wasted,\ t1}$	Sum of all nitrogen losses to the environment in reference year t1 (including N_2 and all N_r species)	[kt N]
$N_{wasted,\ t2}$	Sum of all nitrogen losses to the environment in year t2 (including N_2 and all N_r species)	[kt N]

The reduction in total N wasted emphasizes the benefit of all reductions in N losses, by all approaches at national, regional and global scales (UNECE 2022). This approach comes without the disadvantage of the efficiency approach, which implies that two systems with the very same N efficiency can have very different environmental impacts depending on whether a nitrogen intensive (with high absolute amounts of N wasted) or less intensive system (with low absolute amounts of N wasted) is considered. The idea to “halve nitrogen waste” was born in 2018 in New York University, based on the fact that over the last decades, global nitrogen waste has steadily increased, tripling in magnitude (Sutton et al. 2021). With the target variable “N wasted”, the goal of „halving global nitrogen waste“ becomes relevant both for countries with too much and too little nitrogen (Sutton et al. 2013) and for intensive and agro-ecological farming likewise, given that reducing waste enables available N_r resources to go further (Sutton et al. 2020). With respect to systems with low N availability, the N wasted approach is more equitable than goals to increase the nitrogen-use efficiency[12], because less waste means less action is needed (Sutton et al. 2021). At the same time, it allows flexibility for national and local actors to tune according to their own priorities (by sector, source, nitrogen form, effect, etc.) (Sutton et al. 2021).

A new global target to halving global nitrogen waste, as suggested at the Colombo Declaration of 2019 of the UN Global Campaign on Sustainable Nitrogen Management (UNECE 2022), has become more widely embraced in recent years and is being adopted more and more frequently,

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[12] For example, the 2011 proposal of the Global Conference on Land-Ocean Connections to increase nitrogen-use efficiency (NUE) by 20% relative to the base year 2008 (https://enb.iisd.org/events/3rd-intergovernmental-review-meeting-implementation-global-programme-action-protection-0)

with the target year of 2030[13]. However, this goal is ambitious, hence using NNBs to determine achievement may remain relevant also for a longer term.

Loss of reactive nitrogen to the environment

Another possible target variable is to consider simply total N_r losses to the environment, or losses of single N_r species such as ammonia (NH_3), nitrous oxide (N_2O) etc. Total N_r losses correspond to the sum of polluting N inputs to the environment, mainly NH_3 and N_2O and NO_x to the atmosphere and NO_3^- to water bodies. One of the major challenges in reducing losses of reactive nitrogen is to avoid “pollution swapping”: one-sided avoidance strategies that lead to increased losses through another channel (Sutton et al. 2022, Heldstab et al. 2010). For example, measures to reduce ammonia emissions during manure application can lead to increased nitrate leaching, if the same amount of manure is applied (Heldstab et al. 2010).

A.10 Guidance for the first steps of the NNB

Setting up an NNB begins with setting up the structure of the NNB with its pools, sub-pools and nitrogen flows that occur. By sketching the NNB’s pools and sub-pools, and listing the relevant flows, the structure for the NNB is provided.

The NNBs with pools, sub-pools and flows, as defined in the following Annexes, can be visualized by the “Nitrogen budget visualisation tool”[14] , which was specifically developed for this purpose by the UK Centre for Ecology & Hydrology. Alternatively, the NNB structure that has been set up in the software STAN[15] can be used; for this the ‘STAN template’[16] is available to visualize the NNB. Otherwise, simple graphic programs or even manual sketches can be used to illustrate the NNB.

The next step is to identify and quantify the relevant flows in the NNB. For this step, a list of the flows is necessary. For the quantification, it is advisable to start with the most relevant pool; this is usually the pool “agriculture”. The Excel reporting template[17] developed in addition to the Annexes provides the list of flows identified in the following Annexes. Alternatively, a separate list can be used. Once the flows are quantified, they can be imported from the Excel reporting template into the tool used for visualisation. For this purpose, the Excel template provides an interface table to the "NNB visualization tool" developed by the "UK Centre for Ecology & Hydrology". If data import into the STAN template is preferred, the ‘Interface to NNB-STAN’ worksheet in the Excel reporting template is available.

The Excel reporting template also allows to create figures and tables showing the results of the NNB, once the list of N flows is filled. In addition, it provides information on the resulting

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[13] At the Colombo Declaration of 2019 of the UN Global Campaign on Sustainable Nitrogen Management it was agreed on the ambition to halve nitrogen waste by 2030 as part of National Nitrogen Action Plans (https://papersmart.unon.org/resolution/sustainable-nitrogen-management). Further example: Decision of the European Commission 2020 to include the goal to “reduce nutrient pollution by 50% by 2030” in both its Farm to Fork and Biodiversity Strategies.

[14] Nitrogen budget visualisation tool (developed in the programming language R), available at https://connect-apps.ceh.ac.uk/Nbudget_app/

[15] Software STAN: https://www.stan2web.net/

[16] STAN template: https://www.clrtap-tfrn.org/sites/default/files/2025-04/NNB%20model%20STAN%20-%20master_V1.0.zmfa__0.zip

[17] Excel reporting template: https://www.clrtap-tfrn.org/sites/default/files/2025-05/Reporting-Template-NNB_V1.0.xlsx

nitrogen use efficiencies (NUE), and it shows time series of input and output flows, as well as N wasted and N losses to the environment.

It is possible to adapt both the system structure (pools and sub-pools) and the flows of the predefined NNB to country-specific conditions. Such adjustments can be implemented directly in the tools provided (Excel reporting template, STAN template).

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A.12 Document version

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Update of previous Version 2016 by Judith Reutimann, Bettina Schäppi, Sophie Bogler (INFRAS, Zurich).

Reviewers Version 09/2024: Kazuya Nishina (nishina.kazuya@nies.go.jp; Biogeochemical Cycle Modeling and Analysis, Section Earth System Division, Nationale Institute for Environmental

Studies, Tsukuba, Japan), Wilfried Winiwarter (winiwart@iiasa.ac.at, Mitigation of Air Pollution and Greenhouse Gases, iiasa, Laxenburg, Austria), Filip Moldan (filip.moldan@ivl.se, IVL Swedish Environmental Research Institute, Göteborg, Sweden), Julia Tanzer (j.tanzer@proman.pro, Proman, Auersthal, Austria), Oliver Cencic (oliver.cencic@tuwien.ac.at, Abfallwirtschaft und Ressourcenmanagement, TU Wien, Vienna, Austria)

Authors Version 2016: Wilfried Winiwarter (winiwarter@iiasa.ac.at), Adrian Leip (adrian.leip@jrc.ec.europa.eu)

Reviewers Version 2016: Judith Reutimann, Jürg Heldstab (INFRAS, Zurich), Markus Geupel (UBA, Dessau)

1 Annex 1 – Energy and fuels (EF)

This Annex describes the nitrogen flows in the pool "energy and fuels" (EF) and provides methodologies for the quantification of the major nitrogen flows to the other pools of the NNB. It comprises methodologies for a simplified approach in case of limited data availability based on default values and existing data sources that are available for most countries. In addition, the data sources and limitations in the estimation of nitrogen flows and stock changes in the pool are documented.

1.1 Description of flows to other pools

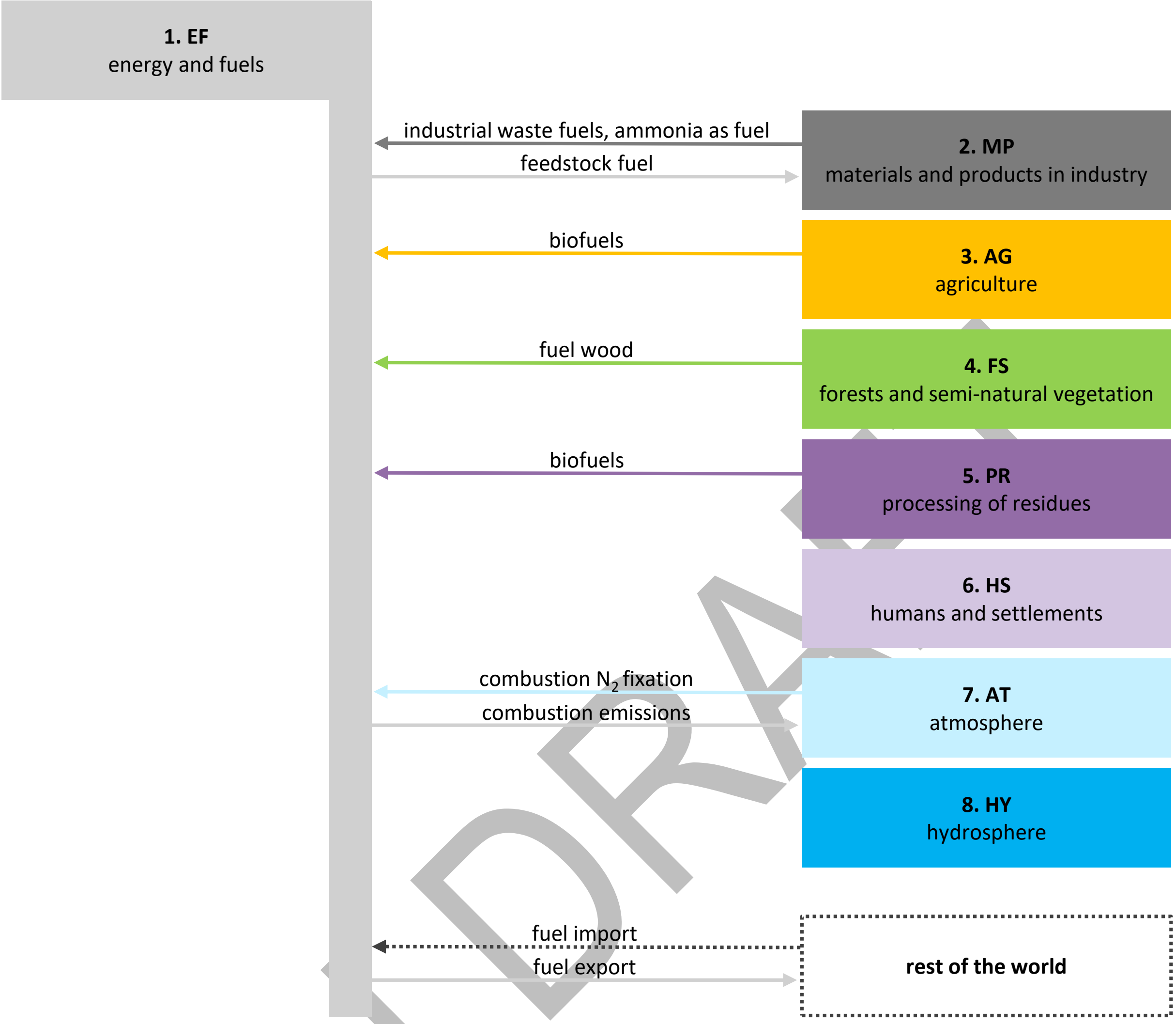
The pool "energy and fuels" comprises all fuel combustion and energy conversion activities.

- Fuel combustion includes the transport sector, fuel combustion in industrial processes, in the commercial/institutional and in the residential sector.
- Energy conversion processes include heat and electricity production as well as refineries and other fuel production processes apart from biofuel production, which is accounted for in the pools "agriculture" (AG) and "processing of residues" (PR).

The most important flows of reactive nitrogen in the pool EF originate from fuel combustion activities. During fuel combustion, atmospheric nitrogen N_2 is transformed into reactive nitrogen species, such as NO_x, NH_3 and N_2O. Emissions of nitrogen oxides formed by thermal fixation of atmospheric nitrogen are also referred to as "thermal NO_x".

Besides fixation of atmospheric nitrogen, various types of fuels (e.g. coal, wood) contain chemically bound nitrogen. The weight fraction of chemically bound nitrogen varies depending on the fuel type. Also, ammonia itself is becoming relevant as a carbon-free alternative fuel for certain countries and specific vehicle types (e.g. in shipping, heavy-duty vehicles). During combustion processes, chemically bound nitrogen is also converted to NO_x. These NO_x emissions are referred to as "fuel NO_x" (note that thermal NO_x typically dominates the total NO_x emissions). Therefore, each pool that provides fuels is linked to the pool EF by a flow of nitrogen. This includes wood fuel from pool FS, fossil fuels from the "rest of the world" (RW), waste fuels from pool "materials and products in industry" (MP) and biofuels from the pools AG and PR. All the flows entering the pool EF consist of reactive nitrogen bound to materials (N_{mix}). Imports and exports of fuels need to be considered for all types of fuels.

Figure 4: N flows between pool “energy and fuels” (EF) and other pools



Source: illustration by INFRAS

1.2 Boundaries

NNBs are determined at the national level following the territorial principle (see Annex 0, Chapter A.2.1). Basis for the quantification of nitrogen flows is therefore the amount of fuel used within the territory rather than the amount of fuel sold. This implies that the amount of fuel sold needs to be corrected for all fuel exports and imports. Besides exports and imports provided by the customs statistics this includes also fuel tourism due to fuel price differences between countries, which is mostly relevant in the transport sector.

Data sources used for quantification of the NNB therefore need to be provided for the same system boundaries. National inventories on emissions of air pollutants and greenhouse gases differ in terms of their system boundaries. Under the United Nations Framework Convention on Climate Change (UNFCCC), the national total for assessing compliance is based on fuel sold within the national territory. Under the Convention on Long-range Transboundary Air Pollution (CLRTAP), two types of reporting occur based on fuel sold as under the UNFCCC and based on fuel used within the territory. Thus, transport fuel sold in a country but consumed abroad (“fuel tourism”) is accounted for in greenhouse gas inventories, but not in every country reporting under the CLRTAP. The system boundary for countries reporting under the CLRTAP based on fuel used is therefore consistent with the present guidance documents. For other countries, the national air pollutant and greenhouse gas inventories differ in terms of the amount of fuel consumed abroad and therefore the reported emissions of NO_x, NH_3 and N_2O need to be corrected for net import and export of fuels due to "fuel tourism".

1.3 Pool structure and N flows

The pool „energy and fuels" consists of four sub-pools (Figure 5). The sub-pool „energy conversion" (EC) comprises all fuel conversion activities, such as refining processes, manufacturing of solid fuels and heat and electricity production. It excludes production of biofuels (e.g. biodiesel, bioethanol, biogas), which is accounted for in the sub-pool "biofuel production and composting" of pool AG and in the sub-pool "solid waste" of pool PR. The sub-pool „manufacturing industries and construction" (IC) includes all fuel combustion processes in the industrial sector and in construction. The sub-pool „transport" (TR) comprises all fuel combustion in transport activities (land, water, air) and the sub-pool „other energy and fuels" (OE) accounts for all remaining fuel combustion processes out of which heating in residential and commercial/institutional buildings is one of the most important sources.

1.3.1 Overview of N flows

This section describes the major flows of nitrogen between the pool EF and the other pools[19] of the NNB. An overview of the nitrogen flows between the pool EF and the other pools of the NNB is presented Table 9 and Table 10.

Besides exchanges with other pools, there are also N flows within the pool EF to be accounted for, notably the exchange between the sub-pool "energy conversion" (EF.EC) and the sub-pools "manufacturing industry and construction" (EF.IC), transport (EF.TR) and "other energy and fuels" (EF.OE).

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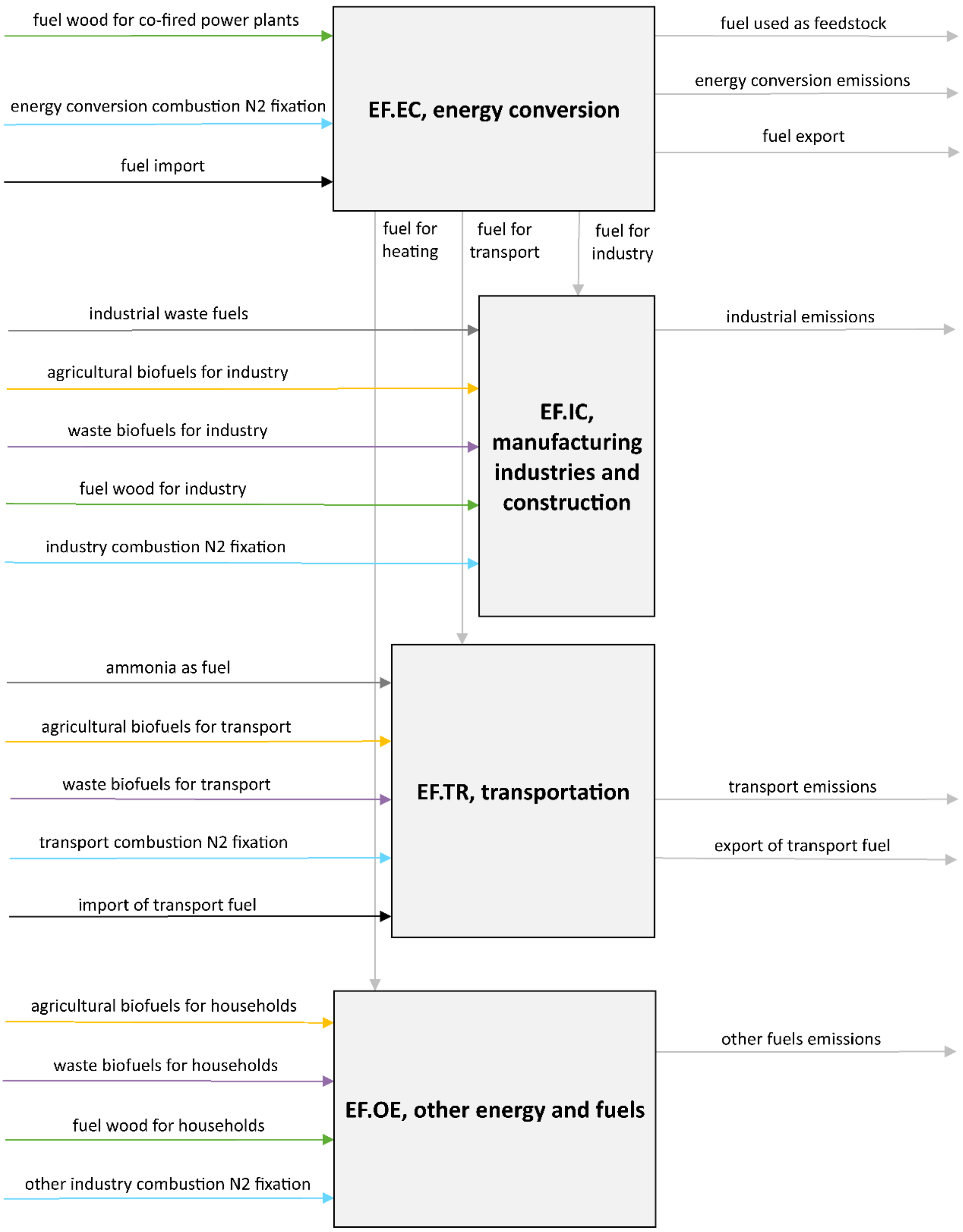
[19] Acronyms of the different pools used in the National Nitrogen Budget (NNB) are documented in Annex 0, Table 6

Figure 5: N flows between sub-pools of "energy and fuels" (EF) and other pools



The arrows characterize the nitrogen flows between the sub-pools. Colours indicate from which pool the flows originate (the colours assigned to the pools can be seen in the overview graphics "n flows between pools"). Stock changes are not depicted. The flow names used in the graph here contain some details for clear identification and can deviate from the flow names given in the table below, because the latter correspond exactly to the flow names given in the Excel-Template for NNBs.

Source: illustration by INFRAS, generated in STAN

Table 9: N flows going out of the pool “energy and fuels” (EF)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
Energy conversion	EF.EC	EF.IC	Manufacturing industries and construction	Fuel for industry	N flow from fuels produced within the country to the sub-pool IC	N_{mix}	1.4.2.1
	EF.EC	EF.TR	Transport	Fuel for transport	N flow from fuels produced within the country to the sub-pool TR	N_{mix}	1.4.2.2
	EF.EC	EF.OE	Other energy and fuels	Fuel for heating	N flow from fuels produced within the country to the sub-pool OE	N_{mix}	1.4.2.3
	EF.EC	MP.OP	Other producing industry	Fuel used as feedstock	Fuels used as feedstock in industrial processes	N_{mix}	1.4.2.4
	EF.EC	AT	Atmosphere	Emissions	Release of nitrogen species during fuel combustion process	NO_x, NH_3, N_2O N_2	1.4.1.2
	EF.EC	RW	Rest of the world	Fuel export	Export of fuels	N_{mix}	1.4.2.5
Manufacturing industries and construction	EF.IC	AT	Atmosphere	Emissions	Release of nitrogen species during fuel combustion process	NO_x, NH_3, N_2O N_2	1.4.1.3
Transport	EF.TR	AT	Atmosphere	Emissions	Release of nitrogen species during fuel combustion process	NO_x, NH_3, N_2O N_2	1.4.1.4
	EF.TR	RW	Rest of the world	Export of transport fuels	Export of fuels (fuel tourism)	N_{mix}	1.4.2.5
Other energy and fuels	EF.OE	AT	Atmosphere	Emissions	Release of nitrogen species during fuel combustion process	NO_x, NH_3, N_2O N_2	1.4.1.5

The following table shows the N flows entering the pool ”energy and fuels”. They are described in the Annexes of the pools from which these N flows originate.

Table 10: N flows entering the pool "energy and fuels" (EF)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Species	Chapter
Other producing industry	MP.OP	EF.IC	Manufacturing industries and construction	Industrial waste fuels	N_{mix}	2.4.1.6
	MP.OP	EF.TR	Transport	Ammonia as fuel	NH_3	2.4.4.1
Biofuel production and composting	AG.BC	EF.IC	Manufacturing industries and construction	Biofuels for industry	N_{mix}	3.4.5.1
	AG.BC	EF.TR	Transport	Biofuels for transport	N_{mix}	3.4.5.1
	AG.BC	EF.OE	Other energy and fuels	Biofuels for households	N_{mix}	3.4.5.1
Forests	FS.FO	EF.OE	Other energy and fuels	Fuel wood for households	N_{mix}	4.4.4
	FS.FO	EF.IC	Manufacturing industries and construction	Fuel wood for industry	N_{mix}	4.4.4
	FS.FO	EF.EC	Energy conversion	Fuel wood for co-fired power plants	N_{mix}	4.4.4
Atmosphere	AT	EF.IC	Manufacturing industries and construction	Combustion N_2 fixation	N_2	7.4.3.1
	AT	EF.OE	Other energy and fuels	Combustion N_2 fixation	N_2	7.4.3.1
	AT	EF.TR	Transport	Combustion N_2 fixation	N_2	7.4.3.1
	AT	EF.EC	Energy conversion	Combustion N_2 fixation	N_2	7.4.3.1
Rest of the world	RW	EF.EC	Energy conversion	Fuel import	N_{mix}	1.4.2.6
	RW	EF.TR	Transport	Import of transport fuel	N_{mix}	1.4.2.6

1.3.2 Sub-pool "energy conversion" (EC)

This sub-pool comprises all domestic heat and electricity production. Fuel production processes (e.g. refining of petroleum, manufacturing of solid fuels) is also accounted for in this sub-pool. Furthermore, emissions from flaring processes and fugitive emissions from fuels are also covered in the pool "energy and fuels".

Excluded are waste incineration plants, which are included in the sub-pool "solid waste" in pool „processing of residues" (Annex 5, Chapter 5) and biofuel production, which is accounted for in the sub-pool "biofuel production and composting" and pool "agriculture" (Annex 3, Chapter 3).

Oil refining: Oil represents the most important source of energy in Europe. About 94 % of the fuels required for transport originated from oil products. In 2012, there were 655 refineries worldwide, with a total capacity of around 4,400 million t / yr (JRC 2015). The oil industry uses a wide range of processes. Petroleum refining processes require a large amount of thermal energy, which is obtained by burning different fuels. As part of the technological processes at the refinery, there are three main categories that are relevant for the pool "energy and fuels":

- Separation processes of crude oil into boiling fractions. The main amount of reactive nitrogen is released when fuel is burned. A small amount of reactive nitrogen can also be formed when the crude oil and its fractions are heated;
- Oil processing processes stabilize and improve petroleum products. Undesirable elements, such as nitrogen, are removed from the intermediates. In the industry, the hydrotreating method is mainly used. At the hydrotreatment stage, nitrogen is released from the oil fractions in the reactive form (ammonia). The obtained purified products are sent to other pools for use or to the next stage of processing;
- Deasphalting is used to separate asphalt from other products. The basic source of bitumen or asphalt is the residue remaining after vacuum distillation of crude. Asphalt is sent to the pool "material and products in industry" (MP), where it is used to create pavements. Asphalt contains the residues quantity of nitrogen, which can form reactive nitrogen when heated. The flow of nitrogen contained in the asphalt is described here as part of the pool EF.

When constructing the nitrogen budget of the pool "energy and fuels", it is necessary to consider reactive nitrogen released during fuel combustion processes (N_2O, NO_x) as described in the IPCC Guidelines for National Greenhouse Gas Inventories and the EMEP EEA Guidebook 2013, 2016, 2023 for air pollutants.

In addition, emissions of ammonia (NH_3) result from an incomplete reaction of NH_3 additive in NO_x abatement systems, i.e. selective catalytic and non-catalytic reduction (SCR and SNCR). These emissions also need to be accounted for in the NNB (JRC 2015). The Tier 2 methodologies described in the EMEP EEA Guidebook 2013, 2016, 2023 account also for emissions from application of abatement technologies, such as SCR and SNCR. Therefore, when using the data from the national greenhouse gas inventories or air pollutant inventories for the NNB, these abatement techniques are likely to be already accounted for if a country applies Tier 2 methods in their inventories.

1.3.3 Sub-pool "manufacturing industries and construction" (IC)

This sub-pool accounts for all fuel combustion processes in the manufacturing industry and construction sector, such as iron and steel production, non-ferrous metal industry, chemical industry, pulp and paper production, food processing and production of non-metallic minerals. Besides stationary combustion, mobile combustion from machinery and vehicles operating on construction sites as well as industrial vehicles are included in this sub-pool.

Note that potential N flows from the manufacturing industry that are not related to fuel combustion activities, are reported in the pool "materials and products in industry".

1.3.4 Sub-pool "transport" (TR)

This sub-pool covers all fuel combustion activities within the transport sector. This includes road and rail transport as well as shipping and aviation. Pipeline transport is also included in this sub-pool.

In line with the guidelines of the UN Climate Convention, N flows related to international aviation and navigation are not included in the sub-pool "transport". It is possible to apply the same methods also to quantify N flows from international transport and these N flows can be included optionally. However, they need to be excluded when comparing the NNB with other countries, since by default international transport is excluded.

1.3.5 Sub-pool "other energy and fuels" (OE)

This sub-pool accounts for all energy combustion activities that are not already covered in one of the other sub-pools. The most important activity is stationary fuel combustion in the residential and commercial sector. Furthermore, this sub-pool includes fuel combustion of mobile sources, such as off-road vehicles and other machinery used in the commercial and residential sector (i.e. household devices and gardening equipment) as well as fuel combustion processes in the agriculture, forestry and fishing sector.

1.4 Quantification of flows

1.4.1 Quantification of emissions to the atmosphere

The relevant fuel combustion processes and related emission factors of air pollutants and greenhouse gases are documented in the EMEP/EEA Guidebook (EEA 2013, 2016, 2023) and in the IPCC 2006 Guidelines (IPCC 2006, 2019) respectively. Both guidance documents provide a nomenclature for reporting (NFR), which assigns each process to a source category. They also provide a methodology for estimating related emissions. Potentially relevant sources of nitrogen flows to the atmosphere can be identified from existing inventories of greenhouse gas and air pollutant emissions. The following section provides an overview of the relevant source categories.

The emissions of reactive nitrogen compounds can be converted to nitrogen flows by applying the corresponding nitrogen content (Table 3).

$$\begin{aligned} F_{EF.EC-AT} &= \sum_F E_F \cdot f_N \\ F_{EF.IC-AT} &= \sum_F E_F \cdot f_N \\ F_{EF.TR-AT} &= \sum_F E_F \cdot f_N \\ F_{EF.OE-AT} &= \sum_F E_F \cdot f_N \end{aligned} \qquad \text{(Eq. 7)}$$

With:

$F_{EF.EC-AT}$ **$F_{EF.IC-AT}$** **$F_{EF.TR-AT}$** **$F_{EF.OE-AT}$**	N flow due to emissions from combustion of different types of fuel from sub-pools of EF to pool AT	[kt N]
E_F	Emissions of different nitrogen species (NO_x, NH_3, N_2O) and different fuel types F transferred between the sub-pools of EF and pool AT	[kt]

$\mathbf{f_N}$	Nitrogen content of emissions of reactive nitrogen (Table 3)	[% N]

Note on alternative method

If a country does not submit an air pollutant or a greenhouse gas inventory, the corresponding emissions need to be calculated according to the Tier methods described in the EMEP EEA Guidebook (EEA 2013, 2016, 2023) for air pollutants (i.e. NH_3 and NO_x) and IPCC Guidelines (IPCC 2006, 2019) for greenhouse gases (i.e. N_2O). For a Tier 1 approach based on default emission factors, the only data requirement are fuel quantities consumed in each process. For higher Tier methods, additional information on combustion technologies used and application of abatement technologies is required. In addition, higher Tier methods may also require country-specific emission factors.

During combustion of fuels with substantial N content (e.g. coal) and subsequent catalytic denitrification processes, emissions of N_2 are formed. In those cases, the net amount of N_2 emissions from fuel combustion can directly be estimated based on a mass balance using other N flows related to the combustion process, i.e. the input of nitrogen bound to fuels and the emissions of N_r to the atmosphere, as described above. The nitrogen contained in the fuel is partly converted to NO_x emissions and partly to N_2 (denitrification). As both N_r emissions to the atmosphere as well as nitrogen contents of the fuels are available, the resulting N flow related to N_2 emissions can be calculated directly from those N flows (i.e. $N_{2,emission} = N_{fuels} - N_{r,emissions}$). Therefore, the N flows related to N_2 emissions (denitrification) can be calculated as follows (note that for fuels with low N content, such as natural gas, these N flows do not occur, since in this case combustion results in a net input of N_2 from the atmosphere, see Chapter 7.4.3.1):

$$\begin{aligned}
\boldsymbol{F}_{\boldsymbol{EF.EC-AT}} &= \boldsymbol{F}_{\boldsymbol{RW-EF.EC}} - \boldsymbol{F}_{\boldsymbol{EF.EC-AT}} \\
\boldsymbol{F}_{\boldsymbol{EF.IC-AT}} &= \boldsymbol{F}_{\boldsymbol{EF.EC-EF.IC}} - \boldsymbol{F}_{\boldsymbol{EF.IC-AT}} \\
\boldsymbol{F}_{\boldsymbol{EF.TR-AT}} &= \boldsymbol{F}_{\boldsymbol{EF.EC-EF.TR}} - \boldsymbol{F}_{\boldsymbol{EF.TR-AT}} \\
\boldsymbol{F}_{\boldsymbol{EF.OE-AT}} &= \boldsymbol{F}_{\boldsymbol{EF.EC-EF.IC}} - \boldsymbol{F}_{\boldsymbol{EF.OE-AT}}
\end{aligned} \qquad \text{(Eq. 8)}$$

With:

$\mathbf{F_{EF.EC\text{-}AT}}$ $\mathbf{F_{EF.IC\text{-}AT}}$ $\mathbf{F_{EF.TR\text{-}AT}}$ $\mathbf{F_{EF.OE\text{-}AT}}$	**N_2 emissions:** Flow of N_2 from the atmosphere due to nitrogen fixation in the combustion processes in sub-pools of the pool “energy” (i.e. EC, IC, TR, OE)	[t N]
$\boldsymbol{F}_{\boldsymbol{EF.EC-AT}}$ $\boldsymbol{F}_{\boldsymbol{EF.IC-AT}}$ $\boldsymbol{F}_{\boldsymbol{EF.TR-AT}}$ $\boldsymbol{F}_{\boldsymbol{EF.OE-AT}}$	**N_r emissions:** Total emissions of N_r from fuel combustion processes in sub-pool YY (i.e. EF.EC, EF.IC, EF.TR, EF.OE)	[t N]
$\boldsymbol{F}_{\boldsymbol{RW-EF.EC}}$ $\boldsymbol{F}_{\boldsymbol{EF.EC-EF.IC}}$ $\boldsymbol{F}_{\boldsymbol{EF.EC-EF.TR}}$ $\boldsymbol{F}_{\boldsymbol{EF.EC-EF.OE}}$	**N bound to fuel:** Flow of nitrogen bound to fuels, see Chapters 1.4.2.1-1.4.2.3.	[t N]

1.4.1.1.1 Data sources

The estimation of this N_2 emissions is quantified based on information on the following N flows.

- N_r emissions: Total emissions of reactive N from fuel combustion processes in sub-pool EF.EC EF.IC, EF.TR and EF.OE, see Chapter 1.4.1.
- N bound to fuel: Flow of nitrogen bound to fuels, see Chapters 1.4.2.1-1.4.2.3.

1.4.1.2 Emissions from fuel combustion in energy conversion processes (EF.EC-AT)

Fuel combustion in energy conversion processes result in emissions of reactive nitrogen to the atmosphere.

1.4.1.2.1 Data sources

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions[20]
- Emission data for N_2O: UNFCCC National Inventory Submissions[21]

Emission sources relevant for the sub-pool "energy conversion" are provided in the following table. Emissions from source category "1A1a: public electricity and heat production" need to be corrected for the emissions from waste incineration plants, which are accounted for in the pool "processing of residues" (see Chapter 5.4.1). In addition, emissions from fuel combustion during biofuel production processes, which are reported in the pool "agriculture" or the pool "processing of residues", need to be subtracted from this source category (see Chapter 3.4.6.3 and Chapter 5.4.1.1). On the other hand, emissions from combustion of biofuels are accounted for in the sub-pools of the pool EF (i.e. in the sub-pool in which biofuels are consumed).

Table 11: Emission sources to be accounted for in the sub-pool "energy conversion" (EC)

NFR Code	Description
1A1a	Public electricity and heat production
1A1b	Petroleum refining
1A1c	Manufacture of solid fuels and other energy industries
1B1a	Fugitive emission from solid fuels: Coal mining and handling
1B1b	Fugitive emission from solid fuels: Solid fuel transformation
1B1c	Other fugitive emissions from solid fuels
1B2ai	Fugitive emissions oil: Exploration, production, transport

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[20] https://www.ceip.at/

[21] https://unfccc.int/ghg-inventories-annex-i-parties/2024

NFR Code	Description
1B2aiv	Fugitive emissions oil: Refining / storage
1B2av	Distribution of oil products
1B2b	Fugitive emissions from natural gas (exploration, production, processing, transmission, storage, distribution and other)
1B2	Venting and flaring (oil, gas, combined oil and gas)
1B2d	Other fugitive emissions from energy production

1.4.1.3 Emissions from fuel combustion in industrial processes (EF.IC-AT)

Fuel combustion in energy conversion processes result in emissions of reactive nitrogen to the atmosphere.

1.4.1.3.1 Data sources

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions[22]
- Emission data for N_2O: UNFCCC National Inventory Submissions[23]

Emission sources relevant for the sub-pool "manufacturing industry and construction" are provided in the following table.

Table 12: Emission sources to be accounted for in the sub-pool "manufacturing industries and construction" (IC)

NFR Code	Description
1A2a	Stationary combustion in manufacturing industries and construction: Iron and steel
1A2b	Stationary combustion in manufacturing industries and construction: Non-ferrous metals
1A2c	Stationary combustion in manufacturing industries and construction: Chemicals
1A2d	Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print
1A2e	Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco
1A2f	Stationary combustion in manufacturing industries and construction: Non-metallic minerals
1A2gvii	Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)
1A2gviii	Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)

22https://www.ceip.at/https://www.ceip.at/

23https://unfccc.int/ghg-inventories-annex-i-parties/2024https://unfccc.int/ghg-inventories-annex-i-parties/2024

1.4.1.4 Emissions from fuel combustion in transport (EF.TR-AT)

Fuel combustion in the transport sector result in emissions of reactive nitrogen to the atmosphere.

1.4.1.4.1 Data sources

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions[24]
- Emission data for N_2O: UNFCCC National Inventory Submissions[25]

Emission sources relevant for the sub-pool “transport” are provided in the following table.

Table 13: Emission sources to be accounted for in the sub-pool “transport” (TR)

NFR Code	Description
1A3ai(i)	International aviation LTO (civil)
1A3aii(i)	Domestic aviation LTO (civil)
1A3bi	Road transport: Passenger cars
1A3bii	Road transport: Light duty vehicles
1A3biii	Road transport: Heavy duty vehicles and buses
1A3biv	Road transport: Mopeds & motorcycles
1A3bv	Road transport: Gasoline evaporation
1A3bvi	Road transport: Automobile tyre and brake wear
1A3bvii	Road transport: Automobile road abrasion
1A3c	Railways
1A3di(ii)	International inland waterways
1A3dii	National navigation (shipping)
1A3ei	Pipeline transport
1A3eii	Other (please specify in the IIR)

1.4.1.5 Emissions from fuel combustion in other energy processes (EF.OE-AT)

Fuel combustion in processes other than described in Chapters 1.4.1.2 - 1.4.1.4, such as heating of residential buildings and in the commercial sector result in emissions of reactive nitrogen to the atmosphere.

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[24] https://www.ceip.at/https://www.ceip.at/

[25] https://unfccc.int/ghg-inventories-annex-i-parties/2024

1.4.1.5.1 Data sources

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions[26]
- Emission data for N_2O: UNFCCC National Inventory Submissions[27]

Emission sources relevant for the sub-pool "other energy" are provided in the following table.

Table 14: Emission sources to be accounted for in the sub-pool "other energy" (OE)

NFR Code	Description
1A4ai	Commercial/institutional: Stationary
1A4aii	Commercial/institutional: Mobile
1A4bi	Residential: Stationary
1A4bii	Residential: Household and gardening (mobile)
1A4ci	Agriculture/Forestry/Fishing: Stationary
1A4cii	Agriculture/Forestry/Fishing: Off-road vehicles and other machinery
1A4ciii	Agriculture/Forestry/Fishing: National fishing
1A5a	Other stationary (including military)
1A5b	Other, Mobile (including military, land based and recreational boats)

1.4.2 Quantification of nitrogen bound to fuels

N flows related to the transfer of fuels across different (sub-)pools is based on fuel quantities multiplied by a corresponding nitrogen content. Since nitrogen contents vary depending on the fuel type, all relevant types of fuels need to be quantified individually and summed up to derive the total N flow.

$$F_{EF.XX-YY.YY} = \sum_F A_F \cdot f_{Nmix,F} \qquad \text{(Eq. 9)}$$

With:

$F_{EF.EC-EF.IC}$ $F_{EF.EC-EF.TR}$ $F_{EF.EC-EF.OE}$ $F_{EF.EC-MP.OP}$	N flow: Transfer of nitrogen contained in all fuels F from sub-pool EF.XX to any other sub-pool YY.YY	[t N]

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[26] https://www.ceip.at/

[27] https://unfccc.int/ghg-inventories-annex-i-parties/2024

$\mathbf{F_{EF.EC\text{-}RW}}$

$\mathbf{F_{RW\text{-}EF.EC}}$

$\mathbf{A_F}$ Amount of fuel F transferred between the sub-pools [t]

$\mathbf{f_{Nmix,F}}$ Nitrogen content of fuel F quantified as N_{mix}. [% N]

Typical ranges of nitrogen contents of different types of fuels are provided in the following table.

Table 15: Range of N content of different fuels according to the structure of the IPCC Guidelines (IPCC 2006, 2019). Data sources of the different N contents are provided in the last column.

Fuel class	Fuel Type	Nitrogen content in weight %			Data source
		Minimum	Maximum	Average	
Liquid fossil					
Primary fuels	Crude oil	0.02	1.5	0.25	Chempedia 2024, Prado et al. 2017
	Orimulsion	-	-	4.0	Helsinki University of Technology 2017
	Natural gas liquids	-	-	*	-
Secondary fuels	Gasoline	-	-	0	Wielgosiński, G. 2012 (petrol)
	Jet kerosene	-	-	0.1	Flagan et al. 1988
	Other kerosene				
	Shale oil	-	-	*	-
	Gas/diesel oil	-	-	0.0133	Swiss petroleum association 2005
	Residual fuel oil	0.1	0.8	0.45	EEA 2013/2016 (heavy fuel oil)
	Liquefied petroleum gases (LPG)	-	-	*	-
	Ethane	0	0	0	-
	Naphtha	-	-	*	-
	Bitumen	0.2	1.2	0.70	Asphalt Institute 2015
	Lubricants	-	-	*	-
	Petroleum coke	0.6	1.55	1.075	EEA 2013/2016

Fuel class	Fuel Type	Nitrogen content in weight %			Data source
	Refinery feedstocks	-	-	*	**-**
	Other oil	0.005	0.07	0.0375	EEA 2013/2016 (fuel oil)
Other liquid fuel		-	-	*	-
Solid fossil					
Primary fuels	Anthracite	0.2	3.5	1.85	EEA 2013/2016 (hard coal)
	Coking coal	0.57	1.68	1.04	Daishe et al. 2011
	Other bituminous coal	0.5	2.5	1.5	Singh et al. 2023
	Sub-bituminous coal	0.8	1.5	1.15	Singh et al. 2023
	Lignite	0.4	2.5	1.45	EEA 2013/2016
	Oil shale and tar sand	-	-	*	-
Secondary fuels	BKB[28] and patent fuel	-	-	*	-
	Coke oven/gas coke	-	-	12	Wielgosiński, G. 2012
	Coal tar	-	-	1.51	Kershaw et al. 1993
Other solid fossil					
Biomass					
Solid biomass		0.1	0.3	0.2	EEA 2013/2016 (wood)
Liquid biomass		-	-	1	Helsinki University of Technology 2017 (sewage sludge)
Refined biogas		0	0	0	EEA 2013/2016 (natural gas)

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[28] Brown Coal Briquettes

Fuel class	Fuel Type	Nitrogen content in weight %			Data source
Other non-fossil fuels (biogenic waste)		-	-	*	-
Other fuel types					
Gaseous fossil	Natural gas (dry)	0	0	0	EEA 2013/2016
Other gaseous fossil	-	-	*	-	
Waste (non-biomass fraction)		0.3	1.4	0.85	EEA 2013/2016 (waste)
Other fossil fuels	-	-	*	-	
Peat		0.7	3.4	2.05	EEA 2013/2016
Ammonia	-	-	-	82.35	Stochiometry of NH_3

Note on possible simplifications

As the nitrogen content of fuels is small for many types of fuels and since it is chemically bound to the fuel, the quantification is not of high priority. For a simplified NNB the nitrogen bound to fuels can be neglected.

1.4.2.1 Fuel for industry (EF.EC-EF.IC)

1.4.2.1.1 Data sources

Activity data

Amounts of fuel combusted in the industrial sector can be found in the national inventories for greenhouse gases (for relevant emission sources see 1.4.1.3). These inventories provide data on the amount of energy consumed in TJ. To convert these values to kilotons of fuel, the net calorific value (NCV) of the fuel needs to be applied. Default net calorific values (NCVs) and lower and upper limits (95% confidence intervals) can be found in the IPCC Guidelines, Volume 2: Energy, Chapter 1 Introduction, Table 1.2 (IPCC 2016, 2019).

N content

Ranges of nitrogen contents of different types of fuels can be found in Table 15. If no country-specific data are available, it is recommended to assume the average value indicated in Table 15.

1.4.2.2 Fuel for transport (EF.EC-EF.TR)

1.4.2.2.1 Data sources

Activity data

Amounts of fuel combusted in the transport sector can be found in the national inventories for greenhouse gases (for relevant emission sources see 1.4.1.4). These inventories provide data on the amount of energy consumed in TJ. To convert these values to kilotons of fuel, the net calorific value (NCV) of the fuel needs to be applied. Default net calorific values (NCVs) and lower and upper limits (95% confidence intervals) can be found in the IPCC Guidelines, Volume 2: Energy, Chapter 1 Introduction, Table 1.2 (IPCC 2016, 2019).

N content

Ranges of nitrogen contents of different types of fuels can be found in Table 15. If no country-specific data are available, it is recommended to assume the average value indicated in Table 15.

1.4.2.3 Fuel for heating (EF.EC-EF.OE)

1.4.2.3.1 Data sources

Activity data

Amounts of fuel combusted in the residential and commercial sector can be found in the national inventories for greenhouse gases (for relevant emission sources see 1.4.1.5). These inventories provide data on the amount of energy consumed in TJ. To convert these values to kilotons of fuel, the net calorific value (NCV) of the fuel needs to be applied. Default net calorific values (NCVs) and lower and upper limits (95% confidence intervals) can be found in the IPCC Guidelines, Volume 2: Energy, Chapter 1 Introduction, Table 1.2 (IPCC 2016, 2019).

N content

Ranges of nitrogen contents of different types of fuels can be found in Table 15. If no country-specific data are available, it is recommended to assume the average value indicated in Table 15.

1.4.2.4 Fuel used as feedstock (EF.EC-MP.OP)

1.4.2.4.1 Data sources

Activity data

Quantities of fuel used as feedstock in the industry can be found in the national inventories for greenhouse gases[29] (CRF Table “Table1.A(d)”). To convert these values to kilotons of fuel, the net calorific value (NCV) of the fuel needs to be applied. Default net calorific values (NCVs) and lower and upper limits (95% confidence intervals) can be found in the IPCC 2006 Guidelines, Volume 2: Energy, Chapter 1 Introduction, Table 1.2[30]. If data are provided in energy units, they can be converted to mass units by applying net calorific values, which are provided in the IPCC Guidelines for the energy sector (IPCC 2016, 2019).

N content

Ranges of nitrogen contents of different types of fuels can be found in Table 15. If no country-specific data are available, it is recommended to assume the average value indicated in Table 15.

1.4.2.5 Fuel export (EF.EC-RW, EF.TR-RW)

These N flows cover all exports of fuels, including exports of fuel wood. It is assumed that only the sub-pool “energy conversion” exports fuels. With the exception of the transport sector, for

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[29] https://unfccc.int/ghg-inventories-annex-i-parties/2024

[30] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

which a separate N flow is defined for direct export of fuels by cars due to "fuel tourism", which is however of minor relevance and can be neglected.

1.4.2.5.1 Data sources

Activity data

- Total amounts of fuel exported can be found in the national energy statistics or trade statistics[31]. The share of transport fuels imported by fuel tourism needs to be estimated based on country specific data.
- The quantification of fuel wood export is described in Chapter 4.4.4.2.

N content

Ranges of nitrogen contents of different types of fuels can be found in Table 15. If no country-specific data are available, it is recommended to assume the average value indicated in Table 15.

1.4.2.6 Fuel import (RW-EF.EC, RW-EF.TR)

These N flows cover all imports of fuels, including imports of fuel wood. To simplify the number of N flows and since data on imports are often total imports of fuels are not differentiated according to consumers (i.e. industry, households, transport), the total import of fuels based on trade statistics is accounted for in the sub-pool EF.EC. In addition, a separate N flow is defined for direct import of fuels by cars due to "fuel tourism", which is however of minor relevance and can be neglected.

1.4.2.6.1 Data sources

Activity data

- Total amounts of fuel imported can be found in the national energy statistics or trade statistics[32]. The share of transport fuels exported by fuel tourism needs to be estimated based on country specific data.
- The quantification of fuel wood export is described in Chapter 4.4.4.2.

N content

Ranges of nitrogen contents of different types of fuels can be found in Table 15. If no country-specific data are available, it is recommended to assume the average value indicated in Table 15.

1.4.3 Uncertainties

When estimating the uncertainties in the quantification N flows from the pool "energy and fuels" the following should be considered:

- The amount of **energy carries** is generally expected to be well known from national energy balances and from trade statistics. Their N contents show some variability, which may lead to somewhat higher uncertainties in the N flows. But the amount of nitrogen bound to fuels

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[31] https://ec.europa.eu/eurostat/comext/newxtweb/setupdimselection.do

[32] https://ec.europa.eu/eurostat/comext/newxtweb/setupdimselection.do

contributes only a small share of total inputs and outputs to the pool "energy and fuels". Therefore, the uncertainties in the nitrogen bound to fuels is not expected to substantially contribute to total uncertainty of the pool.

- For **emissions of reactive nitrogen to the atmosphere** from energy combustion, uncertainty estimates are provided in the national inventories for greenhouse gases[33] and air pollutants[34] and can be used directly to estimate the corresponding N flows in the NNB.
- Overall, the European Environment Agency assesses the uncertainty in emissions for NO_x and NH_3 as ±20% and ±30% respectively (Pouliot et al. 2015).
- A method for estimating uncertainties based on uncertainty levels is provided in Annex 0, Chapter A.7.

1.5 Quantification of stock changes

Fuels that are stored in the pool "energy and fuels" contain nitrogen. Chances in the amount of stored fuels directly results in a change in the amount of stored nitrogen. To quantify related stock changes, the changes in the stored fuels need to be quantified and multiplied with their nitrogen content (see Chapter 1.4). Most relevant are fuels with high nitrogen contents (e.g. wood and other biomass fuels, coal).

Overall, stock changes in the pool "energy and fuels" are assumed to be of minor relevance, since quantification of input and output flows is expected to be more accurate than quantification of stock changes. Quantification of stock changes is therefore recommended only to check the plausibility of the N budget of the pool EF.

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[33] https://unfccc.int/ghg-inventories-annex-i-parties/2024

[34] https://www.ceip.at/

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1.7 Document Version

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Update of Version 09/2019 by Judith Reutimann, Bettina Schäppi, Sophie Bogler (INFRAS, Zurich).

Reviewers Version 09/2024: Albert Bleeker (albert.bleeker@rivm.nl; Centre for Environmental Quality, National Institute for Public Health and Environment, Bilthoven, Netherlands), Kazuya Nishina (nishina.kazuya@nies.go.jp; Biogeochemical Cycle Modeling and Analysis, Section Earth System Division, Nationale Institute for Environmental Studies, Tsukuba, Japan)

Version 09/2019

Authors Version 09/2019: Bettina Schäppi (bettina.schaeppi@infras.ch), Jürg Heldstab (juerg.heldstab@infras.ch)

Reviewers Version 09/2019: Markus Geupel (UBA, Dessau)

2 Annex 2 – Materials and products in industry (MP)

This Annex defines the pool "material and products in industry" (MP) and its exchanges with other pools in an NNB. The internal structure of pool MP is described with sub-pools and relevant flows between them. The Annex furthermore provides specific guidance on how to calculate relevant N flows related to the MP pool, presenting calculation methods and suggesting possible data sources. It points to information that needs to be provided by and coordinated with other pools. General aspects of nomenclature, definitions and compounds to be covered are being dealt with in the "Annex 0".

2.1 Description of flows to other pools

The pool MP covers industrial processes following the concepts employed by UNFCCC and UNECE for atmospheric emissions (IPCC, 2006, 2019; EEA, 2013, 2016, 2023). Activities described are those of transformation of goods with the purpose of creating a higher-value product to be made available to general economy. Specifically excluded from this pool is combustion of energy carriers, which are being dealt with in pool "energy and fuels" (EF).

Within the pool MP, the Haber-Bosch ammonia synthesis is by far the most important process for the NNB. The process converts inactive N_2 into reactive NH_3, which is then further processed to mineral fertilizer in the form of ammonium nitrates or urea. Globally, ammonia synthesis is the biggest N flow that is induced by anthropogenic activities. The produced fertilizers are crucial to sustain agricultural productivity on a global level. N_2 fixation by other industrial processes (e.g. synthesis of calcium cyanamides) plays a minor role in comparison to the scale of the Haber-Bosch process; as does the rest of chemical industry involving N. For these other industrial processes, it is also assumed that nitrogen occurs only in small and irrelevant quantities. While quantification approaches and data sources are lacking, they are assumed to not be sufficiently relevant to be quantified as part of the NNB. However, for certain countries, specific industries may prevail, and make a quantification reasonable. Furthermore, it is worth mentioning that while many individual flows are negligibly small, the sum of such unquantified flows can have an effect on the N balance of the MP pool and results in an imbalance between incoming and outgoing N quantities.

In addition to this key fixation process, N is exchanged with other pools in the form of organic and inorganic nitrogen bound to materials and products. Nitrogen containing raw materials result in flows from the pools "agriculture" (AG; crops and meat), "forests and semi-natural vegetation" (FS; timber), and "hydrosphere" (HY; fish) to the pool MP, where they are processed and transformed into products of higher value. Inputs may also occur from the pool HS, if waste is collected and transferred to recycling processes in the pool MP.

The products are eventually distributed to consumers (pool HS). Most important N flows in terms of nitrogen content and amount are food for humans and feed for animals. These N flows contain nitrogen mostly in form of protein. Additionally, N flows occur in the form of material goods that contain different N species, from fibers to moldable plastics, from dyes to explosives. The nitrogen bound to these goods is generally less reactive as compared to nitrogen bound to food and feed products. It is however still considered to be a flow of reactive nitrogen (see Chapter A.3.2).

