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Swedish National Nitrogen Budget – Energy and fuels

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Summary

This report presents pool 1 “Energy and fuels” (EF) in the Swedish national nitrogen budget (NNB). The EF pool is divided into four sub-pools; Energy conversion (EC), Manufacturing industries and construction (IC), Transport (TR) and Other energy and fuels (OE).

The Swedish data presented in this report are for 2015 whenever possible. If data were not available for 2015, available information for the year closest to 2015 have been used. The data were collected from Swedish official statistics and reports and preferably from sources that will continue to be updated, to make it easier to evaluate possible changes in N budgets in the future.

Emissions of reactive nitrogen (Nr) to the atmosphere via various combustion processes have been quantified as they have been reported to international conventions (CLRTAP and UNFCCC) broken down by the codes used in those reports.

The largest emissions of Nr occur from transport (24.1 kt), followed by manufacturing and construction (6.7 kt), other energy and fuels (4.9 kt) and energy conversion (4.8 kt). The majority of reactive nitrogen emissions from this sector (> 90 percent) consists of NO_x, and otherwise of N_2O and NH_3.

The import of primarily crude oil and of other oil-based fuels means a flow of N from the rest of the world to Sweden (53.5 kt). A fraction of this amount is converted to reactive forms and emitted to the atmosphere during combustion. The main part of the NO_x that is emitted from fuel combustion is, however, formed when nitrogen in the air is oxidized during the combustion (thermal production of NO_x) and does not originate from the N in the fuel. Remaining N in the crude oil and oil products is either removed from the fuel during cracking in refineries or converted to N_2 during combustion. Development of combustion processes where NO_x is not formed leads to lower emissions.

Biofuels such as ethanol and biodiesel are produced from e.g. wheat and rapeseed. A large part of the nitrogen present in these crops will remain in the residual products after fuel production and can be used for animal feed. They do not result in any emissions of reactive nitrogen in this national nitrogen budget.

The national nitrogen budgets do not include international transport (shipping, aviation), so additional emissions of reactive nitrogen will need to be added if a global aggregation is to be made.

Sammanfattning

I denna rapport presenteras pool 1 ”Energy and fuels” (EF) i den svenska nationella kvävebudgeten (NNB). EF-poolen är indelad i fyra sub-pooler; Energiomvandling (Energy conversion, EC), Tillverkningsindustri och byggande (Manufacturing industries and construction, IC), Transport (TR) and Annan energi och andra bränslen (Other energy and fuels, OE).

De svenska data som presenteras i denna rapport är för år 2015 när så är möjligt. Om data inte fanns tillgängliga för 2015 valdes tillgänglig information för året närmast 2015. Uppgifterna samlades in från svensk officiell statistik och rapporter och företrädesvis från källor som kommer att fortsätta uppdateras, detta för att göra det lättare att utvärdera möjliga förändringar i N-budgetar i framtiden.

Flöden av reaktivt kväve (Nr) till atmosfären via olika förbränningsprocesser har kvantifierats så som de har rapporterats till internationella konventioner (CLRTAP och UNFCCC), uppdelat på de koder som används vid de rapporteringarna.

Störst utsläpp av Nr sker från transporter (24.1 kt), följt av tillverkningsindustri och byggande (6.7 kt), annan energi och andra bränslen (4.9 kt) och energiomvandling (4.8 kt). Den allra största delen av det reaktiva kvävet i den här sektorn (>90 procent) utgörs av NO_x, och i övrigt av N_2O och NH_3.

Importen av framför allt råolja, men även andra oljebaserade bränslen, innebär ett flöde av N från omvärlden till Sverige (53.5 kt). En del av denna mängd omvandlas till reaktiva former och släpps ut till atmosfären under förbränning. Huvuddelen av det NO_x som avges bildas då luftens kväve oxideras vid förbränning (termisk produktion av NO_x) och härrör inte från kvävet i bränslet. Kvarvarande kväve i råoljan och oljeprodukterna avlägsnas antingen från bränslet vid krackning i raffinaderier eller omvandlas till N_2 vid förbränning. Utveckling av förbränningsprocesser där NO_x inte bildas leder till lägre utsläpp.

