Swedish Environmental Research Institute

Swedish National Nitrogen Budget - Material and Products in industry

Report number: C898

Author: Sara Jutterström, Jane Ihrfors, Johanna Stadmark, Filip Moldan

Funded by: The Swedish Environmental Protection Agency (Naturvårdsverket)

ISBN: 978-91-7883-666-6

Nitrogen, food, feed, chemical industry, import, export

Summary

In this report, pool two 'Materials & products in industry' (MP) of the Swedish National Nitrogen Budget (NNB) is presented. The MP pool of the NNB is one of the eight major pools defined by the Task Force of Reactive Nitrogen (TFRN), which together represent a total national nitrogen budget capturing all major flows of all forms of reactive nitrogen (Nr) within a country and across the country borders. The methodology to calculate the NNB has been provided by the Expert Panel on Nitrogen Budgets (EPNB) in the Annexes to the ECE/EB.AIR/119 – "Guidance document on national nitrogen budgets".

The three most important sources of data were Statistics Sweden (SCB), The Swedish Board of Agriculture (Jordbruksverket) and Swedish Chemicals Agency (Kemikalieinspektionen). Data on some chemicals were seen as industrial secrets or - in case of e.g. explosives – as non-public data. The major flows of Nr to and from MP were when possible calculated for the year 2015. The MP pool is dominated by Nr flows associated with chemicals, food and feed. These flows are between MP pool and pools 'Rest of the world' (i.e. outside Sweden), 'Agriculture' and 'Humans & settlements'.

The total input of reactive nitrogen to MP was 696 kt N and the outputs 662 kt N. Of the eight pools considered in a complete national N budget, the MP pool is rather central. MP has the largest flows of Nr in and out of the pool and it includes the major Nr flows associated with import and export of chemicals, products to and from the pool Agriculture, and Nr flows to the pool Humans and settlements.

This report replaces an earlier version published 2024, Report C861, with minor corrections of the nitrogen flows.

Table of contents

The abbreviations used in this report.

Abbreviation	Explanation
AG	Agriculture (Pool)
AT	Atmosphere (Pool)
EF	Energy and Fuels (Pool)
EPNB	The Expert Panel on Nitrogen Budgets
FS	Forest and Semi-natural Vegetation (Pool)
FS.FO	Forest and Semi-natural Vegetation - Forest (Sub-pool)
HS	Humans and Settlements (Pool)
HY	Hydrosphere (Pool)
MP	Materials and Products (Pool)
MP.CI	Materials and Products - Chemical Industry (Sub-pool)
MP.FP	Materials and Products - Food and Feed Processing (Sub-pool)
MP.OP	Materials and Products - Other Producing Industry (Sub-pool)
NNB	National Nitrogen Budget
Nr	Reactive Nitrogen
RW	Rest of the World (Pool)
TFRN	Task Force on Reactive Nitrogen

1 Introduction

The Task Force on Reactive Nitrogen (TFRN) was established under the Working Group on Strategies and Review (WGSR) by the Executive Body at its twenty-fifth session in December 2007.

The purpose of TFRN has been defined as: *"The Task Force will develop in the long-term technical and scientific information and options which can be used for strategy development across the UNECE to encourage coordination of air pollution policies on nitrogen in the context of the nitrogen cycle and which may be used by other bodies outside the Convention in consideration of other control measures."* For the full terms of reference of the Task Force, see Executive Body decision 2007/1[1] (https://unece.org/fileadmin/DAM/env/documents/2007/eb/EB/ece.eb.air.91.Add.1.e.pdf).

At the first meeting (Wageningen, 2008), TFRN agreed to define reactive nitrogen (Nr) as all biologically active, photochemically reactive and radiatively active N compounds in the biosphere and atmosphere, for example, nitric oxides, nitrogen dioxide, nitrate (NO_3^-), organic N compounds, nitrous oxide (N_2O), ammonia (NH_3) and ammonium (NH_4^+). This meant, in practice, all N except for nitrogen gas (N_2). At the same meeting it was proposed that an expert panel could help in preparing for the reporting of national budgets, first exploring methodologies and providing a reference template for the compilation. The Expert Panel on Nitrogen Budgets (EPNB) was established (first as an ad-hoc group) and commenced work to prepare guidelines for compilations of national N budgets of individual countries. EPNB prepared the "Guidance Document on National Nitrogen Budgets"[2]. The document was presented and approved at the 31st meeting of the Executive Body of the Convention on Long-Range Transboundary Air Pollution in December 2012. After that, the work of EPNB continued to provide detailed guidelines for each of the eight main parts of the National Nitrogen Budget (NNB) summarized in

[1] https://unece.org/fileadmin/DAM/env/documents/2007/eb/EB/ece.eb.air.91.Add.1.e.pdf
[2] http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20210302_public.pdf

Annexes to the ECE/EB.AIR/119 – "Guidance document on national nitrogen budgets". It summarizes seven out of the eight pools.

There have been attempts constructing nitrogen budgets in some of the European countries and elsewhere, see for example Switzerland (Heldstab et al., 2010 and 2013), Germany (Geupel et al., 2009), Denmark (Hutchings et al., 2014) or Canada (Clair et al., 2014). These budgets have not followed the same protocol when constructed but provide information on important flows. Bach et al. (UBA 2020) used the TFRN Guidance document and compiled a NNB for Germany which includes all 8 pools described in the document. In Europe, Sutton et al. (2011) estimated that 74% of the total input of reactive nitrogen to the environment stems from the Haber-Bosch process, in which reactive nitrogen is industrially produced, 16% from combustion, and the remaining 10% from biological fixation, import of feed and products. Leip et al. (2011) estimated nitrogen fluxes for EU27, developing and using the same protocol for all countries. Leip et al. (2011) recommends development of nitrogen budgets nationwide, since the assessment and management of the budgets could become an effective tool to prioritize measures and prevent unwanted effects.