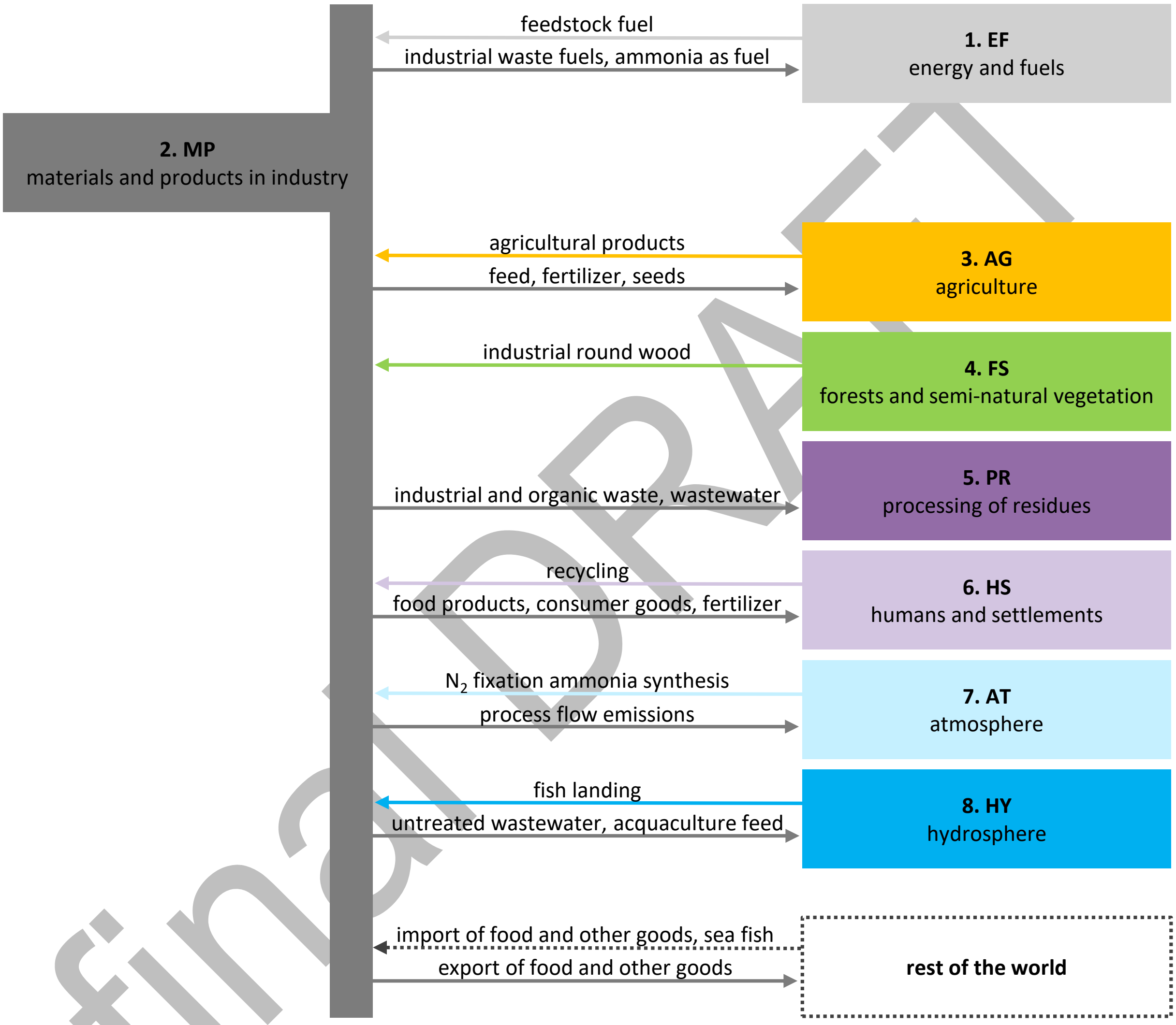
All N flows related to food, feed and materials are relevant beyond a country's borders, meaning the import and export of food, feed and various goods are to be considered for the NNB as well.

Also note that the flow of materials into pool MP for processing and out of it as higher-value products is not always direct, as several intermediate goods circulate within the pool itself. In most cases the N content of incoming N flows (e.g. slaughtered animals) differs from the N content of outgoing N flows (e.g. processed meat).

All industrial activities cause waste. Therefore, several flows of N containing waste are included for the NNB, both to the pool "processing of residues" (PR) and to the pool HY due to runoff of wastewater.

Figure 6 summarizes the most important interactions between the pool MP and other pools.

Figure 6: N flows between pool "materials and products in industry" (MP) and other pools



Source: illustration by INFRAS

2.2 Boundaries and sub-pool definitions

The pool MP consists of all industrial processes that use and produce N containing substances. The boundary of the pool comprises all industrial processes, however only some of them are relevant in terms of the amount of nitrogen that is converted. There are the processes of obtaining targeted N containing substances (e.g. Haber-Bosch ammonia synthesis) and the processes in which N containing substances are participating as a precursor (e.g. food and feed industry). The sources of N for the pool MP are N in atmosphere and N containing organic and inorganic materials and products.

Nitrogen flows related to fuel combustion and oil refining, are accounted for in the pool "energy and fuels" and thus are not covered here.

Since the pool MP integrates a large number of chemical and biological substances and processes that take place inside the pool, a division of the pool MP into two sub-pool is defined (Table 16):

- **Sub-pool "food and feed processing" (MP.FP):** Food processing converts agricultural produce (staple crops, vegetables, slaughtered animal) into products ready for consumption (meat products, processed food). The chemical form of nitrogen will remain unaltered, as protein. Still the N contents will differ between raw material and final products, e.g. due to changes in the protein structures and loss of water after heat treatment etc. These changes need to be considered, together with the amounts of input and product, respectively. This sub-pool also includes wholesale and retail of food and feed products. Even though the nitrogen content is not altered in the trading of products, losses are expected to occur due to food waste (e.g. expiring of products). Therefore, losses to the pool "processing of residues" need to be accounted for. In addition, imports and exports play a major role.

- **Sub-pool "other producing industry" (MP.OP):** This subpool encompasses the production of seven key nitrogen products: ammonia (NH_3), urea (CH_4N_2O), nitric acid (HNO_3), ammonium nitrate (NH_4NO_3), nitrogen solutions, ammonium sulfate ($(NH_4)_2SO_4$) and ammonium phosphates ($(NH_4)_3PO_4$). The cornerstone of this industry is ammonia (Maxwell 2004).

  Traditionally, conversion of nitrogen compounds has been a key element of chemical industry. Production of ammonia (Haber-Bosch synthesis of ammonia from N_2) provides the basis e.g. for urea fertilizer or the production of nitric acid (for fertilizer production, for explosives, or other chemical industry) at a subsequent stage. Ammonia and/or nitrates are used to produce organic compounds used as fibers (polyamids, e.g., Nylon, Perlon) or as dyes. Moldable plastics (e.g. melamine), foams (e.g. polyurethane) or similar polymers often contain nitrogen compounds. Further, ammonia is used as a fuel for shipping and in the industry sector. NH_3 thereby acts as an energy carrier: due to its low energy density it can be used for transporting hydrogen.
  In organic compounds, nitrogen is typically less reactive as compared to other nitrogen species. However, it is still considered to be potentially harmful for the environment. These compounds are therefore also considered as reactive nitrogen. Due to the size of production, a few of the production processes are considered to be of specific importance (e.g. synthesis of ammonia). A recent study revealed that ammonia production plants have considerable fugitive emissions of ammonia (Bertagni et al. 2023).

  Basic chemical materials as produced in the sub-pool MP.OP are often used also in other industries. Nitrogen compounds here are either considered throughput (no change of nitrogen content during the use/integration of materials) or they are split or used up (e.g. by using explosives, or by applying nitric acid). Industries that process nitrogen containing products without altering the form of nitrogen of the raw materials are for example the textile industry or the processing of industrial round wood. Part of the nitrogen may recombine into molecular N_2, while parts may be contained in the end product or released into the environment, e.g. as wastes or atmospheric pollutants.

The sub-pools are specified based on different product treatments and statistical attribution. Regarding emissions to the atmosphere the structure of the sub-pools follows the categories of IPCC (2006, 2019) Guidelines. Regarding the classification of inputs and outputs to industrial processes the NACE classification is applied (see Table 16).

Food and feed related industry (MP.FP) focusses on agricultural products that are processed at a quality level that allows human ingestion or use as feed. Other producing industry (MP.OP) covers fixation of nitrogen from the atmosphere and other chemical processes that involve reactive nitrogen. This sub-pool includes also other processes, which use nitrogen containing raw materials or intermediate goods (textiles, application of dyes, explosives, plastics, etc.).

Table 16: Sub-pools of the pool "materials and products in industry" (MP)

Acronym	Sub-pool	Definition (from EU legislation)
MP.FP	Food and feed processing	**Food and feed processing is covered by codes C10 and C11 within the statistical context of the NACE rev. 2 nomenclature[35]. In addition, wholesale and retail of food and beverages are accounted for in this sub-pool (NACE Code 46 and 47)** **Food processing includes:** - 10.1: Processing and preserving of meat and production of meat products - 10.2: Processing and preserving of fish, crustaceans and molluscs - 10.3: Processing and preserving of fruit and vegetables - 10.4: Manufacture of vegetable and animal oils and fats - 10.5: Manufacture of dairy products - 10.6: Manufacture of grain mill products, starches and starch products - 10.7: Manufacture of bakery and farinaceous products - 10.8: Manufacture of other food products - 11: Manufacture of beverages - 46.2: Wholesale of agricultural raw materials and live animals - 46.3: Wholesale of food, beverages and tobacco - 47.1: Retail sale in non-specialised stores - 47.2: Retail sale of food, beverages and tobacco in specialised stores According to the REGULATION (EC) No 178/2002, Article 2, 'feed' (or 'feedingstuff') means any substance or product, including additives, whether processed, partially processed or unprocessed, intended to be used for oral feeding to animals (EC, 2002). Feed production is included in the following sectors: - 10.91: Manufacture of prepared animal feeds for farm animals - 10.92: Manufacture of prepared animal feeds for pets
MP.OP	Other producing industry	**This sub-pool includes industrial processes which utilize feedstocks and/or products containing various nitrogen species** 13: Manufacture of textiles 14: Manufacture of wearing apparel 15: Manufacture of leather and related products 16: Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials 17: Manufacture of paper and paper products 20.11: Manufacture of industrial gases (e.g.) - Gases, such as ammonia, nitrogen oxide 20.12: Manufacture of dyes and pigments

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[35] https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF

Acronym	Sub-pool	Definition (from EU legislation)
		20.13: Production of organic chemicals, such as: - nitrogenous hydrocarbons such as amines, amides, nitrous compounds, nitro compounds or nitrate compounds, nitriles, cyanates, isocyanates; - Surface-active agents and surfactants 20.14: Production of inorganic chemicals, such as: - acids, such as nitric acid, nitrosylsulfuric acid - bases, ammonium hydroxide, - salts, such as ammonium chloride 20.15: Manufacture of fertilisers and nitrogen compounds 20.16 Manufacture of plastics in primary forms - polymers, synthetic fibers and cellulose-based fibers 20.17: Manufacture of synthetic rubber in primary forms 20.2: Manufacture of pesticides and other agrochemical products 20.5: Manufacture of explosives 21.1: Manufacture of basic pharmaceutical products 41: Construction of residential and non-residential buildings 42: Civil engineering 43: Specialized construction activities

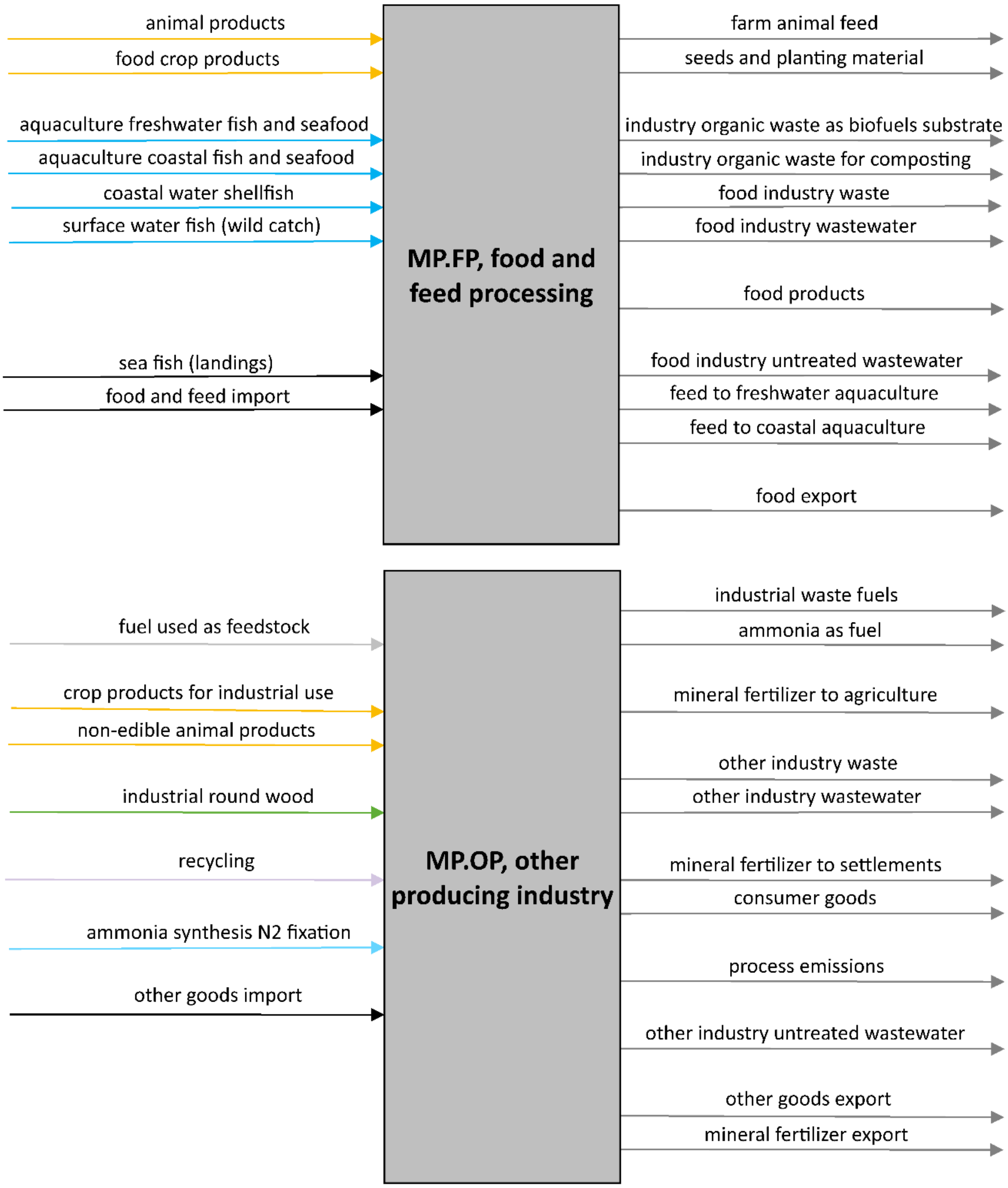
2.3 Pool structure and N flows

2.3.1 Overview of N flows

The pool MP is divided into two sub-pools to structure entering and outgoing N flows between the "food and feed processing" industry (MP.FP) and "other producing industry" (MP.OP). This section provides an overview over all flows involving the pool MP in Table 17 and Table 18 and the flows are visualized in Figure 7.

Chapters 2.3.2 and 2.3.3 discuss the relevant flows for each sub-pool in detail.

Figure 7 : **N flows between the sub-pools of “materials and products in industry” (MP) and other pools**



The arrows characterize the nitrogen flows between the sub-pools. Colours indicate from which pool the flows originate (the colours assigned to the pools can be seen in the overview graphics “n flows between pools”). Stock changes are not depicted. The flow names used in the graph here contain some details for clear identification and can deviate from the flow names given in the table below, because the latter correspond exactly to the flow names given in the Excel-Template for NNBs.

Source: illustration by INFRAS, generated in STAN

Table 17: N flows going out of the pool "materials and products in industry" (MP)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
Food processing	MP.FP	AG.SM	Soil management	Seeds and planting material	Transfer of seeds and seedlings to agricultural soils	N_{mix}	2.4.1.4
	MP.FP	AG.MM	Manure management, storage and animal husbandry	Farm animal feed	Animal feed used in animal husbandry	N_{mix}	2.4.1.2
	MP.FP	PR.SO	Solid waste	Organic waste as biofuels substrate	Industrial food waste used for biofuel production	N_{mix}	2.4.4.3
	MP.FP	PR.SO	Solid waste	Organic waste for composting	Industrial food waste used for composting	N_{mix}	2.4.4.4
	MP.FP	PR.SO	Solid waste	Food industry waste	Industrial food waste transferred to landfills or waste incineration plants	N_{mix}	2.4.2.1
	MP.FP	PR.WW	Wastewater	Food industry wastewater	Wastewater from food industry treated in wastewater treatment plants	N_{mix}	2.4.2.2
	MP.FP	HS	Humans and settlements	Food products	Food products consumed by private households including restautants and pets	N_{mix}	2.4.1.1
	MP.FP	HY.SW	Surface water	Untreated wastewater	Untreated wastewater from food industry transferred to surface waters	N_{mix}	2.4.4.2
	MP.FP	HY.AC	Aquaculture	Feed to coastal aquaculture	feed purchased/supplied to fish in aquaculture (coastal waters)	N_{mix}	8.4.4
	MP.FP	HY.AC	Aquaculture	Feed to freshwater aquaculture	feed purchased/supplied to fish in	N_{mix}	8.4.4

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
					aquaculture fresh water/surface waters)		
	MP.FP	RW	Rest of the world	Food export	Export of food products	N_{mix}	2.4.1.5
Other producing industry	MP.OP	EF.IC	Manufacturing industries and construction	Industrial waste fuels	Waste from industrial processes that is used for energy production	N_{mix}	2.4.1.6
	MP.OP	EF.TR	Transport	Ammonia as fuel	Ammonia that is used as an alternative fuel for vehicles	NH_3	2.4.4.1
	MP.OP	AG.SM	Soil management	Mineral fertilizer	Mineral fertilizer applied on agricultural soils	N_{mix}	2.4.1.5
	MP.OP	PR.SO	Solid waste	Other industry waste	Other industrial waste transferred to landfills or waste incineration plants	N_{mix}	2.4.2.1
	MP.OP	PR.WW	Wastewater	Other industry wastewater	Other industrial waste treated in wastewater treatment plants	N_{mix}	2.4.2.2
	MP.OP	HS	Humans and settlements	Mineral fertilizer	Mineral fertilizer used in private gardens and public green spaces	N_{mix}	2.4.1.6
	MP.OP	HS	Humans and settlements	Consumer goods	Other products consumed by private households	N_{mix}	2.4.1.3
	MP.OP	AT	Atmosphere	Emissions	Emissions of reactive nitrogen from other industry	NH_3 NO_x N_2O	2.4.3.1
	MP.OP	HY.SW	Surface water	Untreated wastewater	Untreated wastewater from other industry transferred to surface waters	N_{mix}	2.4.4.2

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
	MP.OP	RW	Rest of the world	Mineral fertilizer export	Export of mineral fertilizer	N_{mix}	2.4.1.8
	MP.OP	RW	Rest of the world	Other goods export	Export of other goods	N_{mix}	2.4.1.5

The following table shows the N flows entering the pool “materials and products in industry”. They are described in the Annexes of the pools from which these N flows originate.

Table 18: N flows entering the pool “materials and products in industry” (MP)

Sub-Pool Out	Out	In	Sub-Pool in	Flow Name	Species	Chapter
Energy conversion	EF.EC	MP.OP	Other producing industry	Fuel used as feedstock	N_{mix}	1.4.2.4
Soil management	AG.SM	MP.FP	Food and feed processing	Food crop products	N_{mix}	3.4.2.2
	AG.SM	MP.OP	Other producing industry	Crop products for industrial use	N_{mix}	3.4.2.3
Manure management, storage and animal husbandry	AG.MM	MP.FP	Food and feed processing	Animal products	N_{mix}	3.4.2.6
	AG.MM	MP.OP	Other producing industry	Non-edible animal products	N_{mix}	3.4.2.7
Forests	FS.FO	MP.OP	Other producing industry	Industrial round wood	N_{mix}	4.4.4
Humans and settlements	HS	MP.OP	Other producing industry	Recycling	N_{mix}	6.4.1.3
Atmosphere	AT	MP.OP	Other producing industry	Ammonia synthesis N_2-fixation	N_2	7.4.3.1.1
Surface water	HY.SW	MP.FP	Food and feed processing	Fish (wild catch)	N_{mix}	8.4.4
Aquaculture	HY.AC	MP.FP	Food and feed processing	Freshwater fish and seafood	N_{mix}	8.4.4.
	HY.AC	MP.FP	Food and feed processing	Coastal fish and seafood	N_{mix}	8.4.4.

Sub-Pool Out	Out	In	Sub-Pool in	Flow Name	Species	Chapter
Coastal water	HY.CW	MP.FP	Food and feed processing	Shellfish	N_{mix}	8.4.4.
Rest of the world	RW	MP.OP	Other producing industry	Other goods import	N_{mix}	2.4.1.5
	RW	MP.FP	Food and feed processing	Sea fish (landings)	N_{mix}	8.4.4.
	RW	MP.FP	Food and feed processing	Food import	N_{mix}	2.4.1.5

2.3.2 Sub-pool "food and feed processing" (FP)

Major incoming flows for this sub-pool are all N-flows from raw products that are then processed into food for humans and (compound) feed for animals. The most important source are the agricultural products from domestic production (crops and animal products) and aquaculture (fish landing). Food as well as raw products can also be imported.

Outgoing from this sub-pool are the N-flows from processed food and feed, which go on to consumers in the pool "humans and settlements", to animal husbandry in the pool "agriculture" (pool AG) or are exported. The pool AG also receives seeds and planting material from domestic production and imports in sub-pool MP.FP. Furthermore, several outgoing waste flows need to be considered, since the food and feed industry produces waste. In some countries, the organic fraction of this waste can still find use as a substrate for biofuel production or composting (note that this flow of organic waste is directed to the pool „processing of residues" and treated separately from biofuel production and composting in the pool "agriculture" which is considering only agricultural substrates.).

In this guidance for constructing a NNB, nitrogen from all food and feed products flows from the initial source in pool AG via the pool MP to the final consumers / animal husbandry in pool HS or pool AG. This includes food that is not or only minimally processed in the pool MP, e.g. fresh fruits or vegetables. Food retail is also part of pool MP, therefore food waste from the retail sector is also accounted for in this sub-pool.

2.3.3 Sub-pool "other producing industry" (OP)

This sub-pool includes the flows of all industrial sectors that have N-containing products, but are not related to food.

The central process for this sub-pool is the Haber-Bosch ammonia synthesis, i.e. the fixation of atmospheric N_2 into NH_3. This flow activating N is the major input flow into the sub-pool MP.OP. The process of ammonia production is based on the ammonia synthesis reaction (also referred to as the Haber-Bosch process) of nitrogen (derived from process air) with hydrogen to form anhydrous liquid ammonia. (European Commission 2007; Smil 2001; Haber 1920).

Further input comes from the import of other goods. Namely, N-flows from the industrial sectors "detergents and washing preparations", "textiles, wearing apparel and leather products", and "wood & paper and products thereof" are of interest. Incoming flows for this sub-pool are organic and inorganic raw materials and intermediate goods required for production. The raw materials are provided by the pool AG (crops and non-edible animal products) and pool FS (industrial round wood) and imports from other countries (RW). Also flows from material that can be recycled that is coming from the pool HS enter sub-pool MP.OP for further material use.

The most important outgoing flows is the N in mineral fertilizers that are distributed to agriculture (pool AG) and to a minor extent also to green spaces in human settlements (pool HS). Other goods and products from sub-pool MP.OP are either transferred to the pool humans and settlements or exported to other countries. More outgoing flows of relevance are industrial waste flows, which can partially runoff to surface waters of the pool "hydrosphere" instead of being led to treatment into the pool "processing of residues". Some chemical waste can still be used as fuel and therefore one N waste flow is directed to the pool "energy and fuels". Lastly, the other producing industry produces atmospheric emissions of NO_x, NH_3 and N_2O.

2.4 Quantification of flows

This section provides methods and suggests data sources to calculate the N flows going out of the pool MP. Many flows in the pool MP require information on product quantities and their composition. While even product quantities are not easy to assess (confidentiality issues), estimating nitrogen contents becomes even more difficult on the product level. However, some production statistics exist and may serve as a quantification tool. As it may be difficult or impossible to estimate N content by product categories, it is worthwhile to obtain information on the material composition of products or quantify the production of specific materials and their elemental composition rather than that of the final products.

2.4.1 Quantification of N flows from industrial products

The general method to quantify N flows from industrial products is to multiply the production amount with the N content of the specific product. For the following N flows, several types of products are aggregated in each flow that each have a specific N content (e.g. types of food, types of feed or types of consumer goods). N flows related to the transfer of chemicals from chemical industry to consumers are calculated from the amount of chemical and the N content of the chemical compounds. The N content can often be calculated from the stoichiometry of the chemical compounds or from the total N content of the product, in cases where the product contains a mix of chemicals. For some N flows total amount of nitrogen is directly available from international statistics (e.g. fertilizer statistics of the FAO, national GHG inventories). For other products N contents are provided in Chapter 2.4.5.

The most important N flow results from production, import and export of mineral fertilizer for agricultural purposes. There are other nitrogen containing chemicals, which are however less important in terms of amount and/or nitrogen content.

$$\boldsymbol{F_{MP.XX-YY.ZZ}} = \sum_{i} \boldsymbol{A_i \cdot f_{i,Nmix}} \qquad \text{(Eq. 10)}$$

With:

$\mathbf{F_{MP.XX\text{-}YY.ZZ}}$	N flow due to industrial products being transferred from a sub-pool MP.XX to a destination sub-pool YY.ZZ	[t N]
$\mathbf{A_i}$	Production amount of product i	[t]
$\mathbf{f_{i,\,Nmix}}$	Nitrogen content of product i of reactive nitrogen	[% N]

Note on alternative approach for food and feed products

If the absolute N content of a product group is not available, the N flow can be quantified instead based on the protein content. Proteins have an average N content of 16%[36]. Therefore, the N flow for a specific product group is calculated by multiplying the production amount times the protein content times the factor of 0.16.

2.4.1.1 Food products for humans and pets (MP.FP-HS)

Agricultural products are processed industrially in the sub-pool MP.FP into ingestible goods to be eaten by humans or by pets. This N flow aggregates both human and pet food, including food that is not or only minimally processed.

2.4.1.1.1 Data sources

Activity data

Production statistics for the availability of human food are provided by international databases like FAO statistics on food availability37. This database provides easily accessible and consistent information on protein supply from different food categories (in g/cap/day) for a wide range of countries. Food availability accounts include both domestically produced food as well as imported food. Where available, national statistics can be used instead. Attention must be paid to avoid double counting, for instance when the meat used to produce sausages is also accounted for as raw meat. In general, data on primary equivalents, before extensive processing, is preferable.

For pets, if no statistics are available on the consumption of feed, the total feed intake of each type of pet can be calculated based on the number of animals and daily food intake. National statistics on the number of pets are more readily available. For instance, the European pet food industry association (FEDIAF) provides data on total numbers of pets per country (FEDIAF 2024). The daily food intake for the most popular pets is shown in Table 19.

Table 19: Average daily feed intake of pets and the feed’s protein content

	Average food intake per year (kg)	Protein content in food	Protein intake per year (kg)	N intake per year (kg)
Mouse	1.8	13% [a]	0.24	0.04
Rat	6.4	13% [a]	0.83	0.13
Hamster	3.7	13% [a]	0.47	0.08
Guinea pig	19.2	10%	1.92	0.31
Rabbit	91.3	16%	14.60	2.34
Average small mammals	24.5		3.61	0.58
Cat[b]	73.0	26%	18.98	3.04

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36 https://www.fao.org/4/y5022e/y5022e03.html (24.9.2024)

37 https://www.fao.org/faostat/en/#data/SUA (24.9.2024)

	Average food intake per year (kg)	Protein content in food	Protein intake per year (kg)	N intake per year (kg)
Dog[c]	164.3	18%	29.57	4.73
Ornamental birds[d]	n.a.	10-15%	0.06	0.009
Ornamental fish (Goldfish)	1.5	40%	0.58	0.09
Sources	Weiss et al. 2003, Mette 2011	Hand et al. 2002; Methling & Unshelm 2002, Rühle 2013; Mette 2011; Knauer 2013	Calculated; Knauer 2013	calculated

[a] Calculated as average from guinea pig and rabbit
[b] Assumed average weight of cats: 4 kg
[c] Assumed average weight of dogs: 15 kg
[d] Assumed average weight of ornamental birds: 50 g

N content

- A table of N contents of typical food products is provided in Chapter 2.4.5.
- In more details, the N content of food supply for human consumption is also provided in the FAO food composition database:

  FAO/INFOODS Analytical Food Composition Database Version 2.0 (AnFooD2.0) (Excel: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.fao.org%2Ffileadmin%2Ftemplates%2Ffood_composition%2Fdocuments%2FAnFooD2.0.xlsx&wdOrigin=BROWSELINK)

  "The FAO/INFOODS Analytical Food Composition Database is a global compendium of scrutinized analytical data (without any additional estimations, imputation or calculation of missing values) for commonly consumed foods. It allows food composition database compilers to easily retrieve analytical data of good quality and to incorporate them into their databases (by citing the source). It can also be helpful to assess other analytical data if they are within a reasonable range."
- An overview of food composition databases can be found here: https://www.fao.org/infoods/infoods/tables-and-databases/en/
- For pet feed, Table 19 provides the relevant information based on the average protein content.
- Ertl et al. (2016) provided an estimate of offal (liver, tongue etc.) and blood used as food. They provided information on the percentage of offal or blood of live weight per livestock category as well as the respective protein content, further an estimate of slaughter losses and share of bones etc.

2.4.1.2 Farm animal feed (MP.FP-AG.MM) and feed for aquaculture (MP.FP-HY.AQ (coastal waters), MP.FP-HY.AQ (surface waters))

The N flow "farm animal feed" covers nitrogen contents of animal feed that is produced in the pool "materials and products in industry". The main challenge is the split between domestic production and imports of feed. For some feed products information might be available (such as for compound feed from the feed industry) and some other feed products are not traded (non-marketable feed) and are to 100% from domestic productions. For all other feed products, it is recommended to use trade balances (such as the FAO Food Balance Sheets).

The N flows "feed to aquaculture" covers feed input into coastal aquaculture and feed input to surface/freshwater aquaculture. It is calculated as the amount of feed used by aquaculture multiplied by the N content.

2.4.1.2.1 Data sources

Activity data

There are two approaches for estimating feed intake, i.e., (i) quantifying the intake of offered feed, and (ii) calculating the feed requirements on the basis of animal productivity and literature data. Both approaches should yield similar results and they may be used both for giving insight into the relative accuracy of the estimated feed intake (Oenema et al 2014).

Data on total feed intake is available from FAO food balances:

- https://www.fao.org/faostat/en/#data/FBS [38] (24.9.2024)

N contents

N contents are available from following sources:

- Feedipedia http://www.feedipedia.org/ (24.9.2024)
- Fodder tree database for Europe: https://www.voederbomen.nl/nutritionalvalues/ (24.9.2024)
- Literature (e.g., Lassaletta et al. 2014, FAO 2004)
- Aquaculture N contents: SEPA for regulatory purposes; N.B. SEPA currently (Nov 2021) reviewing approach

2.4.1.3 Consumer goods (MP.OP-HS)

This N flow considers nitrogen containing non-food products that are directed to consumers. Of particular relevance in terms of N content are the following group of sectors:

- detergents and washing preparations
- textiles, wearing apparel and leather products
- wood and paper and products thereof

2.4.1.3.1 Data sources

Activity data

The national consumption can be calculated via the "apparent consumption", based on official statistics (import – export + sold domestic production). If possible, consumption data can also be

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[38] Note: for direct access to this webpage this link needs to be copied and pasted to the browser, otherwiese the website redirects to the main webpage of FAOSTAT. The same holds for other linkts to FAOSTAT throughout this document.

gathered from published data e.g. of industry associations. The following data sources for domestic production amounts can be used:

- domestic production of resources for Textiles, Wearing apparel and Leather products: FAO-Stat Production/Crops (http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E)
    - *query: "Production Quantity" for "Fibre Crops Primary + (Total)" and "Jute & Jute-like Fibres + (Total)"*
      FAO-Stat Production/Livestock Primary
    - *query: "Production Quantity" for "Hair, horse" and "Hides, buffalo, fresh" and "Hides, cattle, fresh" and "Silk-worm cocoons, reelable" and "Skins, furs" and "Skins, goat, fresh" and "Skins, sheep, fresh" and "Skins, sheep, with wool" and "Wool, greasy".*
- domestic production of resources for Wood & Paper and Products thereof: FAO-Stat_Forestry (https://www.fao.org/forestry-fao/statistics/84922/en/).
    - *query: "Production Quantity" for "Industrial Roundwood + (Total)" and "Chips and Particles"* [39]
- domestic production of detergents: National business cycle statistics. Use the domestic sold production volume of cationic surfactants as a representative flow.
- Industry reports published by national industry associations (e.g. paper and pulp industry, wood and wood manufacturing industry, chemical industry) often contain mass flow analyses or information about production amounts, kind of products, waste generation and more.

N contents

N contents of products from the listed sectors are given in Table 24 to Table 25.

2.4.1.4 Seeds and planting material (MP.FP-AG.SM)

Note on possible simplification

The N contribution of seeds and planting material as agricultural input is generally less than 2%[40]. Therefore, if no sufficient data sources can be found, this flow can be neglected for simplification purposes.

The total N input by seeds and planting material applied to agricultural soils is estimated by summing up the application of different seeds multiplied by the N content of each seed or planting material. It is sufficient to consider wheat, other cereals and potatoes, since they account for the majority of the N input by seeds. If no country specific data are available, the

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[39] Values of the FAO-Stat_Forestry are given in m^3. Following conversion-factors can be used: Density of industrial roundwood ~0.65 kg/m^3 (mean value of 48 wood species with a moisture of 13 m%). Density of chips and particles ~0.20 kg/m^3 (0.33 m^3 roundwood gives 1 m^3 wood chips G30 or fine saw-dust on average (Francescato et al. 2008)).

[40] https://ec.europa.eu/eurostat/cache/metadata/en/aei_pr_gnb_esms.html

gross nutrient balances provided by Eurostat can be used to estimate this N flow, as described in the following chapter.

2.4.1.4.1 Data sources

Crop N input by seeds and planting material is part of the Eurostat Gross Nutrient Balance (GNB) reporting, therefore this N flow can be taken directly from the Eurostat database. The relevant agricultural indicator in the database is "Other nutrient inputs: Seeds and planting material" (code: I_OTH_SEED). This database directly provides nutrient inputs to agricultural soils from seeds and planting material in tons of nitrogen.

If no data is available in the GNB reporting, methodologies to assess N inputs by seeds and planting material, possible data sources and coherence with UNFCCC/UNECE guidelines are given in Section 3.11 on the pages 54-56 of the Eurostat GNB handbook (Eurostat 2013).

2.4.1.5 Mineral fertilizer (MP.OP-AG.SM)

This N flow is relevant only in countries that produce mineral fertilizer domestically. For countries without any domestic production this nitrogen flow is not relevant. In those countries, the imported amount of nitrogen is expected to be important (see Chapter 3.4.2.10).

2.4.1.5.1 Data sources

- For countries that report annual GHG inventories under the UNFCCC data on mineral fertilizer application is directly available from the GHG inventory (CRF table Table3.D).
- Data on domestic fertilizer production and use is provided by the FAO statistics "Fertilizers by Nutrient" ("use of domestically produced fertilizer" = "Domestic fertilizer production" - "Export of domestically produced fertilizer"): https://www.fao.org/faostat/en/#data/RFN
- The amount of fertilizer applied in agriculture is assumed to be 98% of total fertilizer production (and imports). 2% of the domestic production are deducted for fertilizers applied to private gardens and public green spaces (Chapter 2.4.1.6).

2.4.1.6 Fertilizer for private gardens and public green spaces (MP.OP-HS)

About 1 to 3 % of total mineral fertilizer is used in private gardens and public green spaces, while the rest is consumed by agriculture (estimate for Austria, Egle et al. 2014). It is suggested to use the mean value of 2%, or adapt this value if possible (i.e., if more appropriate national estimates are available). For simplification reasons it is assumed that the split between domestic production and imports is equal.

$$\boldsymbol{F_{MP.OP-HS}} = \frac{(\boldsymbol{F_{MP.OP-AG.SM}} + \boldsymbol{F_{RW-AG.SM}})}{\mathbf{0.98}} * \mathbf{0.02} \qquad \text{(Eq. 11)}$$

With:

$F_{MP.OP-HS}$	N flow: Transfer of nitrogen in mineral fertilizer from sub-pool MP.OP to the pool HS	[t N]
$F_{MP.OP-AG.SM}$	N flow: Transfer of nitrogen in mineral fertilizer from sub-pool MP.OP to the sub-pool AG.SM (Chapter 2.4.1.5)	[t N]
$F_{RW-AG.SM}$	N flow: Transfer of nitrogen in mineral fertilizer from imports to the sub-pool AG.SM (Chapter 3.4.2.10)	[t N]

2.4.1.6.1 Data sources

This N flow can be quantified in a simplified approach from the N flow of fertilizer to agricultural soils (Chapter 2.4.1.5) and the amount of fertilizer imports (Chapter 3.4.2.10).

If available, national statistics on the domestic use of mineral fertilizers can be consulted for a more precise quantification.

2.4.1.7 Industrial waste fuels (MP.OP-EF.IC)

Some industrial waste is used as fuel for industrial processes (e.g. cement industry). Examples of waste fuels are solvents, waste tyres, plastics and also fuels that contain organic material, e.g. from paper manufacturing, from the wood industry and from the food industry (e.g. animal meal). According to inquiries by EIB (2024) energy recovery and/or incineration in the EU-27 point to 12–18% of municipal waste being converted into refuse derived fuel (RDF) by 2030. The projected conversion of 28% of municipal waste into refuse derived fuel (RDF) corresponds to ~69 million tonnes of out of a projected 246 million tonnes of municipal waste. RDF from commercial and industrial waste are estimated at ~73 million tonnes.

2.4.1.7.1 Data sources

As composition of these waste fuels is very heterogeneous, both amounts and corresponding N contents need to be determined in collaboration with the industries that produce or use these waste fuels.

- Data regarding waste quantities differentiated by type of treatment or disposal can be drawn from the data bases of EUROSTAT, in particular industrial waste this data browser: https://ec.europa.eu/eurostat/databrowser/view/env_wastrt/default/table?lang=en&category=env.env_was.env_wasgt
  It should be noted that the data cannot be clearly differentiated between industrial and municipal waste. The plants are also not specified, as the majority of incineration plants are categorised as plants for energy recovery.

- A major data source for these values is the ABANDA data bank by the State Environmental Agency (LANUV) of the Federal State Northrhine-Westfalia, Germany. https://www.abfallbewertung.org/ipa/abanda/script/lua_db_portal.php?application=abanda&runmode=aida&initform=MK_Auswertemenue
  This data base provides N content data for more than 150 waste types, specified according to the European List of Waste codes) (Data for a relevant selection of waste types are given in the Annex “processing of residues”, Table 50).

2.4.1.8 Import and export of food, feed and other goods (MP.FP-RW, MP.OP-RW, RW-MP.FP, RW-MP.OP)

Goods and materials that are imported for intermediate consumption in the domestic industry or used for final consumption accounted for as incoming N flows to the pool “materials and products in industry”.

Relevant in terms of total nitrogen contents are imports and exports of food products, industrial round wood and wood products, and exports of mineral fertilizers (imports of mineral fertilizers are accounted for in the pool “agriculture”).

Information and data sources to calculate the N flows with import and export of industrial round wood can be found in the Annex FS, Chapter 4.4.4.2.

Information for the calculation of the N flows with sea fish (landings) can be found in Chapter 8.4.4.

2.4.1.8.1 Data sources

Depending on the type of exported or imported product, different statistics are available:

- **Import and export of agricultural products** (MP.FP-RW, RW-MP.FP). Imported and exported quantities of crops and livestock products are provided in the FAO statistics "Crops and livestock products": https://www.fao.org/faostat/en/#data/TCL

  Related nitrogen contents need to be applied, as an approximation. Lassaletta et al (2014) could be a reference for crop N contents.

- **Exports[41] of mineral fertilizer** (MP.OP-RW): Relevant exports of nitrogen may occur in the form of domestically produced mineral fertilizer. Data on exports of mineral fertilizers are provided in the following database: Nitrogen flows related to the export of mineral fertilizer are available from the FAO statistics "Fertilizers by nutrient": https://www.fao.org/faostat/en/#data/RFN

  Data are provided as total amount of nitrogen and can directly be used to quantify this N flow.

- **Export of other goods** (MP.OP-RW, RW-MP.OP): quantities of exported goods are provided in trade statistics, such as the comext database: https://ec.europa.eu/eurostat/comext/newxtweb/.
- Corresponding N contents can be found in Chapter 2.4.5.

2.4.2 Quantification of waste N flows

2.4.2.1 Solid industrial waste (MP.FP-PR.SO, MP.OP-PR.SO)

This N flow covers nitrogen contained in solid waste that is either deposited on landfills or incinerated in waste incineration plants. The method for quantifying this N flow is based on the amount of solid waste and a corresponding nitrogen content.

$$F_{MP.FP-WS.SO} = A_{MP.FP-WS.SO} \cdot f_{Nmix}$$
$$F_{MP.OP-WS.SO} = A_{MP.OP-WS.SO} \cdot f_{Nmix} \qquad \text{(Eq. 12)}$$

With:

$F_{MP.FP-PR.SO}$ **$F_{MP.OP-PR.SO}$**	N flow of industrial solid waste	[kt N]
$A_{MP.FP-PR.SO}$ **$A_{MP.OP-PR.SO}$**	Amount of solid waste from industry (MP.FP, MP.OP) that is incinerated in waste incineration plants (or transferred to landfills).	[kt]

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[41] Imports of mineral fertilizer are accounted for in the pool "agriculture", see Chapter 3.4.2.10.

f_{Nmix}	Nitrogen content of solid industrial waste	[% N]

2.4.2.1.1 Data sources

Activity data

- Amounts of solid waste with relevant nitrogen content need to be determined for each country individually. There are no standardized statistics on industrial wastes. If this N flow is considered to be relevant, amounts of industrial solid waste need to be determined in collaboration with the relevant industries.
- To a certain extent, the EUROSTAT database provides information on quantities of industrial waste. Here, 45 types of waste, some of which are very specific, are categorised by annual volume in the EU MS. Further information can be obtained from the Annex Processing of residues (Chapter 5).

N content

Composition of industrial solid waste is expected to be very heterogeneous. Therefore, no default values are provided. If this N flow is considered to be relevant, N contents need to be determined in collaboration with the relevant industries.

Information on N contents of different types of wastes can be found in the ABANDA data base mentioned above (Chapter 2.4.1.6). Data for a relevant selection of waste types are given in the Annex processing of residues (Chapter 5, Table 50).

2.4.2.2 Industrial wastewater (MP.FP-PR.WW, MP.OP-PR.WW)

This N flow covers nitrogen contained in industrial wastewater that is treated in industrial treatment plants and/or municipal treatment plants[42]. The method for quantifying this N flow is based on the volume of wastewater and a corresponding nitrogen content.

$$\begin{aligned} F_{MP.FP-WS.WW} &= A_{MP.FP-WS.WW} \cdot f_{Nmix} \cdot 10^{-9} \\ F_{MP.OP-WS.WW} &= A_{MP.OP-WS.WW} \cdot f_{Nmix} \cdot 10^{-9} \end{aligned} \qquad \text{(Eq. 13)}$$

With:

$F_{MP.FP-PR.WW}$ **$F_{MP.OP-PR.WW}$**	N flow from industrial wastewater that is treated in wastewater treatment plants	[kt N]
$A_{MP.FP-PR.WW}$ **$A_{MP.OP-PR.WW}$**	Amount of wastewater from industry (MP.FP, MP.OP) that is treated in industrial treatment plants and/or municipal treatment plants	[m³]
f_{Nmix}	Nitrogen content of industrial wastewater	[g/m³]

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[42] Sometimes wastewater is pre-treated in industrial treatment plants before being introduced into the sewage system or discharged to a municipal treatment plants.

2.4.2.2.1 Data sources

Activity data

Amounts of industrial wastewater with relevant nitrogen content need to be determined for each country individually. There are no standardized statistics on industrial wastewater. If this N flow is considered to be relevant, amounts of industrial wastewater need to be determined in collaboration with the relevant industries.

- Vall (2001), a somewhat older source but with direct reference to the EUROSTAT system, provides information on industrial wastewater volumes. This clearly shows that the chemical, the metal, the pulp and paper, the textile and the food industry are the main wastewater-generating branches.
- Current data can be drawn from EUROSTAT data browser at least by specifying generation of industrial wastewater by total industry, mining and quarrying, manufacturing industries and food processing industry: https://ec.europa.eu/eurostat/databrowser/view/env_ww_genv__custom_12952864/default/table?lang=en

N content

- Composition of industrial wastewater is expected to be very heterogeneous. Therefore, no default values are provided. If this N flow is considered to be relevant, N contents need to be determined in collaboration with the relevant industries.
- High N loads are to be expected from food industry (majorly where meat, dairy and poultry products are processed), partly from paper industry (from Kraft mills according to Ashrafi et al. 2015)

2.4.3 Quantification of emissions to the atmosphere

Information of flows of reactive nitrogen to the atmosphere can be taken directly from national inventories on air pollutants and greenhouse gases. The emissions of reactive nitrogen compounds can be converted to nitrogen flows by applying the corresponding nitrogen content (Table 3).

$$F_{MP.OP-AT} = \sum_{I,i} E_{I,i} \cdot f_{N,i} \qquad \text{(Eq. 14)}$$

With:

$F_{MP.OP-AT}$	N flow due to emissions from different industrial processes from sub-pool "other producing industry" to pool AT	[t N]
E_I	Emissions of different nitrogen species (i) (NO_x, NH_3, N_2O) from industrial processes (I) transferred between the sub-pools MP.OP and pool AT	[t]
$f_{N,i}$	Nitrogen content of emissions of reactive nitrogen compound (i) (Table 3)	[% N]

The national inventories provide data on emissions of NO_x, NH_3, and N_2O. If emissions of other organic N-containing compounds—such as N-containing (semi-)volatile organic compounds like nitrous acid—are to be included in the NNB, country-specific data sources must be consulted as there is no standardized database available. These additional emissions must be incorporated into the NNB as additional flows to the atmosphere.

Note on alternative method

If a country does not submit an air pollutant or a greenhouse gas inventory, the corresponding emissions need to be calculated according to the Tier methods described in the EMEP EEA Guidebook (EEA2013, 2016, 2023) for air pollutants (i.e. NH_3 and NO_x) and IPCC Guidelines (IPCC 2006, 2019) for greenhouse gases (i.e. N_2O). For a Tier 1 approach based on default emission factors, the only data requirement are fuel quantities consumed in each process. For higher Tier methods, additional information on combustion technologies used and application of abatement technologies is required. In addition, higher Tier methods may also require country-specific emission factors.

2.4.3.1 Emissions from other producing industry (MP.OP-AT)

This N flow covers emissions from other producing industry, excluding emissions from fuel combustion, which are covered in the pool “energy and fuels” (see Chapter 1).

2.4.3.1.1 Data sources

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions[43]
- Emission data for N_2O: UNFCCC National Inventory Submissions[44]

Emission sources potentially relevant for the sub-pool “other producing industry” are provided in the following table.

Table 20: Emission sources to be accounted for in the sub-pool “other producing industry” (OP)

NFR Code	Description
2B	**Chemical industry**
2A	Mineral industry
2C	Metal industry
2D	Non-energy products from fuels and solvent use
2G	**Other product manufacture and use**
2H	Other

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[43] https://www.ceip.at/

[44] https://unfccc.int/ghg-inventories-annex-i-parties/2024

2.4.4 N flows with specific quantification methods

2.4.4.1 Ammonia as fuel (MP.OP-EF.TR)

Note on possible simplification

This flow is only relevant for countries that produce ammonia that is used as an alternative fuel for transportation.

Otherwise, this flow can be neglected.

Ammonia is increasingly being considered and used as a fuel in a variety of areas due to its potential as a carbon-free energy carrier, e.g. for heavy-duty vehicles or marine shipping.

2.4.4.1.1 Data sources

Activity data

The amounts of ammonia used as fuel need to be determined for each country individually, based on e.g. import/export or transportation statistics.

N content

N content of ammonia can be calculated by use of stoichiometry (see Table 13).

2.4.4.2 Untreated wastewater discharge (MP.FP-HY.SW, MP.OP-HY.SW)

Note on possible simplification

This flow is only relevant for countries where a significant fraction of industrial wastewater containing nitrogen compounds is not directed to treatment plants but instead discharged to the surface water bodies.

Otherwise, this flow can be neglected.

$$\begin{aligned} F_{MP.FP-HY.SW} &= A \cdot f_{Nmix} \cdot 10^{-9} \\ F_{MP.OP-HY.SW} &= A \cdot f_{Nmix} \cdot 10^{-9} \end{aligned} \qquad \text{(Eq. 15)}$$

With:

$F_{MP.FP-HY.SW}$ $F_{MP.OP-HY.SW}$	N flow due to discharge of industrial wastewater to the hydrosphere (HY.SW)	[kt N]
A	Amount of wastewater lost to the hydrosphere	[m^3]
f_{Nmix}	Nitrogen content of wastewater	[g/m^3]

2.4.4.2.1 Data sources

Activity data

If it is expected that relevant amounts of wastewater are lost to the hydrosphere, quantities need to be estimated for each country individually. Generally, a poor data availability is assumed for this N flow.

N content

Nitrogen content of industrial wastewater that is lost to the hydrosphere needs to be determined for each country individually.

2.4.4.3 Organic waste as biofuels substrate (MP.FP-PR.SO)

Note on possible simplification

This flow is only relevant for countries where organic waste is treated separately from other waste and used as biofuel substrate. If this process is not substantially relevant, the flow can be neglected for simplification purposes.

This N flow consists of organic waste from food production and retailers (i.e. food waste from production and retail, including waste from slaughter houses) which is used as substrate in biofuel production.

$$\boldsymbol{F_{MP.FP-WS.SO} = A \cdot f_{Nmix}} \qquad \text{(Eq. 16)}$$

With:

$\mathbf{F_{MP.FP-PR.SO}}$	N flow related to food waste from food industry and retail that is used as substrate for biofuel production (PR.SO)	[kt N]
A	Amount of food waste used in biofuel production	[kt]
$\mathbf{f_{Nmix}}$	Nitrogen content of food waste used as biofuel substrate	[% N]

2.4.4.3.1 Data sources

Acitvity data

- Biofuel can be distinguished between biogas and liquid biofuels. Biofuels based on N containing organic waste are majorly counted to biogas. For liquid biofuels a major waste-based source is used cooking oil (UCO) and animal tallow. Both materials are nearly free from proteins or N containing derivates. Therefore, focus can be laid on biogas substrates.
- Annual reports on national biogas production and feedstock information are published by the European Biogas Association (EBA): https://www.europeanbiogas.eu/eba-statistical-report-2023/ . However, these rather high-priced reports must be purchased.

N content

The waste-based biogas substrates are majorly agricultural residues, such as manure (see Chapter 3.4.4.2) and harvest residues (see Chapter 3.4.2.4), but also municipal organic waste (see Chapter 6.4.1.4), industrial organic waste from food and beverage and sewage sludge[45] (Wouters et al. 2020).

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[45] Sewage sludge is assumed to be of minor relevance for biogas production and is therefore not accounted for as individual N flow from WS.WW to AG.BC. For countries, in which this N flow is relevant, it is recommended to add this N flow in the NNB.

In this N flow industrial organic waste from food and beverage industries and retail is accounted for. For these wastes N content data can be taken from the annexes „processing of residues"(see Table 50) and "agriculture" (see Chapter 3.4.4.1.1).

2.4.4.4 Organic waste for composting (MP.FP-PR.SO)

Note on possible simplification

This flow is only relevant for countries where organic waste is treated separately from other household waste and processed further in composting plants. If this process is not substantially relevant, the flow can be neglected for simplification purposes.

This N flow accounts for food waste from food industry and retail that is recycled as compost. The N flow is calculated on the amount of organic waste from the food processing industry and corresponding nitrogen content.

$$\boldsymbol{F_{MP.FP-WS.SO} = A \cdot f_{Nmix}} \qquad \text{(Eq. 17)}$$

With:

$\mathbf{F_{MP.FP\text{-}PR.SO}}$	N flow related to food waste from food industry and retail that is recycled as compost (PR.SO)	[kt N]
A	Amount of industrial food waste (including food waste from retail) recycled as compost	[kt]
$\mathbf{f_{Nmix}}$	Nitrogen content of industrial food waste recycled as compost	[% N]

2.4.4.4.1 Data sources

Acitvity data

- Volumes of organic waste, separately collected and treated in composting plants can be drawn from EUROSTAT, where also the distribution to several ways of treatment is documented: https://ec.europa.eu/eurostat/databrowser/view/env_wasmun__custom_12954295/default/table?lang=en

N content

- N content data of organic wastes can be taken from the pool „processing of residues"(see Table 50).