Biodrivmedel som etanol och biodiesel produceras av t.ex. vete och raps. En stor del av det kväve som finns i dessa grödor kommer att finnas kvar i restprodukterna efter framställningen och kan användas till djurföda. De medför inte några utsläpp av reaktivt kväve i denna nationella kvävebudget.

I de nationella kvävebudgeterna ingår inte internationella transporter (båt, flyg) så ytterligare utsläpp av reaktivt kväve tillkommer om en global sammanläggning ska göras.

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 https://www.unece.org/env/lrtap/executivebody/eb_decision.html.

At the first meeting in 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. This meant, in practice, all N except N_2 gas; for example, nitric oxide, nitrogen dioxide, nitrate (NO_3^-), organic N compounds, nitrous oxide (N_2O), ammonia (NH_3) and ammonium (NH_4^+). 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". 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. The document can be downloaded from http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/ECE_EB.AIR_119_ENG.pdf. After that, the work of EPNB continued to provide detailed guidelines for each of the eight main parts of the National Nitrogen Budget (NNB) summarised in Annexes to the ECE/EB.AIR/119 – "Guidance document on national nitrogen budgets". Currently the version dated 02.03.2021 is available at http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20210302_public.pdf and it summarises seven out of the eight pools. Annex 5 Waste is still under development.

NNB have been constructed for Switzerland (Heldstab et al., 2010 and 2013), Germany (Geupel et al., 2009), Denmark (Hutchings et al., 2014) and for Canada (Clair et al., 2014). These national budget calculations have not followed the EPBN methodology as it was not available at the time but provide information on the most important flows. Bach et al. (UBA, 2020) used the TFRN Guidance document and compiled a NNB for Germany which includes all eight 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, 16% from combustion, and the remaining 10% from biological fixation, import of feed and products. Leip et al. (2011) calculated nitrogen fluxes for EU27 developing and using the same protocol for all countries. The study by Leip et al. (2011) also recommend development of national nitrogen budgets since the assessment and management of the budgets could become an effective tool to prioritise measures and prevent unwanted effects.

NNB following the TFRN methodology are constructed based on eight pools (Figure 1). In this report, pool 1 "Energy and fuels" is presented. Detailed guidelines on constructing the "Energy and fuels" (EF) pool can be found in Annex 1 of the ECE/EB.AIR/119 "Guidance document on national nitrogen budgets" and will hereafter in this report be referred to as Annex 1. As described in Annex 1, the EF-pool is divided into: Energy conversion, Manufacturing industries and construction, Transport and Other energy and fuels.