National nitrogen budgets (NNB) following the EPNB methodology are constructed based on eight pools (Figure 1). In a previous report on the Agriculture pool of the Swedish NNB (Stadmark et al., 2019) year 2015 was chosen since that year was the most recent year with available statistics. In this report, where data on pool 2 (Material & products in industry) is presented, we therefore use year 2015 when data is available, and other years, indicated in text, when no data was available for 2015. The data presented in this report consist of data from the Swedish Board of Agriculture, Swedish Food Agency, Statistics Sweden, Swedish Chemicals Agency, and Swedish Medical Products Agency. The custom declaration codes used for imported and exported goods.

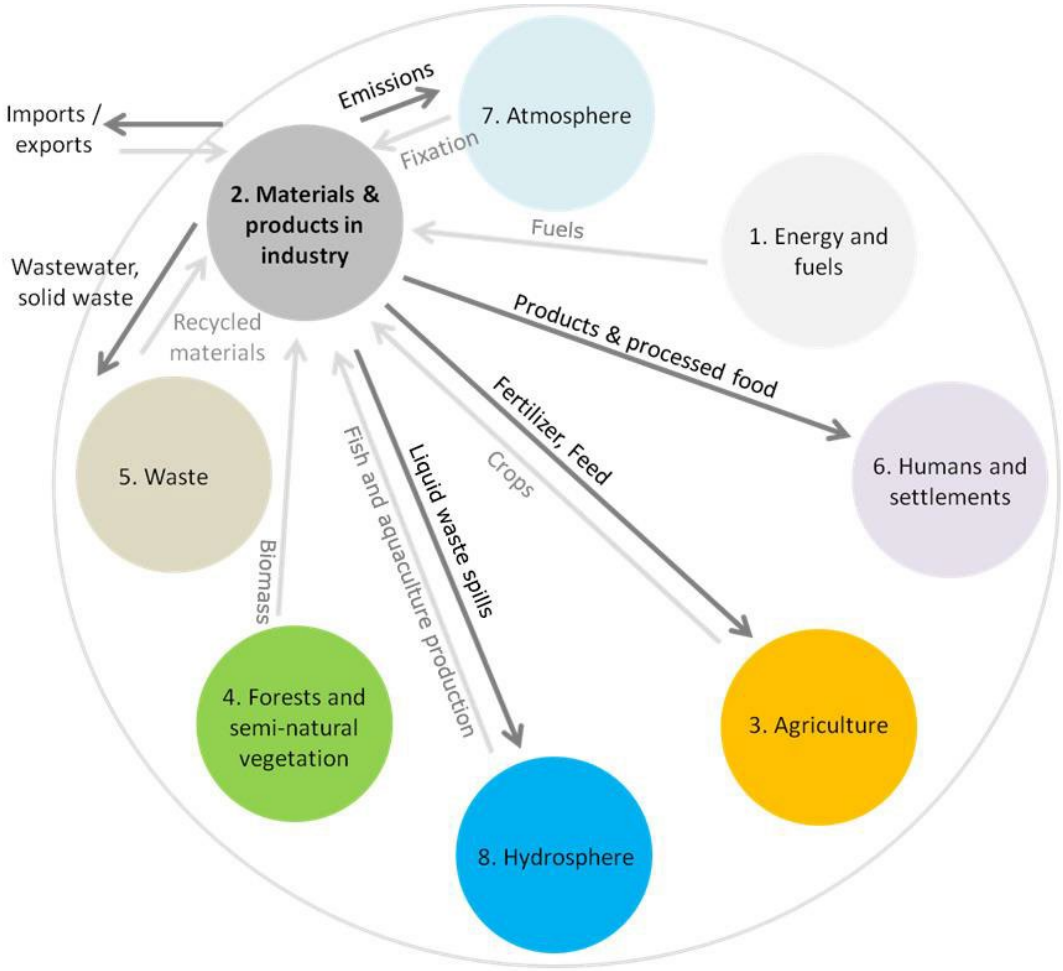

Figure 1. Nitrogen flows between the Materials and products in industry and the other pools of the National Nitrogen Budget (including the pool "Rest of the world"). Light grey arrows represent nitrogen flows entering the Materials and products in industry from the other pools; dark grey arrows show nitrogen flows from the Materials and products in industry to the other pools. *(Source: http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20210302_public.pdf)*

2 Methodology

The EPNB methodology divides the Materials and product in industry pool into three types of industry: sub pools food and feed industry, chemical industry, and other industry. In this report we focus primarily on the exchanges of Nr that occur between the Materials and products pool and other pools in the Swedish NNB (Figure 2). The subdivision between the three sub-pools is to an extent less important and we do not aim to disentangle the internal flows between the different industry sub pools within the Materials and products in industry in any great detail.