2.4.5 Default N contents

Table 21: N content of food groups according to FAO classification (FAOSTAT 2024; N contents from Heldstab et al. 2010, Souci et al., 2008)

Item Code	Item Name / Activity Data	N content (%)	Definition – default composition
Crops – Primary Equivalent			
2617	Apples	0.1%	515 Apples, 518 Juice, apple, single strength, 519 Juice, apple, concentrated
2615	Bananas	0.2%	486 Bananas
2513	Barley	1.7%	44 Barley, 45 Barley, pot, 46 Barley, pearled, 49 Malt, 50 Malt extract; nutrient data only: 47 Bran, barley, 48 Flour, barley and grits
2546	Beans	3.6%	176 Beans, dry
2656	Beer	0.1%	51 Beer of barley
2658	Beverages. Alcoholic	0.0%	634 Beverages, distilled alcoholic
2657	Beverages. Fermented	0.0%	26 Beverages, fermented wheat, 39 Beverages, fermented rice, 66 Beer of maize, 82 Beer of millet, 86 Beer of sorghum, 517 Cider etc
2532	Cassava	0.2%	125 Cassava, 126 Flour, cassava, 127 Tapioca, cassava, 128 Cassava dried, 129 Starch, cassava
2520	Cereals. Other	1.5%	68 Popcorn, 89 Buckwheat, 90 Flour, buckwheat, 92 Quinoa, 94 Fonio, 95 Flour, fonio, 97 Triticale, 98 Flour, triticale, 101 Canary seed, 103 Grain, mixed, 104 Flour, mixed grain, 108 Cereals, nes, 111 Flour, cereals, 113 Cereal preparations, nes; nutrient data only: 91 Bran, buckwheat, 96 Bran, fonio, 99 Bran, triticale, 105 Bran, mixed grains, 112 Bran, cereals nes
2614	Citrus. Other	0.1%	512 Fruit, citrus nes, 513 Juice, citrus, single strength, 514 Juice, citrus, concentrated
2642	Cloves	1.8%	698 Cloves
2633	Cocoa Beans	3.2%	661 Cocoa, beans, 662 Cocoa, paste, 665 Cocoa, powder and cake, 666 Chocolate products nes

Item Code	Item Name / Activity Data	N content (%)	Definition – default composition
2560	Coconuts - Incl Copra	0.7%	249 Coconuts, 250 Coconuts, desiccated, 251 Copra
2630	Coffee	1.8%	656 Coffee, green, 657 Coffee, roasted, 659 Coffee, extracts
2619	Dates	0.3%	577 Dates
2625	Fruits. Other	0.1%	521 Pears, 523 Quinces, 526 Apricots, 527 Apricots, dry, 530 Cherries, sour, 531 Cherries, 534 Peaches and nectarines, 536 Plums and sloes, 537 Plums dried (prunes), 538 Juice, plum, single strength, 539 Juice, plum, concentrated, 541 Fruit, stone nes, 542 Fruit, pome nes, 544 Strawberries, 547 Raspberries, 549 Gooseberries, 550 Currants, 552 Blueberries, 554 Cranberries, 558 Berries nes, 567 Watermelons, 568 Melons, other (inc.cantaloupes), 569 Figs, 570 Figs dried, 571 Mangoes, mangosteens, guavas, 572 Avocados, 583 Juice, mango, 587 Persimmons, 591 Cashewapple, 592 Kiwi fruit, 600 Papayas, 603 Fruit, tropical fresh nes, 604 Fruit, tropical dried nes, 619 Fruit, fresh nes, 620 Fruit, dried nes, 622 Juice, fruit nes, 623 Fruit, prepared nes, 624 Flour, fruit, 625 Fruits, nuts, peel, sugar preserved, 626 Fruit, cooked, homogenized preparations
2613	Grapefruit	0.1%	507 Grapefruit (inc. pomelos), 509 Juice, grapefruit, 510 Juice, grapefruit, concentrated
2620	Grapes	0.1%	560 Grapes, 561 Raisins, 562 Juice, grape, 563 Grapes, must
2556	Groundnuts (Shelled Eq)	4.8%	242 Groundnuts, with shell, 243 Groundnuts, shelled, 246 Groundnuts, prepared, 247 Peanut butter
2612	Lemons. Limes	0.1%	497 Lemons and limes, 498 Juice, lemon, single strength, 499 Juice, lemon, concentrated
2514	Maize	1.3%	56 Maize, 58 Flour, maize, 64 Starch, maize, 846 Feed and meal, gluten; nutrient data only: 57 Germ, maize, 59 Bran, maize, 63 Gluten, maize
2517	Millet	1.5%	79 Millet, 80 Flour, millet; nutrient data only: 81 Bran, millet
2544	Molasses	1.4%	
2551	Nuts	3.2%	216 Brazil nuts, with shell, 217 Cashew nuts, with shell, 220 Chestnut, 221 Almonds, with shell, 222 Walnuts, with shell, 223 Pistachios, 224 Kola nuts, 225 Hazelnuts, with shell, 226 Areca nuts, 229 Brazil nuts, shelled, 230 Cashew nuts, shelled, 231 Almonds shelled, 232 Walnuts, shelled, 233 Hazelnuts, shelled, 234 Nuts, nes, 235 Nuts, prepared (exc. groundnuts)
2516	Oats	1.8%	75 Oats, 76 Oats rolled; nutrient data only: 77 Bran, oats

Item Code	Item Name / Activity Data	N content (%)	Definition – default composition
2570	Oilcrops. Other	3.9%	263 Karite nuts (sheanuts), 265 Castor oil seed, 275 Tung nuts, 277 Jojoba seed, 280 Safflower seed, 296 Poppy seed, 299 Melonseed, 305 Tallowtree seed, 310 Kapok fruit, 311 Kapokseed in shell, 312 Kapokseed shelled, 333 Linseed, 336 Hempseed, 339 Oilseeds nes, 343 Flour, oilseeds
2563	Olives	0.2%	260 Olives, 262 Olives preserved
2602	Onions	0.2%	403 Onions, dry
2611	Oranges. Mandarines	0.1%	490 Oranges, 491 Juice, orange, single strength, 492 Juice, orange, concentrated, 495 Tangerines, mandarins, clementines, satsumas, 496 Juice, tangerine
2547	Peas	3.6%	187 Peas, dry
2640	Pepper	1.8%	687 Pepper (piper spp.)
2641	Pimento	1.8%	689 Chillies and peppers, dry
2618	Pineapples	0.1%	574 Pineapples, 575 Pineapples canned, 576 Juice, pineapple, 580 Juice, pineapple, concentrated
2531	Potatoes	0.3%	116 Potatoes, 117 Flour, potatoes, 118 Potatoes, frozen, 119 Starch, potatoes, 121 Tapioca, potatoes
2549	Pulses. Other	3.6%	181 Broad beans, horse beans, dry, 191 Chick peas, 195 Cow peas, dry, 197 Pigeon peas, 201 Lentils, 203 Bambara beans, 205 Vetches, 210 Lupins, 211 Pulses, nes, 212 Flour, pulses; nutrient data only: 213 Bran, pulses
2805	Rice (Milled Eq.)	1.2%	27 Rice, paddy, 28 Rice, husked, 29 Rice, milled/husked, 31 Rice, milled, 32 Rice, broken, 34 Starch, rice, 38 Flour, rice; nutrient data only: 33 Gluten, rice, 35 Bran, rice
2804	Rice (Paddy Eq.)	1.2%	
2534	Roots. Other	0.3%	135 Yautia (cocoyam), 136 Taro (cocoyam), 149 Roots and tubers, nes, 150 Flour, roots and tubers nes, 151 Roots and tubers dried
2515	Rye	1.7%	71 Rye, 72 Flour, rye; nutrient data only: 73 Bran, rye
2561	Sesameseed	3.9%	289 Sesame seed
2518	Sorghum	1.5%	83 Sorghum, 84 Flour, sorghum; nutrient data only: 85 Bran, sorghum

Item Code	Item Name / Activity Data	N content (%)	Definition – default composition
2555	Soyabeans	6.0%	236 Soybeans, 239 Soya sauce, 240 Soya paste, 241 Soya curd
2645	Spices. Other	1.8%	692 Vanilla, 693 Cinnamon (canella), 702 Nutmeg, mace and cardamoms, 711 Anise, badian, fennel, coriander, 720 Ginger, 723 Spices, nes
2557	Sunflowerseed	3.4%	267 Sunflower seed
2533	Sweet Potatoes	0.3%	122 Sweet potatoes
2635	Tea	1.8%	667 Tea, 671 Mate, 672 Tea, mate extracts
2601	Tomatoes	0.2%	388 Tomatoes, 389 Juice, tomato, concentrated, 390 Juice, tomato, 391 Tomatoes, paste, 392 Tomatoes, peeled
2605	Vegetables. Other	0.3%	358 Cabbages and other brassicas, 366 Artichokes, 367 Asparagus, 372 Lettuce and chicory, 373 Spinach, 378 Cassava leaves, 393 Cauliflowers and broccoli, 394 Pumpkins, squash and gourds, 397 Cucumbers and gherkins, 399 Eggplants (aubergines), 401 Chillies and peppers, green, 402 Onions, shallots, green, 406 Garlic, 407 Leeks, other alliaceous vegetables, 414 Beans, green, 417 Peas, green, 420 Vegetables, leguminous nes, 423 String beans, 426 Carrots and turnips, 430 Okra, 446 Maize, green, 447 Sweet corn frozen, 448 Sweet corn prep or preserved, 449 Mushrooms and truffles, 450 Mushrooms, dried, 451 Mushrooms, canned, 459 Chicory roots, 461 Carobs, 463 Vegetables, fresh nes, 464 Vegetables, dried nes, 465 Vegetables, canned nes, 466 Juice, vegetables nes, 469 Vegetables, dehydrated, 471 Vegetables in vinegar, 472 Vegetables, preserved nes, 473 Vegetables, frozen, 474 Vegetables, temporarily preserved, 475 Vegetables, preserved, frozen, 476 Vegetables, homogenized preparations, 567 Watermelons, 568 Melons, other (inc.cantaloupes), 658 Coffee, substitutes containing coffee
2511	Wheat	2.3%	15 Wheat, 16 Flour, wheat, 18 Macaroni, 20 Bread, 21 Bulgur, 22 Pastry, 23 Starch, wheat, 41 Cereals, breakfast, 110 Wafers; nutrient data only: 17 Bran, wheat, 19 Germ, wheat, 24 Gluten, wheat, 114 Mixes and doughs, 115 Food preparations, flour, malt extract
2655	Wine	0.0%	564 Wine, 565 Vermouths and similar
2535	Yams	0.3%	137 Yams
	Sugars & Sweeteners	0.0%	2542 Sugar (raw equivalent), 2537 Sugar Beet, 2536 Sugar Cane, 2541 Sugar Non-Centrifugal, 2827 Sugar Raw Eq., 2818 Sugar Refined Eq., 2543 Sweeteners – other

Item Code	Item Name / Activity Data	N content (%)	Definition – default composition
	Oils	0.0%	2578 Coconut Oil, 2575 Cottonseed Oil, 2572 Groundnut Oil, 2582 Maize Germ Oil, 2586 Oilcrops Oil – other, 2580 Olive Oil, 2576 Palmkernel Oil, 2577 Palm Oil, 2574 Rape and Mustard Oil, 2581 Ricebran Oil, 2579 Sesameseed Oil, 2571 Soyabean Oil, 2573 Sunflowerseed Oil, etc.
Livestock and Fish – Primary Equivalent			
2769	Aquatic Animals. Others	2.8%	1587 Aqutc Anim F, 1588 Aq A Cured, 1589 Aquatic Animals Meals, 1590 Aq A Prep Ns
2775	Aquatic Plants	4.0%	1594 Aquatic plants, fresh, 1595 Aquatic plants, dried, 1596 Aquatic plants, other preparations
2731	Bovine Meat	2.5%	867 Meat, cattle, 870 Meat, cattle, boneless (beef and veal), 872 Meat, beef, dried, salted, smoked, 873 Meat, extracts, 874 Meat, beef and veal sausages, 875 Meat, beef, preparations, 876 Meat, beef, canned, 877 Meat, homogenized preparations, 947 Meat, buffalo
2740	Butter. Ghee	0.1%	886 Butter, cow milk, 887 Ghee, butteroil of cow milk, 952 Butter, buffalo milk, 953 Ghee, of buffalo milk, 983 Butter and ghee, sheep milk, 1022 Butter of goat mlk
2766	Cephalopods	2.8%	1570 Cephlp Fresh, 1571 Cphlp Frozen, 1572 Cphlp Cured, 1573 Cphlp Canned, 1574 Cphlp Pr nes, 1575 Cphlp Meals
2741	Cheese	4.2%	
2743	Cream	0.5%	885 Cream fresh
2765	Crustaceans	2.8%	1553 Crstaceans F, 1554 Crstc Frozen, 1555 Crstc Cured, 1556 Crstc Canned, 1557 Crstc Pr nes, 1558 Crstc Meals
2762	Demersal Fish	2.8%	1514 Dmrsl Fresh, 1515 Dmrsl Fz Whl, 1516 Dmrsl Fillet, 1517 Dmrsl Fz Flt, 1518 Dmrsl Cured, 1519 Dmrsl Canned, 1520 Dmrsl Pr nes, 1521 Dmrsl Meals
2744	Eggs	1.9%	1062 Eggs, hen, in shell, 1063 Eggs, liquid, 1064 Eggs, dried, 1091 Eggs, other bird, in shell; nutrient data only: 916 Egg albumine
2855	Fish Meal	10.7%	
2761	Freshwater Fish	2.8%	1501 Frwtr Diad F, 1502 Frwtr Fz Whl, 1503 Frwtr Fillet, 1504 Frwtr Fz Flt, 1505 Frwtr Cured, 1506 Frwtr Canned, 1507 Frwtr Pr nes, 1508 Frwtr Meals

Item Code	Item Name / Activity Data	N content (%)	Definition – default composition
2748	Hides & Skins	5.2%	
2745	Honey	0.1%	1182 Honey, natural
2764	Marine Fish. Other	2.8%	1540 Marine nes F, 1541 Marin Fz Whl, 1542 Marin Fillet, 1543 Marin Fz Flt, 1544 Marin Cured, 1545 Marin Canned, 1546 Marin Pr nes, 1547 Marin Meals
2749	Meat Meal	10.7%	
2735	Meat. Other	2.5%	1089 Meat, bird nes, 1097 Meat, horse, 1108 Meat, ass, 1111 Meat, mule, 1127 Meat, camel, 1141 Meat, rabbit, 1151 Meat, other rodents, 1158 Meat, other camelids, 1163 Meat, game, 1164 Meat, dried nes, 1166 Meat, nes, 1172 Meat, nes, preparations, 1176 Snails, not sea
2848	Milk - Excluding Butter	2.1%	882 Milk, whole fresh cow, 888 Milk, skimmed cow, 889 Milk, whole condensed, 890 Whey, condensed, 891 Yoghurt, 892 Yoghurt, concentrated or not, 893 Buttermilk, curdled, acidified milk, 894 Milk, whole evaporated, 895 Milk, skimmed evaporated, 896 Milk, skimmed condensed, 897 Milk, whole dried, 898 Milk, skimmed dried, 899 Milk, dry buttermilk, 900 Whey, dry, 901 Cheese, whole cow milk, 904 Cheese, skimmed cow milk, 905 Whey, cheese, 907 Cheese, processed, 908 Milk, reconstituted, 917 Casein, 951 Milk, whole fresh buffalo, 954 Milk, skimmed buffalo, 955 Cheese, buffalo milk, 982 Milk, whole fresh sheep, 984 Cheese, sheep milk, 985 Milk, skimmed sheep, 1020 Milk, whole fresh goat, 1021 Cheese of goat mlk, 1023 Milk, skimmed goat, 1130 Milk, whole fresh camel; nutrient data only: 903 Whey, fresh, 909 Milk, products of natural constituents nes, 910 Ice cream and edible ice
2738	Milk. Whole	0.5%	
2767	Molluscs. Other	2.8%	1562 Mlluscs Frsh, 1563 Molsc Frozen, 1564 Molsc Cured, 1565 Molsc Canned, 1566 Molsc Meals
2732	Mutton & Goat Meat	2.5%	977 Meat, sheep, 1017 Meat, goat
2736	Offals. Edible	2.5%	868 Offals, edible, cattle, 878 Liver prep., 948 Offals, edible, buffaloes, 978 Offals, sheep,edible, 1018 Offals, edible, goats, 1036 Offals, pigs, edible, 1059 Offals, liver chicken, 1074 Offals, liver geese, 1075 Offals, liver duck, 1081 Offals, liver turkeys, 1098 Offals, horses, 1128 Offals, edible, camels, 1159 Offals, other camelids, 1167 Offals, nes
2763	Pelagic Fish	2.8%	1527 Pelagic Frsh, 1528 Pelgc Fz Whl, 1529 Pelgc Fillet, 1530 Pelgc Fz Flt, 1531 Pelgc Cured, 1532 Pelgc Canned, 1533 Pelgc Pr nes, 1534 Pelgc Meals

Item Code	Item Name / Activity Data	N content (%)	Definition – default composition
2733	Pigmeat	2.2%	1035 Meat, pig, 1038 Meat, pork, 1039 Bacon and ham, 1041 Meat, pig sausages, 1042 Meat, pig, preparations
2734	Poultry Meat	2.6%	1058 Meat, chicken, 1060 Fat, liver prepared (foie gras), 1061 Meat, chicken, canned, 1069 Meat, duck, 1073 Meat, goose and guinea fowl, 1080 Meat, turkey
2742	Whey (dry)	2.0%	
	Fats & Oils	0.0%	2737 Fats, Animals, Raw, 2781 Fish, Body Oil, 2782 Fish, Liver Oil

Table 22: N content for products referring to CPA 2008 Codes and CN Classes.

CN Chapter	CPA 2008 Code C	Description MANUFACTURED PRODUCTS	N [%]
24	12	**Tobacco products**	
		sum of positions	4.0
50 - 67	13, 14	**Textiles and Wearing apparel**	
		Positions outlined to be made of crop fibres[46]	0.2
		Positions outlined to be made of animal hair or animal fibres[47]	15

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[46] Crop fibres: cotton, cellulose, flax, plush, velvet, fleece, chenille. Some positions are outlined to have a content of < 85% plant fibres which is neglected. Neglects are taken into account, since there is no information about the other part of the material (> 15%), which can be of animal, plant or synthetic origin.

[47] Animal hair/ fibres: wool, silk, cashmere, fur, grége, felt. Some positions are outlined to have a content of < 85% of animal fibres, which is neglected. Neglects are taken into account, since there is no information about the other part of the material (> 15%), which can be of animal, plant or synthetic origin.

CN Chapter	CPA 2008 Code C	Description MANUFACTURED PRODUCTS	N [%]
		Positions outlined to be made of Polyamides[48] are included in MP-HS.MW-POLY (Synthetic polymers for product use)	12
41, 42, 43	15	**Leather and related products**	
		Sum of positions	15
44, 45, 46	16	**Wood, products of wood and cork, except furniture; articles of straw and plaiting materials**	
		Sum of positions, excluding: firewood, wood chips, briquettes, pellets, sawdust and charcoal.	0.2
47, 48, 49	17	**Paper and paper products**	
		Sum of positions	0.28
34	20	Chemicals and chemical products (covered by the pool „Industry")	
3402	20.41.32	**Detergents and Washing Preparations**	
34021200	20.41.32	cationic surfactants[49]	2.1
39, 40 and others	22	**Rubber and plastic products** Included in MP-HS.MW-POLY (Synthetic polymers for product use)	
94	31	**Furniture**	
		Positions outlined to be made of wood	0.2

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[48] nylon, PA 66, perlon, PA 6, aramid

[49] mass weight representative calculated basing on an esterquat (quaternary ammonium cations with a relative molecular weight of 648 g/mol).

Table 23: N content and applications of polymers

Synthetic polymers	Chemical structure	Mr (g/mol)	N content (%)	Explanatory notes referring to N content	Applications
Polyamides (PA)					
Perlon (PA 6)	$(C_6H_{11}NO)_n$	113	**12**	calculated	fibres (clothes, carpets), films (packaging), automotive and electronic industry
Nylon (PA 66)	$(C_{12}H_{22}N_2O_2)_n$	226	**12**	calculated	
Polyurethane (PU)	high variance in monomeric composition		**10**	estimated	insulating foams, matresses, automotive parts, building and construction
Melamine/Urea Formaldehyde Resins (MF, MUF, UF)					
MF (melamine formaldehyde)	$(C_7H_{12}N_6)_n$	180	**47**	calculated (N in pure melamine: 66.6 m%)	woody panels, surface coatings for cars, dishes, flame retardants
UF (urea formaldehyde)	$(C_4H_8N_2O)_n$	100	**28**	calculated	Woody panels
Others					
PAN (polyacrylonitrile)	$(C_3H_3N)_n$	53	**26**	calculated	textiles
ABS (acrylonitrile butadiene styrene)	$(C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)_n$	198	**7.1**	calculated	automotive and electronic industry
NBR (nitrile butadiene rubber)	$(C_4H_6)_n(C_3H_3N)_m$	107	**13**	estimated (acrylonitrile amount: 18-50 m%)	sealings, gloves
Polyimide	high variance in monomeric composition		**10**	estimated	electronic industry, coatings
Chitosan	$(C_6H_{13}O_5N)_n$	203	**6.9**	calculated	medical applications, food packaging

Table 24: N content and application of synthetic polymers

Natural polymers	Protein (m%)	N content (m%)	Explanatory notes referring to N content	applications
silk (fibroin, sericin)	>95	**15**	N contents of natural polymers are estimated on the base of 95 m% protein content. N [m%] = protein [m%] * 0.16 Other substances, usually beyond 5 m%, can be carbohydrates, lipids, natural dyes and water.	textiles, wearing apparels
wool, cashmere (keratin)				textiles, wearing apparels
leather (collagen)				textiles, wearing apparels
fur (keratin, collagen)				textiles, wearing apparels
gelatine				coating (color printing papers, photo- papers), pharmaceuticals
collagen				cosmetics
casein				dyes, adhesives
horn, plumes (keratin)				bedding, decoration, trophies, musical instruments

Table 25: N content and application of surfactants

Natural polymers	Protein (m%)	N content (m%)	applications
enyzmes (lipases/proteases/cellulases) (protein)	>95	**15**	cleaning agents
ammonium salts, esterquats, betain, EDTA (ionic)	-	**2.2**[50]	cleaning agents, surfactants in general

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[50] mass weight representative calculated basing on an esterquat (quaternary ammonium cations with a relative molecular weight of 648 g/mol).

2.4.6 Uncertainties

When estimating the uncertainties in the quantification N flows from the pool "materials and products in industry" the following should be considered:

- The amount and composition of **industrial products** is generally expected to be well known. However, uncertainty arises from the fact that the data sources available for quantifying the amounts are not structured in the same way as the data sources available for quantifying N contents.
- Furthermore, there are numerous industrial products that do contain small amounts of nitrogen and a complete quantification of all industrial products would be time consuming. Therefore, it is recommended to focus on the products that exhibit a high N content (e.g. food, feed, mineral fertilizer and other N containing chemicals).
- For industrial **emissions of reactive nitrogen to the atmosphere**, uncertainty estimates are provided in the national inventories for greenhouse gases[51] and air pollutants[52] and can be used directly to estimate the corresponding N flows in the NNB.
- In addition, the need to split the amount of organic waste between composting and biofuel production may lead to additional uncertainties.
- N flows in the form of **industrial waste and wastewater** are highly uncertain, since their composition is heterogeneous and data on amounts of waste might not be available from official statistics.
- A method for estimating uncertainties based on uncertainty levels is provided in Annex 0, Chapter A.7.

2.5 Quantification of stock changes

Nitrogen is stored in products and intermediate goods that are stored in the pool "materials and products in industry". Changes in the amount of stored products directly result in a change in the amount of stored nitrogen. To quantify these stock changes, the changes in the stored products need to be quantified and multiplied with their nitrogen content (see Chapter 2.4). Most relevant are products and intermediate goods with high nitrogen contents (e.g. wood products, food products).

Overall, stock changes in the pool "materials and products in industry" are assumed to be of minor relevance, since quantification of input and output flows is expected to be more accurate than quantification of stock changes. Quantification of stock changes is therefore recommended only to check the plausibility of the N budget of the pool MP.

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[51] https://unfccc.int/ghg-inventories-annex-i-parties/2024

[52] https://www.ceip.at/

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2.7 Document Version

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Update of Version 05/2016 by Judith Reutimann, Bettina Schäppi, Sophie Bogler (INFRAS, Zurich).

Reviewers Version 09/2024: Kazuya Nishina (nishina.kazuya@nies.go.jp, Biogeochemical Cycle Modeling and Analysis Section Earth System Division Nationale Institute for Environmental Studies, Tsukuba, Japan), Kathrin Kaltenegger (kalteneg@iiasa.ac.at, Pollution Management

Research Group, iiasa, Laxenburg, Austria) , Andrea Roskosch (andrea.roskosch@uba.de, Umweltbundesamt, Dessau, Deutschland), Monika Suchowska-Kisielewicz (m.suchowska-kisielewicz@iis.uz.zgora.pl, Institute of Environmental Engineering, University of Zielona Góra, Poland)

Version 05/2016

Authors Version 05/2016: Lidiya Moklyachuk (moklyachuk@ukr.net), Wilfried Winiwarter (winiwarter@iiasa.ac.at), Magdalena Pierer (magdalena.pierer@uni-graz.at), Andrea Schröck (andrea.schroeck@uni-graz.at)

Reviewer Version 05/2016: Markus Geupel (UBA, Dessau)

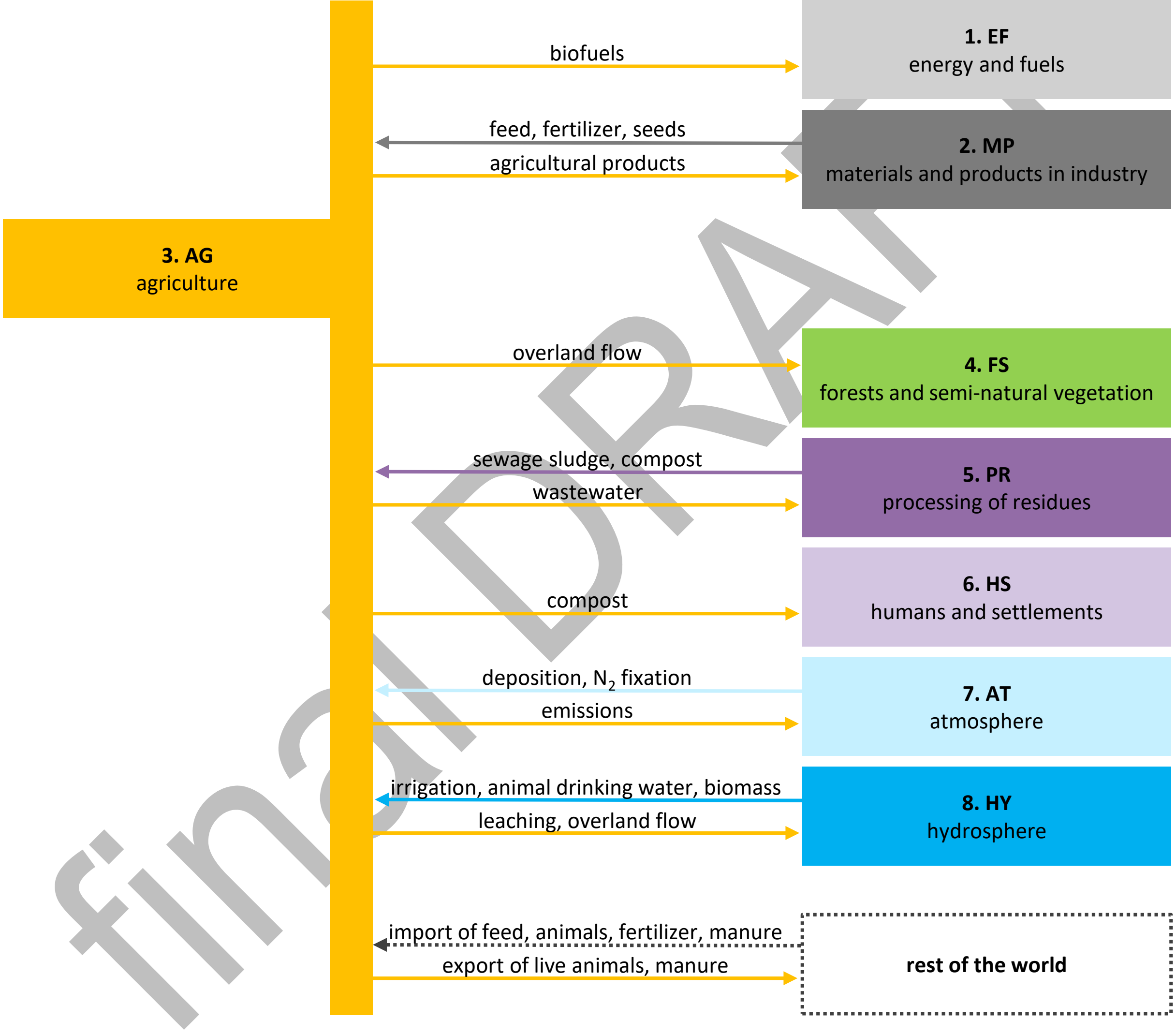
3 Annex 3 – Agriculture (AG)

The pool “agriculture” (AG) is highly relevant for the National Nitrogen Budgets since the biggest N flows within the whole NNBs are nearly always triggered by agriculture. This includes very big N flows between the AG sub-pools and flows between the pool AG and the pool “atmosphere” (AT) and “hydrosphere” (HY).

3.1 Description of flows to other pools

Figure 8 shows how the pool AG interacts with other pools in the NNB.

Figure 8: N flows between pool “agriculture” (AG) and other pools



Source: illustration by INFRAS

The pool AG delivers all agricultural products to the industry (pool “materials and products in industry”, MP), where they are further processed and packaged, before they are brought as foodstuff to consumers in the pool “humans and settlements” (HS) or are used as secondary food products, in feed processing or as non-food products. All trade (retail, wholesale) is part of the pool MP, while consumption of food products occurs in the pool HS. Direct marketing of agricultural products (food and non-food) to the pool “humans and settlements“ (HS) is therefore not included in the structure of this NNB guidance.

Incoming from the industry (pool MP) are animal compound feed, mineral fertilizer as well as seeds and planting material. Besides the national production, feed is often also imported from other countries (pool "rest of the world", RW). Whether feed is represented in two flows depends on whether the data sources allow for a differentiation of feed production within the (national) borders and import. Other exchanges with the pool RW occur via import and export of live animals and manure (dead animals are considered part of agricultural products to the pool MP, even if they are later exported).

For biofuel production in the pool AG, only agricultural products are considered as substrate input (organic waste as substrate e.g. from households is treated in pool "processing of residues"). As an exception, aquatic biomass from the pool "hydrosphere" (HY) is considered as an additional substrate source in certain countries. As output from substrate processing, compost produced in the pool AG is transferred back to the pool HS for use in private and public green spaces.; other outputs like digestate are used within the pool AG itself. Finally, sewage sludge from the pool PR is sometimes used as fertilizer in the pool AG, even though this application is associated with various environmental and health problems and may be banned in certain countries, especially without prior treatment.

N losses to the pool "atmosphere" (AT) and pool HY are flows that disperse to the environment. Small fractions of N emitted to pools AT and HY are returned to agriculture by deposition from the atmosphere or with irrigation and animal drinking water. Biological N_2 fixation delivers new reactive N to the pool AG.

3.2 Boundaries

To describe all N flows within the pool AG and between the pool AG and other pools, the agricultural system of the country is regarded as one "farm" that is representative for all farm activities and associated N flows. The boundary of the pool AG is therefore understood as an "farm gate" including farmland (sub-pool "soil management"), and animal housing and manure storage systems (sub-pool "manure management, storage and animal husbandry"). Biofuel production is also part of the pool AG (sub-pool "biofuel production and composting") since many biofuel production systems are operating exclusively with agricultural products and residues from biofuel production such as digestate from biogas production or extraction meal (rapeseed, sunflower etc.) are used in agriculture for fertilization or as animal feed.

Related to agriculture but outside of the pool AG are processing steps of agricultural products, which are included in the pool MP (slaughterhouses, bakeries, wineries, breweries, etc.).

3.3 Pool structure and N flows

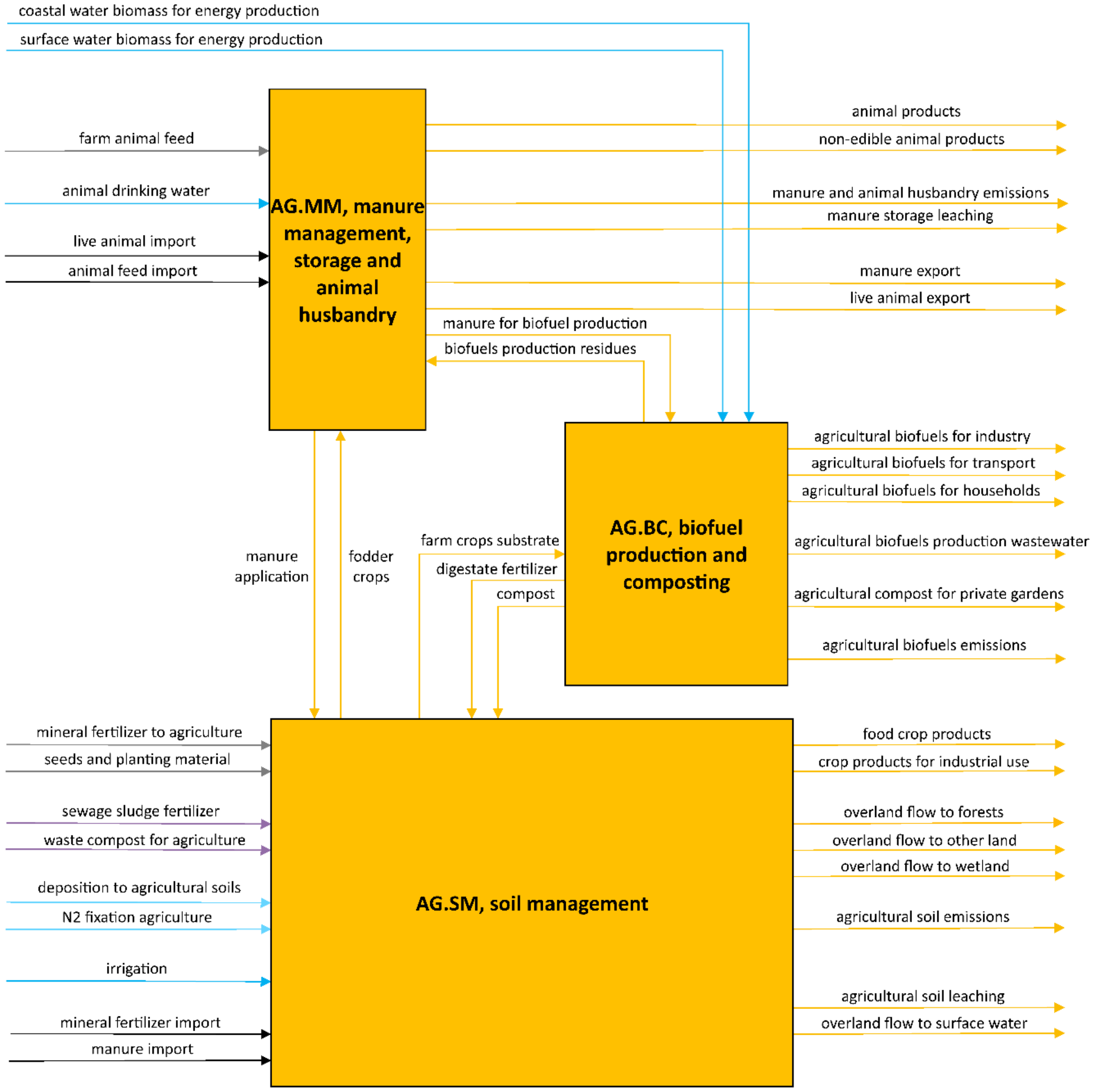
3.3.1 Overview of N flows

Figure 9 shows the pool AG with its sub-pools and all relevant N flows within the pool or from or to other sub-pools. The N flows are further described in Table 26 and Table 27.

The sub-pools of the pool AG are:

- sub-pool "soil management" (AG.SM, Chapter 3.3.2)
- sub-pool „manure management, storage and animal husbandry" (AG.MM, Chapter 3.3.3)
- sub-pool "biofuel production and composting" (AG.BC, Chapter 3.3.4)

Figure 9: N flows between sub-pools of “agriculture” (AG) and other pools



The arrows characterize the nitrogen flows between the sub-pools. Colours indicate from which pool the flows originate (the colours assigned to the pools can be seen in the overview graphics “n flows between pools”). Stock changes are not depicted. The flow names used in the graph here contain some details for clear identification and can deviate from the flow names given in the table below, because the latter correspond exactly to the flow names given in the Excel-Template for NNBs.

Source: illustration by INFRAS, generated in STAN

Table 26: N flows going out of the pool “agriculture” (AG)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
Soil Management	AG.SM	MP.FP	Food processing	Food crop products	Farm crops harvested for the food and feed industry	N_{mix}	3.4.2.2

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
	AG.SM	MP.OP	Other producing industry	Crop products for industrial use	Farm crops harvested for use in industry (starch, oils, fibres)	N_{mix}	3.4.2.3
	AG.SM	AG.MM	Manure management, storage and animal husbandry	Fodder crops	Fodder crops (non-compound feed) from farm production	N_{mix}	3.4.2.5
	AG.SM	AG.BC	Biofuel production and composting	Farm crops substrate	Farm crops used as biofuels substrate	N_{mix}	3.4.2.4
	AG.SM	FS.FO	Forests	Overland flow	Input from agricultural land via runoff, erosion, drainage	N_{mix}	3.4.3.3
	AG.SM	FS.OL	Other land	Overland flow	Input from agricultural land via runoff, erosion, drainage	N_{mix}	3.4.3.3
	AG.SM	FS.WL	Wetland	Overland flow	Input from agricultural land via runoff, erosion, drainage	N_{mix}	3.4.3.3
	AG.SM	AT	Atmosphere	Emissions	Emissions from application of mineral and organic fertilizers and soil cultivation, denitrification	NH_3 NO_x N_2O N_2	3.4.6.2
	AG.SM	HY.GW	Groundwater	Leaching	Leaching from agricultural land	N_{mix}	3.4.3.2
	AG.SM	HY.SW	Surface water	Overland flow	Input from agricultural land via runoff, erosion, drainage	N_{mix}	3.4.3.3
Manure management, storage and animal husbandry	AG.MM	MP.FP	Food processing	Animal products	Farm animal products (meat, milk, eggs) used for food; excluding milk used as feed	N_{mix}	3.4.2.6
	AG.MM	MP.OP	Other producing industry	Non-edible animal products	Other farm animal products (wool, leather)	N_{mix}	3.4.2.7

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
	AG.MM	AG.SM	Soil management	Manure application	Application of manure to agricultural land	N_{mix}	3.4.4.1
	AG.MM	AG.BC	Biofuel production and composting	Manure for biofuel production	Animal excrements used as biofuels substrate	N_{mix}	3.4.4.2
	AG.MM	AT	Atmosphere	Emissions	Emissions from livestock production (incl. manure management)	NH_3 NO_x N_2O	3.4.6.1
	AG.MM	HY.GW	Groundwater	Leaching	Leaching from manure storage	N_{mix}	3.4.3.1
	AG.MM	RW	Rest of the world	Live animal export	Export of live animals	N_{mix}	3.4.2.8
	AG.MM	RW	Rest of the world	Manure export	Export of manure	N_{mix}	3.4.4.3
Biofuel production and composting	AG.BC	EF.IC	Manufacturing industries and construction	Biofuels	Biofuels produced from agricultural substrates	N_{mix}	3.4.5.1
	AG.BC	EF.TR	Transport	Biofuels	Biofuels (biodiesel) produced from agricultural substrates	N_{mix}	3.4.5.1
	AG.BC	EF.OE	Other energy and fuels	Biofuels	Biofuels produced from agricultural substrates	N_{mix}	3.4.5.1
	AG.BC	AG.SM	Soil management	Digestate fertilizer	Digestate used as fertilizer on agricultural land	N_{mix}	3.4.5.1
	AG.BC	AG.SM	Soil management	Compost for agriculture	Compost used on agricultural soils	N_{mix}	3.4.5.3
	AG.BC	AG.MM	Manure management, storage and animal husbandry	Biofuels production residues	Biofuels production residues used as fodder	N_{mix}	3.4.5.4
	AG.BC	PR.WW	Wastewater	Wastewater	Wastewater from biofuel production	N_{mix}	3.4.5.6

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
	AG.BC	HS	Humans and settlements	Compost for private gardens	Compost used in private gardens	N_{mix}	3.4.5.5
	AG.BC	AT	Atmosphere	Emissions	Ammonia, NO_x and N_2O emission from biofuels production	NH_3 NO_x N_2O	3.4.6.3

The following table shows the N flows entering the pool “agriculture”. They are described in the Annexes of the pools from which these N flows originate.

Table 27: N flows entering the pool “agriculture” (AG)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Species	Chapter
Food processing	MP.FP	AG.SM	Soil management	Seeds and planting material	N_{mix}	2.4.1.4
	MP.FP	AG.MM	Manure management, storage and animal husbandry	Farm animal feed	N_{mix}	2.4.1.2
Other producing industry	MP.OP	AG.SM	Soil management	Mineral fertilizer	N_{mix}	2.4.1.5
Solid waste	PR.SO	AG.SM	Soil management	Compost for agriculture	N_{mix}	5.4.4.2
Wastewater	PR.WW	AG.SM	Soil management	Sewage sludge fertilizer	N_{mix}	5.4.6.2
Atmosphere	AT	AG.SM	Soil management	Deposition	OXN RDN	7.4.1
	AT	AG.SM	Soil management	Biological N_2 fixation	N_2	7.4.2
Groundwater	HY.GW	AG.SM	Soil management	Irrigation	N_{mix}	8.4.1.3
	HY.GW	AG.MM	Manure management, storage and animal husbandry	Animal drinking water	N_{mix}	8.4.1.2
Surface water	HY.SW	AG.BC	Biofuel production and composting	Biomass for energy production	N_{mix}	8.4.3.1
Coastal water	HY.CW	AG.BC	Biofuel production and composting	Biomass for energy production	N_{mix}	8.4.3.1

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Species	Chapter
Rest of the world	RW	AG.SM	Soil management	Manure import	N_{mix}	3.4.4.3
	RW	AG.SM	Soil management	Mineral fertilizer import	N_{mix}	3.4.2.10
	RW	AG.MM	Manure management, storage and animal husbandry	Animal feed import	N_{mix}	3.4.2.9
	RW	AG.MM	Manure management, storage and animal husbandry	Live animal import	N_{mix}	3.4.2.8

3.3.2 Sub-pool “soil management” (SM)

The pool consists of agricultural land, the so-called “agricultural area”. According to the Common Agricultural Policy of the European Union (EU 2013, Article 4) “agricultural area” means any area taken up by arable land, permanent grassland and permanent pasture, or permanent crops:

- arable land: land cultivated for crop production or areas available for crop production but lying fallow, including areas set aside, irrespective of whether or not that land is under greenhouses or under fixed or mobile cover;
- permanent crops: non-rotational crops other than permanent grassland and permanent pasture that occupy the land for five years or more and yield repeated harvests, including nurseries and short rotation coppice;
- permanent grassland and permanent pasture (together referred to as permanent grassland: land used to grow grasses or other herbaceous forage naturally (self-seeded) or through cultivation (sown) and that has not been included in a crop rotation for five years or more; it may include other species such as shrubs and/or trees which can be grazed provided that the grasses and other herbaceous forage remain predominant.

3.3.2.1 Description of flows

The sub-pool AG.SM receives mainly N in mineral fertilizer from the pool MP and with manure from the sub-pool “manure management, storage and animal husbandry”; further, there are N inputs with organic fertilizers from sewage sludge from pool WS, as digestate from sub-pool AG.BC and from manure import. Industry also supplies N-containing seed and planting materials to AG.SM. Reactive N is further supplied by biological N_2 fixation, through wet and dry deposition, as well as to a smaller degree with irrigation water. Outgoing N flows from the sub-pool AG.SM to natural systems include emissions to the atmosphere of NH_3, NO_x and N_2O as well as N_2 by denitrification and N flows to the hydrosphere by leaching.

N flows out of AG.SM occur with crop products for fodder, food and other industrial use, emissions to the atmosphere and losses to the hydrosphere via leaching and runoff.

3.3.3 Sub-pool “manure management, storage and animal husbandry” (MM)

The sub-pool is defined by all kinds of animal husbandry and related manure management and storage.

N flows related to animal husbandry depend on the number and type of animals in the country. The animal types that are most used in livestock farming of the country are the relevant ones for the NNB. In most countries dairy and non-dairy cattle, swine and poultry are the most important categories; sheep and goats are also important in some countries.

3.3.3.1 Description of flows

Livestock in the animal husbandry of the pool AG.MM receives N in fodder crops from the sub-pool AG.SM, from industry and the rest of the world. N output occurs with the export of animal products to the “rest of the world” and with delivery of animal products to the industry (pool MP) where they are prepared and processed for retail (including non-consumable parts). Nitrogen in animal manure is introduced into other pools in three ways: First, manure is deposited on agricultural land (AG.SM) by livestock directly (on pasture, range and paddock) during grazing and when farmers deliberately apply manure as fertilizer. Second, manure is used as substrate for energy generation in the sub-pool AG.BC, for example in biogas plants. Third, manure can be exported to another country (RW). Reactive N is emitted from AG.MM as NH_3, NO_x and N_2O; also N is emitted by denitrification and enters the hydrosphere by leaching from manure storage. A probably small input of N to AG.MM comes through animal drinking water.

3.3.4 Sub-pool “biofuel production and composting” (BC)

The sub-pool AG.BC encompasses biofuel production (e.g. production of biofuels for transport or production of biogas) and composting facilities. It comprises not only agricultural facilities, but also industrial biofuel production plants. This sub-pool belongs to the pool AG and not the pool “energy and fuels” (EF), even though the purpose of these types of facilities is energy production. This is because the plants considered here are operated with agricultural products and residues, which is the N-relevant process. Biofuel production from waste substrates supplied by the industry and with organic waste from humans and settlements are treated separately in the pool „processing of residues“(PR).

3.3.4.1 Description of flows

N flows into the sub-pool AG.BC occur with farm crops and animal excrements that are used as biofuels substrates. Outgoing N flows from AG.BC occur with the biofuel used as energy source in the pool EF. Further outgoing flows are digestate used as fertilizer in the sub-pool AG.SM, residues used as feed in the sub-pool AG.MM and with compost used in the pool HS. Also, nitrogen leaves the sub-pool with wastewater and with emissions to the atmosphere.

3.4 Quantification of flows

This section describes calculation methods and data sources that can be used to derive all relevant N flows out of the pool AG.

3.4.1 Overall methodology and existing guidelines

For the pool AG, comprehensive data are collected by national agencies in response to legislation serving global or regional environmental agreements. These data sources introduced below are each applicable to several N flows that enter or exit the pool AG. The following list provides an overview; further details and complementary data sources are described in each flow chapter.

- **Data sources for N flows related to emissions to the atmosphere:**
  - GHG inventories submitted to the UNFCCC: https://unfccc.int/ghg-inventories-annex-i-parties/2024
  - Emission inventories for air pollutants based on the EMEP/EEA air pollutant emission inventory guidebook for countries that are parties to the UN-ECE Convention on Long-Range Boundary Air Pollution (CLRTAP): https://www.ceip.at/
- **Data sources for N flows related to crops and manure:**
  - Where available, data from the **Gross Nutrient Balance (GNB)**[53] **of the Eurostat database** can be directly used for specific N flows[54]. Estimates of the GNB are seen as key agri-environmental indicators (AEI) and are included in the lists of AEIs regularly reported by Eurostat: https://ec.europa.eu/eurostat/databrowser/product/page/AEI_PR_GNB
  - Where no data is available, the Methodology and Handbook, Nutrient Budgets for EU27, NO, and CH published by Eurostat/OECD can be used (Eurostat, https://ec.europa.eu/eurostat/cache/metadata/Annexes/aei_pr_gnb_esms_an_1.pdf). These guidelines give detailed recommendations on the estimation of all flows relevant for the quantification of the gross N budget (also called land N budget). In particular, N flows with a strong link to statistical data sources are discussed in great detail.
- **Data sources for N flows related to animal products, feed and mineral fertilizer**
  - The **FAOSTAT database**, managed by the Food and Agriculture Organization of the United Nations (FAO), is a comprehensive database for global agricultural and environmental statistics (https://www.fao.org/faostat/en/#data). Updated annually, it provides data that can be filtered by country, year, and specific sectors. The database is both useful for obtaining activity data, and in some cases, the data can be directly utilized for the N flows when it is reported in amounts of N.
  - For a number of N flows related to the pool AG, the following statistics of the FAOSTAT database are recommended as useful data sources: “Commodity balances (non-food)”, “Crops and livestock products”, “Fertilizers by nutrient” and “Livestock manure”. The direct links can be found in the respective N flow chapters below.
- **Data sources for N flows related to biofuel production:**
  - For liquid biofuels activity data can be taken from national reporting under the Renewable Energy Directive (EU); the N content depends on the feedstock type, data can be taken from literature dedicated to agricultural practice, direct links can be found in the respective N flow chapters below.

The data quality and level of detail of the comprehensive data sources suggested here depend directly on the input data provided. It is important to note that uncertainty levels and

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[53] http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Gross_nitrogen_balance

[54] Note that the database is updated with a time gap of n+3 years.

completeness may vary, and additional data sources are likely required for the pool AG. Therefore, wherever possible, it is recommended to use country-specific data sources directly.

3.4.2 Quantification for agricultural product N flows

3.4.2.1 Method

Several N flows in the pool AG can be quantified based on the amount of agricultural product being transferred between two pools times the specific nitrogen content of each product. Typically, more than one category of agricultural product is relevant in each of those flows. The total N flow is calculated by summing over all categories (e.g. different crop types).

$$\boldsymbol{F_{AG.XX-YY.YY} = \sum_{P} A_P \cdot C_{Nmix,P}} \qquad \text{(Eq. 18)}$$

With:

$\mathbf{F_{AG.XX\text{-}YY.YY}}$	N flow: Transfer of nitrogen contained in all products P from sub-pool “AG.XX” to any other sub-pool “YY.YY”	[kt N]
$\mathbf{A_P}$	Amount of agricultural product P transferred between the sub-pools “AG.XX” and “YY.YY”	[kt]
$\mathbf{C_{Nmix,P}}$	Nitrogen content of product P quantified as $N_{mix.}$	[% N]

The N flows involving the sub-pool AG.SM are quantified at the level of crop type and their respective N contents. N contents can be obtained from feed databases, either directly or calculated via the content of amino acids or protein.

The N flows involving the sub-pool AG.MM are quantified at the level of livestock types. Which livestock types are relevant for the NNB is country specific. In most countries dairy and non-dairy cattle, swine and poultry are the most important categories; sheep and goats are also important in some countries. The UNFCCC reporting format (CRF), Table 3(I)[55] can be referred to for a complete list of livestock types that could be included and a proposed disaggregation depending on national data availability.

For countries where aquaculture plays a significant role, fish cultivated in aquaculture must be included as separate animal type. Related flows are treated in the sub-pool “aquaculture” of the pool “hydrosphere” (Chapter 8.4.4).

3.4.2.2 Food crop products (AG.SM-MP.FP)

Crop N removal for food products is part of the Eurostat GNB reporting, therefore this N flow can be taken directly from the Eurostat database. The relevant agricultural indicator in the database is “Nutrient removal by harvest of crops” (code: O_CRP). As this is the sum for all crops, nutrient removal by industrial crops and ornamental crops (O_CRP_IND, O_CRP_ORN) must be deducted.

If the GNB is not available, the N flow from harvested crops for food production is estimated by multiplying the crop yield by the N content for each crop (crop removal coefficient) and then

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[55] https://unfccc.int/sites/default/files/set_2_afolu_final.pdf

summing up all N crop yields. If each crop yield is determined based on area as t N per ha, a multiplication by crop cultivation area is needed additionally.

The detailed methodology to assess crop N removal, possible data sources and coherence with UNFCCC/UNECE guidelines are given in Section 3.13 on the pages 44-46 of the Eurostat GNB handbook (Eurostat, 2013). This includes also a reference to which crop types need to be considered. Possible data sources for activity data and N contents are also listed here.

3.4.2.2.1 Data sources

- Eurostat GNB reporting: https://ec.europa.eu/eurostat/databrowser/view/aei_pr_gnb__custom_12642408/default/table?lang=en
- Eurostat GNB handbook (Eurostat, 2013)

Activity data

- Crop production and area: Eurostat Crop Statistics for data on the main crops. https://doi.org/10.2908/APRO_CPSH1
- Crop removal coefficients for N (Ludemann et al., 2023)

  https://datadryad.org/stash/dataset/doi:10.5061/dryad.n2z34tn0x

N contents

- N contents for unprocessed agricultural products can be obtained from feed databases, either directly or calculated via the content of amino acids or protein. To convert the protein content into N content, an average N content of 16%[56] for protein can be applied. More detailed conversion factors for different food types are available from the FAO (https://www.fao.org/4/y5022e/y5022e03.html, see Table 2.1).

$$C_{Nmix,P} = f_{N,protein} * f_{Protein,P} \qquad \text{(Eq. 19)}$$

With:

$C_{Nmix,P}$	Nitrogen content of product P quantified as $N_{mix.}$	[% N]
$f_{N,protein}$	Nitrogen content of protein Default: 0.16	[%]
$f_{Protein,P}$	Protein content of product P	[% of weight]

The crude protein (CP) content for a large selection of crop types can be obtained from the nutritional tables of these data sources:

- Feedipedia (https://www.feedipedia.org/content/feeds?category=All)
- Swiss Feed Database (https://www.feedbase.ch/index.php; column "CP g/kg, dry matter")

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[56] https://www.fao.org/4/y5022e/y5022e03.htm

3.4.2.3 Crop products for industrial use (AG.SM-MP.OP)

This flow covers N removal from crops produced for industry and not for food. This includes e.g. oilseeds to produce biofuels or fiber crops like cotton. Crop N removal for industrial use is part of the Eurostat GNB reporting, therefore this N flow can be taken directly from the Eurostat database. The relevant agricultural indicator in the database is "Nutrient removal by harvest of industrial crops" (code: O_CRP_IND). If no data is available in the GNB reporting, the same approach as for the N flow for food products (AG.SM-MP.FP, Chapter 3.4.2.2) can be followed.

3.4.2.3.1 Data sources

See Chapter 3.4.2.2.1.

3.4.2.4 Farm crops substrate for biofuels productions (AG.SM-AG.BC)

Note on possible simplification

These N flows are only relevant for countries that produce biofuels. If no or only small amounts of biofuel are produced, these flows can be neglected for simplification purposes.

Crops like maize, sugar beet, rye or catch crops can be used as substrate for biofuel production. This N flow is estimated like the N flow from harvested crops for food production based on yield, area and N content (Chapter 3.4.2.2).

3.4.2.4.1 Data sources

Activity data

- For countries with relevant crop cultivation to produce biofuel substrates, national crop statistics can be consulted.

N contents

- See Chapter 3.4.2.2.1.

3.4.2.5 Fodder crops (AG.SM-AG.MM)

This N flow covers N removal with grass and fodder production for livestock feeding. It includes grass from temporary and permanent pasture, as well as fodder plants harvested green (forage, e.g. green maize). This N flow is estimated like the N flow from harvested crops for food production based on yield, area and N contents (Chapter 3.4.3.3.1).

3.4.2.5.1 Data sources

Currently, no data on N removal from fodder crops are available with the GNB reporting of Eurostat. But methodologies to assess possible data sources and coherence with UNFCCC/UNECE guidelines are given in the Eurostat GNB handbook, Section 3.14 on the pages 59-65 (Eurostat, 2013). A short summary is given below.