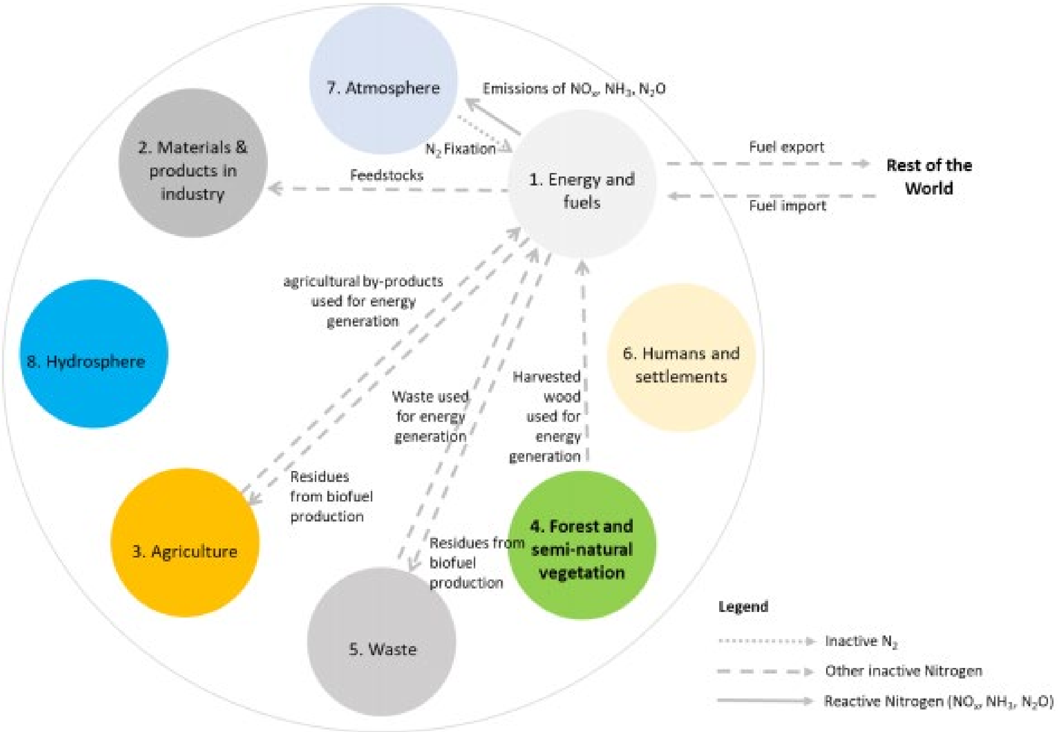

Figure 1 Nitrogen flows between the "Energy and fuels" pool and the other pools of the National Nitrogen Budget (including the pool "Rest of the world", RoW). Solid arrows indicate flows of reactive nitrogen compounds (NO_x, NH_3, N_2O); dotted arrows represent flows of N_2, and dashed arrows indicate flows of other forms of inactive nitrogen (e.g. chemically bound nitrogen in fuels). (Source: http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20210302_public.pdf)

National nitrogen budget (NNB) for Energy and fuels (pool 1)

Identification of flows and data sources

The EF pool consists of four sub-pools: Energy conversion (EC), Manufacturing industries and construction (IC), Transport (TR) and Other energy and fuels (OE), (Figure 2).