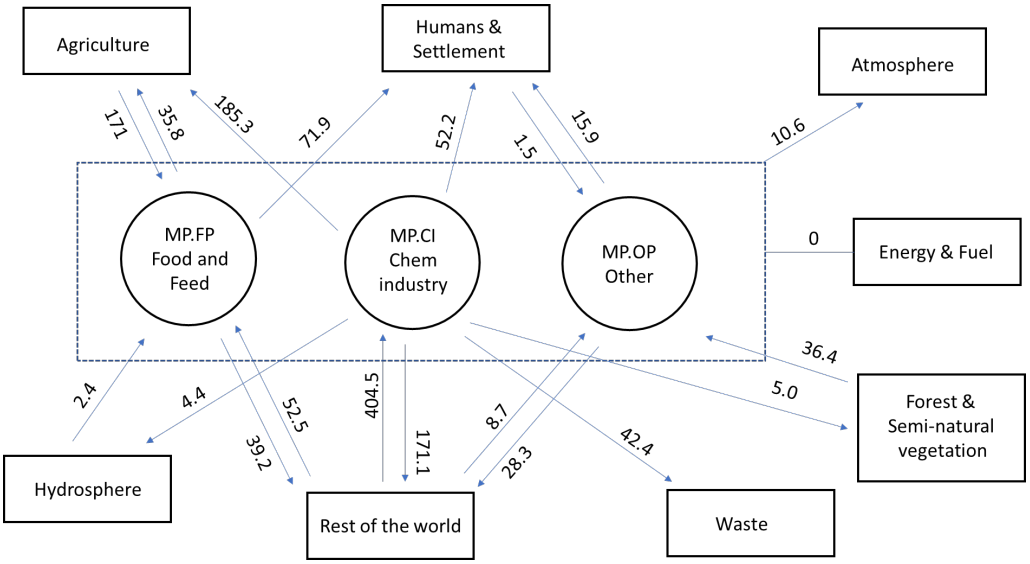

Figure 2. Flows of nitrogen between the Materials and product in industry pool and the other pools in the Swedish national nitrogen budget, in kilotonnes (kt) N.

Data source for chemicals in industry

The Swedish Chemicals Agency (KEMI) is an authority under the Government that supervise that companies comply with the rules for chemical products, pesticides, and chemicals in goods. KEMI uses the Products Register to store information on e.g. chemical products that are manufactured in Sweden, or transferred or imported into the country. If a company manufactures or imports chemical products into Sweden that are among the Notifiable chemical products registered in the list of customs numbers (Tullnummerlistan) then they must report to KEMI.

The rules also apply to those who package, repackage, or change the name of chemical products in Sweden. Apart from the products on the Tullnummerlistan, companies must also report if the annual volume per product manufactured or imported is at least 100 kg.

KemI-stat is a tool for compiling statistical information based on the data in the Products Register and Pesticides Register of KEMI available at: https://apps.kemi.se/kemistat/.

The total reported amounts for ca 50 N-containing substances were extracted from KemI-stat for the year 2015 (note that this includes the amounts of these substances in products, e.g. fertilizers). Table 1 shows the substances with the highest amount of N (per weight).

Table 1. The major substances containing N (in weight) extracted from KemI-stat for year 2015, (includes both production and import, potentially double counted).

Substance	Weight (kt)	Nomenclature	N content	kt N
Ammonium nitrate	1057	NH4NO3	0.35	369.7
Ammonia	173	NH3	0.82	142.1
Urea	159	CH4N2O	0.47	74.2
Formaldehyde urea polymer	49	(CH4N2O.CH2O)x	0.31	15.1
Ethylenediamine	30	C2H8N2	0.47	14.2
Calcium nitrate	52	Ca(NO3)2	0.24	12.6
Ammonium hydroxide	24	NH5OH	0.39	9.3
Formaldehyde-melamine-urea polymer	16	(C3H6N6.CH4N2O.CH2O)x	0.52	8.3
Ammonium sulfate	38	(NH4)2SO4	0.21	8.1
Hexamethylene diisocyanate polymer	22	(C8H12N2O2)x	0.17	3.7
Nitric acid	17	HNO3	0.22	3.7
Diethylenetriamine	7	C4H13N3	0.41	2.9
Ammonium chloride	11	NH4Cl	0.26	2.8
Rest				30
(Nitrogen	*1493*	*N2*		*1493)*
			SUM:	697 *(2190)*

Included in KemI-stat is also, for most of the substances, a breakdown of the products the substances are included in and in what sector the substances/products are used. Examples of the sectors are agriculture, retail trade and different

industries (chemical-, metal-, paper-, plastics- etc.). Important flows for the NNB are the flows to the Agriculture pool (AG), Humans and settlements (HS), and as an export to the rest of the world (RW), or flow as N_2 to the atmosphere (RW). KEMI also produces flow analysis for selected chemical substances, where the specific import, export, and production numbers are shown.

Although N_2 is by far the largest post in Table 1, it is inert and therefore not considered in the NNBs. N_2 is used as inhibitor (inert) gas, purging agent, in welding products, and in fire extinguishing agents. However, N_2 can be converted into Nr in industrial N fixation through the Haber-Bosch process. After N_2, the largest posts in Table 1 are ammonium nitrate, ammonia, and urea, both for weight of substances as well as total amount of N contained.

3 Results

3.1 Energy and fuels (EF) – Materials and products in industry

This flow constitutes of fuels used as feedstock in industrial processes, that is non-energy use of fuels, such as use of bitumen and asphalt for road paving, lubricating oils in engines etc. The N compounds in these fuels are not considered reactive N and therefore this flow is considered zero in this report.