Activity data

- Fodder from grasslands: Consult national statistics. If no national statistics are available, several approaches to estimate production are suggested in the Eurostat GNB handbook. The areas used for pasture are available from the annual Eurostat's Crop Statistics (Regulation (EC) No 543/2009) for temporary grasses and grazing (area under cultivation) and permanent grassland (main areas, also at regional level: NUTS2, UK and DE at NUTS1).

- Forage: Consult national statistics. If no national statistics are available, production and areas for green maize are available from the annual Eurostat's Crop Statistics.

N contents

- Grass and forage nutrient contents: Default values (in gN/kg fresh weight) that could be used vary between 4.4-10.8 for grass and between 13.6 and 18.1 for maize.
- More detailed N contents can be calculated based on the crude protein contents of various forage types obtained from the Swiss Feed Database (https://www.feedbase.ch/index.php)

3.4.2.6 Animal products (AG.MM-MP.FP)

Animal products are one of the most substantial N flows in the pool "agriculture". Animal products have a high protein content and therefore, their nitrogen content is also high. Data on quantity of primary livestock are expected to be available for most countries, however the nitrogen content of the primary livestock production is difficult to quantify, their nitrogen contents differ from the nitrogen content of processed meat and are not readily available.

3.4.2.6.1 Data sources

Activity data

- Quantities of primary livestock production are provided by the FAO statistics ("Crops and livestock products"): https://www.fao.org/faostat/en/#data/QCL[57]

N content

- Nitrogen contents of primary livestock are listed in Table 28 (Müller et al., 2024). The listed N content is based on the total living weight of the animal (including bones etc.).[58]

Table 28: N contents of animal meat and other animal products (Table 28 from Müller et al., 2024)

Product type		**N content** (in kg N/t meat)
Meat		
Beef and veal	Veal	25
	Ox	25
	Bull	27
	Cow	25
	Heifer	25
Pork		25.6
Sheep and goat meat		26

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[57] Note: for direct access to this webpage this link needs to be copied and pasted to the browser, otherwise the website redirects to the main webpage of FAOSTAT

[58] Note: For processed animal products, the N content may be different than listed here. For these products, data sources for N contents are listed separately in the corresponding flow descriptions that are part of pool MP (e.g. Chapters 2.4.1.1 and 2.4.5).

Product type		**N content** (in kg N/t meat)
Poultry	Chicken	30
	Soup hen	35
	Duck	30
	Goose	30
	Turkey	33
	Other poultry	35
Other meat	Horse	30
	Game	28
	Rabbit	28
Other animal products		
Milk		5.3
Eggs		19

3.4.2.7 Non-edible animal products (AG.MM-MP.OP)

Animal products are not only relevant for food production but also for producing other goods such as fibers for textile production.

3.4.2.7.1 Data sources

Activity data

- Data on domestic production of some non-edible animal products (e.g. wool, silk) are provided by the FAO statistics “Commodity Balances (non-food)”. https://www.fao.org/faostat/en/#data/CB

N contents

- Typical nitrogen contents of non-food animal products can be found in Chapter 2.4.5 or need to be determined from scientific literature.

3.4.2.8 Live animal export and import (AG.MM-RW, RW-AG.MM)

Note on possible simplification

Import and export of live animals does not directly lead to a flow of reactive N. If no statistics are readily available, these flows can be neglected for simplification purposes.

3.4.2.8.1 Data sources

Activity data

- Quantities of imported and exported animals are provided in the following statistics of the FAO “Crops and livestock products” for each country: https://www.fao.org/faostat/en/#data/TCL

N contents

- See Chapter 3.4.2.6.

3.4.2.9 Animal feed export and import (AG.MM-RW, RW-AG.MM)

This N flow covers N import and export of compound feed as well as fodder for livestock feeding. Fodder includes grass from temporary and permanent pasture, as well as fodder plants harvested green (forage, e.g. green maize). This N flow is estimated like the N flow from harvested crops for food production based on yield, area and N contents (Chapter 3.4.2.2).

3.4.2.9.1 Data sources

Activity data

Quantities of imported and exported animal feed are provided in the following statistics of the FAO „Crops and livestock products“ for each country:
https://www.fao.org/faostat/en/#data/TCL

N contents

- For fodder: see Chapter 3.4.2.5.1
- For compound feed: see Chapter 2.4.1.2.1

3.4.2.10 Mineral fertilizer import (RW-AG.SM)

Import of mineral fertilizer is highly relevant for countries that do not produce enough (mineral) fertilizer to fully cover the domestic need.

3.4.2.10.1 Data sources

- Data on nitrogen flows related to the import of mineral fertilizers are provided by the FAO in the statistics “Fertilizers by Nutrient” for each country:
https://www.fao.org/faostat/en/#data/RFN
- The amount of fertilizer applied in agriculture is assumed to be 98% of total fertilizer imports (and domestic production). 2% of the imports are deducted for fertilizers applied to private gardens and public green spaces (Chapter 2.4.1.6).

3.4.3 Quantification for N flows to the hydrosphere and forests and semi-natural vegetation

Losses to the hydrosphere or forests and semi-natural vegetation occur mainly via leaching and overland flow of N contained in manure. The amount of N lost can be estimated based on the amount of N in the manure times a loss factor.

$$
\begin{aligned}
F_{\mathrm{AG.MM-HY.GW}} &= A_{storage} \cdot f_{N,l,storage} \\
F_{\mathrm{AG.SM-HY.GW}} &= A_{soils} \cdot f_{N,l,soils} \\
F_{\mathrm{AG.SM-HY.SW}} &= A_{soils} \cdot f_{N,o,HY.SW} \\
F_{\mathrm{AG.SM-FS.XX}} &= A_{soils} \cdot f_{N,o,FS.XX}
\end{aligned}
\qquad \text{(Eq. 20)}
$$

With:

$F_{\mathrm{AG.MM\text{-}HY.GW}}$ $F_{\mathrm{AG.SM\text{-}HY.GW}}$ $F_{\mathrm{AG.SM\text{-}HY.SW}}$ $F_{\mathrm{AG.SM\text{-}FS.XX}}$	N flow due to leaching and overland flow from manure storage or agricultural soils to groundwater, surface water or a sub-pool of the pool “forests and semi-natural vegetation”, respectively	[kt N]

$A_{storage}$	Amount of manure stored on bare soil	[kt]
A_{soils}	Amount of manure applied to agricultural soils	
$f_{N,l,storage}$	Fraction of leaching of nitrogen from manure stored on bare soil	[% N]
$f_{N,l,soils}$	Fraction of leaching of nitrogen from manure applied to soils	
$f_{N,r,\ HY.SW}$	Fraction of overland flow of nitrogen to the hydrosphere from manure applied to soils	
$f_{N,r,\ FS.XX}$	Fraction of overland flow of nitrogen to a sub-pool of the pool “forests and semi-natural vegetation” from manure applied to soils	

In a first approach, the amount of N from leaching and overland flow is quantified as N_{mix}. The largest fraction of N_{mix} is expected to be N in the form of nitrate, with smaller fractions being N in dissolved organic matter, suspended organic material, or additional inorganic species (see Chapter 4.4.3 for more details).

For losses from manure application, the quantification and separation of leaching and overland flow into the different sub-pools is complex, i.e. determining the loss factors f_N (Eq. 21). Therefore, for the purpose of the NNBs, the first approach is to aggregate the flows and report the processes as one. As leaching is assumed to be the dominant pathway, it is recommended to aggregate all other flows together with this one for simplification. If country-specific data are available to make a distinction, it is recommended to quantify the flows separately.

3.4.3.1 Leaching from manure storage (AG.MM-HY.GW)

When manure heaps are stored on bare soil, the manure can partially dissolve into the soil’s water phase and seep down to the groundwater. The loss fraction depends e.g. on the manure’s age and the amount of rainfall.

Note on possible simplification

Overall, this point source is expected to be of minor relevance. Specifically, it is only relevant for countries where significant amounts of manure are stored on bare soil. If this is not common practice, this flow can be neglected for simplification purposes.

3.4.3.1.1 Data sources

- To quantify this flow, country-specific statistics and/or scientific literature have to be consulted.

3.4.3.2 Leaching from manure application (AG.SM-HY.GW)

Nitrogen from manure applied to agricultural soils partially dissolves in the soil’s water phase, seep downward and eventually enters the groundwater.

3.4.3.2.1 Data sources

- Data on manure applied to soils by leaching is supplied by the FAO statistics “Livestock Manure” by animal category for each country: https://www.fao.org/faostat/en/#data/EMN
- The database directly provides total amount of nitrogen, so no further calculations are required.
- If country specific data are available, the method described above can be applied.

3.4.3.3 Overland flow (AG.SM-HY.SW, AG.SM-FS.FO, AG.SM-FS.WL, AG.SM-FS.OL)

Nitrogen in manure can be carried by wind, rain or irrigation water as surface overland flow from agricultural fields into nearby surface water bodies or vegetation.

Note on possible simplification

In a first approximation it can be assumed that N losses to hydrosphere or forests and semi-natural vegetation occur mainly via leaching. If no country specific data is available on fractions for overland flow of N, the overland flows can be neglected for simplification purposes.

Note on alternative method: In certain countries, the intentional (and potentially illegal) deposition of manure directly into forests and semi-natural vegetation may occur. If data on this practice is available, the resulting N flow can be included in the reporting of these overland flows under AG.SM-FS.XX.

3.4.3.3.1 Data sources

- ► See Chapter 3.4.4.1 for the amount of manure applied to the agricultural soils.
- ► National statistics on N loss factors through overland flow depending on the type of water body or vegetation adjacent to the agricultural fields.

3.4.4 Quantification for N flows in the form of manure

$$\begin{aligned} \boldsymbol{F}_{\mathrm{AG.MM-AG.SM}} &= \boldsymbol{A} \cdot \boldsymbol{f}_{\boldsymbol{N}} \\ \boldsymbol{F}_{\mathrm{AG.MM-AG.BC}} &= \boldsymbol{A} \cdot \boldsymbol{f}_{\boldsymbol{N}} \\ \boldsymbol{F}_{\mathrm{AG.MM-RW}} &= \boldsymbol{A} \cdot \boldsymbol{f}_{\boldsymbol{N}} \\ \boldsymbol{F}_{\mathrm{RW-AG.MM}} &= \boldsymbol{A} \cdot \boldsymbol{f}_{\boldsymbol{N}} \end{aligned} \qquad \text{(Eq. 21)}$$

With:

$\mathbf{F}_{\mathbf{AG.MM\text{-}AG.SM}}$	N flow due to transfer of manure to other pools/sub-pools	[kt N]
$\mathbf{F}_{\mathbf{AG.MM\text{-}AG.BC}}$		
$\mathbf{F}_{\mathbf{AG.MM\text{-}AG.RW}}$		
$\mathbf{F}_{\mathbf{RW\text{-}AG.MM}}$		
A	Amount of manure transferred to other pools/sub-pools and to RW	[kt]
$\mathbf{f}_{\mathbf{N}}$	Nitrogen content of manure	[% N]

3.4.4.1 Manure application (AG.MM-AG.SM)

This nitrogen flow accounts for manure that is transferred to agricultural soils either during application of solid and liquid manure or by grazing animals. Even though the process of grazing actually occurs in the sub-pool “soil management”, the process is accounted for in the sub-pool “manure management, storage and animal husbandry” to simplify the N flows related to animal husbandry. For simplifications it is assumed that all excretions occur in the sub-pool AG.MM and manure is transferred to soils either by application or by grazing of animals.

3.4.4.1.1 Data sources

The FAO provides a statistic on livestock manure: https://www.fao.org/faostat/en/#data/EMN

Data on nitrogen amounts of different manure flows are available per country and animal category.

To quantify the amount of manure transferred to soils both inputs from application and grazing need to be accounted for (i.e. the database needs to be filtered for the following entries: “Manure applied to soils” and “Manure left on pasture”). The database directly provides information on total nitrogen flows. So no activity data and N contents are required to quantify this N flow.

If country specific information on amount of manure application and nitrogen contents are available, the method described in Chapter 3.4.4 can be applied.

3.4.4.2 Manure for biofuel production (AG.MM-AG.BC)

Manure from livestock is partly used as substrate for production of biogas. The transfer of manure from sub-pool “manure management, storage and animal husbandry” to the sub-pool “biofuel production and composting” results in an internal N flow.

Note on possible simplification

These N flows are only relevant for countries that produce biofuels. If no or only small amounts of biofuel are produced, these flows can be neglected for simplification purposes.

3.4.4.2.1 Data sources

Activity data

- National statistics on biofuel production from manure.

N content

- National statistics of N contents of manure

3.4.4.3 Manure export and import (AG.MM-RW, RW-AG.MM)

Manure may be imported or exported, which results in a N flow across the borders.

Note on possible simplification

These N flows can be neglected if a country does not trade with manure to significant extent. A possible threshold to determine the relevance of these flows is when the net import or exports are > 5% of the country’s manure production.

3.4.4.3.1 Data sources

Activity data

- National import and export statistics for manure

N content

- National statistics of N contents of manure

3.4.5 Quantification for N flows from biofuel production and composting

Note on possible simplification

These N flows are only relevant for countries that produce biofuels and compost from agricultural substrates. If no or only small amounts of biofuel and compost from these sources are produced, these flows can be neglected for simplification purposes.

Per default, biofuel production and composting from waste substrates is treated within the pool “processing of residues” (Chapter 5.4.4). In a simplified approach and depending on a country’s specific production conditions, it is suggested to report the nitrogen flows for all types of substrates in either pool “agriculture” or pool “processing of residues” together.

Biofuels, typically biogas and biodiesel, are used as energy source. Residues from their production (anaerobic fermentation of organic residues or other organic materials) are termed digestate. The product of aerobic treatment of organic matter is known as compost. The N content of this substance is primarily dependent on the N content of the substrates. However, the treatment also removes a smaller proportion via the exhaust air (NH_3, N_2, N_2O) or overland flow. Composts and digestates are usually applied in agriculture, garden landscaping, or in private gardens i.e. on soils.

$$\begin{gathered} \boldsymbol{F}_{\text{AG.BC-EF.XX}} = \boldsymbol{A} \cdot \boldsymbol{f_N} \\ \boldsymbol{F}_{\text{AG.BC-AG.SM}} = \boldsymbol{A} \cdot \boldsymbol{f_N} \\ \boldsymbol{F}_{\text{AG.BC-AG.MM}} = \boldsymbol{A} \cdot \boldsymbol{f_N} \\ \boldsymbol{F}_{\text{AG.BC-HS}} = \boldsymbol{A} \cdot \boldsymbol{f_N} \end{gathered} \tag{Eq. 22}$$

With:

F $_{\text{AG.BC-EF.XX}}$	N flow due to biofuels used as energy source in sub-pool XX (IC, TR or OE) of the pool “energy and fuels”	[kt N]
F $_{\text{AG.BC-AG.SM}}$	N flow due to residues from biofuel production that are used as digestate fertilizer on agricultural soils	[kt N]
F $_{\text{AG.BC-AG.MM}}$	N flow due to residues from biofuel production that are used as animal feed	[kt N]
F $_{\text{AG.BC-HS}}$	N flow due to compost that is transferred to private and public green spaces	[kt N]
A	Amount of biofuel, biofuel residues and compost transferred to other pools/sub-pools	[kt]
$\mathbf{f_N}$	Corresponding nitrogen content of biofuel, biofuel residues and compost	[% N]

3.4.5.1 Biofuels (AG.BC-EF.IC, AG.BC-EF.TR, AG.BC-EF.OE)

This N flow comprises nitrogen in the form of biofuels that are used as energy source for industrial processes or residential heating and as fuel for transportation.

3.4.5.1.1 Data sources

Activity data

- National statistics on biofuel production (biogas) from agricultural residues

N content

- National data for N content of agricutural residues or refer to Table 50 for input data

3.4.5.2 Digestate fertilizer (AG.BC-AG.SM)

This N flow comprises nitrogen in the form of residues from biofuel production and compost, which are used as fertilizer on agricultural soils.

3.4.5.2.1 Data sources

Activity data

The quantitative output of a digester depends on the type of substrate. During the process organic substance is degraded (→ CO_2, CH_4) and water is evaporated. As a proxy, 50% of the input material is transformed to compost or digestate.

N content

N contents of digestates are dependent on the N content of the substrates, as mentioned above. Substrates in digestion plants often have higher N-contents than such in composting plants, whose have a N content around 1.35 % d.m. (BGK 2023). In particular in the agricultural sector, the N content is dominated by the major substrate manure. Since the digestion process hardly leads to N losses, the N content in the input (e.g. according to the source given in Chapter 3.4.4.1.1) and in view of the halving of the organic matter quantity should therefore be calculated with an enrichment factor of 2 for the fermentation residue.

3.4.5.3 Compost for agriculture (AG.BC-AG.SM)

This N flow comprises nitrogen in the form of compost that is used as fertilizer on agricultural soil.

3.4.5.3.1 Data sources

Activity data

- National statistics on compost production.

N content

- N contents of compost are dependent on the N content of the substrates, as mentioned above. The average N content of all controlled composts in Germany is 1.35 % d.m. (BGK 2023). See also Chapter 3.4.5.2.1.

3.4.5.4 Biofuels production residues (AG.BC-AG.MM)

This N flow comprises nitrogen in the form of residues from biofuel production, which are used as animal feed. Two major flows are typical: 1. Extraction meal from oilseeds (mostly rapeseed and sunflower in Europe) from biodiesel production and 2. Stillage (wet or dried) as residues from distillation of bioethanol, when grains from cereals are fermented.

3.4.5.4.1 Data sources

Activity data

The mass flow primarily depends on the production of biofuel. Every European country reports its biofuel production very detailed within the framework of the Renewable Energie Directive (RED).[59]

Following the RED-related GHG -calculation tool BioGrace,[60] the

- ratio between extraction meal and biodiesel is: 0.77 to 1
- ratio between stillage (d.m.) and bioethanol is: 1.14 to 1

N content

According to LfL (2013), N contents of typical biofuel production residues used as animal feed are:

- Oilseed extraction meal: 2.31%
- Stillage from cereals: 2.39%

3.4.5.5 Compost for private gardens (AG.BC-HS)

Note on possible simplification

This flow is expected to be small, since the amount of compost from agriculture applied to private gardens is small compared to agricultural applications.

For simplification purposes, this flow can therefore be neglected.

This N flow comprises nitrogen in the form of compost that is used as fertilizer in private gardens and public green spaces. Privately produced compost is not part of this flow.

3.4.5.5.1 Data sources

Activity data

- National statistics on compost production.

N content

- See Chapter 3.4.5.2.1.

3.4.5.6 Wastewater from biofuels production (AG.BC-PR.WW)

This N flow comprises nitrogen in the wastewater of biofuel production and composting plants. In most cases, leachate from the composting process is returned to the compost piles. The water evaporates via the process and no wastewater is discharged.

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[59] Directive (EU) 2018/2001 (= RED II), recast by Directive (EU) 2023/2413 (= RED III)

[60] www.biograce.net

3.4.5.6.1 Data sources

Activity data

- In general, a leachate quantity of between 10-60 litres per tonne of waste can be assumed (Hupe et al. 1998).

N content

- Studies in the USA show N contents of between 100 to 400 mg/L of for NH_4^+ and 100 to 700 mg/L for NO_3^- (Chatterjee et al. 2013).

3.4.6 Quantification of emissions to the atmosphere

Information of flows of reactive nitrogen to the atmosphere can be taken mostly directly from national inventories on air pollutants and greenhouse gases. The emissions of reactive nitrogen compounds can be converted to nitrogen flows by applying the corresponding nitrogen content (Table 3).

$$F_{AG.XX-AT} = E \cdot f_N \qquad \text{(Eq. 23)}$$

With:

$\mathbf{F_{AG.XX\text{-}AT}}$	N flow due to emissions from different agricultural processes from sub-pool AG.XX to pool AT	[kt N]
E	Emissions of different nitrogen species (NO_x, NH_3, N_2O) and different animal categories transferred between the sub-pools AG.XX and pool AT	[kt]
$\mathbf{f_N}$	Nitrogen content of emissions of reactive nitrogen (Table 3)	[% N]

The national inventories provide data on emissions of NO_x, NH_3, and N_2O. If emissions of other organic N-containing compounds—such as N-containing (semi-)volatile organic compounds like nitrous acid—are to be included in the NNB, country-specific data sources must be consulted as there is no standardized database available. These additional emissions must be incorporated into the NNB as additional flows to the atmosphere.

Note on alternative method

If a country does not submit an air pollutant or a greenhouse gas inventory, the corresponding emissions need to be calculated according to the Tier methods described in the EMEP EEA Guidebook (EEA2013, 2016, 2023) for air pollutants (i.e. NH_3 and NO_x) and IPCC Guidelines (IPCC 2006, 2019) for greenhouse gases (i.e. N_2O). For a Tier 1 approach based on default emission factors, the only data requirement are fuel quantities consumed in each process. For higher Tier methods, additional information on combustion technologies used and application of abatement technologies is required. In addition, higher Tier methods may also require country-specific emission factors.

3.4.6.1 Emissions from manure management, storage and animal husbandry (AG.MM-AT)

This N flow covers emissions from different manure management processes, such as storage of solid and liquid manure as well as emissions from housing and yard. Most relevant nitrogen species are NH_3 and N_2O.

3.4.6.1.1 Data sources

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions (https://www.ceip.at/)
- Emission data for N_2O: UNFCCC National Inventory Submissions (https://unfccc.int/ghg-inventories-annex-i-parties/2024)

Emission sources relevant for the sub-pool “manure management, storage and animal husbandry” are provided in the following table.

Table 29: Emission sources to be accounted for in the sub-pool “manure management, storage and animal husbandry” (MM)

NFR Code	Description
3B1a	Manure management – Dairy cattle
3B1b	Manure management – Non-dairy cattle
3B2	Manure management – Sheep
3B3	Manure management – Swine
3B4a	Manure management – Buffalo
3B4d	Manure management – Goats
3B4e	Manure management – Horses
3B4f	Manure management – Mules and asses
3B4gi	Manure management – Laying hens
3B4gii	Manure management – Broilers
3B4giii	Manure management – Turkeys
3B4giv	Manure management – Other poultry
3B4h	Manure management – Other animals (please specify in the IIR)

3.4.6.2 Emissions from agricultural soils (AG.SM-AT)

This N flow covers emissions from agricultural soils, which are both emissions from reactive (NH_3, NO_x, N_2O) and inactive N species, i.e. N_2 from denitrification.

Ammonia (NH_3) emissions from soils occur due to manure application, manure dropped on pastures during grazing, application of mineral fertilizers, and application of other organic fertilizers, crop residues and field burning of agricultural wastes. NH_3 emissions are equal to the N amounts that are applied by these N source multiplied by NH_3 emission factors for each source.

N emissions due to denitrification in agricultural soils are quantified as a loss rate times the agricultural area. Depending on factors like soil type, management practices and weather, the loss rate can vary greatly between minimal levels (< 10 kg N ha^{-1} yr^{-1}) and complete nitrate depletion (> 150 kg N ha^{-1} yr^{-1}) in waterlogged peat soils (NLfB 2015, Well et al. 2016). In Well et al., 2016, a loss rate of 14 kg N ha^{-1} yr^{-1} is estimated for agricultural soils in Germany. If no more country-specific estimates are available, it is recommended to use this value as a first estimate.

Note that this approach based on a fixed denitrification rate provides an uncertain estimate only, since the variability in the loss rate is generally high.

$$F_{AG.SM-AT} = \text{loss rate} \cdot \text{agricultural area} \qquad \text{(Eq. 24)}$$

In this guidance, the N loss by denitrification is defined by default as a flow of N_2. Where data is available, a more precise breakdown of different N species' contributions (e.g. NO_x, N_2O) is useful. The emissions from denitrification are then summed with emissions from other sources for each species.

3.4.6.2.1 Data sources

Reactive nitrogen

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions (https://www.ceip.at/)
- Emission data for N_2O: UNFCCC National Inventory Submissions (https://unfccc.int/ghg-inventories-annex-i-parties/2024)

Emission sources relevant for the sub-pool "soil management" are provided in the following table.

Table 30: Emission sources to be accounted for in the sub-pool "soil management" (SM)

NFR Code	Description
3Da1	Inorganic N-fertilizers (including also urea application)
3Da2a	Animal manure applied to soils
3Da2b	Sewage sludge applied to soils
3Da2c	Other organic fertilisers applied to soils (including compost)
3Da3	Urine and dung deposited by grazing animals
3Da4	Crop residues applied to soils
3Db	Indirect emissions from managed soils
3Dc	Farm-level agricultural operations including storage, handling and transport of agricultural products
3Dd	Off-farm storage, handling and transport of bulk agricultural products
3De	Cultivated crops
3Df	Use of pesticides
4B1	Cropland remaining cropland
4B2	Land converted to cropland
4C1	Grassland remaining grassland
4C2	Land converted to grassland

Uncertainties are relatively large, especially due to uncertainties in NH_3 emission factors for each source, and are likely more than 20 % (see Oenema and Heinen, 1999).

Denitrification

- Loss rate: 14 kg N ha^{-1} yr^{-1} (Well et al., 2016) or country-specific estimates
- The agricultural area can be obtained from national statistics or Eurostat's farmland Statistics[61].

3.4.6.3 Emissions from biofuel production and composting (AG.BC-AT)

This N flow comprises emissions of nitrogen to the atmosphere that result from biofuel production processes (e.g. biogas facilities, biofuel refining) and from composting of green wastes.

3.4.6.3.1 Data sources

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions (https://www.ceip.at/)
- Emission data for N_2O: UNFCCC National Inventory Submissions (https://unfccc.int/ghg-inventories-annex-i-parties/2024)

Emission sources relevant for the sub-pool "biofuel production and composting" are provided in the following table.

Table 31: Emission sources to be accounted for in the sub-pool "biofuel production and composting" (SM)

NFR Code	Description
1A1	Energy Industries (*Note: only biofuel production, other emissions from 1A1 are reported as N flow in the pool "energy", see Chapter 1.4.1.2*)
5B1	Biological treatment of waste – Composting
5B2	Biological treatment of waste – Anaerobic digestion at biogas facilities

3.4.7 Uncertainties

When estimating the uncertainties in the quantification N flows from the pool "agriculture" the following should be considered:

- The amount of **agricultural products** is expected to be well known, however the nitrogen content of primary agricultural products may be difficult to quantify reliably. In general, application of average nitrogen contents is affected by uncertainty, since composition of agricultural products may vary depending on the local conditions.
- N flows related to the **application and processing of manure** e.g. in biogas plants and are affected by uncertainty since composition of manure depends on the animal feed but also on

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[61] https://ec.europa.eu/eurostat/databrowser/explore/all/agric?lang=en&subtheme=agr&display=list&sort=category

environmental conditions. Their quantification is therefore affected by high uncertainty. The same is expected for N flows related to **composting of agricultural residues**.

- For agricultural **emissions of reactive nitrogen to the atmosphere**, uncertainty estimates are provided in the national inventories for greenhouse gases[62] and air pollutants[63] and can be used directly to estimate the corresponding N flows in the NNB.
- **Denitrification** processes are very difficult to quantify, and an estimation based on a constant defaults value is expected to be highly uncertain.
- Quantification of the N flow related **leaching and runoff** are uncertain due to the heterogeneity of the amount and composition of the leachate and runoff that are transferred to the pool HY.
- A method for estimating uncertainties based on uncertainty levels is provided in Annex 0, Chapter A.7.

3.5 Quantification of stock changes

The largest nitrogen stock in the pool "agriculture" are agricultural soils. Stock changes therefore occur if nitrogen is accumulated in soils or depleted from soils. In addition, nitrogen is stored in the form of fertilizer, agricultural products and live animals. Any change in the amount of nitrogen stored in the pool AG, e.g. due to an increase in the number of livestock or warehousing and storage of fertilizer results in a stock change. In the sub-pool "biofuel production and composting" stock changes may also occur, if the stored amounts of nitrogen containing substrates change.

Because flows in and out as well as within the pool AG are large and come along with uncertainties, we recommend to use approach a) for stock change estimation described in Annex 0, Chapter A.6.2. ; which makes use of mass balance analyses of the pool AG and its sub-pools and qualitative interpretation. For the direct quantification of stock changes (approach b), it is however recommended to check the plausibility of the N budget of the pool AG. To quantify stock changes, the changes in soil nitrogen as well as the changes in the nitrogen contained in stored products (including livestock) need to be quantified (see Chapter 3.4).

Overall, stock changes in the pool "agriculture" are to be considered mainly for soil nitrogen, since they store the largest amount of nitrogen. Quantification of other stock changes is less relevant, since they are a direct result of inflows and outflows of nitrogen, or – in the case of livestock changes – will result in higher/lower in- and output flows (feed input, manure output) that are of higher relevance than the stock change itself.

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[62] https://unfccc.int/ghg-inventories-annex-i-parties/2024

[63] https://www.ceip.at/

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3.7 Document Version

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Update of Version 05/2016 by Judith Reutimann, Bettina Schäppi, Sophie Bogler (INFRAS, Zurich).

Reviewers Version 09/2024: Barbara Amon (bamon@atb-potsdam.de, ATB, Potsdam, Germany), Bernard Hyde (B.Hyde@epa.ie, EPA Research, Ireland), Monika Suchowska-Kisielewicz

(m.suchowska-kisielewicz@iis.uz.zgora.pl, Institute of Environmental Engineering, University of Zielona Góra, Poland), Sergiy Medinets (SerMed@ceh.ac.uk, Centre for Ecology & Hydrology, UK), Tim Hermann (time.hermann@uba.de, Umweltbundesamt, Dessau, Germany)

Version 05/2016

Authors Version 05/2016: Adrian Leip (adrian.leip@jrc.ec.europa.eu), Wim de Vries (wim.devries@wur.nl), Karin Groenestein (karin.groenestein@wur.nl)

Reviewers Version 05/2016: Natalia Kozlova (IEEP, St. Petersburg), Jürg Heldstab (INFRAS, Zurich)

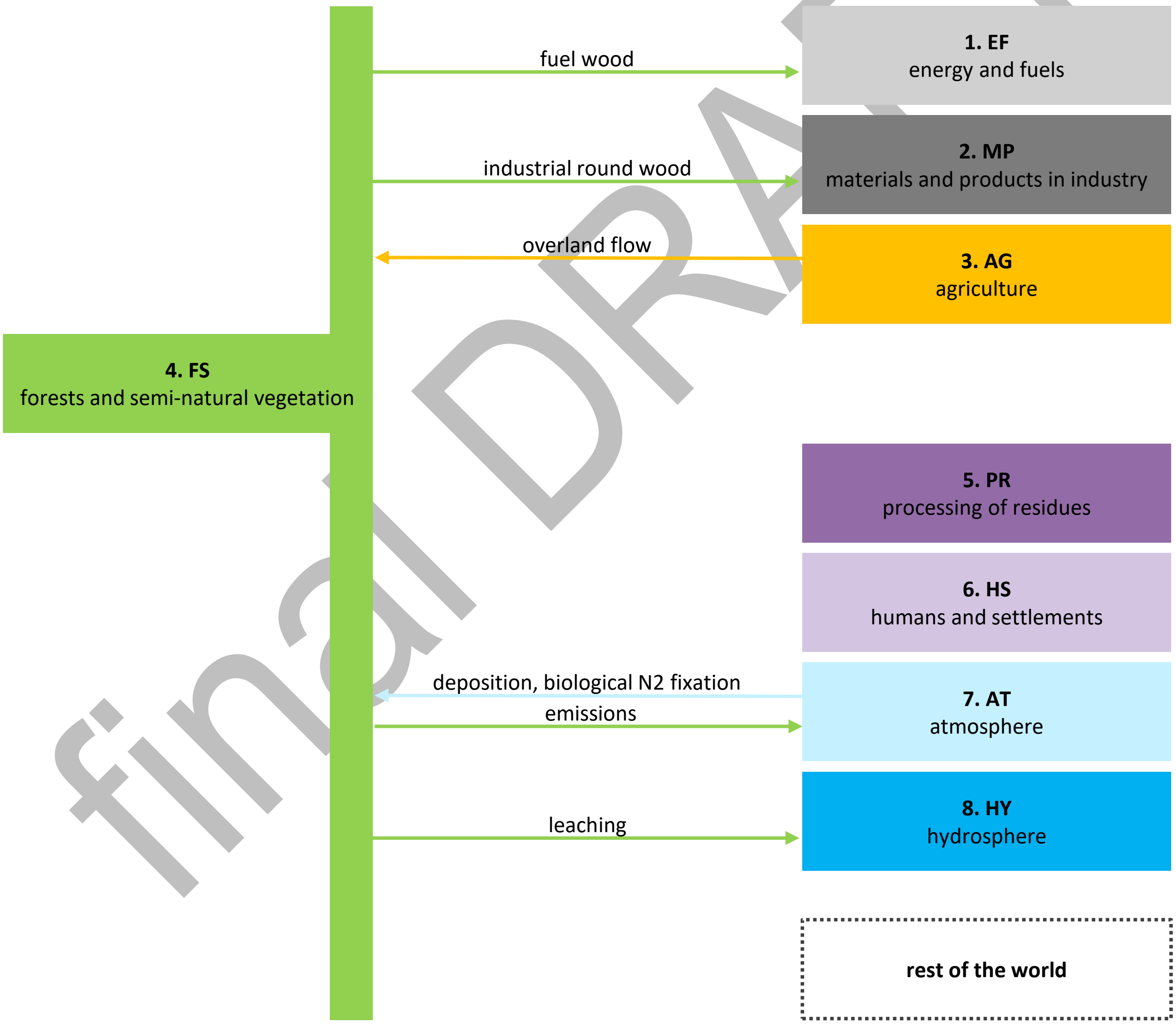
4 Annex 4 – Forests and semi-natural vegetation (FS)

This Annex defines the pool "forests and semi-natural vegetation" (FS) to the "guidance document on national nitrogen budgets" (UN ECE 2013). It describes the relevant nitrogen sub-pools (i.e. the pools "forests", "other lands" and "wetlands") of the pool FS, encompassing vegetation and soil, as well as the relevant nitrogen transformation processes. In addition, by presenting calculation methods and possible data sources, it provides guidance on how to quantify a) the relevant flows of nitrogen that occur between pool FS and other pools or in the pool internally between sub-pools (Chapter 4.4), and b) the stock changes (Chapter 4.5).

4.1 Description of flows to other pools

The main N flows between the pool FS and other pools are presented in Figure 10.

Figure 10: N flows between pool "forests and semi-natural vegetation" (FS) and other pools



Source: illustration by INFRAS

The most significant inflows of nitrogen into the pool FS occur from the atmosphere (Leip et al., 2011). Such nitrogen inputs include atmospheric deposition as well as biological nitrogen fixation (BNF), which is the fixation of elementary nitrogen (N_2) by microbes in association with the roots of higher plants and soil heterotrophic microorganisms. Further, there might be overland flow of nitrogen (lateral transport) from the pool "agriculture" (AG) to the sub-pools of the pool FS.

Nitrogen undergoes various transformation processes in the pool FS (e.g. Butterbach-Bahl et al., 2013). To our current knowledge, the most relevant processes are:

- Ammonification (mineralization): During the decomposition of litter and soil organic matter, different organic nitrogen compounds are mineralized to ammonium (NH_4^+).
- Nitrification: Under aerobic conditions Ammonium (NH_4^+) is oxidized by microbes to nitrite (NO_2^-) and further to nitrate (NO_3^-).

The inorganic N species, ammonium (NH_4^+) and nitrate (NO_3^-) can either be taken up by plants (uptake) or immobilized by soil microorganisms in the form of organic nitrogen compounds (immobilisation). Moreover, ammonium can also be adsorbed on clay minerals and so precluded from further transformation (adsorption). Hence uptake, immobilisation and adsorption ensure for the N retention within the pool.

The most significant outflows from the FS pool are leaching of nitrate ($NO_3^{-,}$ N_{mix}) into the hydrosphere, nitrogen in harvested biomass and emission of gaseous denitrification products (NO_x, N_2O, N_2) and anammox products (N_2O, N_2) to the atmosphere (AT). Further, wood harvest from the sub-pool "forests" occurs.

Leaching of nitrate (NO_3^-) into water bodies such as streams, lakes, and groundwater occurs when $NO_3^-$is not completely consumed by plants and microorganisms.

Emissions of N to the atmosphere occurs due to two major processes:

- Denitrification: Under anoxic condition, nitrate (NO_3^-) and nitrite (NO_2^-) are transformed into gaseous compounds such as nitrogen oxide (NO)[64], nitrous oxide (N_2O) and elementary nitrogen (N_2) and are emitted back to the atmosphere.
- Anammox (Anaerobic ammonium oxidation): Also under anoxic condition, nitrite (NO_2) and ammonium (NH_4^+) can be converted into dinitrogen (N_2), which again is emitted.

Biomass losses through tree harvest and wildfires may occur (Peng et al 2020, Theys et al 2020), and natural disturbances such as insect outbreaks, diseases, and windfall typically cause N to move from living biomass to dead biomass and soil. These processes may lead to losses in N stocks. On the other hand, increases in biomass (e.g. tree growth) is resulting in changes in the N stock. Further, stock changes can also be induced by flows related to land use changes.

4.2 Boundaries and sub-pool definitions

Forests and semi-natural vegetation comprise all natural and semi-natural terrestrial ecosystems (i.e., forests and other lands such as fallow land, rocks and mountains), as well as wetlands. For the scope of the NNB, the pool FS is therefore divided into three sub-pools, namely "forests" (FS.FO), "other land" (FS.OL), and "wetland" (FS.WL).

The spatial boundary of the NNB system is given through the national border. As the physical boundaries of the natural areas of the sub-pools "forests", "other lands" and "wetlands" delineate

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[64] Note that NO emissions from denitrification are reported in this guidance as part of the species NOx.

the geographical area, data from land classification systems or national data (e.g. from GIS classifications) can be used to determine the areas. We recommend using the LULUCF sector classification (Greenhouse Gas source/sink categories) from the UNFCCC Greenhouse Gas Inventory (UNFCCC n.d.), as this data is also used to define other nitrogen flows of the NNB, such as atmospheric emissions, ensuring high compatibility.

The area of the sub-pool “forests” corresponds to category *A. Forest land* of the UNFCCC and the sub-pool “other land” to *F. Other*. The delineation of the sub-pool “wetland” is particularly difficult, because wetlands often merge smoothly into other natural ecosystems such as surface waters or forests. By definition of the LULUCF sector of the GHG Inventory (UNFCCC n.d.), wetlands refer to “land that is covered or saturated by water for all or part of the year”, which explicitly includes rivers and lakes (UNFCCC n.d.). This definition is distinctly different from the one to be used for the NNB, where the sub-pool “wetland” (FS.WL) must be distinguished from the sub-pool “surface waters” of the pool “hydrosphere”. To determine the area of wetlands (excl. surface waters), we recommend using the proportion of wetlands in another classification system such as the CORINE Land Cover (CLC 2018) and calculate the area of wetlands, that are *not* open waters from the UNFCCC data (e.g. to calculate the share of wetlands in the classes “wetlands” and “water bodies” under the CORINE classification and then apply this percentage to the class wetlands of the UNFCCC).

Table 32: Land use classification systems

LULUCF of the IPCC (2006/2019) [ha]	CORINE Land Cover (CLC 2018) [ha]
A. Forest land	Forest and semi-natural areas
B. Cropland	Agricultural areas
C. Grassland	
D. Wetlands*	Wetlands
	Water bodies
E. Settlements	Artificial surfaces
F. Other	

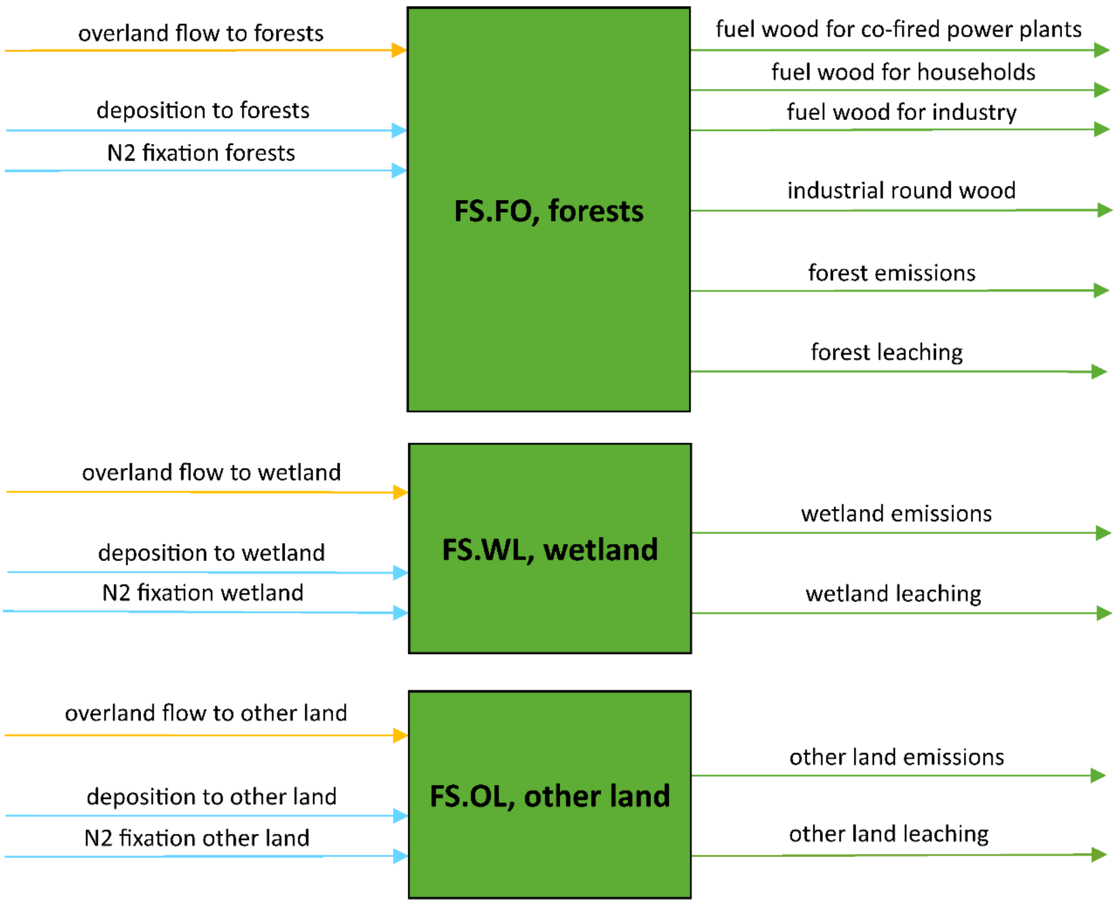
Land use classification according to the LULUCF sector (left, UNFCCC n.d.) and CORINE Land Cover (right, CLC 2018). *Wetlands include surface waters and rivers according to the LULUCF sector of the UNFCCC n.d.

4.3 Pool structure and N flows

Figure 11 shows the internal structure of the pool "forests and semi-natural vegetation" (FS) with its specific N flows within the pool and to other pools.

4.3.1 Overview of N flows

Figure 11: N flows between sub-pools of "forests and semi-natural vegetation" (FS) and other pools



The arrows characterize the nitrogen flows between the sub-pools. Colours indicate from which pool the flows originate (the colours assigned to the pools can be seen in the overview graphics "n flows between pools"). Stock changes are not depicted. The flow names used in the graph here contain some details for clear identification and can deviate from the flow names given in the table below, because the latter correspond exactly to the flow names given in the Excel-Template for NNBs.

Source: illustration by INFRAS, generated in STAN

Table 33: N flows going out of the pool "forests and semi-natural vegetation" (FS)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
Forests	FS.FO	AT.AT	Atmosphere	Emissions	NO, N_2O and N_2 emissions due to natural denitrification	NO_x, N_2O N_2	4.4.2.1

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
	FS.FO	HY.GW	Groundwater	Leaching	Leaching into groundwater from forest soil	N_{mix}	4.4.3.1
	FS.FO	MP.OP	Other producing industry	Industrial round wood	Industrial round wood to industry within the country	N_{mix}	4.4.4
	FS.FO	EF.OE	Other energy and fuels	Fuel wood for households	Fuel wood used in households	N_{mix}	4.4.4
	FS.FO	EF.IC	Manufacturing industries and construction	Fuel wood for industry	Fuel wood used in industry	N_{mix}	4.4.4
	FS.FO	EF.EC	Energy conversion	Fuel wood for co-fired power plants	Fuel wood used in co-fired power plants	N_{mix}	4.4.4
Other land	FS.OL	AT	Atmosphere	Emissions	NO, N_2O and N_2 emissions from other lands to the atmosphere due to denitrification	NO_x, N_2O N_2	4.4.2.1
	FS.OL	HY.GW	Groundwater	Leaching	Leaching to groundwater from other lands	N_{mix}	4.4.3.2
Wetland	FS.WL	AT	Atmosphere	Emissions	NO, N_2O and N_2 emission from wetlands to the atmosphere due to denitrification	NO_x, N_2O N_2	4.4.2.1
	FS.WL	HY.GW	Groundwater	Leaching	Leaching to groundwater from wetlands	N_{mix}	4.4.3.3

The following table shows the N flows entering the pool "forests and semi-natural vegetation". They are described in the Annexes of the pools from which these N flows originate.

Table 34: N flows entering the pool "forests and semi-natural vegetation" (FS)

Sub-Pool Out	Out	In	Sub-Pool in	Flow Name	Species	Chapter
Soil management	AG.SM	FS.FO	Forests	Overland flow	N_{mix}	3.4.3.3
	AG.SM	FS.OL	Other land	Overland flow	N_{mix}	3.4.3.3
	AG.SM	FS.WL	Wetland	Overland flow	N_{mix}	3.4.3.3
Atmosphere	AT	FS.FO	Forests	Deposition	OXN RDN	7.4.1
	AT	FS.FO	Forests	N_2 fixation	N_2	7.4.2.2
	AT	FS.OL	Other land	Deposition	OXN RDN	7.4.1
	AT	FS.OL	Other land	N_2 fixation	N_2	7.4.2.3
	AT	FS.WL	Wetland	Deposition	OXN RDN	7.4.1
	AT	FS.WL	Wetland	N_2 fixation	N_2	7.4.2.4

For certain countries, N fertilizer is applied to forests. For example, in Sweden this is allowed and used to increase growth in the northern part of the country[65]. In other countries, manure might be illegally disposed of in forests. In case such forest fertilization occurs in relevant quantities, we recommend to add an additional flow from MP.OP or AG.MM to FS.FO, and to quantify it based on country specific information.

4.3.2 Sub-pool "forests" (FO)

Forest land is per definition a land with an area more than 0.5 hectares, and a canopy cover of more than 5 -10 % that has been under forest for over 20 years (IPCC 2006). Atmospheric deposition and biological N_2 fixation constitute the inflows of N into the system; a possible inflow might also occur due to N fertilization. Harvested biomass, leaching, and denitrification account for the relevant outflows. Natural disturbances such as fire and bark beetle calamities may cause additional losses (resulting in emissions of N compounds to the atmosphere and wood/biomass removal after calamities).

4.3.3 Sub-pool "other land" (OL)

The sub-pool "other land" encompasses bare land (i.e., as a result of development of settlements), soil with thin vegetation in high mountains above the tree line, rock and ice.

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[65] https://www.skogsstyrelsen.se/en/statistics/subject-areas/silvicultural-activities/ (06.01.2025)

Atmospheric deposition is the main inflow, while the leaching/runoff represent the most relevant outflow. "Other land" is mostly unmanaged, and in that case changes in N stocks as well as biological N_2 fixation and denitrification are assumed to be very small and can thus be neglected. Further, no significant N flows are likely between the sub-pool "other land", with the other sub-pools of the pool FS.

4.3.4 Sub-pool "wetland" (WL)

In the Guidelines for National Greenhouse Gas Inventories (UNFCCC n.d., IPCC 2006) wetlands are defined as any lands that are covered or saturated by water for all or part of the year, and do not fall into the Forest Land, Cropland, or Grassland categories. However, this definition explicitly includes rivers and lakes, whereas the definition to be used for the NNBs excludes them from wetlands and assigns them to the pool "hydrosphere" (sub-pool "surface waters").

Numerous environmental factors (i.e., water table depth, water flow, nutrient availability) form a diverse picture of wetland types with various vegetation communities and biogeochemical cycles (Smith et al. 2007, Frazier 1999). N inflow pathways into wetlands are complex and include N deposition, biological N_2 fixation and N inflow via surface water inflow (runon), pipe and tile drainage from neighboring agricultural fields, interflow, young oxic and anoxic groundwater, old anoxic groundwater from a deeper aquifer and river water inflow (Trepel and Kluge 2004). N retention within the wetland is governed by plant N uptake (and sedimentation) (Saunders and Kalff, 2001; Jordan et al. 2011). N outflows also include a number of processes, whereupon the most relevant are emissions due to denitrification, forest/grass harvest and N leaching via saturated overland flow, ditch outflow, overbank flow due to flooding, subsurface discharge and river flow (Trepel and Kluge 2004).

For the NNB, N inflows are simplified to overland flows from agricultural soils, deposition and biological N_2 fixation from the atmosphere and N outflows are described by denitrification emissions to the atmosphere and leaching to groundwater. It is assumed that no overland flow to other pools occurs, since the general pathway of water is by leaching to groundwater from where it flows further into surface and coastal water.

4.4 Quantification of flows

This section describes calculation methods and data sources to derive all relevant N flows in and out of the pool "forests and semi-natural vegetation". Overall, the nitrogen flows between the pool FS and the other pools are difficult to quantify, because complexity of processes and variations in natural and semi-natural ecosystems are high and in some cases, no standardized data sources or default values are available.

4.4.1 Overall methodology and existing guidelines

The following data sources can be used to quantify N flows that enter or exit the pool FS. Further details and complementary data sources are described in the following chapters.

- **Data sources for N flows related to emissions to the atmosphere:** GHG inventories submitted to the UNFCCC: https://unfccc.int/ghg-inventories-annex-i-parties/2024 (see Chapter 4.4.3, and details in Annex 7 – Atmosphere).

- **Quantification of flows related to forest products:** https://unece.org/forests/data-forest-products-production-and-trade or data from FAO Statistics (http://www.fao.org/faostat/en/#data/FO) can be used as well as national forest inventories (see Chapter 4.4.4).

- **Quantification of N flows related to leaching:** no international statistics are available. Instead, if no national data is available either, local ecosystem-specific conditions should be considered and specific methods should be used (see Chapter 4.4.3).

4.4.2 Quantification of emissions to the atmosphere

Information of flows of reactive nitrogen to the atmosphere can be taken directly from national inventories on greenhouse gases. The emissions of reactive nitrogen compounds can be converted to nitrogen flows by applying the corresponding nitrogen content (Table 3).

$$\begin{aligned} \boldsymbol{F}_{\boldsymbol{FS.FO-AT}} &= \boldsymbol{E} \cdot \boldsymbol{f}_{\boldsymbol{N}} \\ \boldsymbol{F}_{\boldsymbol{FS.WL-AT}} &= \boldsymbol{E} \cdot \boldsymbol{f}_{\boldsymbol{N}} \\ \boldsymbol{F}_{\boldsymbol{FS.OL-AT}} &= \boldsymbol{E} \cdot \boldsymbol{f}_{\boldsymbol{N}} \end{aligned} \qquad \text{(Eq. 25)}$$

With:

$\mathbf{F}_{\mathbf{FS.SO\text{-}AT}}$ $\mathbf{F}_{\mathbf{FS.OL\text{-}AT}}$ $\mathbf{F}_{\mathbf{FS.WL\text{-}AT}}$	N flow due to emissions from denitrification processes from sub-pools FS.SO, FS.WL and FS.OL to pool AT	[kt N]
E	Emissions of different nitrogen species (NO_x, N_2O) and different land use classes	[kt]
$\mathbf{f}_{\mathbf{N}}$	Nitrogen content of emissions of reactive nitrogen (Table 3)	[% N]

The national inventories provide data on emissions of NO_x, NH_3, and N_2O. If emissions of other organic N-containing compounds are to be included in the NNB, country-specific data sources must be consulted as there is no standardized database available. These additional emissions must be incorporated into the NNB as additional flows to the atmosphere.

N_2 emissions are not part of national GHG inventories, but can be calculated from N_2O:N_2 ratios or by use of default values.

Note on alternative method

If a country does not submit an air pollutant or a greenhouse gas inventory or does not have data on greenhouse gas emissions, the corresponding emissions need to be calculated according to the Tier methods described in the IPCC Guidelines (IPCC 2006, 2019) for greenhouse gases (i.e. N_2O).

4.4.2.1 Emissions from "forests" (FS.FO-AT), "other land" (FS.OL-AT) and "wetland" (FS.WL-AT)

This N flow covers emissions from denitrification as well as from natural disturbances such as wildfires. Most relevant nitrogen species are N_2O, NO[66], and N_2, however, also NH_3, VOC and HONO (nitrous acid) may occur.

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[66] Note that NO emissions from denitrification are reported in this guidance as part of the species NOx.

4.4.2.1.1 Data sources

N_2O and NO_x emissions

Data on N_2O and NO_x emissions can be obtained from National Inventory Submissions to the UNFCCC in the Common Reporting Format (CRF)[67]. For explanations of the methodology and data sources, please refer to the corresponding national inventory document.

- Emission data for N_2O, NO_x: UNFCCC National Inventory Submissions[68]

Emission sources relevant for the sub-pool "forests" are provided in the following table.

Table 35: Emission sources to be accounted for in the sub-pool "forests" (FO)

NFR Code	Description
4A1	Forest land remaining forest land
4A2	Land converted to forest land

Emission sources relevant for the sub-pool "other land" are provided in the following table.

Table 36: Emission sources to be accounted for in the sub-pool "other land" (OL)

NFR Code	Description
4F1	Other land remaining other land
4F2	Land converted to other land

Emission sources relevant for the sub-pool "wetland" are provided in the following table.

Table 37: Emission sources to be accounted for in the sub-pool "wetland" (WL)

NFR Code	Description
4D1	Wetland remaining wetland
4D2	Land converted to wetland

As described in Chapter 4.2, the definition of "wetlands" according to the UNFCCC ("land that is covered or saturated by water for all or part of the year") is distinctly different from the definition used for NNBs, which does not include surface waters. Therefore, we recommend using the proportion of wetlands and calculate the emissions related to that area of wetlands, that are *not* open waters from the UNFCCC (2006) data (see also Chapter 4.2).