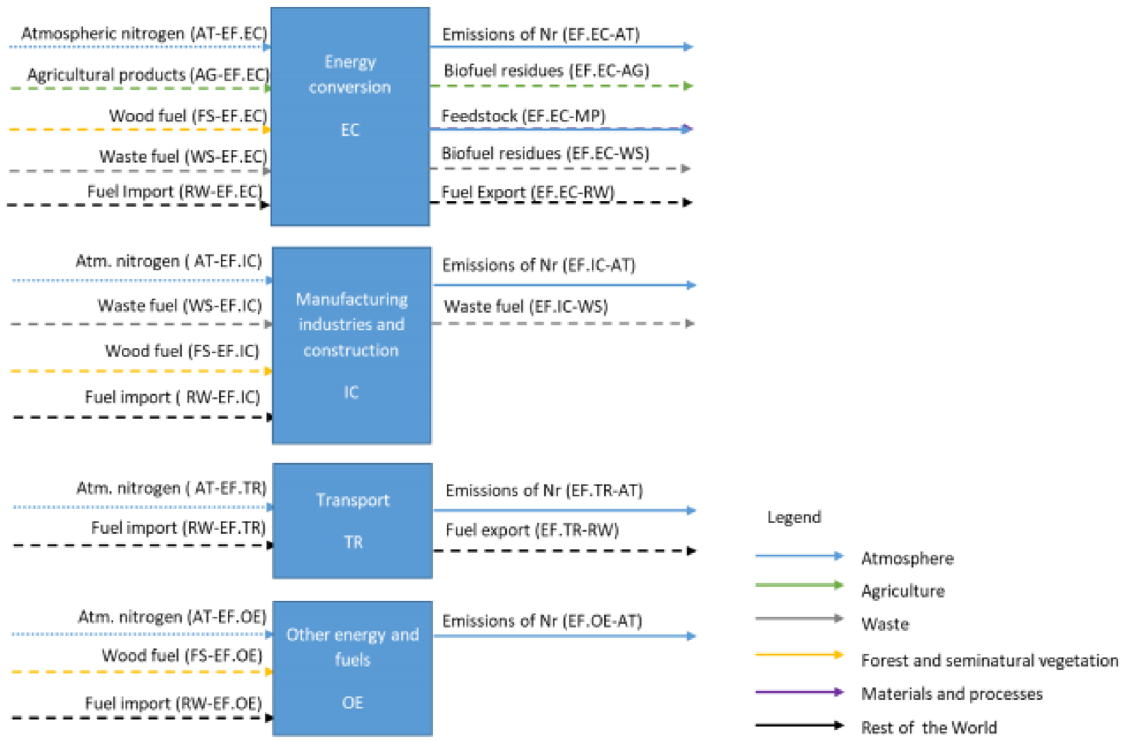

Figure 2 Simplified schematic representation of the sub-pools within the pool ´Energy and fuels´. Solid arrows indicate flows of reactive nitrogen compounds (NO_x, NH_3, N_2O); dotted arrows represent flows of N_2, and dashed arrows indicate flows of other forms of inactive nitrogen. (Source: http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20210302_public.pdf)

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 for air pollutants.

The relevant fuel combustion processes and related emission factors of air pollutants and greenhouse gases are documented in the EMEP/EEA Guidebook (EEA 2013) and in the IPCC 2006 Guidelines (IPCC 2006) 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. (Annex 1)

First, we present the Nr flows from the EF pool to the atmosphere (AT), then (from Table 5), the interactions with other pools in the Swedish national nitrogen budget are discussed.

Energy and fuels – Atmosphere (EF_AT, AT_EF)

All flows of reactive nitrogen between Energy and fuels pool and the atmosphere are from EF to AT. For clarity the sources of the flows are presented divided into the four sub-pools. There is a release of reactive nitrogen species during fuel combustion processes. In this report we have used the Swedish data reported to CLRTAP and UNFCCC for 2015 (data retrieved in 2021). NH_3 and NO_x have been reported according to CLRTAP Inventory Submissions (http://www.ceip.at/status_reporting/) and N_2O according to UNFCCC National Inventory (http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php, https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/emissions/greenhouse-gas-emissions-and-removals/).

A large proportion of the NO_x produced in the combustion process is derived from thermal oxidation of N_2 in the air, and a lower proportion is derived from oxidation of nitrogen compounds in the fuels themselves. UBA (2020) estimated the proportions of NOx from thermal oxidation to be 100% in combustion of gas, diesel and petroleum and 20% in energy generation from coal. There is also N in the residual oil, the proportion of fuel-originated Nr in combustion is roughly 10%. Hybrid fuels (e.g. low sulphur fuel oil) also contain some N. Therefore, we assume that a large proportion, but not all, of the NO_x emitted to the atmosphere in Sweden in 2015 originates from thermal oxidation of N_2 in air.

Sub-pool Energy conversion (EF.EC_AT)

The sub-pool Energy conversion includes N-flows from the generation of electrical power and heat by the combustion of fossil fuels, including for example extraction, production or refining of the fuel. It also includes the production of bioethanol and biodiesel. Power generation in waste incineration plants is considered to belong to the Waste pool as well as biogas plants.

Table 1 Emissons from Sweden reported to CLRTAP for 2015 (kt). NO = not occuring, NA = not applicable and NE = not estimated.

NFR Code	Description	kt N_2O	kt NH_3	kt NOx (as NO_2)
1A1a	Public electricity and heat production	0.810	0.282	11.449
1A1b	Petroleum refining	0.004	0.075	1.033
1A1c	Manufacture of solid fuels and other energy industries	0.000	NE	0.493
1B1a	Fugitive emission from solid fuels: Coal mining and handling	NO	NO	NO
1B1b	Fugitive emission from solid fuels: Solid fuel transformation	NA/NE	0.004	0.000
1B1c	Other fugitive emissions from solid fuels	0.000	NE	0.015
1B2ai	Fugitive emissions oil: Exploration, production, transport	0.000	0.006	0.095
1B2aiv	Fugitive emissions oil: Refining and storage	0.004	0.001	0.040
1B2av	Distribution of oil products	NA	NA	NA
1B2b	Fugitive emissions from natural gas (exploration, production, processing, transmission, storage, distribution and other)	NO	NO	NO
1B2c	Venting and flaring (oil, gas, combined oil and gas)	0.000	0.001	0.038
	Total from EF.EC to AT	**0.82**	**0.37**	**13.16**
	Total from EF.EC to AT (kt N)	**0.52**	**0.30**	**4.01**

The N emissions to the atmosphere from the sub-pool Energy conversion (Table 1) were 4.8 kt in 2015, of which 4.2 kt originated from public electricity and heat production and 0.4 kt from petroleum refining. NO_x was the major (83%) form of Nr emitted to the atmosphere from this sub-pool. 6% was emitted as NH_3 and 11% as N_2O.