EF – MP and MP – EF: 0 kt N

3.2 Agriculture (AG) - Materials and products in industry

Part of the raw materials produced in the Agriculture pool is refined within the food industry and then sold to either the domestic market (HS) or exported to foreign markets (RW). The Nr flows for the Swedish NNB Agriculture-pool is described in Stadmark et al. (2019). In that report, the outflow of Nr from the Agriculture-pool to the other pools were however not specified individually but reported as sums. There are flows of 135 kt N from Soil management in AG and 35

kt N from Animal husbandry in AG to MP, HS and RW. In Stadmark et al. (2019) the flow from animal husbandry consisted of milk (16 kt N), eggs (2.5 kt N) and meat (16.5 kt N). These flows can be considered to go into MP and then continue to HS. The numbers are similar, but not identical, to the numbers used in the food calculations in the MP to HS flow.

AG – MP/HS/RW: Agricultural raw materials 171 kt N

In this report we have used fodder statistics (Foderstatistik – 2015, Swedish Board of Agriculture) and the Products Register from KEMI (the Swedish Chemicals Agency) to estimate feed and fertilizer/chemical flows from MP to AG.

Feed to agricultural animals was quantified in Agriculture (Stadmark et al. 2019). Imported feed to cattle, pig, poultry, horses and other contained 22.4 kt N and feed manufactured in Sweden (domestic compound feed; soy or other (oil seed) cakes mm., energy-rich feedstuff e.g. starch etc. from domestic production) contained 37.0 kt N. Horses should not be part of Agriculture and in this report the imported Nr in feed to cattle, pig, poultry and other are therefore estimated to 22.3 and the manufactured to 35.8 kt N (Foderstatistik – 2015, Swedish Board of Agriculture). The category *other* also includes feed to animals such as rabbits, goats, sheep, rodents, and reindeers, that partly belong to NNB sub-pools FS and HS, but the overall amounts are low in comparison to cattle, pigs, and poultry.

Summarizing the N content of the products/substances from chemical industry to the agriculture sector for each of the substances in Table 1, the flow from MP to AG is 185.3 kt N, most of which is fertilizer.

MP – AG: 35.8 kt N feed + 185.3 kt N fertilizer and other chemicals = 221.1 kt N

3.3 Forests and Semi-natural vegetation Forest (FS.FO) – Materials and products in industry

Approximately 58% of Sweden is covered with forest and the production of pulp and paper products is one of Sweden's biggest industry sectors. Sweden is also a large producer of wood for manufacturing and building industry. The N-budget for the Forest and-seminatural vegetation which includes biomass harvest and flow from the forest to other parts of the Swedish NNB is described in detail in the

report “Swedish National Nitrogen Budget - Forest and semi-natural vegetation” (Jutterström et al., 2020). For 2015, the net removal of biomass in the Swedish forest was 74.3 million m^3 under bark (89.1 million m^3 over bark) resulting in an outflow of N of 58,5 kt N.

The removals are divided into three main flows: fuel wood for domestic use, industrial roundwood for domestic use, and export of industrial round wood and fuel wood. Fuel wood for domestic use was set as a flow between FS.FO and HS and export of industrial round wood and fuel wood was set as a flow between FS.FO and RW. Industrial roundwood for domestic use was set as a flow from FS.FO to MP.OP and was calculated to be:

FS.FO – MP: 36.4 kt N

Industrial roundwood can be further divided into the following categories: sawlogs and veneer logs, pulpwood and other industrial roundwood. This, however, was not done in the FS-report where only the total amount from industrial roundwood was considered. For this report data was collected from the EUROSTAT database under Forestry: Timber removals, wood products and trade, focusing on basic and primary products such as wood chips particles and residues, sawlogs and veneer logs, pulpwood, sawnwood, wood-based panels, wood pulp, and paper and paperboard. For these categories data on production, export, and import (in m^3 or t) for Sweden for year 2015 was extracted. To estimate the N-amount (Table 2), the same density and N content factor (1.2 kg/t) was used as in FS.FO calculations for stem wood. Non-wood products can be included in the data from the database, such as woodfree paper and pulp from other fibres. These posts have been removed from the calculations.

Table 2. Nitrogen content of the production, export and import of basic and primary wood and wood products.

	Basic and primary wood and wood products		
	Production (kt N)	Export (kt N)	Import (kt N)
Round wood	*	**	4.8
Wood chips, particles and residues	N/A	0.2	0.9
Sawnwood incl. Sleepers	9.8	6.9	0.2
Wood-based panels	0.4	0.1	0.6
Wood pulp	13.9	4.2	0.5
Paper and paperboard	12.3	11.8	1
Recovered paper	1.5	0.6	0.7
sum	37.9	23.8	8.7

*round wood from FS:FO and from RW (import) is raw material for all other product categories in the table

** export of round wood is a direct flow of N from FS:FO to RW

MP – RW: 23.8 kt N

RW – MP: 8.7 kt N

At present the N-flow associated with recovered paper production is small (1.5 kt N), as is the export (0.56 kt N) and import (0.73 kt N), however it might be larger in the future. The flow of Nr of recovered paper is set from HS to MP.OP without passing WS:

HS – MP: 1.5 kt N

Data of import and export of secondary wood products reported in the EUROSTAT database were reported in currency (EUR or SEK) and thus in need to be converted mass of products and to Nr flow using N-content. Secondary wood products include for example further processed sawn wood, wooden wrapping and packaging material, wooden furniture, and prefabricated buildings. The UN Comtrade Database[3] also include wood and wood products and in many cases also report the trade in weight. While many descriptions of the groups of goods are very similar and, in some cases, the same in the Eurostat and the UN Comtrade databases, some categories in the UN Comtrade database were difficult to assign to the Eurostat

[3] https://comtradeplus.un.org/

division in primary and secondary products. The categories including wooden furniture, books, casks packing cases etc (EN categories 4414-4421, 4901-4911, 940330-940360) amount to an export of 1.2 kt N. For paper and paper products the Nr flow is calculated using a N content of 0.2 %. For more solid wood products, the N content for stem wood was used (1.2 kg/t).