Note on alternative method

From a nitrogen budget perspective N_2O is not very important and the real difficulties are not in estimating the N_2O part of denitrification losses to the atmosphere. However, if nevertheless N_2O emissions from denitrification in wetlands are to be quantified, the following approach can be

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[67] UNFCCC National Inventory Submissions 2024: https://unfccc.int/ghg-inventories-annex-i-parties/2024?gad_source=1&gclid=CjwKCAjw59q2BhBOEiwAKc0ijSHx6BNoosVLAFQnYpTI9hrIneUBcZ2ifAc2mdt-I6VwQhNXg6iXxxoCApkQAvD_BwE

[68] https://unfccc.int/ghg-inventories-annex-i-parties/2024

applied. A classification of the national wetlands according to nutrient status is provided in Table 38. The N_2O-N emission from soils with C:N ratios > 25 are insignificant (Klemedtson et al., 2005) or very low (e.g. <0.01 kg N_2O-N ha^{-1} in case of undrained ombrotrophic peatlands; Maljanen et al., 2010) so that N_2O emissions from wetlands with medium, poor or very poor nutrient status can be considered as negligible. For wetland types with higher nutrient status, Table 39 provides a number of annual N_2O emission rates from relevant studies. In case wetland types are unknown, an approach using a reference value could be applied, similar to the average value approach for "forests" and "other land".

Table 38: Enhanced Wetland Classification class crosswalk to inferred nutrient classes

Nutrient Class			**Enhanced wetland classification classes**
		Main categories	**Examples**
High	**Very Rich**	Marsh	Emergent Marsh, Mudflats, Meadow Marsh
Dissolved available nutrients	**Rich**	Swamp, Fen	Mixedwood Swamp, Hardwood Swamp, Shrub Swamp, Shrubby Rich Fen, Graminoid Rich Fen, Treed Rich Fen
	Medium	Swamp	Conifer Swamp, Tamarack Swamp
	Poor	Fen	Treed poor Fen, Shrubby Poor Fen, Graminoid Poor Fen
Low	**Very Poor**	Bog	Open Bog, Shrubby Bog, Treed Bog

Source: Smith et al., 2007

Table 39: Nitrous oxide fluxes from different wetland soils

Nutrient class*	**Wetland type**	**Location**	**N_2O-N flux [kg N_2O-N ha^{-2} y^{-1}]**	**References**
Rich - very rich	Marsh (permanently inundated)	Sanjiang Experimental Station of Wetland Ecology	1.24	Song et al. 2009
Rich - very rich	Marsh (seasonally inundated)		1.1	
Rich - very rich	Swamp (shrub swamp)		2.8	
Medium	Marsh (freshwater marsh)	Sanjiang Mire Wetland Experimental Station	2.6	Jiang et al. 2009
-	Marsh	Nature Reserve of Yellow River Delta	0.71	Sun et al. 2014
-	Swamp (peat swamp forest)	Central Kalimantan Province, Indonesia	0.56	Jauhiainen et al. 2012
Very poor	Mire (forested)	Harz Mountain (central Germany)	0.4	Tauchnitz et al. 2008
Very poor	Mire (non-forested)	Harz Mountain (central Germany)	0.2	

Nutrient class*	Wetland type	Location	N_2O-N flux [kg N_2O-N ha^{-2} y^{-1}]	References
Very poor	Swamp (forested)	Asa Experimental Forest, Southern Sweden	0.63	Von Arnold et al. 2005

*) Classified (as far as possible) using the classes proposed in Table 38 based on chemical parameters presented in the respective studies. Source: Table adapted from Moseman-Valtierra (2012) and Chen et al. (2010)

N_2 emissions

N_2 emissions from denitrification are likely higher than N_2O and NO from denitrification combined. However, despite decades of research on this topic, continuous year-round measurements of N_2O, NO and N_2 emissions from forest soils are still lacking. Hence available information on N_2 emissions or $N_2O:N_2$ ratios are scarce and highly uncertain (Sutton et al. 2011).

Nevertheless, N_2 flows can be calculated by $N_2O:N_2$ ratios or with an average value for denitrification per square meter and corresponding land areas. For "forests", values are given by Andreae et al., 2016 (used by e.g. Sweden and Germany for their NNBs). For "wetland", values are given by Van Cleemput et al. (2007).

- **Ratio**: A mean $N_2:N_2O$ ratio of 19.5 (+/- 26.8) has been calculated from studies of forest ecosystems (n = 6; for temperate beech and spruce forests in Germany) by Butterbach-Bahl et al. (2013).
- **Average values**:
  - Andreae et al. (2016) suggests an average value of 1.1 kg N ha^{-1} a^{-1} for denitrification of N_2 in forest soils. Range of uncertainty is unknown but can be assumed to be high (UBA 2020). The denitrification from the sub-pool „other land“ is even more uncertain. To compute a corresponding N-flow, for "other soils", the average value of denitrification from forests (i.e. 1.1 kg N ha^{-1} a^{-1}; Andreae et al. 2016) has been used by UBA (2020); depending on the type of soil, denitrification could also be negligible. Due to lack of information this value for denitrification is subject to a high degree of uncertainty and should be regarded as a placeholder value.
  - Van Cleemput et al. (1998) describes the effect on parameters on the N_2O/N_2 ratio

Note on alternative method

Oulehle et al. (2021), took a different approach to N_2 and found a correlation between nitrate leaching to waters and gaseous losses of N to the atmosphere. The paper suggests a relationship between the two based on studies from several regions. If nitrate leaching is known (or estimated) then this could be used to estimate N losses to the atmosphere.

Further data sources:

- RAMSAR database, contains information on wetland area (ha) designed as RAMSA sites all over the world (https://rsis.ramsar.org/)
- National data (e.g. GIS layers) containing information about the land coverage and land use.

- CORINE Land Cover (CLC 2018) contains information on the coverage and land use all over Europe: www.eea.europa.eu/data-and-maps/data/corine-land-cover
- Denitrification rates: Gutknecht et al. (2006)
- National wetland databases (if available) or wetland inventories

Other emissions (from wildfires and wildlife)

Wildfires may lead to emissions of NO_x, NH_3, HONO (nitrous acid), and N-containing VOCs (Peng et al 2020, Theys et al 2020), further Wildlife can emit NH_3. While the latter is assumed to be negligible for the NNBs, emissions from wildfires can be added to the emission flow FS.FO-AT. Data can be obtained from this data source:

- Global Fire Assimilation System (GFAS) in the Atmosphere data store: https://ads.atmosphere.copernicus.eu/datasets/cams-global-fire-emissions-gfas?tab=overview

4.4.3 Quantification of leaching

N leaching to the groundwater occurs when N deposition (input) and net mineralization (status) exceed plant demand (Gundersen et al. 2006), and microbial demand.

Besides leaching, which is assumed to be the dominant pathway to the hydrosphere, overland flow to the hydrosphere can occur from all the three FS sub-pools. The quantification and separation of the flows is however complex and specific information about local geographical conditions and ecosystems may need to be considered. If such country specific data allow for a distinction, more differentiated flows can be added to the NNB.

Otherwise, it is assumed for the NNBs that no overland flows from the pool FS into surface waters occurs, since the general pathway of water between FS and HY is by leaching to groundwater from where it flows further into surface and coastal water. In other words, leaching accounts for the sum of all flows from FS to HY.

$$
\begin{aligned}
F_{FS.FO-HY.GW} &= A \cdot r_N \cdot 10^{-6} \\
F_{FS.WL-HY.GW} &= A \cdot r_N \, 10^{-6} \\
F_{FS.OL-HY.GW} &= A \cdot r_N \, 10^{-6}
\end{aligned}
\qquad \text{(Eq. 26)}
$$

With:

$F_{FS.FO\text{-}HY.SW/GW}$ $F_{FS.OL\text{-}HY.SW/GW}$ $F_{FS.WL\text{-}HY.SW/GW}$	N leaching from the sub-pools FS.FO, FS.WL and FS.OL to the sub-pool HY.GW (groundwater)	[kt N]
A	Land area from which leaching occurs	[ha]
r_N	Rate of nitrogen leaching	[kg N ha^{-1} y^{-1}]

4.4.3.1 Leaching from "forests" (FS.FO-HY.GW)

In case no measurements are available, several indicators can be used as proxies for nitrate leaching.

N leaching is strongly dependent on the amount of N deposited in throughfall. The mean annual inorganic nitrogen (NH_4^+-N and NO_3^--N) throughfall depositions [kg N ha^{-1} y^{-1}] are reported

(Waldner et al. 2014, ICP Integrated Monitoring Programme Center). No significant N leaching could be expected when the throughfall fluxes are less than 8 kg N ha^{-1} y^{-1}, while above 25 kg N ha^{-1} y^{-1} leaching of nitrogen is very probable (Dise et al., 2009; Gundersen et al., 2006, Gundersen et al. 1998). Also, a significant relationship was found between organic layer of forest soils C:N ratios and leaching (Cools et al. 2014).). Elevated nitrate leaching tends to occur at C:N ratio <25 and hence this threshold shall be used as a default. In order to evaluate the risk for nitrate leaching from the forest status of the soil, mean C:N ratios are given according to tree species occurrence and the soil type in the Table 41 (Cools et al. 2014). Predicted rates of N leaching related to throughfall N (95% confidence intervals are ± 10 kg N ha^{-1} y^{-1}) for soils with C:N ratios higher or lower than 25 are given in Table 49.

Likewise, foliage N content as well as N density (total aboveground N input to the soil i.e. throughfall + litterfall, excluding belowground root litter input) can be used as a proxy for the nitrate leaching (Gundersen et al. 2006) – see Table 42.

Finally, the N status of the system (limited vs. saturated) will also determine its retention capacity. Basically, N-poor systems have a higher retention than N-rich systems.

4.4.3.1.1 Data sources

- IFEF, Indicators of Forest Ecosystem Functioning (Dise et al. 1998); contains data on input-output budgets published in scientific papers for 250 forest sites.
- Level II database, expanded from De Vries et al. (2006); contains input-output budgets derived from UN-ECE/EC intensive monitoring plots for the period 1995-2000 for approximately 110 forest sites.
- Holmberg et al. (2013) contains input-output budgets for ICP Integrated Monitoring sites across Europe.
- Waldner et al. (2014) to provide information on mean annual inorganic N-throughfall
- National forest inventories, that may provide information on tree species cover
- National soil inventories, that may provide information on floor C:N ratios and/or soil type
- CLRTAP (2014). Mapping critical loads on ecosystems, Chapter V of Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. UNECE Convention on Long-range Transboundary Air Pollution, www.icpmapping.org
- National or regional surface water monitoring programs might be a data source for N transported by rivers and of specific importance, if the rivers have their catchments dominated by forests and semi-natural vegetation.

Table 40: Predicted rates of NO_3^- leaching from forests

Throughfall N (kg ha-1 y-1)	C: N ratio organic layer	Leached N (low/high 95% CI)
10	≤25	3 (0-11)
10	>25	2 (0-11)
20	≤25	8 (0-18)
20	>25	4 (0-14)

Throughfall N (kg ha-1 y-1)	C: N ratio organic layer	Leached N (low/high 95% CI)
30	≤25	15 (5-25)
30	>25	9 (0-18)
< 10	any	Assumption: 0 (0-3)

Source: MacDonald et al. 2002; Assumption for throughfall below 10.

Table 41: Mean C:N ratios of the tops soil (0-10cm) with their 95% confidence interval (in brackets) grouped by WRB reference soil groups for the eight most frequently recorded main tree species on ICP Forests

Mean tree species Reference soil group	Scote pine	Norway spruce	Common beach	Silver birch	Pedunculate oak	Holm oak	Maritime pine	Aleppo pine
Arenosols	20.9 (20.4;21.4)	20.8 (19.0;22.4)		17.6 (16.0;20.2)	19.4 (17.7;21.9)	14.4 (12.9;16.0)	27.9 (23.0;32.8)	
Cambisols	20.3 (19.3;21.5)	18.3 (17.8;18.8)	15.7 (15.2;16.2)	16.6 (15.4;18.4)	15.3 (14.7;15.9)		24.6 (21.6;30.1)	13.3 (10.3;15.2)
Gleysols	20.9 (18.7;23.4)	18.3 (16.5;20.4)		17.2 (14.7;21.5)				
Histosols	30.7 (29.2;32.2)	26.4 (24.4;30.8)		16.7 (15.1;18.4)				
Leptosols	20.2 (18.6;22.0)	18.4 (17.4;19.5)	15.8 (14.7;17.6)			13.5 (12.6;14.6)		17.0 (14.3;20.0)
Luvisols	16.4 (14.4;18.2)	14.9 (13.9;15.8)	14.9 (14.2;15.7)		15.1 (14.2;16.1)			
Phaeozems	18.2 (16.6;20.3)	17.2 (16.3;18.5)	14.9 (14.0;16.2)					
Podzols	23.6 (22.9;24.5)	20.8 (20.1;21.6)		22.0 (19.4;25.4)			30.5 (26.6;34.5)	
Regosols	21.5 (20.8;22.2)	19.4 (18.8;20.0)	16.6 (14.9;18.5)	21.0 (18.3;24.2)		13.7 (12.2;15.5)	23.8 (20.8;26.2)	15.1 (11.3;20.2)
Stagnosols	21.3 (19.8;22.9)	19.3 (18.0;20.7)	17.5 (16.0;20.2)		16.4 (14.7;18.2)			
Umbrisosl	16.1 (14.4;17.9)	18.0 (16.7;19.2)	18.0 (16.7;19.2)				20.0 (18.0;22.0)	

Source: Cools et al. 2014

Table 42: An overview of ranges in N leaching as a function of the N status of the ecosystem (Gundersen et al. 2006) Predicted rates of NO_3^- leaching from forest (MacDonald et al. 2002)

Nitrogen status	Low status (N-limited)	Intermediate	High N status (N-saturated)
Input [kg N $ha^{-1}y^{-1}$]	0-15	15-40	40-100
Needle N (in spruce) [%]	<1.4	1.4-1.7	1.7-2.5
C:N ratio	>30	25-30	<25
Soil flux density proxy (litterfall + throughfall) [kg N $ha^{-1}y^{-1}$]	<60	60-80	>80
Proportion of input leached	<10	0-60	30-100

Sources: Gundersen et al. 2006; MacDonald et al. 2002.

4.4.3.2 Leaching from "other land" (FS.OL-HY.GW)

In N limited ecosystems it can be assumed that N deposited from the atmosphere will stay in soil (i.e. zero leaching), while in the N rich areas N will be leached. If no specific data on nitrate leaching from natural lands are available, then the nitrate leaching from the pool "other lands" can be estimated by using default or proxy values or expert judgements; alternatively, the same data as for forests could be used (as was done in the German and Austrian NNBs).

4.4.3.2.1 Data sources

- National meteorological stations shall provide data on N deposition with precipitation.
- Proxy values could be obtained through expert judgements (i.e. from experts of national environmental agencies)

4.4.3.3 Leaching from "wetland" (FS.WL-HY.GW)

Nitrogen leaching and runoff from wetlands occurs via saturated overland flow, ditch outflow, overbank flow due to flooding, subsurface discharge, and river flow (Trepel and Kluge 2004).

If no specific data on nitrate leaching from wetlands are available, the following approach can be used. In general, N leaching can be estimated by calculating the difference from the N load into wetlands by deposition, N_2 fixation and runoff from other land surfaces and N removal from wetlands by emissions to the atmosphere. Please consider that this equation is only valid if the N stock of wetland is constant, which is frequently not the case, e.g. for wetlands with sphagnum vegetation that are known to be able to accumulate organic matter over long time.

$$F_{leaching\ (wetlands)} = F_{load} - F_{removal} \qquad \text{(Eq. 27)}$$

With:

$F_{\text{leaching, wetlands}}$	N flow due to leaching from wetlands	[kt N]
F_{load}	N inflow to wetlands by deposition and biological N_2 fixation	[kt N]

$F_{removal}$	N removal from wetlands	[kt N]

A very robust relationship was found between the reactive N load to the system and the N leaching from the system based on observation of 190 datasets with sufficient information for spatially and temporally normalized input-output models of reactive N reduction by wetlands (Jordan et al. 2011). Accordingly, N leaching can be estimated as:

$$log10_{(N\ leaching)} = -0.033 + 0.943 \times log10_{(Fload)} \quad \text{(Eq. 28)}$$

4.4.3.3.1 Data sources

- CORINE land cover, contains information on the coverage and land use all over the Europe: www.eea.europa.eu/data-and-maps/data/corine-land-cover, FAO – www.fao.org, aerial /satellite photo
- EMEP MSC-W chemical transport model provides data on atmospheric deposition to semi-natural vegetation (non-forested area)
- Default values for N fixation see Table 19
- RAMSAR database, contains information on wetlands area (ha) designed as RAMSA sites all over the world (https://rsis.ramsar.org/)

4.4.4 Quantification of flows related to forest products (FS.FO-MP.OP, FS.FO-EF.OE, FS.FO-EF.IC, FS.FO-EF.EC)

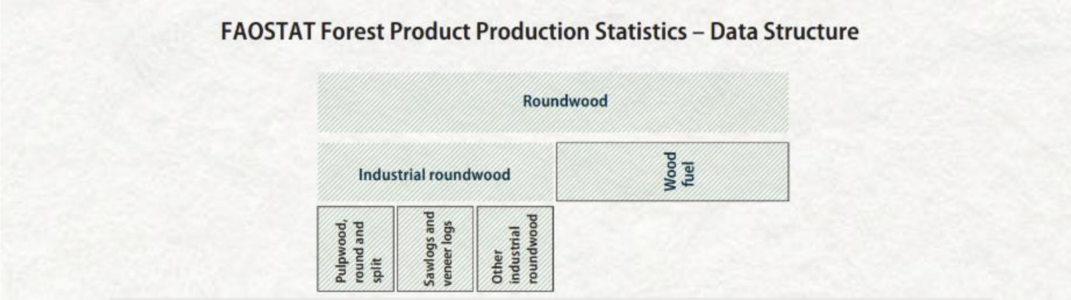
Removal of wood by exploitation is highly relevant for the N budget of forest ecosystems. While most wood is harvested in forests, a part of the wood harvest may also come from wetlands (if covered by forest). For simplification purposes, total wood harvest is allocated to the FO sub-pool in the NNB.

4.4.4.1 Definitions

Total **removals** refer to **all roundwood** felled or otherwise harvested and removed. According to FAO (2022), this comprises all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period, calendar year or forest year. This includes removals from all sources within the country including public, private, and informal sources. It excludes bark and other non-woody biomass and any wood that is not removed, e.g. stumps, branches and tree tops (where these are not harvested) and felling residues (harvesting waste).

According to the FAO classification, the total wood harvested from forests (i.e. wood in the rough or roundwood) is further divided into "wood fuel" and "wood in the rough other than wood fuel", i.e. industrial round wood. **Industrial round wood (wood in the rough)** is an aggregate comprising sawlogs and veneer logs; pulpwood, round and split; and other industrial roundwood (FAO 2022). **Wood fuel** is defined as roundwood that will be used as fuel for purposes such as cooking, heating or power production (FAO 2022).

Figure 12: **Forest products classification by FAO**



Source: FAO 2022, forestry statistics.

Given this relation, two main nitrogen flows are derived for the NNB:

- N-flow with **industrial round wood** from domestic forests for domestic industrial use or to the pool "materials and products", sub-pool "other producing industry" (FS.FO-MP.OP).
- N-flow with **wood fuel** to the pool "energy and fuel" for domestic use or export (N flow with export occurs from the EF pool). Within the pool „energy and fuels", fuel wood can be used for heating plants, industrial production and household. Hence the N flow with fuel wood needs to be split into a maximum of three flows to the different sub-pools:
  - fuel wood to "energy conversion" (EC) consisting of wood fuel used in wood fired heating plants (**FS.FO-EF.EC**).
  - fuel wood to "manufacturing industries and construction" (IC) consisting of fuel wood used in the industry (**FS.FO-EF.IC**)
  - fuel wood to "other energy and fuels" (EF) consisting of N in fuel wood for households (**FS.FO-EF.OE**)

The separation and quantification of the three flows can be done in accordance to the description in Chapter 1.4.2 (quantification of nitrogen bound to fuels).

For the NNB of countries that identify only one dominant flow of fuel wood into one of the sub-pools of the pool "energy and fuels", we recommend neglecting the flows to the other sub-pools and quantify just one flow from FS.FO to EF.OE.

4.4.4.2 Wood export and import

Wood export includes, according to FAO products of domestic origin or manufacture shipped out of the country. It includes exports from free economic zones and re-exports. It excludes "in-transit" shipments.

Wood import is defined as products imported for domestic consumption or processing shipped into a country. It includes imports into free economic zones or for re-export. It excludes "in-transit" shipments (FAO 2022).

For the NNB, we recommend that the N flow with export of wood products is considered to originate in the pools "materials and products", resp. "energy and fuels", and is not defined as a flow from the pool "FS" directly to "RW". With this approach, no further distinction between export of domestic products and re-exports are necessary, which allows for a simple quantification of N flow with wood export based on the FAO statistics. Correspondingly, the N flow with imported wood products ends in the pools MP and EF.

The nitrogen flows related to export and import of wood and wood products are as follows:

- N flows with export/import of industrial round wood and wood products from/to the pool "materials and products", sub-pool "other producing industry". These flows are quantified as part of the flows "import and export of food, feed and other goods" (MP.OP-RW, RW-MP.OP). They are further described in Chapter 2.4.1.5.
- N flows with export or import of fuel wood from/to the pool "energy and fuels", sub-pool "energy conversion". These flows are quantified as part of the flows "import of fuel" and "export of fuel" (EF.EC-RW, RW-EF.EC); see Chapters 1.4.2.5 and 1.4.2.6.

4.4.4.3 Method

For the quantification of N flows related to forest products, the total removals of roundwood has to be split into the two wood types „industrial round wood" and „wood fuel".

Hence, the estimation of nitrogen losses due to removal of wood is based on the following equation.

$$F_{total\ wood\ removal} = F_{industrial\ round\ wood} + F_{fuel\ wood} \qquad \text{(Eq. 29)}$$

With:

$F_{\text{total wood removal}}$	Total annual wood removal (roundwood)	[t]
$F_{\text{industrial round wood}}$	Annual industrial round wood removals	[t]
$F_{\text{wood fuel}}$	Annual fuel wood removals	[t]

Removals refer to the volume of all trees, living or dead, that are felled and removed from the forest and other wooded land. It includes removals of stem and non-stem wood (i.e. harvest) and removal of trees killed or damaged by natural causes (i.e. natural losses). It is reported in cubic meters solid volume under bark (i.e. excluding bark). The biomass that is removed from forests in form of stems, branches, tops and stumps is divided into two categories: Industrial round wood and Wood fuel.

Industrial round wood consists of all removals except wood fuel.

Wood fuel includes wood harvested from main stems, branches and other parts of trees (where these are harvested for fuel) and wood that will be used for the production of charcoal (e.g. in pit kilns and portable ovens), wood pellets and other agglomerates. It also includes wood chips to be used for fuel that are made directly (i.e. in the forest) from roundwood. It excludes wood charcoal, pellets and other agglomerates. It is reported in cubic metres solid volume underbark (i.e. excluding bark).

For the estimations of nitrogen flows due to biomass removals the following calculation can be applied:

$$F_{biomass-removals} = H \times D \times f_N \qquad \text{(Eq. 30)}$$

With:

$F_{\text{biomass-removals}}$	Annual N flow due to biomass removals	[t N yr^{-1}]
H	Annual wood removals [1000 $m^3 yr^{-1}$]	[1000 m^3]

D	Basic wood density [oven-dry t (moist m^{-3})], see Table 44	[oven-dry t (moist m^{-3})]
f_N	N content in tree compartments [mg g^{-1}], see Table 45	[mg g^{-1}]

The amount of N in wood depends on tree species, growth, and nutrient contents in different tree compartments. The most general distinction is made between coniferous and non-coniferous trees (deciduous) (FAO 2022).

In a similar way, conversion factors (based on UNFCCC reporting) to calculate total tree biomass from stemwood can be used, applying differnt N-contents for different tree compartments.

4.4.4.4 Data sources

Table 43 gives an overview over the categorization of data available in the UNECE/FAO Timber database, with indications for which N-flows it is relevant. Data per country on removal, import and export of wood and wood products can be found in the UNECE/FAO TIMBER database, 1964-2022, which is published as a complete dataset for all products and years[69] or can be accessed via the FAOSTAT (https://www.fao.org/faostat/en/#home) database. Alternatively, Eurostat or national databases might provide good data.

More specifically, the following data shall be applied. For the wood density of any sub-category of roundwood, the mean value shall be used (Table 44), while for the content of N in tree compartment the values for "whole tree" shall be used (Table 45). This is however a simplification because densities refer to stemwood incl. bark and N-content in whole tree is larger than for stemwood. If no other data is available, this simplification may be useful, however, there are uncertainties associated. If possible, data on bark and non-woody biomass removal from national timber harvest records should be used.

- **Industrial round wood**: Data on coniferous and non-coniferous industrial round wood removals (1000 m^3) shall be used (UNECE/FAO database; see Table 43).
- **Fuel wood**: Data on coniferous and non-coniferous wood fuel removals shall be used (UNECE/FAO database; see Table 43).
- **Wood exports and imports**: as suggested above, exports / imports of industrial round wood and wood fuel are considered separately.
    - **Industrial round wood**: Data on coniferous and non-coniferous industrial round wood export / import (1000 m3) shall be used (UNECE/FAO database; vgl. Table 41).
    - **Wood products:** For the quantification of N in the export / import of **further processed wood**, products categoried by FAO under “production” (product codes 2 to 12 in Table 43) shall be used. For the N content of wood products, there is no standard reference value. If no specific data are available, most appropriate values from Table 45 can be used.
    - **Wood fuel**: Data on coniferous and non-coniferous wood fuel export (1000 m^3) shall be used (UNECE/FAO database; vgl. Table 43).

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[69] UNECE/FAO TIMBER database, 1964-2022, as of February 2024: https://unece.org/forests/data-forest-products-production-and-trade and https://unece.org/sites/default/files/2024-07/Flat File JFSQ 2022.xlsx

Table 43: Categorization of removals of roundwood (wood in the rough)

Product Name	Product Code	Flow (UNECE/FAO)	Wood type for NNB	N-flow (NNB)
REMOVALS OF ROUNDWOOD (WOOD IN THE ROUGH				
Roundwood (wood in the rough)	1			FS.FO-RW
- Coniferous roundwood	1.C			
- Non-Coniferous roundwood	1.NC			
Wood fuel, including wood for charcoal	1.1	REMOVALS	Fuel wood	FS.FO-EF.OE, FS.FO-EF.IC, FS.FO-EF.EC
- Coniferous wood fuel	1.1.C			Part of FS.FO-EF.IC
- Non-Coniferous wood fuel	1.1.NC	EXPORT		
Industrial roundwood	1.2	REMOVALS	Industrial round wood	FS.FO-MP.OP
- Coniferous industrial roundwood	1.2.C			
- Non-Coniferous industrial roundwood	1.2.NC	EXPORT		part of MP.OP-RW

Source: FAO 2022: Classification and definitions of forest products 2022. Forest product statistics (fao.org); Forest Sector Questionnaire: https://www.fao.org/forestry-fao/32128-0249d76257c5ae2ac2c0a92899e952e2f.pdf

Table 44: Basic wood density (D) of selected temperate and boreal tree taxa

Taxon	D [oven-dry t (moist m^{-3})]	Source
Abies spp.	0.4	2
Acer spp.	0.52	2
Alnus spp.	0.45	2
Betula spp.	0.51	2
Fagus sylvatica	0.58	2
Fraxinus spp.	0.57	2
Larix decidua	0.46	2
Picea abies	0.4	2
Picea sitchensis	0.4	3
Pinus pinaster	0.44	4
Pinus radiata	0.38 (0.33-0.45)	1
Pinus strobus	0.32	2
Pinus sylvestris	0.42	2

Taxon	D [oven-dry t (moist m^{-3})]	Source
Populus spp.	0.35	2
Prunus spp.	0.49	2
Pseudotsuga menziesii	0.45	2
Quercus spp.	0.58	2
Salix spp.	0.45	2
Tilia spp.	0.43	2
Average	**0.45**	

1 = Beets et al., 2001
2 = Dietz, 1975
3 = Knigge and Schulz, 1966
4 = Rijsijk and Laming, 1994

Source: IPCC 2006

Table 45: Nitrogen fraction of aboveground forest biomass (f_N)

Tree types	Compartment	Nitrogen fraction (f_N) (g kg-1)	References
Evergreens (Pinus sylvestris, Pinus nigra, Picea abies, Abies alba, Pseudotsuga menziesii)	foliage	13.2 ± 3.0 (n=77)	Jacobsen, 2002 Meerts, 2002 Cole, 1981 Genenger, 2003 Kram, 1997 Bauer, 1997
	branches	4.5 ± 1.9 (n=71)	
	stems	1.2 ± 0.5 (n=62)	
	coarse roots	3.0 ± 2.7 (n=27)	
	fine roots	10.0 ± 3.7 (n=23)	
	whole tree (Sweden + Finland, Pinus/Picea)	3.4 ± 1.5	
	whole tree (Austria + Germany, Picea)	2.8 ± 1.2	
	whole tree (Ireland, Picea)	2.7 ± 1.2	
	whole tree (Spain, Pinus/Abies)	2.9 ± 1.5	
Broadleaves (*Fagus silvestris*, *Quercus Petraea*, *Quercus robur*, *Fraxinus excelsior*, *Betula sp.*) (Fagus silvestris, Quercus Petraea, Quercus robur, Fraxinus excelsior, Betula sp.)	foliage	26.0 ± 3.2 (n=48)	Jacobsen, 2002 Hagen-Thorn, 2004 Witthaker, 1979 Bauer, 1997 Meerts, 2002 Cole, 1981 Andre, 2003
	branches	4.6 ± 1.6 (n=24)	
	stems	1.4 ± 0.5 (n=36)	
	coarse roots	3.6 ± 1.6 (n=16)	
	fine roots	9.3 ± 3.6 (n=13)	
	whole tree (Sweden + Finland, mixed broadleaves)	4.3 ± 1.2	
	whole tree (Austria + Germany, Fagus)	2.8 ± 0.9	
	whole tree (Spain, Quercus p./Populus)	2.9 ± 1.0	
	foliage	13.3 (n=1)	Cole, 1981

Tree types	Compartment	Nitrogen fraction (f_N) (g kg-1)	References
Mediterranean broadleaves (Quercus ilex)	branches	5.0 (n=1)	
	stems	2.2 (n=1)	
	coarse roots	-	
	fine roots	-	
Larix kaempferi	foliage	27.0 (n=1)	Jacobsen, 2002
	branches	6.2 ± 1.3 (n=2)	
	stems	1.2 ± 0.4 (n=3)	
	coarse roots	2.8 (n=1)	
	fine roots	-	

- FAO 2022: Forest product statistics with classification and definitions of forest products 2022, https://www.fao.org/forestry-fao/statistics/80572/en/
- UNECE Forestry and Timber Section database: http://www.unece.org/forests/fpm/onlinedata.html
- UNECE/FAO TIMBER database, 1964-2022, as of February 2024: https://unece.org/forests/data-forest-products-production-and-trade (complete dataset in flat file).
- FAOSTAT database: https://www.fao.org/faostat/en/#data/FO
- EUROSTAT database: https://ec.europa.eu/eurostat/
- OECD database: http://www.oecd.org/statistics/ provides information on growing stock in forest, forest land area and exports of forestry products
- National statistics

4.4.5 Uncertainties

Main sources of uncertainties in the quantification N flows from the pool “forests and semi-natural vegetation” are related to the following:

- Quantification of the N flow related **leaching and runoff** are uncertain due to the high variability in the amount and composition of the leachate and runoff that are transferred to the pool „hydrosphere“. In particular the split between leaching and runoff directed to different sub-pools of the pool “hydrosphere” is expected to be very uncertain.
- For **emissions of reactive nitrogen to the atmosphere from the** pool “**forests and semi-natural vegetation**”, uncertainty estimates are provided in the national inventories for

greenhouse gases[70] and air pollutants[71] and can be used directly to estimate the corresponding N flows in the NNB.

- The robust quantifications of N_2O emissions for specific wetland types are highly uncertain due to the low number of available studies. The emission fluxes are highly variable depending on changes in the anoxic conditions and no studies are available providing simple ways to their calculation.
- The estimation of denitrification to N_2 remains highly uncertain, due to difficulties in measurement and a high degree of temporal and spatial variability.
- N fixation is equally uncertain.
- A method for estimating uncertainties based on uncertainty levels is provided in Annex 0, Chapter A.7.

4.5 Quantification of stock changes

Large quantities of nitrogen are stored in living and dead biomass as well as soils of the pool FS. While knowledge of the size of these N stocks is not necessary to understand the processes involving nitrogen and to quantity the nitrogen flows of the NNB, calculations of stock *changes* may provide additional information for the interpretation of the NNB and can help to validate the mass balance of the pool (see Annex 0, Chapter A.6).

Nitrogen stocks in biomass and soil of the pools FS may change over time for various reasons, which are explained in the following chapters. One of the reasons is land conversion, which may, in general, lead to changes in N stocks. According to the definition in the IPCC (2006/2019) land converted to forest land (LF) should have a transition time of 20 years.

In the NNB, by definition, land conversion shall not be represented by an input or output flow or pre-defined stock change (see Annex 0, see Chapter A.6). However, if mass balance calculations of in- and output flows show excess N input into the pool or excess N output from the pool, land conversion may be the reason for that, and therefore, data suggesting that land use change has occurred can be used to explain such mass balance results.

Method

For the NNB, there are in general two approaches to stock change quantification (see also Chapter A.6 in Annex 0):

a) Identification of stock changes based on mass balance analyses and qualitative interpretation. With this approach, the focus lies on explaining N stocks qualitatively, and identifying possible stock changes that may occur.

b) Direct quantification of stock changes. This approach relies on methods and data to calculate the stock changes

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[70] https://unfccc.int/ghg-inventories-annex-i-parties/2024

[71] https://www.ceip.at/

4.5.1 Stock changes in "forests" (FS.FO)

According to the IPCC (2006/2019), it can be distinguished between stock changes in plant biomass, dead organic matter (dead wood + litter) and soil stocks (see Chapters 4.5.1.1 and 4.5.1.2). Stock changes can be induced by land use changes (see Chapter A.6).

- **Biomass** stock changes of nitrogen are related to plant growth, human activities (e.g. harvest, management practices), and natural losses due to disturbances (e.g. windstorms, insect outbreaks, and diseases).

  Changes in N stocks in **dead organic matter** (Δ NDM) are related to the changes in litter and dead wood. The dead wood contains nitrogen in coarse woody debris, dead coarse roots, standing dead trees, and other dead material not included in the litter or soil nitrogen pools. The litter pool contains nitrogen in dead leaves, twigs and small branches (up to a diameter limit of 10 cm), fruits, flowers, roots, and bark (IPCC, 2006). Both harvest (residuals) and natural disturbances add biomass to dead wood and litter pools, while fire and other management practices remove N from these.
  For the estimation of N stock changes information on harvest inputs and outputs and disturbance related inputs and losses are required and have to be calculated separately for dead wood and litter pool. For simplicity reasons, it is assumed that the nitrogen stock remains the same in these pools and N leaching/emission are zero if the land remains within the same land-use category. More sophisticated methods use data from field measurements and models for their implementation are therefore not further elaborated in here[72].

- The **soil nitrogen** stock changes are largely determined by the forest productivity (driving both the production of litter as well as the transfer of N from the soil to the plant biomass), the decomposition of litter (driving the incorporation of nitrogen into the mineral soil) and loss of nitrogen through mineralization and subsequent leaching and gaseous volatilization.

Nationally, there are often good statistics about the amount of biomass in forests. Therefore, such national data should be used for stock change calculated over the years; alternatively C stock change referred to by UNFCCC, in combination with the C:N ratio provides further indication. Data availability is much worse for soils, where possible stock change is poorly documented, and measurements difficult, however, data from UNFCCC (LULUCF) with respect to carbon could be used too.

The approach for stock change calculation described in the following chapters should therefore only be used as an alternative method, if not enough information can be obtain from national/UNFCCC statistics.

4.5.1.1 N stock change in plant biomass (ΔN_B)

For the quantification of change in N stocks (Eq. 31) in biomass (ΔN_B), information on the forest area is used as well as on biomass growth and loss (Eq. 33 and **Fehler! Verweisquelle konnte nicht gefunden werden.**).

Annual changes in N stocks in biomass are calculated according to the Gain-Loss Method:

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[72] detailed quantification method is described in the Version 1/09/2016 of Annex 4 of this document.

$$Changes\ in\ N\ stocks\ in\ biomass\!:\ \Delta N_B = \Delta N_G - \Delta N_L \tag{Eq. 31}$$

ΔN_B	annual change in N stocks in biomass, considering total area [t N y-1]	[t]
ΔN_G	annual increase in N stocks due to biomass growth, considering total area [t N y-1] (Eq. 32)	[t]
ΔN_L	annual decrease in N stocks due to biomass loss, considering total area [t N y-1] Biomass loss can be considered equivalent to wood removal (taking into account simplifications), see Chapter 4.4.4.3.	[t]

Annual increase in biomass N stocks due to biomass increment (ΔN_G) is calculated:

$$Annual\ increase\ in\ biomass\!:\ \Delta N_G = \sum_{i,j} (A_{i,j} \times G_{Total,i,j} \times NF_{i,j}) \tag{Eq. 32}$$

With:

ΔN_G	annual increase in biomass N stocks due to biomass growth	[t N yr-1]
A	area of land	[ha]
G_{Total}	mean annual biomass growth (calculated according to Eq. 33)	[t d. m. ha^{-1} yr^{-1}]
i	ecological zone (i=1 to n); see for this IPCC Guideline for National Greenhouse Gas Inventories 2006 Table 4.1.	
J	climate domain (j =1 to m); see for this IPCC Guideline for National Greenhouse Gas Inventories 2006 Table 4.1.	
NF	nitrogen fraction of dry matter see Table 41. Caution: values in the table are in g kg^{-1}; divide by 1000 in order to get the ratio.	[t N (t d.m.)$^{-1}$]

To estimate average annual biomass growth above and belowground, the biomass increment data of forest inventories (dry matter) can be used directly. The method is based on UNFCCC calculation of carbon stock changes.

$$Average\ annual\ increment\ in\ biomass\!:\ G_{TOTAL} = \sum \{G_W \times (1 + R)\} \tag{Eq. 33}$$

With:

G_{TOTAL}	average annual biomass growth above and belowground	[t N d.m. ha^{-1}yr^{-1}]
G_W	average annual aboveground biomass growth for a specific woody vegetation type [t N d.m. ha^{-1}yr^{-1}];	[t d. m. ha^{-1} yr^{-1}]
R	ratio of belowground biomass to above ground biomass for a specific vegetation type tonne d.m. belowground biomass (tonne	[-]

d.m. aboveground biomass)$^{-1}$. R must be set to zero if assuming no changes of belowground biomass allocation patterns;

Biomass loss can be considered equivalent to wood removal (taking into account simplifications), therefore see Chapter 4.4.4.3.

4.5.1.2 N stock change in soil

In general, N stock changes are difficult to measure directly over short time steps (<10 years) because of small changes and large variation. Moreover, data availability is still scarce so that soil N stock changes are often not included in budget calculation (e.g. Swiss national N budget).

Values for N stock changes in soil can be derived from C stock changes and soil C:N ratios. Both data can be obtained from UNFCCC (example for Austria: changes in soil C stock on forest land remaining forest land are 0.2 t/ha/a; the conversion factor for based on soil C:N ratio is 19 for temperate forests) (Anderl et al. 2021).

In case of organic soils, only drainage of the organic soils are addressed in the following method. Note, that since N stock change in soil is related to land conversion, the following method should only be used to gain information in order to interprete N stock changes already identified by mass balance calculations.

In case of land conversion to forest land on organic soils, the annual N loss can be estimated as:

$$\text{Annual N loss through land conversion on organic soil } L_{organic} = \sum_{c} (A \times EF)c \qquad \text{(Eq. 34)}$$

With:

$L_{organic}$	annual N loss from drained organic soils	[t N yr^{-1}]
A	land area of drained organic soils in climate c	[ha]
EF	emission factor for annual losses of N_2O_N under climate type c, EF = 8 for temperate organic crop and grassland soils, EF =0.6 and 0.1 for temperate and boreal organic nutrient rich and nutrient poor forest soils, respectively.	[kg N ha^{-1} yr^{-1}];

4.5.2 Stock changes in “other land” (FS.OL)

Nitrogen stock changes in the sub-pool “other land” are assumed to be small and depend on the land cover. For areas without soil, such as bare rock, changes in N stocks can be neglected. For areas with soils and vegetation nitrogen stock changes will mainly occur in the soil.

For calculation of the changes in soil N stocks see Eq. 34. N stock change in soil is mainly related to land conversion, and hence, the calculation method should only be used to gain information to interprete N stock changes already identified by mass balance calculations. The following assumptions can be made:

- In case of land conversion from forest land, cropland, grassland, wetlands, and settlements to "other land", respectively, it is assumed that the dominant vegetation is removed entirely, resulting in no N remaining in biomass after conversion.
- For the calculation of N stock changes in dead organic matter after conversion to other lands it can be assumed that there is no accumulation in DM stocks and hence it is not estimated.
- N stock changes in organic soils are assumed to be minimal and very unlikely in other lands. In case of conversion of wetland to other land the annual N loss can be estimated according to Eq. 31.

4.5.3 Stock changes in "wetland" (FS.WL)

Wetlands differ substantially in their above- and belowground properties, spanning from riverine forests to sphagnum peatland. For stock changes in wetlands, it can be distinguished between stock changes in biomass and stock changes in soils.

N stock changes in biomass

In order to minimise the complexity and by taking into account potential data sources, the calculation of biomass stock changes is mainly based on the classification of the aboveground vegetation as forest or non-forest. This differentiation can be done with national and international wetland data bases and (if not available) by aerial photographs and/or satellite images. If classified as forest, biomass stock changes can be assumed to occur for the reasons described in Chapter 4.5.1 or they can be estimated by means of Equation Eq. 31. If the vegetation is dominated by shrubs and grasses, biomass stock changes are considered to be negligible.

N stock changes in soils

Stock changes in wetland **soils** generally occur due to accumulation of nitrogen in undecomposed organic matter, and they can be induced by land use changes. Several studies (Yu 2007, Bridgham et al. 2006) present approaches and data for the calculation of northern peatland carbon stocks and dynamics, which can be adopted for the calculation of soil N stock changes in wetlands. For example, the change in the carbon pool can be used as a "tracer" for nitrogen by using C:N ratios of the organic matter. Hereby N-retention can be estimated as:

$$N_{retention} = \frac{C_{SOM_{accumulation}}}{C:N_{SOM}} \qquad \text{(Eq. 35)}$$

The global average carbon soil organic matter (SOM) accumulation is around 118 g C $m^{-2}y^{-1}$ (range 20-140; Mitsch et al. 2012) and C:N ratio of SOM in wetland is around 30 (range 22-42; Maljanen et al., 2010).

4.5.4 Data sources

- CORINE land cover, contains information of the coverage and land use all over Europe: www.eea.europa.eu/data-and-maps/data/corine-land-cover; also, FAO – www.fao.org
- IPCC 2006 guidelines (www.ipcc.ch) as well as EFDB (www.ipcc-nggip.iges.or.jp) provide information on biomass and SON stocks, growth rates of N pools, biomass conversion and expansion factors, wood density.www.ipcc.chwww.ipcc-nggip.iges.or.jp

- GHG inventories submitted to the UNFCCC: https://unfccc.int/ghg-inventories-annex-i-parties/2024
- National forest inventories: compiled at the European Forest Institute (EFI) - www.efi.int
- National monitoring data on forest management, national soil and climate data, vegetation inventories (e.g. Austrian Forest Inventory).
- UNFCCC

4.6 References

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4.7 Document Version

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Update of Version 2016 by Judith Reutimann, Bettina Schäppi, Sophie Bogler (INFRAS, Zurich).

Reviewers Version 09/2024: Filip Moldan (filip.moldan@ivl.se, IVL Swedish Environmental Research Institute, Göteborg, Sweden), Julia Tanzer (j.tanzer@proman.pro, Proman, Auersthal, Austria)

Version 2016

Authors Version 2016: Ika Djukic (ika.djukic@umweltbundesamt.at), Johannes Kobler (johannes.kobler@umweltbundesamt.at), Claus Beier (cbe@ign.ku.dk), Luc Bonten (luc.bonten@wur.nl), Thomas Dirnböck (thomas.dirnboeck@umweltbundesamt.at)

Reviewers Version 2016: Judith Reutimann, Jürg Heldstab (INFRAS, Zurich).

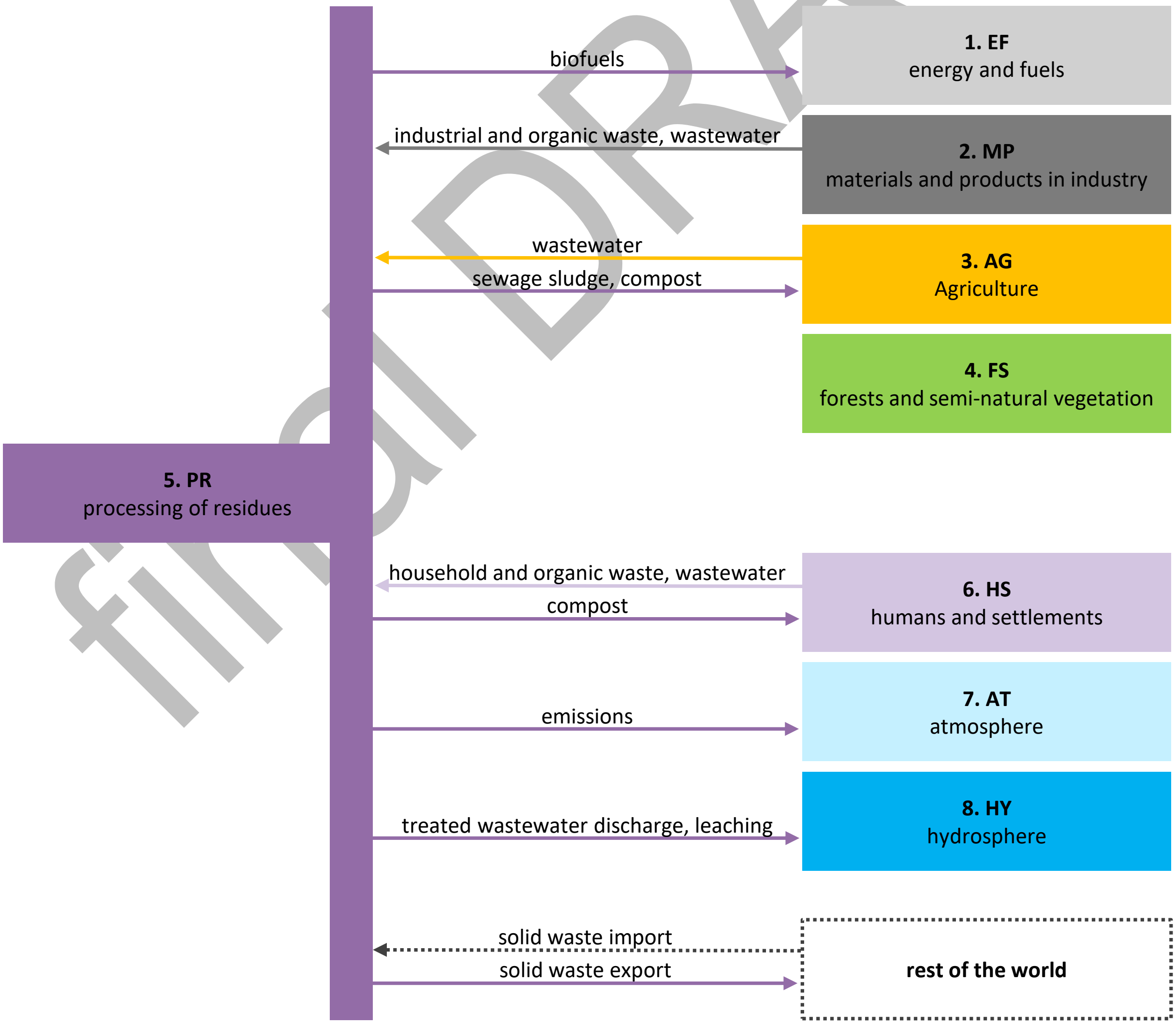
5 Annex 5 – Processing of residues (PR)

The pool "processing of residues" (PR) includes solid waste and wastewater. This pool is relevant for the National Nitrogen Budgets since almost all other pools produce waste and wastewater and therefore waste-based N flows. Significant shares of the agricultural N flows pass via food waste the pool PR. In addition, big N flows between the PR sub-pools (in particular municipal wastewater sewage sludge) and to the pools "atmosphere" (emissions from waste incineration and wastewater treatment) and "hydrosphere" (discharge of treated wastewater) occur.

5.1 Description of flows to other pools

Figure 13 presents the main N flows between the pool PR and other pools. The pool PR is also connected to the rest of the world (RW) via imports and exports of waste, which is a relevant mass flow for some countries. Large input flows of N to the pool PR typically originate from HS (municipal solid waste and wastewater), MP (industrial solid waste and wastewater from food industry) and AG (digestate from biofuel, particular biogas production, in countries, where this activity is relevant).

Figure 13: N flows between pool "processing of residues" (PR) and other pools



Source: illustration by INFRAS

Emissions to the pool "atmosphere" (AT) are caused by the diverse kinds of waste treatment, such as incineration (NO_x, N_2O) as well as landfills and wastewater treatment (NH_3, N_2O, N_2).

N discharge to the pool "hydrosphere" (HY) is predominantly given by all kinds of wastewater treatment (N_{mix}), where the level of technology defines the distribution of N to water (HY) and the atmosphere (AT). In countries where disposal of waste on landfills is usual, leachate can be a relevant flow to hydrosphere. In addition, N flows related to biofuel production and composting of industrial and household wastes are accounted for in the pool "processing of residues".

5.2 Boundaries

Within the pool PR following processes for treating solid waste and waste are included:

- Deposition of waste on landfills,
- Incineration of waste in municipal solid waste incinerators, industrial incinerators or sewage sludge incinerators
- Wastewater treatment plants (for municipal wastewater and industrial wastewater)

Moreover, waste may be collected separately or maybe separated by mechanical sorting facilities. Separate collection requires the distribution of a waste and thus the N flow to the different subsequent treatment steps: parts of the flow might be guided to deposition, incineration or to biological treatment. Parts may also be led to recycling. Recycling is handled outside the pool PR. Material for recycling and its N flows are redistributed to pool MP (materials and products in industry).

Composting and anaerobic digestion of agricultural residues or even cultivated biomass for biogas is accounted for in the pool "agriculture". There, manure is of central relevance. This annex addresses genuine wastes, such as organic waste from households or industries. Nonetheless, the application of composts and digestates happens on agricultural soils. Therefore, these flows are returned to the Annex for the pool AG (Annex 3).

Incoming waste and wastewater flows (including the N content) are specified in the pools from which these flows originate (e.g. humans and settlements for municipal waste and wastewater). This applies also for the waste flows for recycling.

Relevant flows are given between the two sub-pools PR.SO and PR.WW, as described in the subsequent chapter.

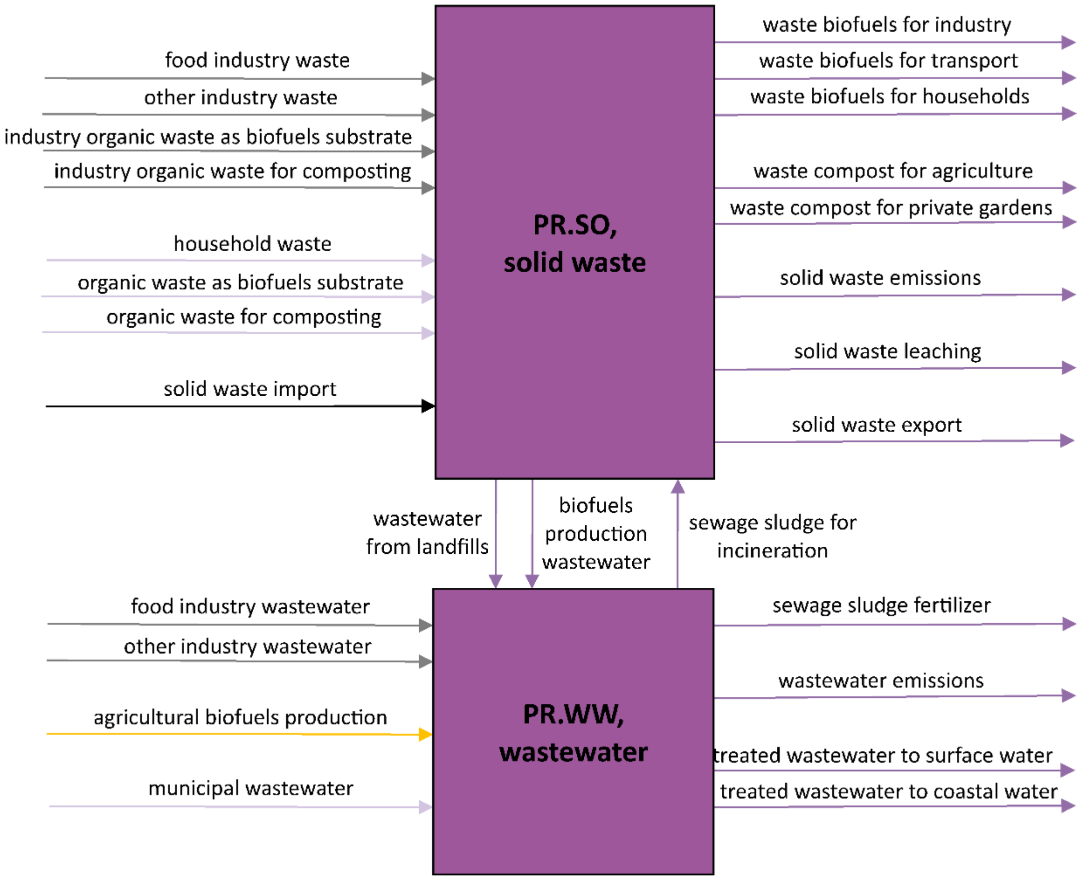
5.3 Pool structure and N flows

5.3.1 Overview of N flows

Figure 14, Table 46 and Table 47 show the sub-pools of pool PR and all relevant N flows from and to the other sub-pools. The sub-pools of pool PR are:

- sub-pool "solid waste" (PR.SO, Chapter 5.3.2)
- sub-pool „wastewater" (PR.WW, Chapter 5.3.3)

Figure 14: N flows between sub-pools of "processing of residues" (PR) and other pools



The arrows characterize the nitrogen flows between the sub-pools. Colours indicate from which pool the flows originate (the colours assigned to the pools can be seen in the overview graphics "n flows between pools"). Stock changes are not depicted. The flow names used in the graph here contain some details for clear identification and can deviate from the flow names given in the table below, because the latter correspond exactly to the flow names given in the Excel-Template for NNBs.