EF.EC_AT: 4.8 kt N

Sub-pool Manufacturing industries and construction (EF.IC_AT)

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 (Table 2). Besides stationary combustion, mobile combustion from machinery and vehicles operating on construction sites as well as industrial vehicles are included in this sub-pool (Table 2). Note that potential N flows from the manufacturing industry that do not originate from fuel combustion activities, are reported in the pool 2 Materials and products in industry (Annex 1).

The N emissions to the atmosphere from the sub-pool Manufacturing industries and construction (EF.IC-AT) were 6.7 kt in Sweden in 2015 (Table 2). The largest sources were Mobile combustion in manufacturing industries and construction (1A2gvii), 2.4 kt and Stationary combustion in manufacturing industries and construction: Other (1A2gviii) with 1.6 kt, Pulp, Paper and Print (1A2d) with 1.2 kt and Non-metallic minerals (1A2f) with 0.9 kt. 94 percent of the Nr from this sub-pool was emitted as NO_x.

EF.IC_AT: 6.7 kt N

Table 2 Emissons from Sweden reported to CLRTAP for 2015 (kt). NO = not occuring, NA = not applicable and NE = not estimated.

NFR Code	Description	kt N_2O	kt NH_3	kt NOx (as NO_2)
1A2a	Stationary combustion in manufacturing industries and construction: Iron and steel	0.002	0.011	0.867
1A2b	Stationary combustion in manufacturing industries and construction: Non-ferrous metals	0.000	0.002	0.086
1A2c	Stationary combustion in manufacturing industries and construction: Chemicals	0.009	0.012	0.622
1A2d	Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print	0.256	0.068	3.095
1A2e	Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco	0.007	0.008	0.390
1A2f	Stationary combustion in manufacturing industries and construction: Non-metallic minerals	0.027	0.020	2.846
1A2gvii	Mobile combustion in manufacturing industries and construction (please specify in the IIR)	0.055	0.003	7.910
1A2gviii	Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	0.108	0.037	4.773
	Total from EF.IC to AT	**0.46**	**0.16**	**20.59**
	Total from EF.IC to AT (kt N)	**0.30**	**0.13**	**6.27**

Sub-pool Transport (EF.TR_AT)

This sub-pool covers all fuel combustion activities within the transport sector (Table 3). This includes road and rail transport as well as national shipping and aviation. Pipeline transport is also included in this sub-pool.

Table 3 Emissions from Sweden reported to CLRTAP for 2015 (kt). NO = not occuring, NA = not applicable and NE = not estimated).

NFR Code	Description	kt N_2O	kt NH_3	kt NOx (as NO_2)
1A3ai(i)	International aviation LTO (civil)	0.038	NA	0.620
1A3aii(i)	Domestic aviation LTO (civil)	NA/NE	NE	0.285
1A3bi	Road transport: Passenger cars	0.203	1.904	27.939
1A3bii	Road transport: Light duty vehicles	0.043	0.036	11.186
1A3biii	Road transport: Heavy duty vehicles and buses	0.236	0.050	21.737
1A3biv	Road transport: Mopeds & motorcycles	0.002	0.002	0.216
1A3bv	Road transport: Gasoline evaporation	NA	NA	NA
1A3bvi	Road transport: Automobile tyre and brake wear	NA	NA	NA
1A3bvii	Road transport: Automobile road abrasion	NA	NA	NA
1A3c	Railways	0.000	0.000	0.579
1A3di(ii)	International inland waterways	NO	NO	NO
1A3dii	National navigation (shipping)	0.028	0.016	9.257
1A3ei	Pipeline transport	0.000	0.000	0.001
1A3eii	Other (please specify in the IIR)	0.008	0.000	0.828
	Total from EF.TR to AT	**0.56**	**2.01**	**72.65**
	Total from EF.TR to AT (kt N)	**0.35**	**1.65**	**22.11**