The sum of the 2015 export of wooden products for Sweden extracted from the UN Comtrade database was 4.2 kt N (including books etc mentioned above). Some categories did not contain data such as prefabricated houses from wood etc. and some of the flows supposed to be from primary sources but should be included in secondary products could be missing.

Export of secondary wood products:

MP – RW: 4.5 kt N

Forest fertilization is an input of N to the forest which for 2015 was calculated to 5.0 kt N and in the FS-report was set as a flow from MP to FS.FO. As Sweden is a net importer of fertilizers it could be argued that the flow should be partly, or in full, from RW to FS.FO. However, to remain consistent with the FS-report, the flow is set as MP to FS.FO.

MP – FS.FO: 5.0 kt N

Import of secondary wood products are assumed to go directly to HS (RW – HS: 6.2 kt N).

The inputs of wood products from FS:FO and from RW (import) to MP exceeds outputs with 18.3 kt N. A part of this, 2.4 kt N, is estimated ending up as waste (see section 3.4). The remainder we have set as a flow from MP to HS (**MP – HS: 15.9 kt N).** For details see below.

3.4 Waste (WS) - Materials and products in industry

The industry sector in Sweden produces approximately 3,7 million ton of waste (Avfall Sverige, 2020), if the waste from mining industry (mostly rock and sand with near zero N content) is excluded. The waste statistics in Sweden are divided into several categories. Waste categories from MP to WS includes e.g. animal waste and mixed food waste; chemical residues; solvent waste; waste oils; wastepaper and paperboard; plastic waste; medical waste and biological waste; acidic, alkaline or saline waste; wood waste; vegetable waste; animal feces, animal urine and manure; industrial effluent sludges; and mixed and undifferentiated materials. The categories are broad and could contain a range of chemicals/materials with different nitrogen content. The nitrogen content set varies between 0.1% (e.g. metallic waste) and 2.7% (animal feces, animal urine and manure).

Based on these sources and numbers the total flow from MP to Waste (WS) is 42.4 kt N.

MP – WS: 42.4 kt N

The largest Nr-flow from MP to WS in a single category is mixed and undifferentiated materials (9.1 kt N). For the categories: chemical residues, solvents, and acidic, alkaline, or saline waste, plastic waste, and rubber waste, the flow of Nr from MP to WS is 9.8 kt N. For the categories wastepaper and paperboard, and wood, the flow of Nr from MP to WS is 2.4 kt N.

3.5 Humans and settlements (HS) - Materials and products in industry

The destination for most industrial production of food is to the consumers on either the domestic market (flow to HS) or exported to other markets (flow to RW).

The statistics on the amount of food processed in Sweden is scarce, however the consumption, as well as import and export are well defined. Consumption statistics were collected from Sveriges officiella statistik, Statistiska meddelanden JO 44 SM 1701 – Livsmedelskonsumtion och näringsinnehåll. Data for food export from Sweden and import to Sweden were collected from the UN Comtrade Database.

In this report we estimate domestic production by available data on export, consumption, and import (production = export + consumption – import) for year 2015. The nitrogen contents (%) used per food category were collected from two sources. For milk and cream, bread, meat and cheese they were taken from Livsmedelsdatabasen[4] from Swedish Food Agency, and for the other categories from NNB Annex 6, Table 12. In the calculations some of the categories found in the Swedish statistics have been generalized to match the categories in Annex 6 Table 12, for example vegetable products such as veggie burgers and similar have been calculated as vegetables. The reason for the two sources of information was that there were large differences between the Swedish N content estimates (Swedish Food Agency) and NNB Annex 6 on the order of 0.6 to 2.8 times for the largest flows (milk and cream, bread, meat and cheese).

Human consumption of food in Sweden (Swedish Board of Agriculture/Swedish Food Agency) contained 65.3 kt N. The largest flows of Nr in food produced are from the categories meat (17.7 kt N), and dairy products (incl. cheese), honey, eggs (13.8 kt N) and flour, bread, pasta (12.5 kt N). In total the estimated production of food amounted to 52.2 kt N (Export + Consumption) - Import, Table 3).

Table 3. Nitrogen content of exported, consumed, imported and produced food in 2015 (kt N).

	Export	Consumption	Import	Production
Meat	4.9	23.1	10.3	17.7
Fish	24.7	4.1	24	4.8
Dairy products, honey, eggs	1.9	15.6	3.6	13.8
Vegetables, root vegetables, potatoes	0.4	3.4	2.4	1.4
Fruit and nuts	0.2	2	2.1	0.1
Coffee, tea and spices	0.4	1.6	1.9	0.1
Flour, bread, pasta	5	12.8	5.3	12.5
Sugar, candy, cacao, chocolate	1.3	1.6	1.9	1
Miscellaneous edible preparation	0.5	1	0.8	0.7
Total	**39.2**	**65.3**	**52.2**	**52.2**

The consumption statistics these calculations were based on did not include food waste in supermarkets. The total food production MP-HS was calculated in Ljunggren et al. (2025) to 52.6 kt. Since 2.5 kt N fish were set as a flow from HY to

[4] https://www.livsmedelsverket.se/livsmedel-och-innehall/naringsamne/livsmedelsdatabasen

HS (Stadmark et al., 2020) the flow from MP – HS of produced food is 50.1 kt N. In addition to the production, the net import of food and food products is also a flow from MP to HS of 13 kt N.