Source: illustration by INFRAS, generated in STAN

Table 46: N flows going out of the pool WS

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
Solid waste	PR.SO	EF.IC	Manufacturing industries and construction	Biofuels	Biofuels produced from organic waste	N_{mix}	5.4.4.1
	PR.SO	EF.TR	Transport	Biofuels	Biofuels (biodiesel) produced from organic waste	N_{mix}	5.4.4.1
	PR.SO	EF.OE	Other energy and fuels	Biofuels	Biofuels produced from organic waste	N_{mix}	5.4.4.1

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
	PR.SO	AG.SM	Soil management	Compost for agriculture	Compost used on agricultural soils	N_{mix}	5.4.4.2
	PR.SO	PR.WW	Wastewater	Wastewater from landfills	Wastewater from landfills treated in wastewater treatment plants.	N_{mix}	5.4.5
	PR.SO	PR.WW	Wastewater	Biofuels production wastewater	Wastewater from biofuel production	N_{mix}	5.4.4.4
	PR.SO	HS	Humans and settlements	Compost for private gardens	Compost for private gardens	N_{mix}	5.4.4.2
	PR.SO	HY.GW	Groundwater	Leaching	Leaching of nitrogen from landfills to groundwater	N_{mix}	5.4.5.1
	PR.SO	AT	Atmosphere	Emissions	Emissions from solid waste treatment (at waste incineration plant, at landfill)	NH_3 NO_x N_2O	5.4.1.1
	PR.SO	RW	Rest of the world	Solid waste export		N_{mix}	5.4.1.2
Wastewater	PR.WW	AG.SM	Soil management	Sewage sludge fertilizer	Sewage sludge used as fertilizer	N_{mix}	5.4.6.2
	PR.WW	PR.SO	Solid waste	Sewage sludge incineration	Sewage sludge transferred to waste incineration plants	N_{mix}	5.4.6.1
	PR.WW	AT	Atmosphere	Emissions	Emissions from wastewater treatment	NH_3 NO_x N_2O N_2	5.4.1.2
	PR.WW	HY.SW	Surface water	Treated wastewater discharge	direct/indirect discharge of treated sewage water, wastewater from ships	N_{mix}	5.4.3.1

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
	PR.WW	HY.CW	Coastal water	Treated wastewater discharge	direct/indirect discharge of treated sewage water, wastewater from ships	N_{mix}	5.4.3.1

The following table shows the N flows entering the pool "processing of residues". They are described in the Annexes of the pools from which these N flows originate.

Table 47: N flows entering the pool "processing of residues" (PR)

Sub-Pool Out	Out	In	Sub-Pool in	Flow Name	Species	Chapter
Food processing	MP.FP	PR.SO	Solid waste	Organic waste as biofuels substrate	N_{mix}	2.4.4.3
	MP.FP	PR.SO	Solid waste	Organic waste for composting	N_{mix}	2.4.4.4
	MP.FP	PR.SO	Solid waste	Food industry waste	N_{mix}	2.4.2.1
	MP.FP	PR.WW	Wastewater	Industry wastewater	N_{mix}	2.4.2.2
Other producing industry	MP.OP	PR.SO	Solid waste	Other industry waste	N_{mix}	2.4.2.1
	MP.OP	PR.WW	Wastewater	Other industry wastewater	N_{mix}	2.4.2.2
Biofuel production and composting	AG.BC	PR.WW	Wastewater	Biofuel production wastewater	N_{mix}	3.4.5.6
Humans and settlements	HS	PR.SO	Solid waste	Organic waste as biofuels substrate	N_{mix}	6.4.1.4
	HS	PR.SO	Solid waste	Organic waste for composting	N_{mix}	6.4.1.4
	HS	PR.SO	Solid waste	Household waste	N_{mix}	6.4.1.2
	HS	PR.WW	Wastewater	Municipal wastewater	N_{mix}	6.4.2.1
Rest of the world	RW	PR.SO	Solid waste	Solid waste import	N_{mix}	5.4.2.1

5.3.2 Sub-pool „solid waste“ (SO)

Treatment processes within this sub-pool are waste incinerators, composting and digestions plant for organic waste and landfills.

The sub-pool „solid waste“ PR.SO receives N from several pools, as listed in Table 47: household waste from pool HS is a significant number, diverse industries, such as food industry (MP.FP) and other industry (MP.OP) are also listed. For some countries import and/or export of waste from or to pool RW is relevant.

Outgoing N flows from sub-pool PR.SO to natural systems include NO_x emissions from incinerators and any other form of combustion (e.g. flaring of landfill gas). N_2O and NH_3, are typically emitted by biological treatment. However, N_2O can be significant when sewage sludge is combusted. NH_3 from waste incineration occurs when NO_x is reduced via denox technology. Leaching of nitrogen from landfills to groundwater can be relevant, though the data for N content is wide-ranging. Wastewater from waste incinerators is far less relevant in terms of N, since scrappers are focussed on sulphur and halogens. Depending on the landfill standard, relevant amounts of N might be stored within the landfill for long-term.

As N output flows from incineration, such as NO_x and NH_3, depend on reported or technically determined emission factors (as also given in EEA 2013, 2016, 2023). The N content of the combusted waste is irrelevant for the calculation of emissions to the atmosphere.

Derived composts and digestates are guided to the agriculture pool, serving as organic fertilizer, combined with subpool AG.BC.

5.3.3 Sub-pool „wastewater“ (WW)

The sub-pool “wastewater” PR.WW receives N from the pool “humans and settlements” HS (Municipal wastewater), MP (wastewater from food production and other industries) and AG.BC (wastewater from biofuel production), as given in Table 47.

In addition, the internal flow from this sub-pool into the sub-pool PR.SO are particularly relevant, as the sewage plants generate the waste stream sewage sludge, including N from wastewater. The technical level of the sewage plants is key with regard on the distribution of N to sludge, discharged water to receiving waterbodies and air emissions (N_2O, NH_3 and N_2). Low level technique (only mechanical treatment) branches out only 8 % of the N inflow to sewage sludge, while 90% is discharged. High standard including denitrification directs 24 % N to sewage sludge, more than to air (overly as N_2, but also as NO_x), and just 5% finally discharged via the treated wastewater (DWA 2024). Some countries have limit values for the N content of wastewater to be discharged, which are also based on the state of the art. Where such limit values can be applied directly to the calculation of N emissions, this should be done.

In some cases treatment of waste leads to wastewater, particular in biological waste treatment plant (composting and anaerobic digestion). Mostly, such wastewater flows are circulated for humidification or are included in the digestate (see Chapter 3.4.5.1). Since this is not true for all cases, data for quantities and N-content for such wastewater are provided (see Chapter 5.4.4.4).

This shows that the N flows are interdependent, as are the existing technology and its level. Calculating all of this in a consistent way for the computation of the NNB would require a complex model. However, this would not be in line with the usual calculation method used in this guidance (see also Chapter 5.4). For each of these, a separate calculation of N in the input and N of the species in the input in air, water, etc. is carried out here on the basis of physical output flows (m^3 of wastewater) and corresponding nitrogen content data (mg/L N in the effluent, as a national average or based on national information about technical standard values). In this way, consistency with the reporting can be ensured.

5.4 Quantification of flows

5.4.1 Quantification of emissions to the atmosphere

Information of flows of reactive nitrogen to the atmosphere can be taken directly from national inventories on air pollutants and greenhouse gases. The emissions of nitrogen compounds can be converted to nitrogen flows by applying the corresponding nitrogen content (Table 3).

$$\boldsymbol{F}_{WS.XX-AT} = \sum_{W} \boldsymbol{E}_{W} \cdot \boldsymbol{f}_{N} \qquad \text{(Eq. 36)}$$

With:

$\mathbf{F}_{\mathbf{PR.XX\text{-}AT}}$	N flow due to emissions from different wastes from sub-pool PR.XX to pool AT	[kt N]
$\mathbf{E}_{\mathbf{W}}$	Emissions of different nitrogen species (NO_x, NH_3, N_2O, N_2) from different wastes between the sub-pools PR.XX and pool AT	[kt]
$\mathbf{f}_{\mathbf{N}}$	Nitrogen content of emissions of reactive nitrogen (Table 3)	[% N]

The national inventories provide data on emissions of NO_x[73], NH_3, and N_2O. If emissions of other organic N-containing compounds—such as N-containing (semi-)volatile organic compounds like nitrous acid—are to be included in the NNB, country-specific data sources must be consulted as there is no standardized database available. These additional emissions must be incorporated into the NNB as additional flows to the atmosphere.

Note on alternative method

If a country does not submit an air pollutant or a greenhouse gas inventory, the corresponding emissions need to be calculated according to the Tier methods described in the EMEP EEA Guidebook (EEA 2013, 2016, 2023) for air pollutants (i.e. NH_3 and NO_x) and IPCC Guidelines (IPCC 2006, 2019) for greenhouse gases (i.e. N_2O). For a Tier 1 approach based on default emission factors, the only data requirement are fuel quantities consumed in each process. For higher Tier methods, additional information on combustion technologies used and application of abatement technologies is required. In addition, higher Tier methods may also require country-specific emission factors.

5.4.1.1 Emissions from solid waste (PR.SO-AT)

This N flow covers emissions from solid waste incineration as well as emissions from landfills and from mechanical biological treatment plant (MBT).

5.4.1.1.1 Data sources

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

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[73] Note that NO emissions from denitrification are reported in this guidance as part of the species NOx.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions[74]
- Emission data for N_2O: UNFCCC National Inventory Submissions[75]

Emission sources potentially relevant for the sub-pool "solid waste" are provided in the following table.

Table 48: Emission sources to be accounted for in the sub-pool "solid waste" (SO)

NFR Code	Description
1A1a	Public electricity and heat production[76]
5A	Biological treatment of waste[a)] - Solid waste disposal on land
5C1a	Municipal waste incineration
5C1bi	Industrial waste incineration
5C1bii	Hazardous waste incineration
5C1biii	Clinical waste incineration
5C1biv	Sewage sludge incineration
5C1bv	Cremation
5C1bvi	Other waste incineration (please specify in the IIR)
5E	Other waste

a) Should include also Mechanical biological treatment of waste (MBT), however, this technology is not included within the NFR code of the EMEP/EEA Guidebook.

5.4.1.2 Emissions from wastewater (PR.WW-AT)

This N flow covers emissions from wastewater treatment and discharge.

5.4.1.2.1 Data sources

Data on emissions of reactive nitrogen are available for most countries in the national emission inventories for air pollutants and greenhouse gases.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions[77]
- Emission data for N_2O: UNFCCC National Inventory Submissions[78]

The formation of N_2 takes arises from the reduction of NO_3^- by the process of denitrification. The effect on the N content in wastewater is described in Chapter 5.4.3.1.1 using data from DWA

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[74] https://www.ceip.at/

[75] https://unfccc.int/ghg-inventories-annex-i-parties/2024

[76] Includes only emissions from waste incineration plants. Emissions from other heat and electricity production neeed to be accounted for in the pool "energy", see Chapter 1.3.2.

[77] https://www.ceip.at/

[78] https://unfccc.int/ghg-inventories-annex-i-parties/2024

(2024). The degradation of $N\text{-}NO_3$ described there of an additional 51 % compared to a basic elimination of 24% (by mechanical treatment plus biological nitrification) is manifested in the release of N_2. It can therefore be assumed that 51% of the N input stream is converted to N_2 in a wastewater treatment plant with denitrification.

Table 51 contains exemplary data for the elimination rate of common sewage treatment techniques and the associated N concentrations. These are taken from studies by the DWA (2024)[79].

Emission sources potentially relevant for the sub-pool "wastewater" are provided in the following table.

Table 49: Emission sources to be accounted for in the sub-pool "wastewater" (WW)

NFR Code	Description
5D1	Domestic wastewater handling
5D2	Industrial wastewater handling
5D3	Other wastewater handling

5.4.2 Quantification of export and import of solid waste

$$F_{RW-WS.SO} = \sum_i A_i \cdot f_{i,Nmix}$$

$$F_{WS.SO-RW} = \sum_i A_i \cdot f_{i,Nmix} \qquad \text{(Eq. 37)}$$

With:

$\mathbf{F_{RW\text{-}PR.SO}}$ $\mathbf{F_{PR.SO\text{-}RW}}$	N flow: Transfer of nitrogen in solid waste from pool PR to RW (export) and from RW to PR (import)	[kt N]
$\mathbf{A_i}$	Amount of solid waste of type i transferred between the pool PR and RW	[kt]
$\mathbf{f_{i,\,Nmix}}$	N content in waste of type i quantified as N_{mix}	[% N]

5.4.2.1 Solid waste export and import (PR.SO-RW, RW-PR.SO)

In principle, imported and exported waste can reflect the entire spectrum of waste. Domestic waste or sewage sludge is often transported to countries with higher treatment capacities for disposal. Industrial waste, hazardous waste and special collected fractions (e.g. plastics) are exported to countries that offer more cost-effective disposal, depending on the case. The description of waste for exports and imports therefore covers the entire range of waste generated.

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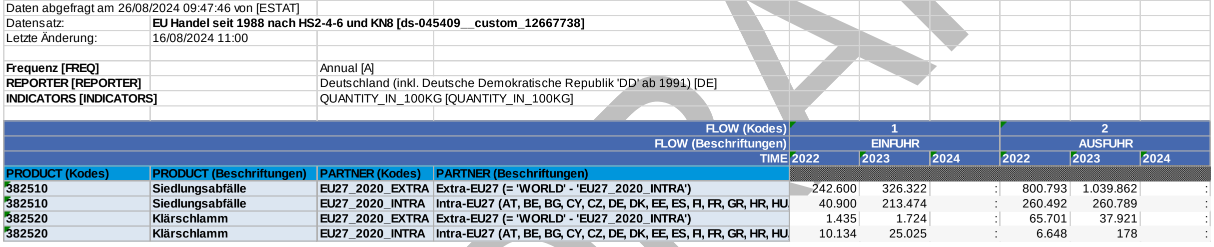
[79] Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. , German Association for Water, Wastewater and Waste

5.4.2.1.1 Data sources

Activity data

- Amounts of imported and exported wastes can be found in national trade statistics.
- EUROSTAT Comext data base[80]: Within the EUROSTAT Comext data base, the amount of any import and export of waste can be extracted. For all non-European countries at least, their export to European countries ca be detected. Figure 15 gives an exemplary extract from a data query for Germany for municipal waste (Siedlungsabfall) and sewage sludge (Klärschlamm).
- Alternatively, for all transboundary shipments of waste EUROSTAT offers Waste shipment statistics reporting every shipment and displaying the waste type (according to the European List of Waste code): https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_shipment_statistics

Figure 15: EUROSTAT Comext data base: Exemplary extract from a data query for Germany for municipal waste (Siedlungsabfall) and sewage sludge (Klärschlamm)



Daten abgefragt am 26/08/2024 09:47:46 von [ESTAT]
Datensatz: **EU Handel seit 1988 nach HS2-4-6 und KN8 [ds-045409__custom_12667738]**
Letzte Änderung: 16/08/2024 11:00

Frequenz [FREQ] Annual [A]
REPORTER [REPORTER] Deutschland (inkl. Deutsche Demokratische Republik 'DD' ab 1991) [DE]
INDICATORS [INDICATORS] QUANTITY_IN_100KG [QUANTITY_IN_100KG]

			FLOW (Kodes)	**1**			**2**		
			FLOW (Beschriftungen)	**EINFUHR**			**AUSFUHR**		
			TIME	**2022**	**2023**	**2024**	**2022**	**2023**	**2024**
PRODUCT (Kodes)	**PRODUCT (Beschriftungen)**	**PARTNER (Kodes)**	**PARTNER (Beschriftungen)**						
382510	**Siedlungsabfälle**	**EU27_2020_EXTRA**	**Extra-EU27 (= 'WORLD' - 'EU27_2020_INTRA')**	242.600	326.322	:	800.793	1.039.862	:
382510	**Siedlungsabfälle**	**EU27_2020_INTRA**	**Intra-EU27 (AT, BE, BG, CY, CZ, DE, DK, EE, ES, FI, FR, GR, HR, HU**	40.900	213.474	:	260.492	260.789	:
382520	**Klärschlamm**	**EU27_2020_EXTRA**	**Extra-EU27 (= 'WORLD' - 'EU27_2020_INTRA')**	1.435	1.724	:	65.701	37.921	:
382520	**Klärschlamm**	**EU27_2020_INTRA**	**Intra-EU27 (AT, BE, BG, CY, CZ, DE, DK, EE, ES, FI, FR, GR, HR, HU**	10.134	25.025	:	6.648	178	:

N content

- If there are data sources (studies, assessments) reporting on N contents of on a regional or national level, such information is to be preferred.
- Data in Table 50 can be taken as reference values, in case no specific data are available. A major data source for these values is the ABANDA data base by the State Environmental Agency (LANUV) of the Federal State Northrhine-Westfalia, Germany. https://www.abfallbewertung.org/ipa/abanda/script/lua_db_portal.php?application=abanda&runmode=aida&initform=MK_Auswertemenue

This data base[81] provides N content data for more than 150 waste types, specified according to the European List of Waste.[82]

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[80] https://ec.europa.eu/eurostat/comext/newxtweb/

[81] ABANDA is part of the Information - Portal - Waste Assessment (IPA), a Germanwide project in which specialised authorities from several federal states and the federal government are participating. The primary aim of IPA is to support the work of the authorities. However, the information is of course also available to private waste management companies and interested members of the public. https://www.abfallbewertung.org/?content=ABANDA

[82] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014D0955

Table 50: N content of waste types

Waste types	N content (%) reference value	Range (%)	Data source
Household wastes			
Household and similar wastes	0.9%	0.1%-1.2%	Fehrenbach et al. (2008); Obernosterer, Reiner (2003)
Organic waste from households	1.65%		Knappe et al. (2012)
Sorting residues	1.20%		ABANDA
Combustion wastes	0.03%	0.01-0.04% (2%)	ABANDA
Mineral wastes from waste treatment and stabilised wastes	0.61%		ABANDA
Common sludges	4.40%	0.01-7.8%	ABANDA
Industry waste (food and processing)			
Animal and mixed food waste	7.40%	10.8-11%	ABANDA
Vegetal wastes	1.30%	0.4-2.4%	ABANDA
Chemical solid waste			
Spent solvents	0.10%	0.1-0.59%	ABANDA
Acid, alkaline or saline wastes	1.80%	0.43-2%	ABANDA
Used oils	1.60%	0.06-3.1	ABANDA
Chemical wastes	1%		ABANDA
Other industrial waste			
Industrial effluent sludges	1.40%	0.13-4.7%	ABANDA
Metal wastes, ferrous	0.10%		ABANDA
Metal wastes, non-ferrous	0.10%		ABANDA
Metal wastes, mixed ferrous and non-ferrous	0.10%		ABANDA
Glass wastes	0%		ABANDA
Paper and cardboard wastes	0.28%		ABANDA
Rubber wastes			ABANDA
Plastic wastes	2.1%	0.15-3.7%	ABANDA
Wood wastes	0.25%	0.1-0.49%	ABANDA
Textile wastes	1.00%	0.17-2.9%	ABANDA
Mixed and undifferentiated materials	1.20%		ABANDA

Waste types	N content (%) reference value	Range (%)	Data source
Mineral waste from construction and demolition	0.28%	0-0.4%	ABANDA
Other mineral wastes (W122+W123+W125)	0.10%	0-0.2%	ABANDA
Soils	0.25%	0.02-0.78%	ABANDA
Dredging spoils	0.26%	0.35-0.53%	ABANDA

5.4.3 Quantification of discharge of treated wastewater to water bodies (PR.WW-HY.CW, PR.WW-HY.SW)

$$F_{WS.XX-HY.YY} = A \cdot f_{Nmix} \qquad \text{(Eq. 38)}$$

With:

$F_{PR.XX\text{-}HY.YY}$	N flow: Transfer of treated wastewater from pool PR to HY	[kt N]
A	Discharged amount of treated wastewater to the pool HY	[m^3]
f_{Nmix}	N content in wastewater quantified as N_{mix}	[% N]

5.4.3.1 Discharge of treated wastewater (PR.WW-HY.SW, PR.WW-HY.CW)

These N flows include flows of treated wastewater from wastewater treatment plants to the pool "hydrosphere". These plants may be of a municipal nature, which primarily treat domestic wastewater, but into which commercial and industrial operations may also discharge. On the other hand, there are industrial wastewater treatment plants, often at large industrial complexes treating a high volume of their own (industrial) wastewater, sometimes including municipal waste water from local settlements.

Domestic wastewater transporting human excretions are a major N flow (see Chapter 6.4.2.1). Thus, one of the purposes of sewage plants to eliminate N (apart from reduction of organic loads, phosphorous and other pollutants) and to meet threshold values for discharge. The final N concentration and load depends on the applied technique. Mere mechanical treatment just removes around 8% of the N load concentration, biological treatment enables additional elimination from 16% up to 50% (DWA 2024).

Industrial wastewater usually contains only low levels of N. Wastewater from the food industry is an exception here - provided it is not treated in municipal plants. Large wastewater-relevant sectors such as the chemical industry, paper industry or metal industry only contain small amounts of N (see Chapter 2.4.2.2). This means, for example, that N must be 'fed in' for the biological degradation of the carbon-rich organic matter in the wastewater for paper mill wastewater plants (Möbius 2017).

As the calculation of the N flow from treated wastewater is based on the input from the HS pool, the first step is to determine the proportion of wastewater that is fed into a wastewater treatment plant (connection rate). For the proportion of wastewater not connected, the N flow from pool HS remains unchanged.

5.4.3.1.1 Data sources

Activity data

- The amount of municipal wastewater can be determined from national statistics on water and/or wastewater or Eurostat water statistics for European countries (see also Chapter 6.4.2.1.2)[83].
- The member states are obliged by the EU Council Directive concerning urban wastewater treatment (91/271/EEC) to ensure that every two years the relevant authorities or bodies publish situation reports on the disposal of urban waste water and sludge in their areas (Article 16).
  eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31991L0271
- Another helpful source is the Freshwater Information System for Europe (WISE Freshwater) with country profiles for urban wastewater (https://water.europa.eu/freshwater/countries/uwwt).

N content

As noted above, the N content of treated municipal wastewater refers to the applied level of technology. Which technology is used in a country or region in turn depends on the legal limits for the discharge of wastewater. If such limit values for N contents in wastewater are available in a country, it can be assumed that these values essentially also represent the actual contents. If no such limit values are availableit should always be possible to provide an indication of the usual status of the installed wastewater technology. This means that the N concentrations in treated wastewater can be inferred from the reference to the usual technical standard.

Table 51 contains exemplary data for the elimination rate of common sewage treatment techniques and the associated N concentrations. These are taken from studies by the DWA (2024)[84].

Table 51: N elimination rate of different sewage treatment techniques and final N concentrations; source DWA (2024)

	N elimination rate [%]	N concentration after treatment [mg/l]
No treatment	0%	62.5
Mechanical treatment	8%	57.5
Mechanical & biological treatment (only C decomposition)	24%	47.5
Mechanical & biological treatment (nitrification)	24%	47.5
Mechanical & biological treatment (nitrification&denitrification)	75%	15.5

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[83] https://ec.europa.eu/eurostat/web/environment/information-data/water (accessed 01.07.2024)

[84] Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V., German Association for Water, Wastewater and Waste

The Freshwater Information System for Europe (WISE Freshwater) includes also information on implemented treatment standards by member states. These data can guide to select the appropriate elimination factor from Table 51.

5.4.4 Quantification of N flows from biofuel production and composting

Note on possible simplification

These N flows are only relevant for countries that produce biofuels and compost from waste substrates. If no or only small amounts of biofuel and compost from these sources are produced, these flows can be neglected for simplification purposes.

Per default, biofuel production and composting from agricultural substrates is treated within the pool "agriculture" (Chapter 3.4.5). In a simplified approach and depending on a country's specific production conditions, it is suggested to report the nitrogen flows for all types of substrates in either pool "agriculture" or pool "processing of residues" together.

Biofuels, typically biogas and biodiesel, are used as energy source. Residues from their production (anaerobic fermentation of organic residues or other organic materials) are termed digestate. The product of aerobic treatment of organic matter is known as compost. The N content of this substance is primarily dependent on the N content of the substrates. However, the treatment also removes a smaller proportion via the exhaust air (NH_3, N_2, N_2O) or overland flow. Composts and digestates are usually applied in agriculture, garden landscaping, or in private gardens i.e. on soils.

$$\begin{gathered} F_{WS.SO-EF.XX} = A \cdot f_N \\ F_{WS.SO-HS} = A \cdot f_N \end{gathered} \qquad \text{(Eq. 39)}$$

With:

$F_{PR.SO-EF.XX}$	N flow due to biofuels used as energy source in sub-pool XX (IC, TR or OE) of the pool "energy and fuels"	[kt N]
$F_{PR.SO-HS}$	N flow due to compost that is transferred to private and public green spaces	[kt N]
A	Amount of biofuel and compost transferred to other pools/sub-pools	[kt]
f_N	Corresponding nitrogen content of biofuel and compost	[% N]

5.4.4.1 Biofuels (PR.SO-EF.IC, PR.SO-EF.TR, PR.SO-EF.OE)

Activity data

- National statistics on biofuel production (biogas) from organic wastes

N content

- National data for N content of organic wastes or refer to Table 50 for input data

5.4.4.2 Compost for agriculture (PR.SO-AG.SM)

Activity data

- National statistics on compost production from organic wastes and where these composts are applied.

N content

- National data for N content of organic composts or
- As a proxy composts from organic wastes have a N content around 1.35 % d.m. (BGK 2023).

5.4.4.3 Compost for private gardens (PR.SO-HS)

Activity data

- National statistics on compost production from organic wastes and where these composts are applied.

N content

- National data for N content of organic composts or
- As a proxy composts from organic wastes have a N content around 1.35 % d.m. (BGK 2023).

5.4.4.4 Wastewater from biofuel production (PR.SO-PR.WW)

This N flow comprises nitrogen in the wastewater of biofuel production and composting plants. In most cases, leachate from the composting process is returned to the compost piles. The water evaporates via the process and no wastewater is discharged.

Activity data

- In general, a leachate quantity of between 10-60 litres per tonne of waste can be assumed (Hupe et al. 1998).

N content

- Studies in the USA show N contents of between 100 to 400 mg/L of for NH_4^+ and 100 to 700 mg/L for NO_3^- (Chatterjee et al. 2013).

5.4.5 Quantification of leaching to water bodies (PR.SO-HY.GW)

Wastewater from landfills may contain nitrogen. The amounts can be calculated based on the volumes of

$$F_{WS.SO-HY.GW} = A \cdot c_{Nmix} \qquad \text{(Eq. 40)}$$

With:

$F_{PR.SO-HY.GW}$	N flow: leaching of nitrogen from landfills to groundwater	[kt N]
A	Amount of leachate volumes from landfills to the sub-pool HY.GW	[m^3]
c_{Nmix}	Concentration of nitrogen in the leachate quantified as N_{mix}	[g N/m^3]

5.4.5.1 Leaching to groundwater (PR.SO-HY.GW)

Landfill leachate occurs when precipitation seeps through the landfill body. Precipitation water that is not discharged as surface water or evaporates or evaporates, infiltrates the waste body and comes into contact with the deposited waste.

Quantities are dependent on:

- Precipitation
- How the landfill surface or parts of the surface are covered.

Precipitation depends on the climate zone. The coverage depends on the usual practice in the respective country.

5.4.5.1.1 Data sources

Activity data

Table 52 gives insight to different leachate volumes from municipal landfills in different countries (Austria, the USA (Ohio) and Poland).

Another point of importance is the whereabout of the leachate. If there is no basis sealing including a leachate collection systema complete discharge into groundwater must be assumed. When leachate is collected further questions have to be answered:

- How efficient is the collection?
- How is the collected treated before discharged to water bodies?

Table 52: Different leachate volumes from municipal landfills in Austria, the USA (Ohio) and Poland

	Austria (UBA-AT 2010) $m^3/(ha \cdot d)$	Ohio, USA (Krause et al. 2023) $m^3/(ha \cdot d)$	Poland (Podlasek 2022) $m^3/(ha \cdot d)$
Open surfaces:	4–10		
Recultivated surfaces:	1–3	1,3 - 2,0	2,2
Sealed surfaces:	< 1		

N content

The nitrogen concentration in leachate is provided in the following table.

Table 53: N concentration in leachate from landfills

	municipal waste	mineral waste	sewage sludge	industrial waste
	mg/l	mg/l	mg/l	mg/l
NH_4-N	615	10	10	258
Total N	1000	52	21	841

Sources:
https://igsvtu.lanuv.nrw.de/vtu/doc.app?DATEI=13/dokus/fabe24.pdf&USER_ID=258
https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0249.pdf

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https://www.researchgate.net/figure/Composition-of-the-raw-landfill-leachate_tbl1_262649149

5.4.6 Quantification of sewage sludge (PR.WW-PR.SO, PR.WW-AG.SM)

Sewage sludge is the major solid product from waste water (sewage) treatment – be municipal and from industrial sewage treatment plants. Due to human excrements municipal waste water tends to have higher N loads, while the N concentration of industrial waste water strongly depends on the type of industry.

Depending on the type of wastewater treatment plant, sewage sludge is disposed of as raw sludge or stabilised aerobically or anaerobically at the plant before being disposed of or recovered. Anaerobic digestion reactors are also used to produce biogas during anaerobic digestion, thereby reducing the volume of sewage sludge. Other processes are also available for this purpose, such as disintegration. In terms of N flows, these treatment steps mostly involve recirculation at the wastewater treatment plant, which consequently changes little in terms of the output flows. However, if the wastewater treatment plants include denitrification stages, the N in the remaining sewage sludge can be removed to a greater extent. Larger proportions can then be released as N_2. However, modelling these material flows is complex and requires comprehensive data on the actual implementation in the plants.

In Europe the application of sewage sludge as a fertilizer is limited due to the Council Directive 86/278/EEC[85]. Sewage sludges which do not apply with the thresholds need to be disposed alternatively. Major alternatives are:

- Application on soils for landscaping, e.g. for the recultivation of opencast mines or other devastated areas (here sewage sludge is appreciated not primarily for its nutrient content but for its organic matter)
- Incineration.
  - In mono combustions plants dedicated for sewage sludge or
  - Co-combustion in coal power plants, or cement works or waste incineration plants (MSWI)
- Finally. disposing on landfills is an option, at least outside the EU.[86]

Possible future options could also be the production of biocomponents based on advanced technologies (e.g. production of biochar, bio-oil in the pyrolysis process) or building materials-

To simplify the N-flow calculation, the thermal processes are summarised below under incineration and the soil-related applications under use as agricultural fertiliser.

$$F_{WS.WW-WW.SO} = A_{WS.WW-WW.SO} \cdot f_{Nmix} \qquad \text{(Eq. 41)}$$

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[85] Council Directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture; last amendment by Regulation (EU) 2019/1010 of the European Parliament and of the Council of 5 June 2019

[86] According to EU regulations (Directive 1999/31/EG and connected regulations), landfilling of waste containing organic matter is highly.

$$F_{WS.WW-AG.SM} = A_{WS.WW-AG.SM} \cdot f_{Nmix}$$

With:

$\mathbf{F_{PR.WW\text{-}PR.SO}}$	N flow: sewage sludge transferred to waste incineration plants	[kt N]
$\mathbf{F_{PR.WW\text{-}AG.SM}}$	N flow: use of sewage sludge as agricultural fertilizer	
$\mathbf{A_{PR.WW\text{-}PR.SO}}$	Amount of sewage sludge transferred to waste incineration plants	[kt]
$\mathbf{A_{PR.WW\text{-}AG.SM}}$	Amount of sewage sludge use of sewage sludge as agricultural fertilizer	
$\mathbf{f_{Nmix}}$	N content of sewage sludge quantified as N_{mix}	[% N]

5.4.6.1 Sewage sludge transferred to waste incineration plants (PR.WW-PR.SO)

Incineration of sewage sludge can be executed by mono-combustion plants or by co-incineration with coal power plants, cement works or waste incineration plants (MSWI). Due to obligations for phosphor-recycling co-incineration loses relevance. Mono-combustion (which offers the option to extract highly concentrated P from ashes) is likely to be the preferred option in future. Therefore, no separate N flows are defined from PR to EF.IC (combustion of sewage sludge in industrial processes). In countries, where relevant amounts of sewage sludge are incinerated in industrial processes. It is recommended to define an additional N flow from PR.WW to EF.IC.

5.4.6.1.1 Data sources

Activity data

The following data sources can be used to determine the total amount of sewage sludge producted by a country.

- Amounts of produced and treated sewage sludge can be found in national waste statistics.
- For European countries such data including the disposal (including incineration) can be drawn from EUROSTAT data browser. https://ec.europa.eu/eurostat/databrowser/view/ten00030/default/table?lang=en&category=t_env.t_env_wat

The split according to the the destination of the sewage sludge (i.e. use as agricultural fertilizer or incineration) needs to be determined based on country-specific data.

N content

The N contents in the following tables can be applied for any kind of municipal sewage sludge.[87] Table 54 gives data from Germany differenciated according to the treatment capacity of the sewage plant.

It is a common simplistic assumption that sludge from smaller plants is more likely to be directed to agriculture than sludge from larger plants. The analyses certainly show differences according to size class: small plants with mostly <30 g N/kg dry matter (DM), maximum values

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[87] N content is not a criterion for the decision to a use sewage as fertilizer. Thus, there is no distinction concerning N content in sludge for application in agriculture and other ways of disposal.

in plants in the medium range around 50 g N/kg DM, while the overall average is slightly below 50 g N/kg d.m. These values are also within the range of the JRC models for Europe (see Table 55). They can therefore serve as reference values.

Table 54: N concentration in sewage sludge by generic model

	Dewatered sludge	Digsted dewatered sludge	Composted sludge
	g / kg dry matter	g / kg dry matter	g / kg dry matter
Total mineral-N	31	52	30
Total N	3.7	2.6	3.6

Source: Huygens et al. (2022)

Table 55: N concentration in sewage sludge from analysis in Germany [in g / kg dry matter]

	1	2	3	4a	4b	5	total
Minimum	0.2	1.0	2.0	2.4	10.1	12.7	0.2
25.Perzentil	16.9	36.2	37.0	36.1	26.5	30.5	32.5
Median	**27.7**	**51.2**	**54.6**	**50.5**	**40.6**	**48.8**	**48.7**
75.Perzentil	43.5	63.6	66.4	64.1	57.2	54.9	63.0
Maximum	95.1	123.2	87.2	339.0	96.4	88.3	339.0

Source: Sichler et al. (2022); the headings (1-5) indicate the treatment capacity oft the sewage plant in increasing size

5.4.6.2 Application of sewage sludge as fertilizer (PR.WW-AG.SM)

In some countries, sewage sludge that is not incinerated is used as fertilizer in agriculture or applied in landscaping as a soil substrate, e.g. for the recultivation of opencast mines or other devastated areas.

In the EU the sewage sludge directive[88] determines threshold values and further criteria determined for sewage sludge applied in agriculture and prescribes the measurement of nitrogen as well. In this context, a report on sewage sludge utilisation in the EU member states is also mandatory.

5.4.6.2.1 Data sources

Activity data

Data sources on total amount of sewage sludge produced are provided in Chapter 5.4.6.1.1. The split according to the the application (i.e. use as agricultural fertilizer or incineration) needs to be determined based on country-specific data.

N content

See Chapter 5.4.6.1.1.

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[88] Council Directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC)

5.4.7 Uncertainties

When estimating the uncertainties in the quantification N flows from the pool "processing of residues" the following should be considered:

- The composition of waste treated in waste incineration plants and deposited on landfills is very heterogeneous and is likely to change in composition over time. Also the output N flows from the pool "processing of residues" are expected to be difficult to quantify both in terms of amounts and nitrogen contents. This leads to a high uncertainty in the corresponding N flows.
- In particular, the N flows out of the pool "processing of residues" are highly dependent on the technique that is used to treat solid wastes and wastewater. Therefore, estimations based on default N contents e.g. for treated wastewater are expected to be highly uncertain as they strongly depend on the type of wastewater treatment plant.
- For emissions of reactive nitrogen to the atmosphere, uncertainty estimates are provided in the national inventories for greenhouse gases[89] and air pollutants[90] and can be used directly to estimate the corresponding N flows in the NNB.
- A method for estimating uncertainties based on uncertainty levels is provided in Annex 0, Chapter A.7.

5.5 Quantification of stock changes

The most important nitrogen stock in the pool "processing of residues" are landfills and possibly intermediate storage of waste materials before incineration. Stock changes therefore occur if amounts of nitrogen containing waste stored in landfills or other storage facilities increase or decrease.

To quantify these stock changes, the changes the amounts of stored waste and their nitrogen contents need to be determined (see Chapter 5.4).

Overall, stock changes in the pool "processing of residues" are assumed to be of minor importance. A quantification of stock changes is recommended to check the plausibility of the N budget of the pool PR.

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[89] https://unfccc.int/ghg-inventories-annex-i-parties/2024

[90] https://www.ceip.at/

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5.7 Document Version

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Authors: Horst Fehrenbach (ifeu, Heidelberg), Judith Reutimann, Bettina Schäppi, Sophie Bogler (INFRAS, Zurich).

Reviewers Version 09/2024: Andrea Roskosch (andrea.roskosch@uba.de, Umweltbundesamt, Dessau, Germany), Monika Suchowska-Kisielewicz (m.suchowska-kisielewicz@iis.uz.zgora.pl, Institute of Environmental Engineering, University of Zielona Góra, Poland), Tim Hermann (tim.hermann@uba.de, Umweltbundesamt, Dessau, Germany)

6 Annex 6 – Humans and settlements (HS)

This Annex defines the pool "humans and settlements" (HS). It provides specific guidance on how to calculate relevant N flows related to the pool HS, presenting calculation methods and suggesting possible data sources. Furthermore, it points to information that needs to be provided by and coordinated with other pools. For the pool HS, exchanges with the pools "agriculture" (AG), "material and products in industry" (MP) and "processing of residues" (PR) are of particular relevance. Domestic inflows into the pool mainly stem from food products as well as from material products from industry. On the other end, N is lost via diffuse release pathways.

6.1 Description of flows to other pools

Figure 16 presents the main N flows between the pool HS and other pools.

The pool HS is dominated by individual human behavior. Important input flows from the pool MP are food and non-food products that are consumed by households. Some of these product flows are characterized by high material heterogeneity and their quantification is therefore affected by uncertainties. On the output side, mainly production of solid waste and wastewater from households are relevant.

The pool HS is not directly connected to the rest of the world (RW), since imports of both food and non-food products are accounted for in the pool MP. Exports from the pool HS are also not considered, as they are also accounted for in the pool MP.

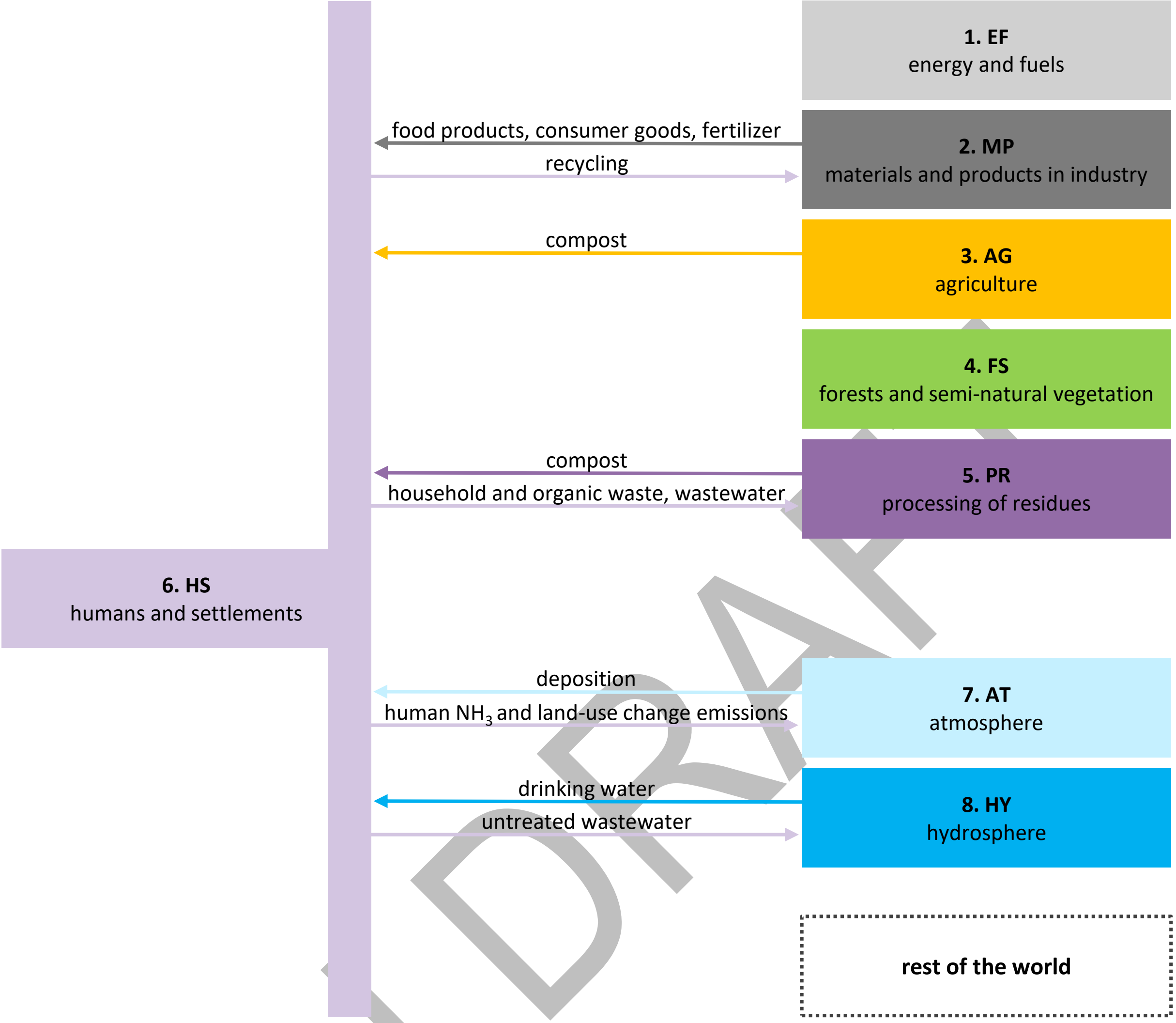
N flows from the pool HS occur mainly in the form of N_{mix} and the N is bound in materials and products (food products, wood and paper products, synthetic polymers for product use, textiles, detergents). This form of nitrogen is less critical regarding its environmental impacts than for instance reactive nitrogen that is formed in combustion processes or agricultural production, when reactive nitrogen species are directly released to the environment. However, nitrogen bound to materials and products is still considered as a reactive form of nitrogen that is potentially harmful for the environment at a later stage and should therefore be included in the NNB. The amount of N embedded in materials and products that are consumed by households can be substantial. According to Leip et al. (2011), more than 50% of the N_{mix} that is available for consumers apparently serves other purposes than nutrition and therefore these flows are highly relevant for the NNB.

The proposed structure of the pool HS for this guidance excludes certain nitrogen flows from the pool HS for simplification purposes. These include for example:

- stock changes due to population dynamics of humans and pets (see Chapter 6.5 on stock changes)
- human excretions, e.g. shed hair, nails, skin, that do not enter the sewage system or the waste management, but enter the environment elsewhere (e.g. via the hydrosphere or in forests or semi-natural vegetation)
- handling of human remains and related activities (e.g. burials)

The amounts of N exchanged with these flows are assumed to be small, and robust quantification approaches and data sources are lacking. While each flow is expected to be negligible, the sum of these unquantified flows may result in a substantial effect on the N balance of the pool HS. In that case, the result is that there is an imbalance between incoming and outgoing amounts of N.

Figure 16: N flows between pool "humans and settlements" (HS) and other pools



Source: illustration by INFRAS

6.2 Boundaries

The pool HS encompasses N flows from processes in settlements and direct emissions from humans and pets. All processes related to consumption of products in private households are accounted for in the pool HS. This includes food products and other goods that are consumed by households (e.g. clothing, furniture, plastics, paper and packaging materials, building materials, etc.). All consumption goods are supplied by retail that is part of the pool MP; therefore, there are no direct connecting flows between pool HS and the pools where the "raw" products are made, e.g. food in pool AG or wood products from pool "forests and semi-natural vegetation" (FS). In addition, this pool includes for N flows related to private gardens as well as public green spaces e.g. parks and sports grounds[91]. However, excluded is the consumption of fuels for heating, which is accounted for in the pool "energy and fuels" (EF).

Concerning N flows related to consumption of food products, the pool HS includes not only consumption of private households at home but also at restaurants. However, food processing and retail (e.g. supermarkets) are not part of the pool HS and fall within the boundaries of the pool MP[92]. This distinction is in particular relevant for N flows related to food waste, since it needs to be split accordingly (e.g. food waste from households and restaurants are included in the pool HS and industrial food waste is accounted for in the pool MP).

Also, with respect to energy combustion the pool definition is based on processes rather than spatial location. Energy consumption of households (e.g. transport, heating) and related fluxes are not included in the pool HS, but in the pool EF even though this process spatially occurs within settlements. Likewise, the manufacturing industry can spatially overlap with human settlements but is accounted for in the pool MP.

6.3 Pool structure and N flows

The pool HS does not have sub-pools. Chapter 6.3.1 gives a complete description of all N flows out of and into the pool HS. N flows are listed in Table 56 and Table 57 and illustrated in Figure 17.

6.3.1 Overview of N flows

Incoming flows

- The primary incoming N flows are from food products intended for human consumption including pet food[93]. This N flow originates from the sub-pool "food and feed processing" of the pool MP. It is assumed that all food products originate from the pool MP (and that there is no direct purchase of agricultural products).
- The pool MP also supplies humans and settlements with various other non-food products and materials that contain nitrogen in multiple forms (such as wood products, synthetic or natural polymers and ionic forms in surfactants). These goods include household items like furniture, packaging material, clothing, paper products, detergents and electronic equipment, as well as materials used in buildings and cars. Lastly, the pool MP is connected to the pool HS by N flows from mineral fertilizers used in private gardens and public spaces.
- Two more inflows of nitrogen occur in the form of compost from the pool AG and pool WS, that is applied as fertilizer in private gardens and public spaces.

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[91] Note that other than parks and sports grounds, fallow areas can be a type of green spaces with vegetative cover that is part of the pool HS. N emissions from these areas are neglected in the default methods described here. If this type of land covers substantial areas in the settlements, the approach from the sub-pool "other land" (Chapter 4) can be followed to quantify N emissions.

[92] All food products enter the pool HS through the pool MP. Direct inflows of food from the pool AG do exist (such as from farmer's markets and farm stores where food is sold directly to consumers), but since the amounts are small compared to the inflows from the food industry, they are not accounted for separately but included in the N flow from MP.

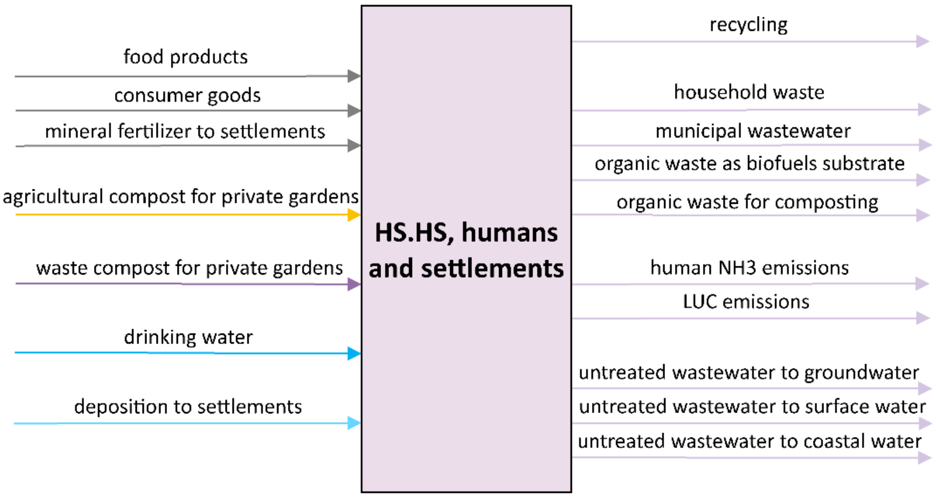
[93] The pool HS includes also N flows related to pets. Pets are considered all non-agricultural or non-productive animals, that are (mostly) not kept for economic reasons. This includes popular cats like cats and dogs as well as sport animals such as racing horses or bulls for fighting and working animals like sniffer dogs. Productive livestock, clearly belonging to agricultural activities, such as cattle, pigs, etc. are considered in the pool AG in the sub-pool "manure management, storage and animal husbandry".

- Other incoming N flows to the pool HS are drinking water from the pool "hydrosphere" (HY) and atmospheric N deposition to human settlements from the pool "atmosphere" (AT).

Outgoing flows

- The primary outgoing N flows from the HS pool are waste flows. This includes municipal wastewater containing human excretions enter the sewage system or go directly to the hydrosphere, if households are not connected to any sewage system. Possibly, these excretion flows with the wastewater also include shed skin, hair and nails.
- Solid waste from the pool HS is divided into several flows.
  - Household waste, that is not reused or recycled, is directed to the sub-pool "solid waste" (PR.SO).
  - In some countries, organic solid waste is collected separately and used as substrate for biofuel production or composting, resulting in a second outgoing N flow to the sub-pool PR.SO. Sources for this N flow include waste related to food consumption of private households as well as green waste from private and public green spaces. Note that this N flow is separate from the processes considered in the agricultural sub-pool "biofuel production and composting" (AG.BC), which considers only agricultural substrates.
  - Recyclable solid waste is sent back to the pool MP for further processing.
  - For the solid waste flows, the materials with N contents are released in the same form as they entered (e.g. synthetic or natural polymers), and transformation processes like waste incineration or biological degradation occur only in the destination pools (e.g. "processing of residues" or "agriculture").
- In addition to waste, ammonia emissions from the human body (sweating and breathing) are quantifiable outflows from the pool HS (Sutton et al. 2000).
- Another potential source of emissions of reactive N to the atmosphere comes from land-use change related to settlements.

Figure 17: N flows in detail between pool "humans and settlements" and other pools



The arrows characterize the nitrogen flows between the sub-pools. Colours indicate from which pool the flows originate (the colours assigned to the pools can be seen in the overview graphics "n flows between pools"). Stock changes are not depicted. The flow names used in the graph here contain some details for clear identification and can deviate from the flow names given in the table below, because the latter correspond exactly to the flow names given in the Excel-Template for NNBs.
Source: illustration by INFRAS, generated in STAN

Table 56: N flows going out of the pool "humans and settlements" (HS)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
Humans and settlements	HS	MP.OP	Other producing industry	Recycling	Waste for recycling (plastic, glass)	N_{mix}	6.4.1.3
	HS	PR.SO	Solid waste	Organic waste as biofuel substrate	Organic waste from households used as biofuel substrate	N_{mix}	6.4.1.4
	HS	PR.SO	Solid waste	Organic waste for composting	Organic waste from households for composting	N_{mix}	6.4.1.5
	HS	PR.SO	Solid waste	Household waste	Solid waste from households for incineration (waste from humans and pets; other material waste); commercial waste	N_{mix}	6.4.1.2

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
	HS	PR.WW	Wastewater	Municipal wastewater	Municipal wastewater (human excretion to sewage system; other wastewater from residential areas)	N_{mix}	6.4.2.1
	HS	AT	Atmosphere	Emissions	Ammonia emissions from human body	NH_3	6.4.3.16.4.2.1
Humans and settlements	HS	AT	Atmosphere	LUC emissions	Emissions from settlements and related LUC	NH_3 NO_x N_2O	6.4.3.2
	HS	HY.GW	Groundwater	Untreated wastewater	Human excretions to the hydrosphere that are not connected to the sewage system	N_{mix}	6.4.2.2
	HS	HY.SW	Surface waters	Untreated wastewater	Human excretions to the hydrosphere that are not connected to the sewage system	N_{mix}	6.4.2.2
	HS	HY.CW	Coastal waters	Untreated wastewater	Human excretions to the hydrosphere that are not connected to the sewage system	N_{mix}	6.4.2.2

The following table shows the N flows entering the pool "humans and settlements". They are described in the Annexes of the pools from which these N flows originate.

Table 57: Flows entering the pool "humans and settlements" (HS)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Species	Chapter
Food processing	MP.FP	HS	Humans and settlements	Food products	N_{mix}	2.4.1.1
Other producing industry	MP.OP	HS	Humans and settlements	Consumer goods	N_{mix}	2.4.1.3
	MP.OP	HS	Humans and settlements	Mineral fertilizer	N_{mix}	2.4.1.6
Biofuel production and composting	AG.BC	HS	Humans and settlements	Compost for private gardens	N_{mix}	3.4.5.5
Solid waste	PR.SO	HS	Humans and settlements	Compost for private gardens	N_{mix}	5.4.4.2
Atmosphere	AT	HS	Humans and settlements	Deposition	OXN RDN	7.4.1
Groundwater	HY.GW	HS	Humans and settlements	Drinking water	N_{mix}	8.4.1.4

6.4 Quantification of flows

This section describes the calculation methods and data sources that are suggested to derive the basic N flows concerning the pool HS.