MP – HS: food and food products 50.1+13=63.1 kt N

Fodder for dogs, cats and horses needs to contain 25.8 kt N based on protein intake and the population of pets and horses in Sweden. 6.4 kt N is imported feed for pets and horses (Ljunggren et al., 2024). On farm fodder production for horses was estimated to 10.6 kt N based on data from Stadmark et al. (2019), assuming that 39% of the feed for agricultural animals came from fodder and 61% from grazing. The combined fodder production should amount up to 25.8 kt N of which 8.8 kt N were not identified in imported fodder or fodder form on farm production. We assume that "these missing" 8.8 kt N passes through MP.

MP – HS: fodder for pets and horses 8.8 kt N

From the 37.9 kt N in the production of basic and primary wood products, 28.3 kt N is exported in basic, primary (23.8 kt N, Table 2) and secondary products (4.5 kt N). This leaves 9.6 kt N in the MP-pool from production and adding the import of basic and primary wood and wood products (8.7 kt N, Table 2) there is **18.3 kt N** still in MP. After removing the flow from MP to waste of wood products estimated in section 3.4 (2.4 kt N), the remainder is set as a flow from MP to HS:

MP – HS: wood products 15.9 kt N

Chemical industry

Our assumption is that after removing the flows to the AG (mainly fertilizers), FS (forest fertilization), Waste and RW (export and emissions of N2) pools, the remainder of the chemicals in the MP-pool will eventually end up in consumer goods. The remainder of the chemicals in the MP-pool is however not straightforward to estimate. There is a substantial risk of double counting as many of the chemicals can be used to synthesize other chemicals and materials also listed in KemI-stat and separate import and production numbers are not available for many of them, nor are flow analysis charts. The only way to avoid all risks for double counting would be to only include the chemicals that had reasonably good import data. Many however have not, and an additional problem is that there are many compounds that have been aggregated which creates large uncertainties when calculating the N-content. To estimate the remainder, we have focused

mainly on the three chemicals with the largest N-amount (Table 1) i.e. ammonia, urea, and ammonium nitrate. According to the Products register all three chemicals also have a substantial amount listed as a raw material for synthesis without any other description. All three have import estimates for 2015 (see next section).

For ammonia one could reasonably assume that there is some domestic production (according also to the KEMI flow analysis) so we will use the number in Table 1 as an estimate of the import +domestic production and although there is a risk for some double counting. However, as the import number is so large (122.9 out of the total 142.1 kt N) the overall effect of that should be small.

In the flow analysis for urea for 2017 from KEMI, it is listed that urea is not produced in Sweden. Therefore, there is little risk of double counting urea and that also removes the risk of double counting ammonia and urea.

For ammonium nitrate, the import estimate is the most uncertain of the three. There are also no production estimates in the flow analysis available. As ammonium nitrate can be synthesized from ammonia together with nitric acid, we have chosen to not include the total listed in KemI-stat, to avoid possible double counting with ammonia.

For the other chemical species in Table 1 we are likely underestimating the remaining pool as we don't have reliable import numbers.

The flows from MP to AG, FS, WS and RW sums up to 371.2 kt N and the import and domestic production is estimated to be 423.4 kt N. This would give a flow to HS of 52.2 kt N for products such as plastics, deicing agents, glue, paint, tensides, etc.

MP – HS: chemicals 52.2 kt N

3.6 Rest of the World (RW) - Materials and products in industry

There are two pathways in which Nr is transferred between MP and RW. The first one is export and import of products containing Nr to and from outside Sweden. Secondly it is transformations between Nr and non-reactive form (N_2) in which Nr is either removed from the MP and converted to N_2, or N_2 is fixed to Nr form by industrial N fixation (such as Haber-Bosch process). The N_2 gas physically leaves

or enters the pool of N_2 in the atmosphere but does not count as a flow of Nr to and from the Atmosphere pool as it is not in reactive form. As such these flows are considered flows between MP and RW. By far the biggest Nr flow is the import of chemicals, followed by import of food and export of chemicals and food.

The amount of N_2 converted to a reactive form is small relative to the 1493 kt N imported as N_2. In 2015 **2.5 kt N** from N_2 was listed as a source of N used in fertilizers in Sweden.

KemI-stat lists the total amount (sum of import and production) of the substances, as a raw material and in products. KEMI also produces flow analysis for selected chemical substances, where the specific import, export, and production numbers are shown. Some of the posts in the flow chart might be omitted e.g. due to confidentiality reasons. Unfortunately, of the flow analysis available for the substances in Table 1, there were none from year 2015. For import and export, some chemicals and fertilizers are available through the UN Comtrade database.

The import for the largest posts in Table 1 (ammonium nitrate, ammonia, and urea) have been quantified using the available information from the flow analyses and import data from the UN Comtrade database. N_2 is excluded as there are no flow analyses available, as well as being inert and would not be included in the Nr flow in and out of Sweden.

For ammonia, the largest amount is imported as raw material according to the flow analysis for year 2013. Only a small part is produced in Sweden and imported in products (in total less than 8%). For 2015 the UN Comtrade database reports a Swedish import of ammonia; anhydrous or in aqueous solution of 149.4 kt, which corresponds to 122.9 kt N. That seems reasonable when comparing to the total amount (production plus import in both raw material and products from Table 1). Using 122.9 kt N as an estimate for import is likely a small underestimate as the amount of ammonia in products is not included.

For urea, the flow analysis from KEMI for year 2017 states that there is no production of urea in Sweden, we assume that this is also the case for 2015 and set the import to 159 kt, which is 74.2 kt N.

For ammonium nitrate there is a flow analysis from 2010, however it does not include Swedish production or export of the raw material. Looking at the import, most of the ammonium nitrate is imported as fertilizer and second largest is in explosives. Less than 10 % of the import is in raw material in 2010. The total pool of

ammonium nitrate in 2010 is 965 kt, with an import of 534 kt, net production for 2010 is about 431 kt (assuming no double counting). Assuming that the proportions are roughly similar in 2015, this would give an import of 205 kt N.

RW – MP: import chemicals 2.5 + 122.9 + 74.2 + 205 = 404.5 kt N

The export of these substances (Table 1), either as raw material or in products is 96.5 kt N. Although the UN Comtrade database also lists the export of several chemicals, these numbers have not been used here as the KemI-stat data also includes products which contains the chemicals.

The chemicals can be used to produce explosives and as reducing agents, products that when used most of the reactive N will be converted to inert N_2. If we assume that the explosives made are either used within Sweden or exported, N will end up in the rest of the world regardless. We estimate that 1% of the N in explosives will turn into NOx instead of N_2 and create a small flow to the Atmosphere pool (AT) of 0.4 kt N. Mainly urea but also ammonium hydroxide and, to a small extent, ammonium sulphate are all used to produce reducing agents. Urea is the preferred reducing agent in SCR (Selective Catalytic Reduction) applications used to reduce the emissions of NOx. 33.3 kt N was used in the production of reducing agents in 2015 (urea 25.8 kt N, ammonium hydroxide 7.0 kt N and ammonium sulphate 0.5 kt N).

MP – RW: export chemicals and conversion to N_2 96.5 + 41.3 + 33.3 = 171.1 kt N

In 2015 the import of food contained 52.2 kt N and the export 39.2 kt N. It is unclear what fraction of imported food goes directly to the consumption and what goes to Swedish food industry for further processing. We assume that the flow which goes directly to human consumption is larger than the flow which goes via Swedish food industry and therefore decided to have the 52.2 kt N to account as RW – HS, without passing MP.

RW – MP: import food 52.5 kt N

MP – RW: export food 39.2 kt N

The flows of wood products are dominated by raw material originating from Sweden's 23 Mha of productive forests. There is, however, also some import of wood and wood products, and there is an export, both of which were discussed under the chapter Forests and Semi-natural vegetation – Materials and products in

industry. These flows were quantified as MP – RW: 23.8 kt N and RW – MP: 8.7 kt N.

3.7 Atmosphere (AT) – Materials and Products in industry

The emissions of NH_3 and NO_x to the atmosphere were those reported to the Centre on Emission Inventories and Projections (CEIP) under the Air convention (The Convention on Long-range Transboundary Air Pollution, CLRTAP) in categories B_Industry (10.5 kt N), and D_Fugitive + E_Solvents (together 0.1 kt N) as reported in the NNB Atmosphere (Moldan et al., 2022). The emissions are dominated by NO_x, NH_3 contributes by about 20% of the total of 10.6 kt N/yr.

MP – AT: 10.6 kt N

3.8 Hydrosphere (HY) – Materials and products in industry

Swedish commercial fishermen harvested fish for feed containing 2.4 kt of N (divided between 0.4 kt N landed in Sweden and 2.0 kt N landed abroad) in 2015, based on the calculations in Swedish nitrogen budget for Hydrosphere pool (Stadmark et al., 2020). This nitrogen will pass through the feed industry and end up in the Agriculture pool as animal feed, in Humans and settlements as pet food or as an export of animal feed to RW.

Fish for human consumption (2.2 kt N) is in Hydrosphere transferred directly to HS. However, Sweden is exporting processed fish such as fish fingers and similar products and, depending on where the fish for this industry comes from, parts of this amount could be directed to MP:

Wastewater from industries contained 4.4 kt of N in 2014 (Ejhed et al., 2016) (PLC6), 2.4 kt of N were emitted to the inland waters and 2.0 kt directly to the coastal waters.

MP – HY: 4.4 kt N

HY – MP: 2.4 kt N

4 Conclusions

Materials and Products in industry is a large pool in the Swedish national nitrogen budget, relative to the 7 other pools defined in the TFRN methodology (Figure 1). For comparison, the total annual inputs of Nr to MP are more than twice as large as inputs to Agriculture or to Atmosphere. It is because chemicals and raw materials to produce food all are passing through this pool.

The largest input of Nr to Materials and Products is from production and import, primarily of chemicals, followed by input of Nr from crops, meat and fish. The largest output is through products to the domestic market (such as chemicals including fertilizers, plastics, and wood products, food or fodder), followed by export of chemicals, food and wood (Figure 3). The total inputs of Nr to the MP pool were 696 kt N and outflows were 662 kt N. This balance between inputs and outputs is to some extent due to our assumption the Nr from imported or produced chemicals is not accumulating in the MP pool. Therefore, the input of Nr from import or production of chemicals that we were not able to attribute to MP, AG, FS, WS or to RW was assumed to end up in products for human consumption, that is in the HS pool.