6.4.1 Quantification for solid waste N flows

6.4.1.1 Method

Solid waste N flows can be quantified based on the amount of solid waste being transferred between two pools times the N content of each waste material. Depending on data availability and waste flow, the total flow is summed up over several types of waste i with specific N contents (Table 50). For example, the N flow for recycling (HS-MP.OP) can be summed over several material types i (e.g. paper, plastics, glass, electronics) as the N content of each material varies considerably.

$$F_{HS-YY.YY} = \sum_i A_i \cdot f_{i,Nmix} \qquad \text{(Eq. 42)}$$

With:

$F_{HS-PR.SO}$ $F_{HS-MP.OP}$ $F_{HS-AG.BC}$	N flow: Transfer of nitrogen in solid waste from pool HS to sub-pool "PR.SO" (solid waste), "MP.OP" (recycling materials), "AG.BC" (organic waste for composting and biofuel production)	[kt N]
A_i	Amount of solid waste of type i transferred between the (sub)-pools	[kt]

$f_{i,Nmix}$	N content in waste of type i quantified as N_{mix}	[% N]

The amount of solid waste (fraction) for each flow can either be taken from a national statistic or can be estimated based on corresponding input flows. For information on data source and estimation approaches see following chapters.

6.4.1.2 Household waste (HS-PR.SO)

Household waste includes all types of solid waste from settlements which are incinerated or deposited on landfills in the sub-pool “solid waste”. Wastes that are repurposed either by recycling, biofuel production or composting are not included in this flow. If repurposing of solid waste is not relevant in a country, this flow comprises all solid waste from households. Note that usage of waste heat from the incineration process is not considered as a waste usage in this definition.

For countries where repurposing processes are relevant, each solid waste fraction is treated separately in specific flows going either to the pool MP (Chapter 6.4.1.3.) or the pool PR (Chapter 6.4.1.4. and 6.4.1.5).

The general approach to calculate the N flow from household waste is based on the amount of solid waste from national waste statistics and its average N content. This approach can be expanded by differentiating between several household waste fractions with each specific N contents – the applicability of this approach depends on data availability.

6.4.1.2.1 Data sources

Activity data

- National waste statistics
- Alternative: estimation based on a fraction of the input flows of consumption goods from the pool MP, assuming the same N content. If food waste is included in this flow (and not treated separately for biofuel production or composting, see Chapters 6.4.1.4 and 6.4.1.5), the fraction can be estimated based on the method in Chapter 6.4.1.4.
- N content data of different types of waste can be taken from the pool PR (see Table 50)

6.4.1.3 Recycling (HS-MP.OP)

Note on possible simplification

This flow is only relevant for countries where a substantial part of solid waste is recycled. Otherwise, the flow can be neglected for simplification purposes.

This N flow contains nitrogen in solid waste that is directed to the sub-pool ”other producing industry” for reuse and recycling (e.g. glass, plastics, textiles, etc.).

6.4.1.3.1 Data sources

Activity data

- National statistics on waste recycling

N contents

- N contents of recycled waste are very heterogeneous. As an approximation the N content of the consumed products (N flow: MP.OP-HS) can be used (see Chapter 2.4.1.3). If available specific nitrogen contents of the recycled materials should be considered.
- Moreover, N content data can be taken from the Annex Processing of residues (see Table 50)

6.4.1.4 Organic waste as biofuels substrate (HS-PR.SO)

Note on possible simplification

This flow is only relevant for countries where organic waste is collected separately from other household waste and used as biofuel substrate. If this process is not relevant, the flow can be neglected for simplification purposes.

Organic waste from the pool HS includes all organic waste that is not a result of industrial or agricultural activities. This category encompasses waste from food preparation and food waste in private households and restaurants[94], as well as garden waste from private gardens and public green spaces.

Organic waste from households can be repurposed as substrate for biofuel production or for composting. For these processes, corresponding N flows are defined from the pool HS to the pool PR (only agricultural substrates are treated in the sub-pool "biofuel production and composting of the pool AG). This chapter provides the method to quantify N flows related to organic waste used for biofuel production. The corresponding method for organic waste used for composting is described in the following Chapter 6.4.1.5.

If neither of these uses for organic waste apply to a country, organic solid waste is likely also transferred to incineration plants together with all household waste and can therefore be included in the N flow for household waste (Chapter 6.4.1.2).

General approach

The general approach to quantifying this flow involves consulting national waste statistics on organic waste that is used as biofuel substrate and multiplying the total amount by a default N content (see basic method in Chapter 6.4.1.1 and detailed data sources below). If available, different fractions of the organic waste (food waste, garden waste) can be differentiated with more specific N content (see Chapter 5.4.2.1.1, Table 50, showing 7.4 % N for animal and mixed food waste and 1.3% for vegetal waste).

Estimation of food waste

If no national waste statistics are available, the fraction of food waste as organic waste can be approximated with the following approach: The amount of N from food waste is determined for individual food commodity groups separately by multiplying the amount of that food group entering the pool HS with its estimated waste percentages (Table 58) and with its specific N content. This option is approximate and best applied in accordance with the flow MP.FP-HS-food

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[94] Note that food waste from industrial food processing and retail is included in the pool MP (Chapters 2.4.4.3-2.4.4.4).

products-Nmix (see Chapter 2.4.1.1), where the amount of N from food products entering the pool HS is determined.

Table 58: Estimate/assumed food waste percentages for food commodity groups for the last step in the Food Supply Chain (FSC). Applicable to Europe incl. Russia. (Gustavsson et al. 2011). Note that no wastage needs to be considered for tobacco.

	Consumption	Assigned categories
Cereals	25.0%	wheat, rice, alcoholic beverages
Roots & Tubers	17.0%	potatoes, starchy roots
Oilseeds & Pulses	4.0%	vegetable oils, nuts
Fruit & Vegetables	19.0%	fruits, vegetables, stimulants, spices, sugar & sweeteners
Meat	11.0%	poultry meat, pigmeat, bovine meat, eggs, animal fats, offals, other meat, mutton & goat meat
Fish & Seafood	11.0%	fish & seafood
Milk	7.0%	milk, cheese

6.4.1.4.1 Data sources

Activity data

- The amount of organic waste that is used as biofuel substrate can be determined from national waste statistics. Depending on the statistics, the fractions of food waste and garden waste can be separated.
- Amount of food waste from households: https://ec.europa.eu/eurostat/databrowser/view/cei_pc035/default/table?lang=en&category=env.env_was.env_wasst

N content

- Default value for organic waste can be taken from the pool WS, specified for a.) meat and mixed waste and b.) vegetal waste (see Table 50)
- Food waste: N contents of specific food commodity groups can be found in Chapter 2.4.1.1.1
- Garden waste: The N content of fresh green waste has been estimated as roughly 0.8% (fresh, not dry matter; Vaughan et al. 2011, Kumar et al. 2010).

6.4.1.5 Organic waste for composting (HS-PR.SO)

Note on possible simplification

This flow is only relevant for countries where organic waste is treated separately from other household waste and processed further in composting plants. If this process is not substantially relevant, the flow can be neglected for simplification purposes.

The method to quantify N flows from repurposing organic waste follows the same approach for both the processes biofuel production and composting. Refer to the preceding Chapter 6.4.1.4 on organic waste used as biofuels substrate for more details and possible data sources.

As a general approach, the N flow can be quantified by consulting national waste statistics on organic waste that is used in composting plants and corresponding default N contents (see basic method in Chapter 6.4.1.1 and detailed data sources below). If available, different fractions of the organic waste (food waste, garden waste) can be differentiated with more specific N contents.

6.4.1.5.1 Data sources

Refer to Chapter 6.4.1.4. for information on activity data and N contents.

6.4.2 Quantification of N flows with wastewater

6.4.2.1 Municipal wastewater (HS-PR.WW)

6.4.2.1.1 Method

The method to quantify the N flow from municipal wastewater is based on the amount of wastewater flowing from the settlements to wastewater treatment plants and the corresponding concentration of nitrogen in the wastewater. Depending on data availability, the outflow of different sources of wastewater, or respectively the inflow at different wastewater treatment plants, with specific concentrations of N, can be considered separately.

$$\boldsymbol{F}_{\boldsymbol{HS-WS.WW}} = \sum_i A_i \cdot C_{Nmix,i} \cdot 10^{-9} \qquad \text{(Eq. 43)}$$

With:

F$_{HS-PR.WW}$	N flow: Transfer of nitrogen dissolved in municipal wastewater from pool HS to sub-pool PR.WW	[kt N]
A$_i$	Amount of wastewater from source i transferred from pool HS sub-pool PR.WW	[m^3]
C$_{Nmix,\,i}$	Total concentration of reactive nitrogen compounds in wastewater source i quantified as N$_{mix}$ (most relevant N-species are organically bound species, and NH_4^+)	[g N/m^3]

If data on the amount of wastewater treated or the concentration of N in the wastewater is unavailable (see possible data sources below), an alternative approach can be employed based on other N flows. Given that no accumulation of N is assumed in the pool HS, the amount of N in municipal wastewater can be estimated by calculating the food intake minus the fraction of non-consumed food and human emissions of NH_3, considering the fraction of households connected to the sewage system. This method is only an approximation, as municipal wastewater is generated from various sources beyond those related to human excretions.

$$\boldsymbol{F}_{\boldsymbol{HS-WS.WW}} = (\boldsymbol{F}_{\boldsymbol{MP.FP-HS}} - \boldsymbol{F}_{\boldsymbol{HS-WS.SO}} \cdot \boldsymbol{f}_{\boldsymbol{food\ waste}} - \boldsymbol{F}_{\boldsymbol{HS-AT}}) \cdot \boldsymbol{f}_{\boldsymbol{s}} \qquad \text{(Eq. 44)}$$

With:

F$_{HS-PR.WW}$	N flow: Transfer of nitrogen dissolved in municipal wastewater from pool HS to sub-pool PR.WW (approximation)	[kt N]

$F_{MP.FP-HS}$	N flow: Transfer of nitrogen contained in food products from the sub-pool MP.FP to the pool HS	[kt N]
$F_{HS-AG.BC}$	N flow: Organic waste used as biofuel substrate or composting	[kt N]
$f_{food\ waste}$	fraction of food waste in the organic waste	[%]
F_{HS-AT}	N flow: Human body emissions of NH_3 to the atmosphere	[kt N]
f_s	Fraction of wastewater connected to the sewage system	[%]

6.4.2.1.2 Data sources

Activity data

- The amount of municipal wastewater can be determined from national statistics on water and/or wastewater or Eurostat water statistics for European countries[95].
- This N flow is defined for the total amount of municipal wastewater, which means that imports and exports need to be accounted for. In case that relevant amounts of wastewater are imported and exported, it is important to adjust the amounts of wastewater for net import and export (e.g. when wastewater treatment plants close to a border are also supplied from settlements across the border).

N content

- With reference to DWA (2024) a default value for the average N content in untreated municipal wastewater can be set at 62.5 mg/l.
- Alternatively the N discharge could be calculated based on the number of inhabitants considering a per capita discharge of 4.56 kg N per year DWA (2024).
- Note that if significant quantities of organic waste (e.g., food waste) are disposed of directly through the household sewage system, such as by using kitchen disposers, the default N content values provided above do not apply. In such cases, it is necessary to determine country-specific nitrogen content values.
- If specific values for N contents, e.g. inflows connected to single wastewater treatment plants are available, the flow can be split and summed up over every plant's contribution.

6.4.2.2 Untreated wastewater discharge (HS-HY.GW, HS-HY.CW, HS-HY.SW)

6.4.2.2.1 Method

Note on possible simplification

This flow is only relevant for countries where a substantial part of the wastewater is not treated. Otherwise, the flow can be neglected for simplification purposes. Small amounts of untreated

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[95] https://ec.europa.eu/eurostat/web/environment/information-data/water (accessed 01.07.2024)

wastewater also originate from overland flow from residential water during rainfall events. However, these amounts can also be assumed to be small and may be neglected.

This flow entails N in human excretions in wastewater from households that are not connected to the sewage system. Depending on the national circumstance, this wastewater flows directly into surface waters, coastal waters or groundwater. The calculation requires the flow for municipal wastewater (see Chapter 6.4.2.1).

Into which sub-pool of the pool "hydrosphere" most of the wastewater is lost and if the N flow should be split into several flows for each HY sub-pool needs to be decided based on the country's urban drainage system. As a default approach, it is suggested that all leaching of wastewater is occurring to surface waters (HY.SW).

A second pathway through which untreated wastewater can reach the hydrosphere occurs when the capacity of wastewater treatment plants is exceeded, such as during extreme rainfall events. In this NNB guidance, this process can be neglected. The events are irregular in frequency, and the N content in the discharged water is likely very small due to the significant dilution by rainwater. However, if country-specific data is available (water volume and N content of the diluted wastewater), the process can be added as a second term in the following equation. As a default, the discharged wastewater enters the surface waters (HY.SW).

$$\boldsymbol{F_{HS-HY.SW} = F_{HS-WS.WW} \cdot (1 - f_s) + A_{overflow} \cdot C_N} \qquad \text{(Eq. 45)}$$

With:

$F_{HS\text{-}HY.SW}$	N flow: Discharge of human excretions from the pool HS into the sub-pool HY.SW (depending on the national circumstances, also N flows to coastal waster and to groundwater may be relevant).	[kt N]
$F_{HS\text{-}HY.PR.WW}$	N flow: Municipal wastewater, see Chapter 6.4.2.1	[kt N]
f_s	Fraction of wastewater discharge connected to the sewage system	[%]
$A_{overflow}$	Amount of overflowing wastewater discharged to the hydrosphere after dilution by rainwater (e.g. after passing the overflow basin of the wastewater treatment plant)	[m^3]
C_N	Total concentration of reactive nitrogen in overflowing wastewater quantified as N_{mix} (most relevant N-species are organically bound nitrogen species and NH_4^+)	[g N/m^3]

6.4.2.2.2 Data sources

Connection rates to the sewage system can usually be found in national statistics on water and/or wastewater, as well as in Eurostat water statistics[96].

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[96] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics#Wastewater_treatment_and_disposal (accessed 01.07.2024)

6.4.3 Quantification of emissions to atmosphere

6.4.3.1 Human body emissions (HS-AT)

6.4.3.1.1 Method

Note on possible simplification

This flow is expected to be small for most countries and can therefore be neglected for simplification purposes.

Sutton et al. (2000) list breath, sweat, and infant excretion as main sources of direct NH_3 emissions from humans. Also, NH_3 emissions from tobacco smoking are relevant (Sutton et al. (2000)).

Tobacco smoking further emits NO_x, which can be calculated based on a factor of 3g NO_x per ton of tobacco smoked (EMEP and EEA, 2009). However, this source is minor and therefore not included explicitly here. Similarly, minor emissions of N_2O in human breath are not included here (Dawson et al., 2023).

$$\boldsymbol{F_{HS-AT} = 1.7 \cdot 10^{-5} P_{total} + 1.17 \cdot 10^{-5} P_{<1y} + 1.46 \cdot 10^{-5} P_{1-3y} + 3.4 \cdot 10^{-9} n} \tag{Eq. 46}$$

With:

$\mathbf{F_{HS\text{-}AT}}$	N flow: Human body emissions of NH_3 to the atmosphere	[t N]
$\mathbf{P_{total}}$	Average total national population	[-]
$\mathbf{P_{<1y}}$	Average national population of children aged <1 year	[-]
$\mathbf{P_{1\text{-}3y}}$	Average national population of children aged 1-3 years	[-]
n	Average number of cigarettes smoked per year	[-]

6.4.3.1.2 Data sources

To calculate the atmospheric NH_3 emissions from respiration and transpiration, it is recommended to use the data from Sutton et al. (2000) as shown in the equation above.

In addition, data on emissions of reactive nitrogen from human respiration and transpiration as well as pets and livestock outside agriculture may be available for most countries in the national emission inventories for air pollutants.

6.4.3.2 Emissions from settlements and related land-use changes (HS-AT)

Furthermore, emissions from land-use changes are accounted for.

- Emission data for NH_3, NO_x: CLRTAP Inventory Submissions[97]

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[97] https://www.ceip.at/

- Emission data for N_2O: UNFCCC National Inventory Submissions[98]

Emission sources relevant for the pool HS are provided in the following table.

Table 59: Emission sources to be accounted for in the pool "humans and settlements" (HS)

NFR Code	Description
6	Other emissions
4E1	Settlements remaining settlements
4E2	Land converted to settlements

6.4.4 Uncertainties

When estimating the uncertainties in the quantification N flows from the pool HS the following should be considered:

- It is expected that the uncertainty of the N outputs from this pool are dominated by the amount and composition of the different waste flows. In most cases, uncertainties of these N flows will not be available and need to be estimated based on expert judgements.
- The composition of waste (i.e. household waste, organic waste) is highly heterogeneous and may show a high variability within a country.
- Besides the nitrogen contents of waste, also the amount of waste may be difficult to determine, in particular if a large portion of the waste is not treated in waste incineration plants but deposited on landfills. In addition, the need to split the amount of organic waste between composting and biofuel production may lead to additional uncertainties in the individual N flows.
- The amount of wastewater also may be affected by uncertainty, in countries with a low connection to sewage treatment plants.
- For recycling flows it is expected that data availability is limited regarding both nitrogen contents as well as amounts.
- A method for estimating uncertainties based on uncertainty levels is provided in Annex 0, Chapter A.7.

6.5 Quantification of stocks and stock changes

Several materials and products that are stored in the pool "humans and settlements" contain nitrogen. Changes in the amount of stored materials directly results in a change in the amount of stored nitrogen. To quantify related stock changes, the changes in the stored products and materials need to be quantified and multiplied with their nitrogen content (see Chapter 6.4). Most relevant are fuels with high nitrogen contents (e.g. wood products, food products, building

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[98] https://unfccc.int/ghg-inventories-annex-i-parties/2024

materials). Furthermore, nitrogen may accumulate in soils of the pool HS, mainly public green spaces and private gardens.

It is assumed that adults do not accumulate significant amounts of N in their body (i.e. N intake and N excretion are balanced). Children, in contrast, do still accumulate some nitrogen, but are not accounted for separately. Similarly, a change in a countries population may lead to a change in nitrogen stocks.

Overall, stock changes in the pool HS are assumed to be of minor relevance, since quantification of input and output flows is expected to be more accurate than quantification of stock changes. Quantification of stock changes is therefore recommended only to check the plausibility of the N budget of the pool HS.

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6.7 Document Version

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Reviewers Version 09/2024: Markus Geupel (markus.geupel@uba.de, Umweltbundesamt, Dessau, Germany), Andrea Roskosch (andrea.roskosch@uba.de, Umweltbundesamt, Dessau, Germany), Monika Suchowska-Kisielewicz (m.suchowska-kisielewicz@iis.uz.zgora.pl, Institute of Environmental Engineering, University of Zielona Góra, Poland), Tim Hermann (tim.hermann@uba.de, Umweltbundesamt, Dessau, Germany)

Version 11/2015

Authors Version 11/2015: Magdalena Pierer (magdalena.pierer@uni-graz.at), Andrea Schröck (andrea.schroeck@uni-graz.at), Wilfried Winiwarter (winiwarter@iiasa.ac.at)

Reviewer Version 11/2015: Barbara Amon, (ATB, Potsdam, Germany)

7 Annex 7 – Atmosphere (AT)

The pool "atmosphere" (AT) mainly functions as a transport medium in terms of N-budgets, as it serves to collect, to form N_r or convert from one N_r-species to another, to deposit and to transport reactive nitrogen under its various chemical forms in the troposphere. The quantification of conversions between compounds of different possible atmospheric sub-pools (e.g., oxidized or reduced N_r-species) is not required but may be considered as a change in stocks of N (e.g. formation of NO_x from N_2 due to lightning).

Main input flows are atmospheric import of N_{mix}, and emissions from all other pools of the National Nitrogen Budget (NNB). Output flows are biological and technical N_2-fixation, export of N_{mix} by atmospheric transport and N deposition to land- and water-based pools. In line with the overall balance equation (Eq. 1a and 1b) and the general treatment of N_2, flows that merely take atmospheric N_2 or release N_2 into the atmosphere (without subsequent transformation to Nr) need not be accounted on the side of the pool Atmosphere (AT).

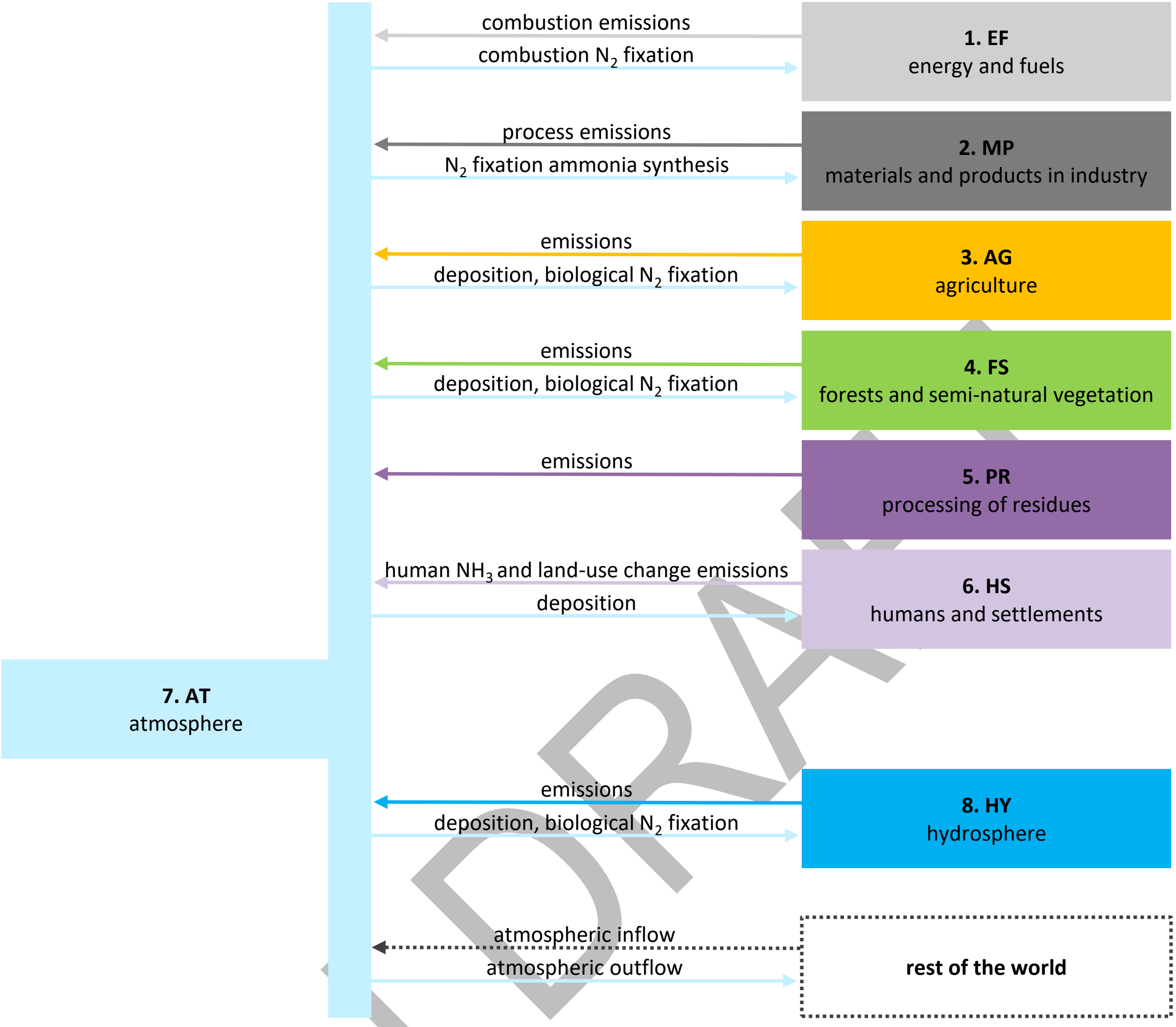
7.1 Description of flows to other pools

Figure 18 shows the N budget scheme for the pool AT. The input N flows are N-emissions from all other pools and transboundary N flows (import of reduced and oxidized N-species). Output N flows are N deposition to national ecosystem (hydrosphere and terrestrial ecosystems) and exports to neighbouring countries.

Nitrogen deposition is the term used to describe the process by which atmospheric N-containing trace constituents, such as aerosols, particles and gases, are deposited onto the earth's surface. Most concern has addressed the impacts of nitrogen deposition to terrestrial ecosystems (Bobbink et al., 2022; CLRTAP, 2023), but impacts may also occur in the aquatic environment (Gauss et al., 2021; Rabalais, 2002). The pollutants that contribute to nitrogen deposition derive mainly from nitrogen oxides (NO_x) and ammonia (NH_3) emissions. In the atmosphere NO_x is transformed to a range of secondary pollutants, including nitric acid (HNO_3), nitrates (NO_3^-) and organic compounds, such as peroxyacetyle nitrate (PAN), while NH_3 is transformed to ammonium (NH_4^+). Both the primary and secondary pollutants are removed by wet deposition (scavenging of gases and aerosols by precipitation) and by dry deposition (direct turbulent deposition of gases and aerosols) (Hornung and Williams, 1994). Organic constituents are rarely measured or monitored and are thus often neglected in calculations and inventories. However, their contribution to total nitrogen deposition is crucial varying substantially between 30 and 80% across different ecosystems (Neff et al., 2002; Cornell et al., 2003; Miayazaki et al, 2011; Zhang et al., 2012; Medinets et al., 2012, 2020, 2024).

Transboundary air pollution is an important flow of reactive nitrogen compounds that are not easily removed from the atmosphere, i.e. have considerable residence time in the atmosphere (e.g. NO_3^-, NH_4^+). These are transboundary pollutants that can be generated in one country and transported to other countries. Transboundary air pollutants can remain in the atmosphere sufficiently long to be transported thousands of kilometers and thus to spread over the whole of Europe, across national borders, far from the original sources of polluting emissions, causing eutrophication and acidification. Transboundary nitrogen deposition for a single country is considered like the balance between nitrogen input from other countries and nitrogen output towards other countries. This balance is very sensitive to climate conditions and to geographical position (Posch 2002).

Figure 18: N flows between pool “atmosphere” (AT) and other pools



Source: illustration by INFRAS

7.2 Boundaries

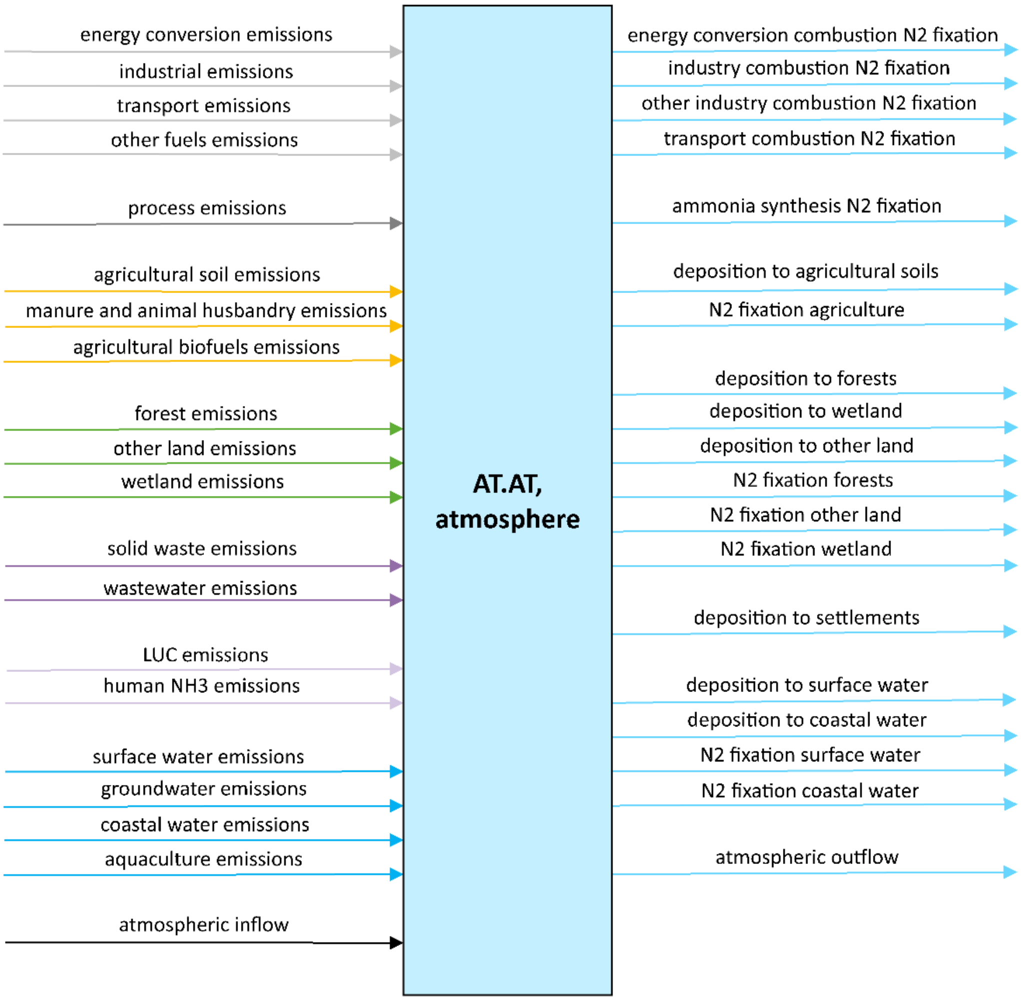
The pool “atmosphere” comprises only the lower layer troposphere (i.e. excluding processes occurring in the tropopause and above). N flows between different atmospheric layers are not quantified, as they are internal flows within the atmosphere.

7.3 Pool structure and N flows

The pool AT does not have sub-pools. Chapter 7.3.1 gives a complete description of all N flows out of and into the pool AT.

7.3.1 Overview of N flows

Figure 19: N flows in detail between pool “atmosphere” (AT) and other pools



The arrows characterize the nitrogen flows between the sub-pools. Colours indicate from which pool the flows originate (the colours assigned to the pools can be seen in the overview graphics “n flows between pools”). Stock changes are not depicted. The flow names used in the graph here contain some details for clear identification and can deviate from the flow names given in the table below, because the latter correspond exactly to the flow names given in the Excel-Template for NNBs.

Sources: illustration by INFRAS, generated in STAN

Table 60: N flows going out of the pool “atmosphere” (AT)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Process description	Species	Chapter
Atmosphere	AT	EF.IC	Manufacturing industries and construction	Combustion N_2 fixation	fixation of N_2 during fuel combustion	N_2	7.4.3.1
Atmosphere	AT	EF.OE	Other energy and fuels	Combustion N_2 fixation	fixation of N_2 during fuel combustion	N_2	7.4.3.1

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Process description	Species	Chapter
Atmosphere	AT	EF.TR	Transport	Combustion N_2 fixation	fixation of N_2 during fuel combustion	N_2	7.4.3.1
Atmosphere	AT	EF.EC	Energy conversion	Combustion N_2 fixation	fixation of N_2 during fuel combustion	N_2	7.4.3.1
Atmosphere	AT	MP.OP	Other producing industry	Ammonia synthesis N_2 fixation	fixation of N_2 during Haber-Bosch ammonia synthesis	N_2	7.4.3.2
Atmosphere	AT	AG.SM	Soil management	Deposition	Dry/wet atmospheric deposition to agricultural land	OXN RDN	7.4.1
Atmosphere	AT	AG.SM	Soil management	Biological N_2 fixation	Biological N_2 fixation on agricultural land	N_2	7.4.2.1
Atmosphere	AT	FS.FO	Forest	Deposition	Dry/wet atmospheric deposition to forest land	OXN RDN	7.4.1
Atmosphere	AT	FS.FO	Forest	N_2 fixation	Biological N_2 fixation on forest land	N_2	7.4.2.2
Atmosphere	AT	FS.OL	Other land	Deposition	Dry/wet atmospheric deposition to semi-natural and other land	OXN RDN	7.4.1
Atmosphere	AT	FS.OL	Other land	N_2 fixation	Biological N_2 fixation on semi-natural and other land	N_2	7.4.2.3
Atmosphere	AT	FS.WL	Wetland	Deposition	Dry/wet atmospheric deposition to wetland	OXN RDN	7.4.1
Atmosphere	AT	FS.WL	Wetland	N_2 fixation	Biological N_2 fixation on wetland	N_2	7.4.2.4
Atmosphere	AT	HS	Humans and settlements	Deposition	Dry/wet atmospheric deposition to human settlements	OXN RDN	7.4.1

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Process description	Species	Chapter
Atmosphere	AT	HY.SW	Surface water	Deposition	Dry/wet atmospheric deposition to surface water	OXN RDN	7.4.1
Atmosphere	AT	HY.SW	Surface water	N_2 fixation surface water	Biological N_2 fixation in surface water	N_2	7.4.2.5
Atmosphere	AT	HY.CW	Coastal water	Deposition	Dry/wet atmospheric deposition to coastal water	OXN RDN	7.4.1
Atmosphere	AT	HY.CW	Coastal water	N_2 fixation coastal water	Biological N_2 fixation in coastal water	N_2	7.4.2.5
Atmosphere	AT	RW	Rest of the world	Atmospheric outflow	Transboundary atmospheric outflow of reactive N species	RDN OXN	7.4.3.3

The following table shows the N flows entering the pool "atmosphere". They are described in the Annexes of the pools from which these N flows originate.

Table 61: N flows entering the pool "atmosphere" (AT)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Species	Chapter
Energy conversion	EF.EC	AT	Atmosphere	Emissions	NH_3 NO_x N_2O N_2	1.4.1.2
Manufacturing industries and construction	EF.IC	AT	Atmosphere	Emissions	NH_3 NO_x N_2O N_2	1.4.1.3
Transport	EF.TR	AT	Atmosphere	Emissions	NH_3 NO_x N_2O N_2	1.4.1.4
Other energy and fuels	EF.OE	AT	Atmosphere	Emissions	NH_3 NO_x N_2O N_2	1.4.1.5
Other producing industry	MP.OP	AT	Atmosphere	Emissions	NH_3 NO_x N_2O	2.4.3.1
Soil management	AG.SM	AT	Atmosphere	Emissions	NH_3 NO_x	3.4.6.2

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Species	Chapter
					N_2O N_2	
Manure management and manure storage	AG.MM	AT	Atmosphere	Emissions	NH_3 NO_x N_2O	3.4.6.1
Biofuel production and composting	AG.BC	AT	Atmosphere	Emissions	NH_3 NO_x N_2O	3.4.6.3
Forest	FS.FO	AT	Atmosphere	Emissions	N_2 NO_x N_2O	4.4.2.1
Other Land	FS.OL	AT	Atmosphere	Emissions	N_2 NO_x N_2O	4.4.2.1
Wetland	FS.WL	AT	Atmosphere	Emissions	N_2 NO_x N_2O	4.4.2.1
Solid waste	PR.SO	AT	Atmosphere	Emissions	NH_3 NO_x N_2O	5.4.1.1
Wastewater	PR.WW	AT	Atmosphere	Emissions	N_2 NH_3 NO_x N_2O	5.4.1.2
Humans and settlements	HS	AT	Atmosphere	Emissions	NH_3	6.4.3
	HS	AT	Atmosphere	LUC emissions	NH_3 NO_x N_2O	6.4.3.2
Groundwater	HY.GW	AT	Atmosphere	Emissions	N_2, N_2O, NH_3	8.4.2
Surface water	HY.SW	AT	Atmosphere	Emissions	N_2,,N_2O, NH_3	8.4.2
Coastal water	HY.CW	AT	Atmosphere	Emissions	N_2, N_2O, NH_3	8.4.2
Aquaculture	HY.AQ	AT	Atmosphere	Emissions	NH_3, N_{mix}	8.4.2
Rest of the world	RW	AT	Atmosphere	Atmospheric inflow	OXN RDN	7.4.3.3

7.4 Quantification of flows

7.4.1 Quantification of N flows from deposition (AT-AG.SM, AT-FS.FO, AT-FS.OL, AT-FS.WL, AT-HS, AT-HY.SW, HY.CW)

Deposition of reduced nitrogen species (RDN) and oxidized species (OXN) from the atmosphere to soils needs to be accounted for in all area-related pools (i.e. AG, FS, HY and HS). Both dry and wet deposition may occur. It is noteworthy that organic N constituents may contribute significantly (30–80%) to total N deposition (see refs in Chapter 7.1) and cannot be neglected if data/ estimates are available. Excessive inputs of nitrogen to soils, vegetation and water bodies are harmful especially for sensitive ecosystems (Bobbink et al., 2022; CLRTAP, 2023). Therefore, quantification of N deposition flows is highly relevant to monitor the atmospheric inputs of nitrogen to the environment. Hereby for NH_3, the surface-atmosphere exchange is bi-directional (Farquhar et al., 1980) and for the quantification of N deposition the net flux needs to be considered (e.g. Sutton et al., 1998).

Method

Air dispersion models are used to provide an estimate of the concentration and deposition of a pollutant emitted from point sources (e.g. industrial process), line sources (e.g. road traffic) and area sources (e.g. agricultural field). Outputs from dispersion models are often used to predict the contribution of a new or existing process to the level of pollutants at specified points. The modeled outputs of concentrations and depositions can then be compared with environmental limits (e.g. critical loads) and air quality limits related to human health. There are numerous models that are used for both short-range local scale modeling (<20 km), and long-range, regional/trans-boundary, air pollution (>50km). Between these models the so-called Chemical Transport Models (CTMs) take into account the strength of anthropogenic and biogenic emissions, their diffusion in the atmosphere, the transport of air masses, the chemical interactions of all modelled substances, and their deposition. When modelling nitrogen deposition, it is important to consider the bi-directional surface-atmosphere exchange of ammonia (e.g. Wichink Kruit et al., 2012). With the help of a CTM it is possible to generate a wide-area forecast/analysis of pollutant load. A precondition for modelling air pollution is knowing the meteorological situation. Hence, data from a meteorological model is needed as input for the CTM.

One of the most accessible tools to obtain pollutant concentrations and depositions over Europe is the EMEP unified model. The unified modelling system has been designed to provide a common core to all MSC-W modelling activities, building upon one Eulerian model structure. The model covers all of Europe with a resolution of, traditionally, about 50 km × 50 km and is extending vertically from ground level to the tropopause (100 hPa). With its flexible processing of chemical schemes, meteorological inputs, and with nesting capability the code can be applied on scales ranging from local (ca. 5 km grid size) to global (with 1 degree resolution) (Simpson et al. 2012). However, organic N deposition remains a significant source of uncertainty, as it is still not included in most current models (Ellis et al., 2013; Walker et al., 2019; Beachley et al., 2024; Schwede et al., 2024). The Source-Receptor Tables of the EMEP model[99] allow to distinguish the

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[99] https://www.emep.int/mscw/mscw_srdata.html (accessed December 20, 2024)

share of deposition originating from imported air pollutants. For a more detailed NNB it is recommended to introduce separate N flows for imported and domestic deposition.

Next to EMEP, pollutant concentration and deposition datasets over Europe are also available from other models (e.g. Leip et al., 2023) and in case a national based dataset exists it should be preferred to a European one.

7.4.1.1 Data sources

Gridded[100] deposition data are available from the 'European Monitoring and Evaluation Programme (EMEP)[101]. The dataset covers both dry and wet deposition for reduced and oxidized nitrogen species.

To differentiate the N deposition per ecosystem type, i.e. per (sub-)pool, gridded data of the N deposition need to be merged with data on landcover classes. Data on landcover are available from the CORINE Land Cover inventory.[102] The rates of organic N deposition can be roughly estimated based on the published literature for the corresponding ecosystems within certain geographical areas (where available).

There are some specific characteristics of deposition to the sub-pools "forests" FS.FO, "other land" FS.OL and "wetland" FS.WL, which are described in the following.

Atmospheric N deposition to "forests" (AT-FS.FO)

The total N deposition varies considerably between forest types, mostly depending on leaf surface, tree species composition and structure such as forest edges (de Vries et al., 2024, Du et al., 2019, Etzold et al., 2020). Only total N deposition is reported in large-scale deposition models (e.g. EMEP/MSC-W model), which include uptake processes for nitrogen occurring in the canopy but not measured in the throughfall. Nitrogen in throughfall is a good indicator of N leaching with the seepage water (Gundersen et al. 2006) and for gaseous emission losses. However, N throughfall deposition is not easily available and a conversion procedure is needed that quantifies throughfall deposition for a given region.

For the quantification of N deposition to forest, we recommend neglecting the throughfall. To differentiate between the vegetation-specific deposition rates, we recommend a breakdown per forest types "deciduous forests", "coniferous forests" and "mixed forests" according to the CORINE Land Cover inventory[103] (CORINE codes 3.1.1, 3.1.2 and 3.1.3).

Atmospheric N deposition to "other land" (AT-FS.OL)

In case that data are not offered for certain countries in the suggested source, the EMEP database, it could be assumed that the atmospheric deposition in semi-natural vegetation is homogenous within a country. Starting from this assumption, the total N deposition in the sub-pool „other land" can be computed by multiplying atmospheric N deposition in non-forested area by the percentage of land area assigned to „other land".

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[100] 0.1º x 0.1º longitude-latitude grid

[101] http://www.emep.int/mscw/index_mscw.html (11.7.2024)

[102] http://www.eea.europa.eu/data-and-maps/data/corine-land-cover (11.7.2024)

[103] http://www.eea.europa.eu/data-and-maps/data/corine-land-cover (22.07.2024)

Atmospheric N deposition to “wetland” (AT-FS.WL)

The N deposition to wetlands can be computed by multiplying atmospheric N deposition in non-forested area by the percentage of land area assigned to „wetland“. The area of wetlands as per definition of the NNBs differs from the IPCC (2006/2019) definition of wetlands, which includes surface waters. The area of the sub-pool „wetland“ can be determined as described in Chapter 4.2, by use of both, the IPCC data (2006/2019) and the CORINE Land Cover (CLC 2018) classification.

7.4.2 Quantification of N flows from biological N_2 fixation

7.4.2.1 Biological N_2 fixation in agricultural soils (AT-AG.SM)

Nitrogen is fixed in the soil by leguminous crops, grass-legume mixtures (leguminous forage crops) and by free living soil organisms. Leguminous crops include beans, soya bean, pulses etc., and are defined in the Handbook of Crop Statistics[104] as leguminous plants grown and harvested green as the whole plant, mainly for forage.

7.4.2.1.1 Method

The biological N_2 fixation by leguminous crops is determined by multiplying the area covered by leguminous crops with an N_2 fixation coefficient. The basic approach assumes that crop N_2 fixation equals total crop biomass, being twice the mass of edible crop (FAO, 1990), multiplied with the N content of the N fixing crop. The estimation of biological N_2 fixation in forage/fodder legumes and legume-grass pastures depends on the productivity and areas of these legumes, which are difficult to assess. The biological N_2 fixation by free living soil organisms has been excluded in the GNB approach due to uncertain and very limited availability of estimates on this flow. Others use fixed values of 2-4 kg N ha^{-1} yr^{-1}.

Methodologies to assess biological N_2 fixation, possible data sources and coherence with UNFCCC/UNECE guidelines on greenhouse gas and air pollutant inventories (IPCC 2006, 2019, EMEP/EEA 2013, 2016, 2023) are given in more detail in Annex 2 of the Eurostat Gross Nutrient Balances (GNB) handbook (Eurostat 2013).

7.4.2.1.2 Data sources

Data on N input by biological N_2 fixation is available from the Gross Nutrient Balances (GNB) provided by EUROSTAT[105]. Requested data are differentiated by leguminous crops (dried pulses, soy bean, leguminous plants (multi-annual fodder/perennial green fodder), pulses, and legume grass mixtures.

N content

- Default coefficients on the N content of the N fixing crop are provided in IPCC Good Practice Guidance to estimate biological N_2 fixation of leguminous crops, as presented in Annex 2 of the GNB handbook (Eurostat 2013).

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[104] https://ec.europa.eu/eurostat/cache/metadata/Annexes/apro_cp_esms_an_1.pdf

[105] https://ec.europa.eu/eurostat/databrowser/view/aei_pr_gnb/default/table?lang=en

- More information can be found in the following studies: Palermo et al. 2022, Herridge et al. 2008, Vitousek et al. 2013, Haas et al. 2013, Butterbach-Bahl et al. 2009

7.4.2.2 Biological N_2 fixation in forests (AT-FS.FO)

7.4.2.2.1 Method

In case stock changes (such as wood growth) are negligible, and wood harvest is known, the biological N_2 fixation can be estimated as a difference between output (leaching, emissions, harvest) and input (deposition).

$$F_{\mathrm{AT-FS.FO,fixation}} = (F_{\mathrm{FS.FO-AT}} + F_{\mathrm{FS.FO-GW}} + F_{\mathrm{FS.FO-MP.OP}} + F_{\mathrm{FS.FO-EF}}) - F_{\mathrm{AT-FS.FO,deposition}} \qquad \text{(Eq. 47)}$$

With:

$F_{\mathrm{AT\text{-}FS.FO,\ fixation}}$	Biological N_2 fixation in forests (AT-FS.FO)	[kt N]
$F_{\mathrm{FS.FO\text{-}AT}}$	Emissions of N_20, NO_x and N_2 due to denitrification	[kt N]
$F_{\mathrm{FS.FO\text{-}GW}}$	Leaching of N	[kt N]
$F_{\mathrm{FS.FO\text{-}MP.OP}}$	N output by industrial round wood	[kt N]
$F_{\mathrm{FS.FO\text{-}MP.OP}}$	N output by fuel wood to sub-pools energy conversion, industrial combustion and other energy consumption.	[kt N]
$F_{\mathrm{FS.FO\text{-}MP.OP}}$	N output by net export (i.e. import-export) of wood	[kt N]
$F_{\mathrm{AT\text{-}FS.FO,\ deposition}}$	N deposition	[kt N]

As an alternative, the N flows can be quantified based on forest area and corresponding N_2 fixation rates as provided in the following chapter.

7.4.2.2.2 Data sources

Activity data

- Data on landcover are available from the CORINE Land Cover inventory. [106]

N content

- N_2 fixation rates on forests are provided by Cleveland et al., 1999.

7.4.2.3 Biological N_2 fixation in "other land" (AT-FS.OL)

To quantify the biological fixation from "other land", the N flows can be quantified based on land cover data and corresponding N_2 fixation rates.

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[106] http://www.eea.europa.eu/data-and-maps/data/corine-land-cover (11.7.2024)

7.4.2.3.1 Data sources

Activity data

- Data on landcover are available from the CORINE Land Cover inventory. [107]

N content

- N_2 fixation rates: Reddy and DeLaune (2008)

7.4.2.4 Biological N_2 fixation in "wetland" (AT-FS.WL)

To quantify the biological fixation from "wetland", the N flows can be quantified based on land cover data and corresponding N_2 fixation rates.

7.4.2.4.1 Data sources

Activity data

- Data on landcover are available from the CORINE Land Cover inventory. [108]

N content

For some wetland types the default values of biological N_2 fixation are provided in Table 62. Where no further information is available, it is suggested to use the mean fixation rate in a first approximation. If none of those wetland types are representative for the given country, then a overall mean value of 45 [kg N ha^{-1} $year^{-1}$] shall be used.

Table 62: Biological N_2 fixation in the wetlands (Reddy and DeLaune, 2008)

Wetland type	Biological N_2 fixation (kg N ha^{-1} $year^{-1}$)		
	Minimum	Maximum	Mean
Rice paddies	7	175	91
Coastal wetlands	4	460	232
Freshwater marshes	0	58	29
Cypress swamps	4	29	17
Peat bog	0	22	11
Flax Pond mud flats	0	7	4
Estuaries	1	18	10
Oligotrophic lakes	0	18	9
Mesotrophic lakes	0	1	1
Eutrophic lakes	2	91	47

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[107] http://www.eea.europa.eu/data-and-maps/data/corine-land-cover (11.7.2024)

[108] http://www.eea.europa.eu/data-and-maps/data/corine-land-cover (11.7.2024)

7.4.2.5 Biological N_2 fixation in costal and surface water (AT-HY.SW, AT-HY.CW)

The uptake of N_2 by nitrogen-fixing microbes is widely recognized as a significant source of bioavailable nitrogen in marine environments (Gruber & Galloway, 2008). Nitrogen fixation is mediated by a variety of autotrophic and heterotrophic bacteria. Cyanobacteria appear responsible for most planktonic fixation in aquatic ecosystems, and rates of fixation are high only when these organisms make up a major percentage of the planktonic biomass.

$$\begin{aligned} F_{AT-HY.SW} &= A_{SW} \cdot f_{Nr,SW} \cdot \mathbf{M} \\ F_{AT-HY.CW} &= A_{CW} \cdot f_{Nr,CW} \cdot \mathbf{M} \end{aligned} \qquad \text{(Eq. 48)}$$

With:

$\mathbf{F_{AT\text{-}HY.SW}}$	N flow: N_2 fixation in surface waters	[kt N]
$\mathbf{F_{AT\text{-}HY.CW}}$	N flow: N_2 fixation in coastal waters	[kt N]
$\mathbf{A_{SW}}$	Volume of surface water	[m^3]
$\mathbf{A_{CW}}$	Volume of coastal water	[m^3]
$\mathbf{f_{Nr,\,SW}}$	Rates of N_2 fixation in surface waters	[mmol N /m^3]
$\mathbf{f_{Nr,\,CW}}$	Rates of N_2 fixation in coastal waters	[mmol N /m^3]
M	Molar weight of nitrogen = 14,0 g mol^{-1}	[g mol^{-1}]

7.4.2.5.1 Data sources

Activity data

- Volumes of surface water bodies and coastal waters need to be determined from national statistics.

N-content

- Nitrogen fixation rates for coastal waters are provided e.g. by Zilius et. al. 2021 (The study reports an average of 2.1 ± 0.1 mmol N m^{-2} d^{-1} or 3 mg N m^{2-} d^{-1} during summer at Europe’s largest coastal lagoon).
- Nitrogen fixation rates for lakes can be found in Howarth et al. 1988: “Planktonic nitrogen fixation tends to be low in oligotrophic and mesotrophic lakes ≪ 0.1 g N m^{-2} yr^{-1}) but is often high in eutrophic lakes (0.2–9.2 g N m^{-2} yr^{-1}).”

7.4.3 N flows with specific quantification methods

7.4.3.1 Combustion N_2 fixation (AT-EF)

During combustion of fuels with low N content (e.g. natural gas) atmospheric nitrogen (N_2) is converted to NO_x. thus resulting in N_2 fixation. The amount of N_2 fixation from fuel combustion can directly be estimated based on a mass balance using other N-flows related to the combustion process, i.e. the input of nitrogen bound to fuels and the emissions to the atmosphere. The nitrogen emissions to the atmosphere originate partly from nitrogen contained in the fuel and partly from fixation of N_2 from the atmosphere. As both nitrogen emissions to the atmosphere as well as nitrogen contents of the fuels are available, the resulting N flow related to N_2 fixation can be calculated directly from those N flows (i.e. $N_{fixation} = N_{emissions} - N_{fuels}$). Therefore, the N flows related to N_2 fixation can be calculated as follows (note that for fuels with high N content, such as coal, these N flows do not occur, since in this case combustion results in a net output of N_2 to the atmosphere, see Chapter 1.4.1):

$$\begin{aligned}
\boldsymbol{F}_{AT-EF.EC} &= \boldsymbol{F}_{EF.EC-AT} - \boldsymbol{F}_{RW-EF.EC} \\
\boldsymbol{F}_{AT-EF.IC} &= \boldsymbol{F}_{EF.IC-AT} - \boldsymbol{F}_{EF.EC-EF.IC} \\
\boldsymbol{F}_{AT-EF.TR} &= \boldsymbol{F}_{EF.TR-AT} - \boldsymbol{F}_{EF.EC-EF.TR} \\
\boldsymbol{F}_{AT-EF.OE} &= \boldsymbol{F}_{EF.OE-AT} - \boldsymbol{F}_{EF.OE-EF.IC}
\end{aligned} \qquad \text{(Eq. 49)}$$

With:

$\mathbf{F}_{AT\text{-}EF.EC}$ $\mathbf{F}_{AT\text{-}EF.IC}$ $\mathbf{F}_{AT\text{-}EF.TR}$ $\mathbf{F}_{AT\text{-}EF.OE}$	**N_2 fixation:** Flow of N_2 from the atmosphere due to nitrogen fixation in the combustion processes in sub-pools of the pool “energy” (i.e. EC, IC, TR, OE)	[t N]
$\boldsymbol{F}_{EF.EC-AT}$ $\boldsymbol{F}_{EF.IC-AT}$ $\boldsymbol{F}_{EF.TR-AT}$ $\boldsymbol{F}_{EF.OE-AT}$	**N emissions:** Total emissions from fuel combustion processes in sub-pool YY (i.e. EF.EC, EF.IC, EF.TR, EF.OE), see Chapter 1.4.1	[t N]
$\boldsymbol{F}_{RW-EF.EC}$ $\boldsymbol{F}_{EF.EC-EF.IC}$ $\boldsymbol{F}_{EF.EC-EF.TR}$ $\boldsymbol{F}_{EF.EC-EF.OE}$	**N bound to fuel:** Flow of nitrogen bound to fuels, see Chapters 1.4.2.1-1.4.2.3.	[t N]

7.4.3.1.1 Data sources

The estimation of this N flow is quantified based on information on the following N flows.

- N emissions: Total emissions from fuel combustion processes in sub-pool EF.EC, EF.IC, EF.TR and EF.OE, see Chapter 1.4.1
- N bound to fuel: Flow of nitrogen bound to fuels, see Chapters 1.4.2.1-1.4.2.3.

7.4.3.2 N_2 fixation during ammonia synthesis (AT-MP.OP)

The amount of inflowing nitrogen from atmosphere during the chemical fixation of nitrogen in the Haber Bosch process is equal to the sum of the nitrogen in the synthesized ammonia. It therefore can be estimated from the N flow related to total domestic fertilizer production.