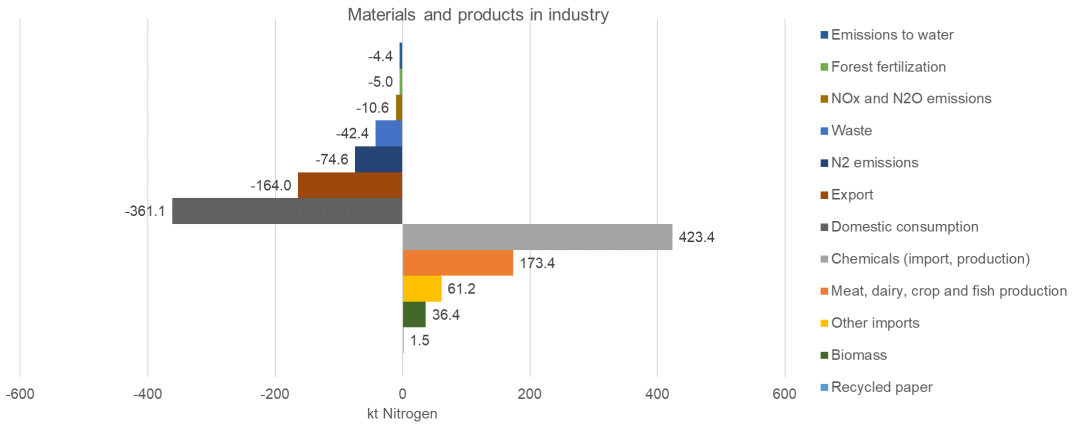

Figure 3. The flows related to the Materials and Product in the industry pool in the Swedish national nitrogen budget, year 2015, outflows to the left, inputs to the right, in kt N/yr.

The inflows (696 kt N) were nearly balanced by the outflows (662 kt N). The import/export and production of chemicals are fairly well documented, albeit with restrictions for certain chemicals. The majority of Nr flow is used in the agricultural sector as fertilizers, as explosives, and as reduction agents, all products which

could be to an extent tracked. But tracking all N containing products, even those with small volumes is much more challenging. The remainder of chemicals which we assumed were used in other products, was however only ca 13 % of the Nr flow in chemicals.

The three most important sources of data were Statistics Sweden (SCB), The Swedish Board of Agriculture (Jordbruksverket) and Swedish Chemicals Agency (Kemikalieinspektionen). Data on some chemicals were seen as industrial secrets or as non-public data.

Acknowledgements

This study was conducted within the Swedish EPA (Naturvårdsverket) project "Nationell kvävebudget, expertstöd och FU för miljömålet Bara naturlig försurning", grant nr 252-21-005. The provided support is gratefully acknowledged. We thank to Swedish EPA officials involved in the work of CLRTAP in general and in this project in particular Anna Engleryd and Petra Hagström. We would also like to thank colleagues at UNECE CLRTAP TFRN Expert Panel on Nitrogen Budget for comprehensive guidelines for constructing NNB.

5 Reference list

Ejhed, H. W.-N. (2016). *Näringsbelastning på Östersjön och Västerhavet 2014. Sveriges underlag till Helcoms sjätte Pollution Load Compilation, Havs- och vattenmyndighetens rapport 2016:12, ISBN 978-91-87967-21-4.* Göteborg: Havs- och Vattenmyndigheten.

Eurostat. (2010). *Guidance on classification of waste according to EWC-Stat categories, Supplement to the Manual for the Implementation of the Regulation (EC) No 2150/2002 on Waste Statistics.*

Forest statistics 2020, Official Statistics of Sweden Swedish University of Agricultural Sciences, Umeå 2020, https://www.slu.se/globalassets/ew/org/centrb/rt/dokument/skogsdata/skogsdata_2020_webb.pdf

Jutterström, S., Stadmark, J., Moldan, F. (2020). *Swedish National Nitrogen Budget - Forest and semi-natural vegetation, IVL report C 549, ISBN 978-91-7883-213-2.* Stockholm: IVL Swedish Environmental Research Institute Ltd.

Ljunggren, J., Stadmark, J., Jutterström, S., Moldan, F. (2025). *Swedish National Nitrogen Budget - Humans and settlements, IVL report C 888, ISBN 978-91-7883-656-7.* Stockholm: IVL Swedish Environmental Research Institute Ltd.

LKAB Kimit AB, Elias Viippola. (2021). *Miljörapport LKAB Kimit AB 2021.* Kuruna: LKAB Kimit AB.

Stadmark, J., Moldan, F., Jutterstöm, S. (2019). *Nitrogen budget – Agriculture Sweden. IVL report C437. ISBN 978-91-7883-102-9.* Stockholm: IVL Swedish Environmental Research Institute Ltd.

Stadmark, J., Jutterström, S., Moldan, F. (2020). *Swedish National Nitrogen Budget - Hydrosphere, IVL report C 548. ISBN 978-91-7883-212-5.* Stockholm: IVL Swedish Environmental Research Institute Ltd.

Statistiska centralbyrån. (2019). Statistikdatabasen.

UBA. (2020). *Reactive nitrogen flows in Germany 2010 - 2014 (DESTINO Report 2). Umweltbundesamt (UBA), Forschungskennzahl 3716 51 200 0.* Dessau-Rosslau.

STOCKHOLM
Box 21060, 100 31 Stockholm

GOTHENBURG
Box 53021, 400 14 Gothenburg

MALMÖ
Nordenskiöldsgatan 24
211 19 Malmö

KRISTINEBERG
(Center for Marine Research and Innovation)
Kristineberg 566
451 78 Fiskebäckskil

SKELLEFTEÅ
Kanalgatan 59
931 32 Skellefteå

BEJING, CHINA
Room 612A
InterChina Commercial Building No.33
Dengshikou Dajie
Dongcheng District
Beijing 100006
China

This report has been reviewed and approved in accordance with IVL's audit and approval management system.