As the total nitrogen content of the produced fertilizers stems from the atmosphere, the N flow related nitrogen fixation equals the nitrogen content of the fertilizers produced in the ammonia synthesis (Haber Bosch process), according to the following chemical reaction:

$$N_2 + 3H_2 \rightarrow 2NH_3 \qquad \text{(Eq. 50)}$$

7.4.3.2.1 Data sources

Data on total domestic fertilizer production is available from the FAO statistics "Fertilizers by nutrient": https://www.fao.org/faostat/en/#data/RFN

7.4.3.3 Atmospheric outflow and inflow (AT-RW, RW-AT)

7.4.3.3.1 Data sources

Transboundary nitrogen flows and deposition are evaluated according to the country to country source-receptor matrices. The matrices are provided by EMEP (source and receptor tables[109]).

7.4.4 Uncertainties

When estimating the uncertainties in the quantification N flows from the pool "atmosphere" the following should be considered:

- The uncertainties in **N deposition** are linked to the model itself and on the quality of data that feed the model. Generally, the uncertainties are strictly linked to the selected model resolution, thus a national based model is to be preferred to a European one. The uncertainties in models may arise from model parameters, or from structural uncertainties as some processes in the climate and air quality system are not fully understood or are impossible to resolve because of computational constraints. Additionally, when projecting on a regional scale, due to the model size and complexity, the GCMsmust have inevitably omitted some factors that affect regional climate. Thus, projection data with less uncertainty at a higher spatial resolution may be more valuable (Madaniyazia et al. 2015).
- Biological N fixation is affected by high uncertainty, since there is high spatial variability and therefore the assumption of a constant N fixation rate will lead to substantial uncertainty.
- Estimation of nitrogen fixation during fuel combustion and during mineral fertilizer production is expected to be uncertain, since they cannot be directly measured but only be estimated based by closing the N balance for the respective fuel combustion processes (e.g. $N_{fixation} = N_{emission} - N_{fuel}$).
- A method for estimating uncertainties based on uncertainty levels is provided in Annex 0, Chapter A.7.

7.5 Quantification of stock changes

The largest nitrogen stock in the pool "atmosphere" is present in the form of inert nitrogen (N_2). A shift of nitrogen may occur in case of lightning in the middle and upper troposphere, when inert nitrogen is transformed to NO_x. Overall, this does not result in a stock change of total nitrogen in the pool "atmosphere", but it leads to a change in the stock of inert and reactive nitrogen species (increase in stocks of NO_x and decrease in stocks of N_2). The knowledge of the lightning-induced nitrogen oxides (LNO_x) source is important for understanding and predicting the nitrogen oxides and ozone distributions in the troposphere and their trends, the oxidizing capacity of the atmosphere, and the lifetime of trace gases destroyed by reactions with OH (Schumann and Huntrieser, 2007). In the middle and upper troposphere, where NO_x is long-

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[109] http://www.emep.int/mscw/SR_data/sr_tables.html

lived and typically at more dilute concentrations, LNO_x is a particularly significant source (Ridley et al., 1996; Huntrieser et al., 1998; Pickering et al., 1998; Zhang et al., 2000; Bond et al., 2001, 2005). Lightning is a transient, high-current electric discharge over a path length of several kilometers in the atmosphere (Uman, 1987). The majority of lightning in the Earth's atmosphere is associated with convective thunderstorms (MacGorman and Rust, 1998; Rakov and Uman, 2003). Lightning forms from the breakdown of charge separation in thunderstorms.

The global LNO_x source is one of the largest natural sources of NO_x in the atmosphere (Galloway et al., 2004) and certainly the largest source of NO_x in the upper troposphere (see below for more detailed quantification). Lightning and corona discharge during thunderstorm events cause atmospheric chemical reactions to take place at high voltages and high temperatures. These reactions cause the production of NO_x in the atmosphere. Global NO_x production by lightning has been estimated in the range of 3–5 Tg N/yr for altitudes below 1 km above Earth's surface (Levy et al. 1996; Simpson et al., 1999).

The methodology to estimate emissions from lightning could be found in the last version of the EMEP/EEA air pollutant emission inventory guidebook 2013 (EEA 2013e) and on the website www.euclid.orgwww.euclid.orgwww.euclid.org.

The LNO_x source rate is considered to be the least known one within the total atmospheric NO_x budget. The global LNO_x amount cannot be measured directly and is difficult to determine. In the last years many progresses have been made which allow reducing the uncertainty of the global LNO_x value, for example satellite observations of global, satellite observations of NO_2 column distributions, improved global models.

Overall, stock changes in the pool "atmosphere" are difficult to quantify. A more accureate picture of the N balance is achieved by quantifying the inflows and outflows of nitrogen to and from the atmosphere respectively. A quantification of stock changes is recommended to check the plausibility of the N budget of the pool AT.

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7.7 Document Version

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Reviewers Version 09/2024: Sabine Banzhaf (sabine.banzhaf@met.fu-berline.de, Institut für Meterologie, Freie Universität Berlin, Germany), Andrea Roskosch (andrea.roskosch@uba.de, Umweltbundesamt, Dessau, Germany), Kazuya Nishina (nishina.kazuya@nies.go.jp; Biogeochemical Cycle Modeling and Analysis, Section Earth System Division, Nationale Institute for Environmental Studies, Tsukuba, Japan),), Sergiy Medinets (SerMed@ceh.ac.uk, Centre for Ecology & Hydrology, UK)

Version 10/2015

Authors Version 10/2015: Alessandra De Marco (alessandra.demarco@enea.it), Ilaria D'Elia (ilaria.delia@enea.it)

Reviewer Version 10/2015: Addo van Pul (RIVM, Bilthoven, The Netherlands)

8 Annex 8 – Hydrosphere (HY)

This chapter describes the pool “hydrosphere” (HY) and provides methodologies for the computation of the major N flows to the other pools of the NNB. In addition, the chapter discusses inherent uncertainties and limitations in the quantification of nitrogen flows and stock changes in the pool.

8.1 Description of flows to other pools

The pool HY consists of all national water bodies that are part of of the (natural) hydrological cycle[110]. This includes groundwater, rivers, lakes, estuaries, coastal and marine waters.

N flows between the pool HY and the other pools of the NNB and the Rest of the world are represented in Figure 20, and are described in detail in Chapter 8.3.

8.2 Boundaries

Given the inherent difficulty in establishing the boundaries of some water bodies (for example groundwater bodies, or the water exchange between territorial and international sea water), for the scope of the NNB we propose the conceptual simplification of the Hydrosphere in three main compartments, i.e., the sub-pools groundwater (GW), surface water (SW) and coastal water (CW; including transitional, coastal and marine water).

For the definition of *groundwater* and *surface water* we refer to the EU Directive 2000/60/EC (Water Framework Directive, WFD). In the definition of *coastal water* we include the transitional and coastal water, as defined by the EU Directive 2000/60/EC, and the marine waters, as defined in the EU Directive 2008/56/EC (Marine Strategy Framework Directive, MSFD). The definitions are reported in Table 1.

Besides the physical boundaries of water bodies, the river basin delineates the natural geographical area relevant for inland water, as it is “the area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta” (Directive 2000/60/EC Article 2(13)).

The boundary of the pool “hydrosphere” with the “rest of the world” might be complex for several reasons. First, the hydrological cycle follows the natural boundaries rather than the national boundaries; this means that water flow between transboundary aquifers, rivers or lakes can be present. Second, the extent and feature of aquifers are known only partially. Third, although the limit of territorial waters and international waters is defined spatially[111], the water

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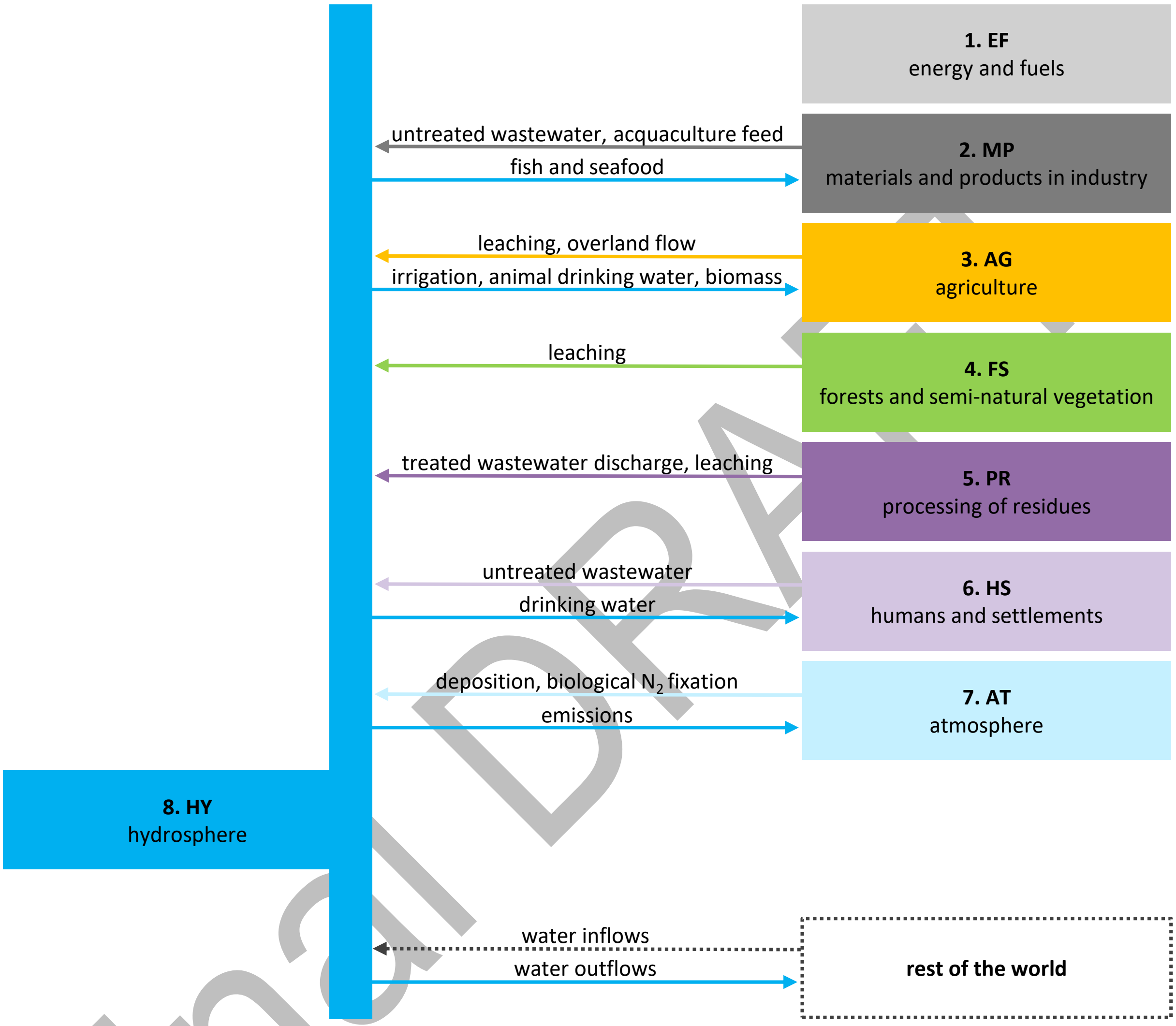
[110] For the definition of the hydrological cycle see the IPCC Fifth Assessment Report, Climate Change 2014: Synthesis Report, Annex II Glossary, available at https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_Annexes.pdf (23/03/2024).

Hydrological cycle: the cycle in which water evaporates from the oceans and the land surface, is carried over the Earth in atmospheric circulation as water vapour, condenses to form clouds, precipitates over ocean and land as rain or snow, which on land can be intercepted by trees and vegetation, provides runoff on the land surface, infiltrates into soils, recharges groundwater, discharges into streams and ultimately flows out into the oceans, from which it will eventually evaporate again. The various systems involved in the hydrological cycle are usually referred to as hydrological systems”.

[111] According to the UNCLOS (United Nations Convention on the Law of the Sea, 1982), every state has the right to establish the breadth of its **territorial sea** up to a limit not exceeding 12 nautical miles, measured from baselines, which is the low-water line along the coast. The **Exclusive Economic Zone** is an area beyond and adjacent to the territorial sea, that extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured. Over this zone the state has sovereign

and nitrogen fluxes between sea areas are very complex to be accounted, as no physical boundaries are present. For these reasons the computation of the nitrogen national budget is not completely closed for the pool "hydrosphere", and river basin outlets (or the coastal line) seem the possible location where computing meaningful water nitrogen budgets.

Figure 20: N flows between pool "hydrosphere" (HY) and other pools



Sources: illustration by INFRAS

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rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds, subject to the legal regime of the UNCLOS.

Table 63: Definition of the sub-pools considered in the pool “hydrosphere” (based on the definition of water bodies from the EU Directives 2000/60/EC and 2008/567EC)

Hydrosphere sub-pool	Definition
Groundwater (GW)	**Groundwater** means all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil (Directive 2000/60/EC Article 2(2)).
Surface water (SW)	**Surface water** means inland waters, except groundwater; transitional waters and coastal waters (Directive 2000/60/EC Article 2(1)). **Inland water** means all standing or flowing water on the surface of the land, and all groundwater on the landward side of the baseline from which the breadth of territorial waters is measured (Directive 2000/60/EC Article 2(3)).
Coastal water (CW)	**Transitional waters** are bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows (Directive 2000/60/EC Article 2(6)). **Coastal water** means surface water on the landward side of a line, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters (Directive 2000/60/EC Article 2(7)). **Marine waters** means: (a) waters, the seabed and subsoil on the seaward side of the baseline from which the extent of territorial waters is measured extending to the outmost reach of the area where a Member State has and/or exercises jurisdictional rights, in accordance with the Unclos[112] , with the exception of waters adjacent to the countries and territories mentioned in Annex II to the Treaty and the French Overseas Departments and Collectivities; and (b) coastal waters as defined by Directive 2000/60/EC, their seabed and their subsoil, in so far as particular aspects of the environmental status of the marine environment are not already addressed through that Directive or other Community legislation (Directive 2008/56/EC Article 3(1)).
Aquaculture (AQ)	This sub-pool is only relevant for countries in which aquaculture plays a role. It encompasses aquaculture and fishery in coastal waters and surface waters. It should be distinguished from the fishery (catched fish/seafood) in marine waters, which happens outside the system boundaries and therefore is displayed as a flow from “rest of the world” to “materials and products”, sub-pool “food and feed production”.

8.3 Pool structure and N flows

8.3.1 Overview of N flows

Figure 21 shows the internal structure of the pool HY with its specific N flows within the pool and to other pools. The pool “hydrosphere” is composed by a number of water bodies connected by the hydrological cycle. It is subdivided into four sub-pools: groundwater (GW), surface water (SW), coastal water (CW) and aquaculture (AC).

The definition of the sub-pools’ boundaries is provided in Section 8.2. The division in sub-pools is related to the location of water bodies in the river basin (above/below soil surface) and the

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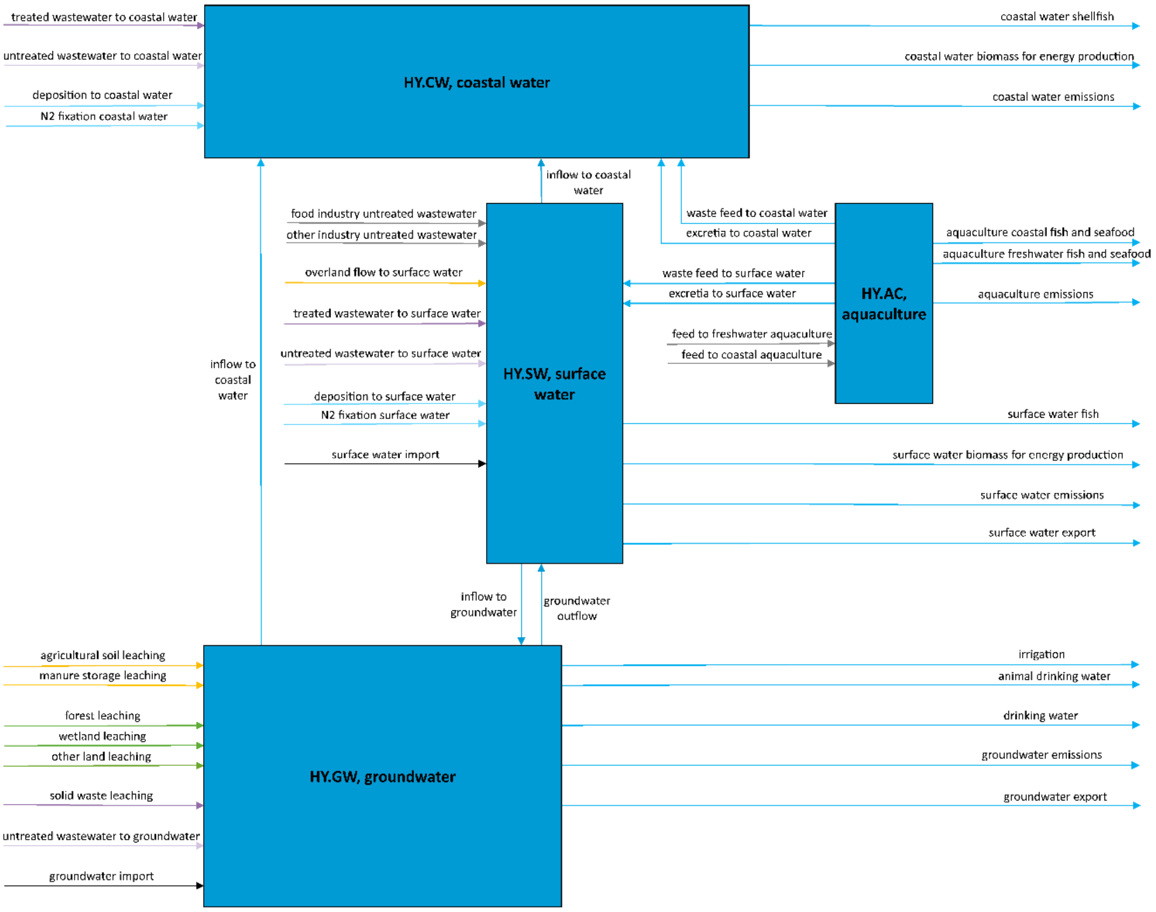
[112] United Nations Convention on the Law of the Sea http://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm (18.12.2024)

salinity (freshwater versus salt water). Within surface waters, sub-pools could be distinguished on the basis of the water residence time into lentic (lakes) and lotic (rivers) water systems. Location, physicochemical characteristics and water residence time have a great influence on the nitrogen's processes in water bodies.

Figure 21: N flows between sub-pools of "hydrosphere" (HY) and other pools



The arrows characterize the nitrogen flows between the sub-pools. Colours indicate from which pool the flows originate (the colours assigned to the pools can be seen in the overview graphics "n flows between pools"). Stock changes are not depicted. The flow names used in the graph here contain some details for clear identification and can deviate from the flow names given in the table below, because the latter correspond exactly to the flow names given in the Excel-Template for NNBs.

Source: illustration by INFRAS, generated in STAN

In the river basin, surface water moves from the land to the sea according to the topographic slope, but the direction of exchanges between groundwater and surface waters can vary locally and temporarily. The boundaries of rivers and lakes are defined (although they are subject to seasonal or temporal local variations), while the extent of aquifers and the temporal variation of the water table are not always known. Also, the limits of territorial and international waters are set legally but do not exist physically. Except for the nitrogen load at the river basin outlet, nitrogen flows between sub-pools cannot be measured in practice (unless specific monitoring networks are in place). Therefore, the internal flows do not need to be quantified. However, as the processes related to nitrogen and their intensity vary greatly in the different water bodies, mainly as a consequences of diverse water residence times, the internal nitrogen flows should accounted for if data are available.

In addition, within surface water bodies nitrogen moves continuously through the trophic chain of the aquatic ecosystem, as described by the nutrient spiraling concept (Newbold et al. 1981; Howard-William 1985), cycling through dissolved forms, living organisms and detritus. Due to the complexity of these processes and the lack of data, these internal flows of nitrogen are not computed in the budget.

Table 64: N flows going out of the pool “hydrosphere” (HY)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
Groundwater	HY.GW	AG.MM	Manure management, storage and animal husbandry	Animal drinking water	Water abstraction from groundwater for animal drinking water	N_{mix}	8.4.1.2
		AG.SM	Soil management	Irrigation	Water abstraction from groundwater for irrigation	N_{mix}	8.4.1.3
		HS	Humans and settlements	Drinking water	Water abstraction from groundwater for drinking water	N_{mix}	8.4.1.4
		AT	Atmosphere	Emissions	Denitrification in vadose zone and groundwater	N_2 N_2O NO_x	8.4.2
		HY.SW	Surface waters	Groundwater outflow	Exchange of surface waters with groundwater	N_{mix}	8.4.1.5
		HY.CW	Coastal waters	Inflow to coastal waters	Exchange of coastal waters with groundwater	N_{mix}	8.4.1.5
		RW	Rest of the world	Export of groundwater	Groundwater export flows in transboundary aquifers	N_{mix}	8.4.1.6
Surface water	HY.SW	MP.FP	Food and feed processing	Fish (wild catch)	Fish from fresh water fishery (wild catch)	N_{mix}	8.4.4
		AG.BC	Biofuel production and composting	Biomass for energy production	Surface water algae and aquatic plants used for energy production	N_{mix}	8.4.3.1
		AT	Atmosphere	Emissions	Denitrification in surface water	N_2 N_2O NO_x	8.4.2

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Description	Species	Chapter
		HY.GW	Groundwater	Inflow to groundwater	Total inflow to groundwater	N_{mix}	8.4.1.5
		HY.CW	Coastal waters	Inflow to coastal waters	Total inflow to coastal waters	N_{mix}	8.4.1.5
		RW	Rest of the world	Export of surface water	Surface water outflows, transboundary rivers, lakes, artificial transfers	N_{mix}	8.4.1.6
Coastal water	HY.CW	AG.BC	Biofuel production and composting	Biomass for energy production	Coastal water algae and aquatic plants used for energy production	N_{mix}	8.4.3.1
		AT	Atmosphere	Emissions	Denitrification in coastal water	N_2 N_2O NO_x	8.4.2
		MP.FP	Food and feed processing	Shellfish	Aquaculture produce (shellfish)	N_{mix}	8.4.4
Aquaculture	HY.AC	MP.FP	Food and feed processing	Coastal fish and seafood	Fish/produce from coastal waters	N_{mix}	8.4.4
		MP.FP	Food and feed processing	Freshwater fish and seafood	Fish/poduce from freshwaters	N_{mix}	8.4.4
		HY.CW	Coastal water	Excretia	aquaculture excretia to coastal waters	N_{mix}	8.4.4
		HY.SW	Surface water	Excretia	aquaculture excretia to surface water	N_{mix}	8.4.4
		HY.CW	Coastal water	Waste feed	Waste feed from aquaculture to coastal waters	N_{mix}	8.4.4
		HY.SW	Surface water	Waste feed	Waste feed from aquaculture to freshwater/surface waters	N_{mix}	8.4.4
		AT	Atmosphere	Emissions	Emissions from fish farms/aquaculture	NH_3 N_{mix}	8.4.2

The following table shows the N flows entering the pool “hydrosphere”. They are described in the Annexes of the pools from which these N flows originate.

Table 65: N flows entering the pool “hydrosphere” (HY)

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Species	Chapter
Food processing	MP.FP	HY.SW	Surface water	Untreated wastewater	N_{mix}	2.4.4.2
	MP.FP	HY.AC	Aquaculture	Feed to coastal aquaculture	N_{mix}	8.4.4
	MP.FP	HY.AC	Aquaculture	Feed to freshwater aquaculture	N_{mix}	8.4.4
Other producing industry	MP.OP	HY.SW	Surface water	Untreated wastewater	N_{mix}	2.4.4.2
Soil management	AG.SM	HY.GW	Groundwater	Leaching	N_{mix}	3.4.3.2
	AG.SM	HY.SW	Surface water	Overland flow	N_{mix}	3.4.3.3
Manure management	AG.MM	HY.GW	Groundwater	Leaching	N_{mix}	3.4.3.2
Forests	FS.FO	HY.GW	Groundwater	Leaching	N_{mix}	4.4.3.1
Wetland	FS.WL	HY.GW	Groundwater	Leaching	N_{mix}	4.4.3.3
Other land	FS.OL	HY.GW	Groundwater	Leaching	N_{mix}	4.4.3.2
Solid waste	PR.SO	HY.GW	Groundwater	Leaching	N_{mix}	5.4.5.1
Wastewater	PR.WW	HY.SW	Surface water	Treated wastewater discharge	N_{mix}	5.4.3.1
	PR.WW	HY.CW	Coastal water	Treated wastewater discharge	N_{mix}	5.4.3.1
Humans and settlements	HS	HY.GW	Groundwater	Untreated wastewater	N_{mix}	6.4.2.2
	HS	HY.SW	Surface water	Untreated wastewater	N_{mix}	6.4.2.2
	HS	HY.CW	Coastal water	Untreated wastewater	N_{mix}	6.4.2.2
Atmosphere	AT	HY.SW	Surface water	Deposition	OXN RDN	7.4.1
	AT	HY.SW	Surface water	N_2 fixation	N_2	7.4.2
	AT	HY.CW	Coastal water	Deposition	OXN RDN	7.4.1
	AT	HY.CW	Coastal water	N_2 fixation	N_2	7.4.2
Rest of the world	RW	HY.GW	Groundwater	Groundwater import	N_{mix}	8.4.1.7

Sub-Pool Out	Out	In	Sub-Pool In	Flow Name	Species	Chapter
	RW	HY.SW	Surface water	Surface water import	N_{mix}	8.4.1.7

Note: The N flow from fish landing of marine fishery is defined as a flow from the rest of the world (RW) to MP, sub-pool "food and feed processing". It is therefore not part of the pool HY (see Figure 7 and Table 18, quantification method in Chapter 8.4.4).

8.3.2 Sub-pool "groundwater" (GW)

Inflows of nitrogen to the sub-pool "groundwater" are leaching from agricultural soils, forests, wetlands and other land. Important inflows of nitrogen may occur if untreated wastewater is leaching to the groundwater bodies and also landfills may contribute to an input of nitrogen to groundwater. Further, nitrogen might be exchanged between groundwater and surface waters and the Rest of the World in aquifers spanning across borders.

Most important outflows of nitrogen from the sub-pool "groundwater" are natural outflows to surface waters or coastal waters, as well as emissions to the atmosphere from the vadose zone. Other nitrogen outflows are abstraction of water for irrigation purposes or as drinking water for humans or animals.

8.3.3 Sub-pool "surface water" (SW)

Important inflows of nitrogen to the sub-pool "surface water" may occur if treated wastewater is discharged or if untreated wastewater from humans and settlements flows overland to surface waters. Further there might be overland flow from agriculture. In terms of nitrogen content and amounts municipal wastewater is considered to be most important, however wastewater from industrial processes might be relevant as well. Further, from the atmosphere, nitrogen fixation and deposition result in nitrogen inputs to surface waters.

Most important outflows of nitrogen from the sub-pool "surface water" are natural outflows to coastal waters, further there are exchanges with ground water, as well as with "rest of the world" via rivers. Furthermore, nitrogen is extracted in the form of fish landing and to a smaller extent in the form of biomass for energy production. In addition, emissions to the atmosphere occurring with denitrification needs to be quantified.

Due to simplification purposes, nitrogen outflows due to abstraction of water for irrigation purposes or as drinking water for humans and animals are assumed to occur from groundwater only. Further, there is assumed that no runoff from the pool FS into surface waters occurs, since the general pathway of water between FS and HY is by leaching to groundwater from where it flows further into surface and coastal water.

8.3.4 Sub-pool "coastal water" (CW)

Important inflows of nitrogen to the sub-pool "coastal water" may occur if treated or untreated wastewater is discharged. Other important inflows of nitrogen are riverine and other inputs from waters bodies (surface waters and Rest of the World). From the atmosphere, nitrogen fixation and deposition also result in nitrogen inputs to coastal waters.

Most important outflows of nitrogen from the sub-pool "coastal water" extraction in the form of fish/seafood landing and to a smaller extent in the form of biomass for energy production. In addition, emissions to the atmosphere due to denitrification needs to be quantified.

For simplification purposes, it is assumed that no direct overland flow from the pools FS and AG into coastal waters occurs, since the general pathway of water is by leaching to groundwater from where it flows further into surface and coastal water.

Note that for the NNB only the input into coastal waters needs to be quantified, while the exchange with the open sea (i.e. the exchange of CW with RW), which is difficult to quantify, does not need to be balanced. Flows from/to CW to/from RW are therefore not considered.

8.3.5 Sub-pool „aquaculture“ (AC)

This sub-pool is only relevant for countries, where aquaculture plays a relevant role. It encompasses aquaculture and fishery in coastal and surface waters. Aquaculture can differ depending on if it is freshwater or seawater based, so inputs and outputs to/from "aquaculture" are distinguished between to/from aquaculture in coastal resp. to/from aquaculture in surface waters.

Main nitrogen inputs occur with feed from the pool "materials and products", sub-pool "food and feed processing". Feed consists mainly of fish meal, but can also contain a lot of other ingredients, including plant-based components. Main outputs are excreta, but to a smaller extent, there are also feed losses (due to feed that drops out of the cages before the fish eat it). With optimized feeding techniques, feeding losses could be kept small.

The aquaculture should be distinguished from the fishery (catched wild fish or seafood inclding by-catch) in marine waters, which happens outside the system boundaries and therefore is displayed as a flow from "rest of the world" to "materials and products", sub-pool "food and feed production".

Further, in some countries, there is shellfish production in coastal waters, which is however not part of the pool "aquaculture", given that it does not need any inputs (no feeding), but there is produce/output with zero input. It is displayed as a flow from the sub-pool "coastal waters" to "food and feed processing".

8.4 Quantification of flows

Overall, the nitrogen flows between the pool Hydrosphere and the other pools are difficult to quantify, since in most cases no standardized data sources or default values are available, due to the complexity of the water system[113]. Some of the flows are also expected to be rather small for most countries (e.g. drinking water, irrigation) and can be neglected for simplification purposes.

More important N flows are the N-load from rivers to coastal waters, which can be estimated based on the discharge and concentrations of reactive nitrogen compounds. In addition, N flows related to aquaculture can be relevant.

8.4.1 Quantification of N flows related to the displacement of water

8.4.1.1 Method

Most N flows in the pool HY can be quantified based on the amount of water flowing between two (sub-)pools and the corresponding concentration of nitrogen compounds. Relevant amounts

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[113] for a description of the nutrient dynamic in the river continuum see Billen et al. 1991; Billen et al. 2007; Bouwman et al. 2013b

of nitrogen are expected in the internal N flows as well as water exports and imports to and from RW. Less relevant in terms of total N are N flows related to water abstraction for irrigation and drinking water.

$$F_{HY.XX-YY.YY} = A \cdot C_{Nmix} \cdot 10^{-9} \qquad \text{(Eq. 51)}$$

With:

$F_{HY.XX-YY.YY}$	N flow: Transfer of nitrogen dissolved in water from sub-pool HY.XX to any other sub-pool "YY.YY"	[kt N]
A	Amount of water transferred between the sub-pools "HY.XX" and "YY.YY"	[m^3]
C_{Nmix}	Total concentration of reactive nitrogen compounds quantified as N_{mix} (most relevant N-species: NO_3^-, reactive nitrogen bound to suspended sediments and biomass, dissolved organic matter)	[g N/m^3]

8.4.1.2 Animal drinking water (HY.GW-AG.MM)

Note on possible simplification

This flow is expected to be small, since the nitrogen intake from drinking water is small compared to the nitrogen intake from animal feed.

For simplification purposes, this flow can therefore be neglected. If it is quantified, we suggest to consider just one flow from groundwater to agriculture, while the flow from surface water is neglected.

In the computation of N flows related to extraction of drinking water for animal husbandry can be calculated based on the amount of drinking water abstraction and the concentration of nitrogen compounds in the groundwater body according to the general method described in Chapter 8.4.1.

Note that depending on the country's specific, animal drinking water can also be abstracted from surface waters. If this source is more relevant, it is recommended to adjust the N flow accordingly to HY.SW-AG.MM or consider both sub-pools with a flow each.

8.4.1.2.1 Data sources

Activity data

- If no country specific statistics are available, the amount of drinking water needs to be estimated based on the number of animals and average water requirements per animal category.
- The AQUASTAT statistics of the FAO provides some information "Water withdrawal for livestock (watering and cleaning)" by country or region: https://data.apps.fao.org/aquastat/?lang=en

N content

- The concentration of nitrogen in the groundwater (C_{Nmix}) can be determined based on representative water quality measurements. Most relevant N-species to be accounted for is NO_3^-.

8.4.1.3 Irrigation (HY.GW-AG.SM)

Note on possible simplification

This flow is expected to be small, since the N flow related to irrigation is small, compared to the nitrogen inputs to soils related to fertilizer application.

For simplification purposes, this flow can therefore be neglected. If it is quantified, we suggest to consider just one flow from groundwater to agriculture, while the flow from surface water is neglected.

In the computation of N flows related to extraction of water for irrigation purposes in agriculture can be calculated based on the amount of water abstraction and the concentration of nitrogen compounds in the groundwater body according to the general method described in Chapter 8.4.1.

Note that depending on the country’s specific, water for irrigation can also be abstracted from surface waters. If this source is more relevant, it is recommended to adjust the N flow accordingly to HY.SW-AG.MM or consider both sub-pools with a flow each.

8.4.1.3.1 Data sources

Activity data

The amount of water (A) used for irrigation purposes can be estimated from the AQUASTAT statistics of the FAO (https://data.apps.fao.org/aquastat/?lang=en). This database provides quantities of “Irrigation water withdrawal” in m^3. As this N flow is likely to be small, it is recommended to assign it to the sub-pool “groundwater” or “surface water”, whichever is more relevant.

N content

The concentration of nitrogen in the water resources used for irrigation (C_{Nr}) can be determined based on representative water quality measurements. Most relevant N species to be accounted for is NO_3^-.

8.4.1.4 Drinking water (HY.GW-HS)

Note on possible simplification

This flow is expected to be small, since the nitrogen intake from drinking water is small, compared to the nitrogen intake from food.

For simplification purposes, this flow can therefore be neglected. If it is quantified, the consideration of only one flow from groundwater to humans and settlements is suggested, so the flow form surface waters can be neglected.

Drinking water for human consumption contains traces of nitrogen compounds (mainly NO_3^-). The Drinking Water Directive (EU 2020) sets the maximum allowable concentration for nitrate at 50mg NO_3 per litre in order to protect human health and water resources.

In the computation of N flows related to extraction of drinking water for humans and pets can be calculated based on the amount of drinking water abstraction from groundwater or surface water bodies and the respective concentration of nitrogen compounds according to the general method described in Chapter 8.4.1.

8.4.1.4.1 Data sources

Activity data

If no country specific statistics are available, the amount of drinking water needs to be estimated based on the population numbers and average water requirements per person.

The AQUASTAT statistics of the FAO provides some data on "Municipal water withdrawal per capita (total population)": https://data.apps.fao.org/aquastat/?lang=en.

N content

The concentration of nitrogen in the groundwater (C_{Nr}) can be determined based on representative water quality measurements. Most relevant N species to be accounted for is NO_3^-. As the Drinking Water Directive (EU 2020) sets the maximum allowable concentration for nitrate at 50mg NO_3 per litre, this value can be used for a very rough estimation of the order of magnitude.

8.4.1.5 Internal flows (HY.GW-HY.SW, HY.GW-HY.CW, HY.SW-HY.CW, HY.SW-HY.GW)

The flow of nitrogen across sub-pools of the pool HY (i.e. groundwater, surface waters and coastal waters) can be computed using annual discharge measured and corresponding nitrogen concentration measurements according to the general method described in Chapter 8.4.1. Also, the output of global or local hydrological models may be one way to go about moving water.

8.4.1.5.1 Data sources

Activity data

The discharge of each water body (i.e. coastal water, surface water, groundwater) to another internal sub-pool needs to be determined based on discharge data of the major water bodies.

N content

The concentration of nitrogen in (C_{Nr}) can be determined based on representative water quality measurements. Most relevant N-species to be accounted for are NO_3^- as well as suspended organic and inorganic material and dissolved organic matter.

8.4.1.6 Water outflows (HY.SW-RW, HY.GW-RW)

The transfer of nitrogen across the borders can be computed using annual discharge measured at the outlet of major river basins in the country and corresponding nitrogen concentration measurements according to the general method described in Chapter. 8.4.1.

The exchange with the open sea (i.e. the exchange of CW with RW), does not need to be balanced and is not considered as a flow.

If no country specific data are available, it can be assumed that the N retention in the river system is around 30% (e.g. Bouwman et al. 2005).

8.4.1.6.1 Data sources

Activity data

The discharge of each water body (i.e. surface water, groundwater) to the rest of the world (A) needs to be determined based on discharge data of the major transboundary water bodies. Data may be found under transboundary river basin conventions, or national statistics.

N content

The concentration of nitrogen in (C_{Nr}) can be determined based on representative water quality measurements. Most relevant N-species to be accounted for are NO_3^- as well as suspended organic and inorganic material and dissolved organic matter.

8.4.1.7 Water inflows (RW-HY.CW, RW-HY.SW, RW-HY.GW)

The N flow across the borders can be computed using annual load measured at the inlet of major rivers in the country according to the general method described in Chapter 8.4.1.

8.4.1.7.1 Data sources

Activity data

The discharge of each water body (i.e. surface water, groundwater) from the rest of the world (A) needs to be determined based on discharge data of the major transboundary water bodies entering the country. Data may be found under transboundary river basin conventions, or national statistics.

N content

The concentration of nitrogen in (C_{Nr}) can be determined based on representative water quality measurements. Most relevant N-species to be accounted for are NO_3^- as well as suspended organic and inorganic material and dissolved organic matter.

8.4.2 Quantification of emissions to the atmosphere (HY.SW-AT, HY.CW-AT, HY.GW-AT, HY.AQ-AT)

The N flows between the pool HY and the pool AT mainly due to denitrification can be calculated based on a mass balance between nitrogen inputs to surface water bodies, costal water bodies and groundwater.

$$\begin{aligned} \boldsymbol{F}_{\boldsymbol{HY.CW-AT}} &= \boldsymbol{N}_{\boldsymbol{input,CW}} - \boldsymbol{N}_{\boldsymbol{output,CW}} \\ \boldsymbol{F}_{\boldsymbol{HY.GW-AT}} &= \boldsymbol{N}_{\boldsymbol{input,GW}} - \boldsymbol{N}_{\boldsymbol{output,GW}} \\ \boldsymbol{F}_{\boldsymbol{HY.SW-AT}} &= \boldsymbol{N}_{\boldsymbol{input,SW}} - \boldsymbol{N}_{\boldsymbol{output,SW}} \end{aligned} \qquad \text{(Eq. 52)}$$

With:

$\mathbf{F}_{\mathbf{HY.CW\text{-}AT}}$	N flow: Denitrification from coastal water	[kt N]
$\mathbf{F}_{\mathbf{HY.GW\text{-}AT}}$	N flow: Denitrification from groundwater	[kt N]
$\mathbf{F}_{\mathbf{HY.SW\text{-}AT}}$	N flow: Denitrification from surface water	[kt N]
$\mathbf{N}_{\mathbf{input,CW/SW/GW}}$	Total input of reactive nitrogen to costal water, surface water or groundwater respectively	[kt N]
$\mathbf{N}_{\mathbf{output,CW/SW/GW}}$	Total output of reactive nitrogen from costal water, surface water or groundwater respectively	[kt N]

The emissions of nitrogen toward the pool "atmosphere" are in the form of N_2 and N_2O and NO.

For aquaculture, volatilisation in the form of NH_3 from fish farms placed in rivers and coastal waters can be high (Bouwman et al. 2013a); the exchanges in the water medium are expressed as total nitrogen.

8.4.2.1.1 Data sources

At this stage and for a large-scale estimation we can consider a range of N elimination (mostly denitrification) of 20-45 %, associated to a coefficient for N_2O emission of 1-20 % (depending on controlling factors, including the lack of knowledge in modelling water fluxes at the interfaces).

In the computation of the N flows due to denitrification, it would be useful to distinguish between emissions of N_2, which is inert, and emissions of N_2O, which act as greenhouse gas. Smaller-scale emissions of NO from the hydrosphere occur as well but are not quantified in this guidance for simplification purposes (more details e.g. in Tian et al. 2020, Gong et al. 2023, Kong et al. 2023). They are however, listed as a species (NO_x) in in the respective emission flows to the atmosphere.

In-stream N-retention of N-loading:

- 7-45% (studies reported by Howarth et al. 1996)
- 5-20% (estimated by Howarth et al. 1996)
- 30% (estimated by Bouwman et al. 2005 and Van Drecht et al. 2003)
- Regression equation Saunders and Kalff (2001)
- Retention in lakes and reservoirs (Harrison et al. 2009)
- Retention in drainage network (Billen and Garnier 1999)

Studies on denitrification:

- Review of processes and global estimates (Seitzinger et al. 2006, Zheng et al. 2022)
- Review of methods (Boyer et al. 2006, Robertson et al. 2019)
- Modelling and global estimations (Bouwman et al. 2013a, 2013b; Galloway et al. 2004)
- Meta-analysis (Pina-Ochoa and Cobelas 2009)
- Estimate for the Baltic Sea Region (Asmala et al. 2017)
- Other studies (Alexander et al. 2007; Mulholland et al. 2008; Voss et al. 2013, Thouvenot-Korppoo et al. 2009; Jurado et al. 2017; Klionsky et al. 2024; Kortelainen et al. 2020, Arevalo-Martinez et al. 2015)

According to the IPCC Guidelines (IPCC 2006) the annual amount of N_2O–N (kg N_2O–N/yr) produced from leaching and runoff (of N additions to managed soils in regions where leaching/runoff occurs) is estimated by multiplying the amount of N in leaching and runoff by the emission factor EF5 (emission factor for N_2O emissions from N leaching and runoff (kg N_2O–N/kg N leached and runoff)), whose default value is 0.0075 and uncertainty range 0.0005-0.0025 (from Chapter 11 Table 11.3 IPCC Guidelines 2006).

8.4.3 N flows with specific quantification methods

8.4.3.1 Aquatic biomass for energy production (HY.CW-AG.BC, HY.SW-AG.BC)

Note on possible simplification

This flow is expected to be small for most countries and can therefore be neglected for simplification purposes.

Quantification is only required if a substantial share of energy is produced from aquatic biomass.

8.4.3.1.1 Method

The computation of N flows related to aquatic biomass used for energy production is based on the amount of aquatic biomass (A) and its nitrogen content (f_N). Depending on data availability, several species of aquatic biomass can be considered in each flow, therefore the computation is defined as a sum over all species.

$$F_{HY.CW-AG.BF} = \sum_i A_{CW,i} \cdot f_{N,CW,i}$$
$$F_{HY.SW-AG.BF} = \sum_i A_{SW,i} \cdot f_{N,SW,i} \qquad \text{(Eq. 53)}$$

With:

$F_{HY.CW-AG.BC}$	N flow: Aquatic biomass from coastal water for energy production	[kt N]
$F_{HY.SW-AG.BC}$	N flow: Aquatic biomass from surface water for energy production	[kt N]
$A_{CW,i}$	Amount of aquatic biomass of species i from costal water used for energy production	[kt]
$A_{SW,i}$	Amount of aquatic biomass of species i from surface water used for energy production	[kt]
$f_{N,CW,i}$	N content of aquatic biomass of species i from coastal water used for energy production	[% N]
$f_{N,SW,i}$	N content of aquatic biomass of species ifrom surface water used for energy production	[% N]

8.4.3.1.2 Data sources

Activity data

The amount of aquatic biomass used for energy production can be determined from national energy statistics.

N content

The nitrogen content of aquatic biomass used for energy production can be determined from measurements of the composition or based on literature. Relevant N-species are organically bound nitrogen species. As this flow is expected to be small for most countries, no default values are provided in this Annex.

8.4.4 Quantification of N flows related to aquaculture and fishery

8.4.4.1 Fish/produce (HY.AQ-MP.FP (coastal waters), HY.AQ-MP.FP (surface waters)), shellfish produce (HY.CW-MP.FP), fish (wild catch) (HY.SW-MP.FP), and sea fish (landings) (RW-MP.FP)

8.4.4.1.1 Method

The computation of N flows related to fish and seafood production as well as fishery (wild catch) and shellfish are based on the amount of landing (A), the protein content (fP) and the nitrogen content of protein (fp,N). Depending on data availability, several species of fish (i) with specific protein contents can be considered separately and then be added up to one flow. For aquaculture, a separation of coastal and surface water aquaculture is expressed in separate flows.

$$
\begin{aligned}
F_{HY.AQ-MP.FP\ (coastal)} &= \sum_i A_{CW,i} \cdot f_{p,i} \cdot f_{p,N} \\
F_{HY.AQ-MP.FP\ (surface)} &= \sum_i A_{SW,i} \cdot f_{p,i} \cdot f_{p,N} \\
F_{HY.CW-MP.FP} &= \sum_i A_{SW,i} \cdot f_{p,i} \cdot f_{p,N} \\
F_{ROW-MP.FP} &= \sum_i A_{SW,i} \cdot f_{p,i} \cdot f_{p,N}
\end{aligned}
\tag{Eq. 54}
$$

With:

$\mathbf{F_{HY.AQ\text{-}MP.FP}}$	N flow: Fish produce/landing, coastal water	[kt N]
$\mathbf{F_{HY.AQ\text{-}MP.FP}}$	N flow: Fish produce/landing, surface water	[kt N]
$\mathbf{F_{HY.CW\text{-}MP.FP}}$	N flow: Shellfish produce from coastal waters	[kt N]
$\mathbf{F_{ROW\text{-}MP.FP}}$	N flow: landing from sea fishery (RW-MP.FP)	[kt N]
$\mathbf{A_{CW}}$	Amount of fish production of species i in costal water	[kt]
$\mathbf{A_{SW}}$	Amount of fish production of species i in surface water	[kt]
$\mathbf{f_{p,i}}$	Protein fraction of fish (species i)	[%]
$\mathbf{f_{p,N}}$	N content of protein	[% N]

Note on quantification of N flows related to aquaculture

Some countries dispose of a substantial aquaculture production, which leads to nutrient enrichment in the water bodies and emissions of NH_3 to the atmosphere (Bouwman et al. 2013a). It is suggested to include related products in this N flow and add an additional N flow for nutrient inputs to aquaculture facilities.

8.4.4.1.2 Data sources

Activity data

The food and agricultural organization of the United Nations (FAO) provides food balance sheets[114], which provide data on fish and fishery products, including production, imports,

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[114] FAO Database: https://www.fao.org/faostat/en/#data/SUA (23.5.2024)

FAO 2024a. Consumption of Aquatic Products. In: Fisheries and Aquaculture. Rome. https://www.fao.org/fishery/en/collection/global_fish_consump (23.5.2024) exports and food supply. The FAO Food Balance Sheet provides the total food supply (tonnes), the population and the protein supply quantity (g/capita/day). From these data is possible to compute the average fraction of proteins in fish and fishery products per country. For a more detailed calculation, the fish and fishery products from inland and coastal waters can be distinguished and their consumption multiplied by the respective protein contents.

Country specific sea fishery statistics contain information about fish and shellfish landed.

N content

- The USDA National Nutrient Database for Standard Reference provides detailed protein contents ($f_{P,i}$) for different food groups, including a large number of fish products[115]. Similarly, the FAO information on protein content in different fish types[116].
- Nitrogen in the diet is present as amino acids in proteins and the average nitrogen content ($f_{p,N}$) in proteins is 16%.[117]
- N content in fish and shellfish: 2.8% according to UNECE Guidance, Annex 6 Table 12.

8.4.4.2 Excretion from "aquaculture" (HY.AQ-HY.CW, HY.AQ-HY.SW) and waste feed from "aquaculture" (HY.AQ-HY.CW, HY.AQ.HY.SW)

8.4.4.2.1 Method

The N flows due to excreta from aquaculture in coastal waters (e.g. from farmed salmon) and from aquaculture in freshwater/surface water (e.g. rainbow trout) can be calculated as a percentage of N content of feed input.

Similarly, the N flows due to waste feed from „aquaculture" are calculated as a percentage of N content of feed input.

8.4.4.2.2 Data sources

Activity data

The calculation of feed intake as explained in Chapter 2.4.1.2 builds the basis for further calculation of N flows with excretion.

N contents

For the N content of excretia, a default value of 60% can be used, as it has been reported from he Scottish Aquaculture website[118], including both excreted N and feed loss N (waste feed).

For feed waste, a default value of 3% is suggested, as used by Scotland's Aquaculture website/ emission calculations by the Scottish Environment Protection Agency SEPA[119] for regulatory purposes (SEPA expert knowledge).

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[115] USDA 2024: https://fdc.nal.usda.gov/ (23.5.2024)

[116] FAO 2024b: https://www.fao.org/infoods/infoods/tables-and-databases/faoinfoods-databases/en/ (23.5.2024)

[117] http://www.fao.org/docrep/006/y5022e/y5022e03.htm (03/2015)

[118] Scotland's Aquaculture: https://aquaculture.scotland.gov.uk/our_aquaculture/our_aquaculture.aspx (27.12.2024)

[119] SEPA: https://www.sepa.org.uk/regulations/water/aquaculture/ (27.12.2024)

Depending on the country's specific aquaculture and fish type, the use of more specific values for the N contents can be reasonable. In case feeding techniques have been optimised and very little feed drops out of the cages before the fish eat it, the waste feed flows can be neglegted.

8.4.5 Uncertainties

When estimating the uncertainties in the quantification N flows from the pool "hydrosphere" the following should be considered:

- the nature of the pool's boundaries, that follow basin rather than national borders, and the difficulty or even the impossibility to measure the N stock and flow within and across the water bodies, such as aquifers, large lakes, coastal water and open sea;
- the complexity of quantifying nitrogen processes and water fluxes at the interfaces (such as river-coastal zone, river-aquifer or water body-sediments);
- the complexity of the nitrogen cycling within the aquatic ecosystem, where nitrogen continuously moves between water (where it is present as different chemical species) and living organisms through the trophic chain and microbial processes;
- the spatial and temporal variability of the processes involved in the N exchanges with the other pools, such as denitrification, fixation, sedimentation, which depends on local physic-chemical conditions and are mediated by microbial activities;
- the spatial location of nitrogen loading to the water system and the spatial connectivity of the elements of the river continuum, which influence the magnitude of the retention (in this respect the way the wetlands are represented in the NNB might not be appropriate); clearly the other pools can be easily simplified to one-dimensional balances, while this simplification does not hold for the hydrosphere.
- the natural water cycle, which affects the fate and transport of nitrogen determining different water residence time, that can accelerate or delay the flow of nitrogen in the different water bodies, making it difficult to measure the variation of nitrogen over time (for example the lag time observed in aquifers);
- the lack of measurements of water flow and nitrogen concentration in aquifers, rivers and water abstractions.
- the way aquaculture (freshwater aquaculture/mariculture) is accounted (at the moment it is under the pool AG, but this representation might not be optimal for mariculture). In addition, fish production from the pool HY is assigned to HS, although the origin of the fish could be from the country's sea Exclusive Economic Zone or even beyond).
- A method for estimating uncertainties based on uncertainty levels is provided in Annex 0, Chapter A.7.

When looking at all these sources of uncertainty, it appears that closing the nitrogen budget of the pool "hydrosphere" is challenging. However, quantifying nitrogen flows into/from the water system is extremely relevant for monitoring purposes and for raising awareness on unaccounted nitrogen flows. In fact, water is a final and important receptor of nitrogen pollution. The excess nitrogen can impair the quality of water resources and alter the functioning of aquatic ecosystems. Quantifying the nitrogen flows would reveal the contribution of different sources to the impacts and offer an early warning on possible accumulation of nitrogen in the water system.

8.5 Quantification of stock changes

The pool "hydrosphere" stores nitrogen bound in the form of dissolved nitrogen and in the form of aquatic biomass. Stock changes therefore occur if nitrogen dissolved in the water bodies accumulates or decreases. Stock changes also occur if the amount of nitrogen stored in aquatic biomass changes. Any change in these stocks result in a change in the amount of nitrogen stored in the pool "hydrosphere".

To quantify these stock changes, the changes in aquatic biomass as well as the changes in the amount of dissolved nitrogen need to be quantified (see Chapter 8.4).

Furthermore, there are N exchanges between the surface water bodies and the sediments. Nitrogen can be stored in the form of sediments or be resuspended from the sediment, which leads to a change in the stocks of nitrogen within the pool "hydrosphere". This process varies greatly with the water body type. N flows to coastal sediments and reservoirs can be significant. However, nitrogen processes and water exchanges at the interfaces, such as river-coastal zone, river-aquifer or water body-bottom sediments, are complex and difficult to be quantified. In addition, in the first layers of sediments anoxic conditions can foster the process of denitrification producing nitrogen losses towards the atmosphere.

There is no standardized data source for the amount of sedimentation resuspension of sediments in coastal and surface waters. Some information can be found in scientific literature[120]. Also for the nitrogen content in the resuspended sediments there are no standardized data and they need to be determined based on representative measurements of the composition of the resuspended material.

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[120] Nitrogen fixation rates in coastal sediments by heterotrphic communities (Liesirova et al. 2023) and phototrophic groups (Sundbäk et al. 2004)

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Update of Version 12/2015 by Judith Reutimann, Bettina Schäppi, Sophie Bogler (INFRAS, Zurich).

Reviewers Version 09/2024: Øyvind Kaste (oeyvind.kaste@niva.no, Research Institute for Water and the Environment, Oslo, Norway), Kazuya Nishina (nishina.kazuya@nies.go.jp, Biogeochemical Cycle Modeling and Analysis Section Earth System Division Nationale Institute for Environmental Studies, Tsukuba, Japan), Marianne Stave Sekkenes (marianne.sekkenes@niva.no, Research Institute for Water and the Environment, Oslo, Norway), Maren Voss (maren.voss@io-warnemuende.de, Leibniz-Institut für Ostseeforschung, Warnemünde, Germany)

Version 12/2015

Authors Version 12/2015: Bruna Grizzetti (bruna.grizzetti@jrc.ec.europa.eu), Faycal Bouraoui (faycal.bouraoui@jrc.ec.europa.eu), Maren Voss (maren.voss@io-warnemuende.de)

Reviewers Version 12/2015: Luis Lassaletta (PBL, Bilthoven, The Netherlands), Josette Garnier (UPMC & CNRS, Paris), Natalya Buchkina (Agrophysical Research Institute, St. Petersburg)