The N emissions to the atmosphere from the sub-pool Transport were 24.1 kt in 2015 (Table 3). The major sources were Road transport: Passenger cars (1A3bi) with 10.2 kt, Heavy duty vehicles and buses (1A3biii) with 6.8 kt, Light duty vehicles with 3.5 kt and National navigation (shipping) with 2.8 kt. 92 percent of the Nr from this sub-pool was emitted as NO_x.

EF.TR-AT: 24.1 kt N

Sub-pool Other energy and fuels (EF.OE_AT)

This sub-pool accounts for all energy combustion activities that are not already covered in one of the other sub-pools (Table 4). Activities include stationary fuel combustion in the residential and commercial sector and emissions from 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 in the agriculture, forestry and fishing sectors.

Table 4 Emissons from Sweden reported to CLRTAP for 2015 (kt). NO = not occuring, NA = not applicable and NE = not estimated

NFR Code	Description	kt N_2O	kt NH_3	kt NOx (as NO_2)
1A4ai	Commercial/Institutional: Stationary	0.012	0.011	0.392
1A4aii	Commercial/Institutional: Mobile	0.013	0.001	1.642
1A4bi	Residential: Stationary	0.216	0.130	3.520
1A4bii	Residential: Household and gardening (mobile)	0.006	0.000	1.140
1A4ci	Agriculture/Forestry/Fishing: Stationary	0.026	0.013	0.484
1A4cii	Agriculture/Forestry/Fishing: Off-road vehicles and other machinery	0.044	0.003	4.470
1A4ciii	Agriculture/Forestry/Fishing: National fishing	0.006	0.001	2.355
1A5a	Other stationary (including military)	NO	NO	NO
1A5b	Other, Mobile (including military, land based and recreational boats)	0.009	0.001	1.060
	Total from EF.OE to AT	**0.33**	**0.16**	**15.06**
	Total from EF.OE to AT (kt N)	**0.21**	**0.13**	**4.58**

The N emissions to the atmosphere from the sub-pool Other energy and fuels were 4.9 kt in 2015 (Table 4). The largest sources were from Off-road vehicles and other machinery used in agriculture/forestry/fishing (1A4cii) with 1.4 kt, Residential: stationary (1A4bi) with 1.3 kt and National fishing (1A4ciii) with 0.7 kt. 93 percent of the Nr from this sub-pool was emitted as NO_x.

EF.OE_AT: 4.9 kt N

Description of other flows

Table 5 Nitrogen flows between the pool ´Energy and fuels´ and the other pools and sub-pools of the NNB. (Source: http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20210302_public.pdf)

Flow name	Pool		Pro-cess	Major N forms	Sub-pools involved	Flow Codes	Description	Annex describing the method
	Out	In						
		Materials & Products						
EF_MP	EF	MP	Feedstock	N feedstock	EC	EF.EC_MP.OP	Fuels used as feedstock in industrial processes	Annex EF
		Agriculture						
AG_EF	AG	EF	Agricultural fuels	N fuel	EC	AG_EF.EC	Agricultural products used for energy generation and fuel production	Annex AG
EF_AG	EF	AG	Digestate	N_{org}	EC	EF.EC_AG	Residues from biofuel production that are used as animal feed	Annex EF
		Forest and semi-natural vegetation						
FS_EF	FS	EF	Wood fuel	N fuel	EC, IC, OE	FS.FO_EF.EC FS.FO_EF.IC FS.FO_EF.OE	Direct use of wood fuel and use of wood fuel in energy conversion processes	Annex FS
		Waste						
WS_EF	WS	EF	Waste fuel	N fuel	IC	WS_EF.IC	Direct use of waste fuel in industrial processes	Annex WS
EF_WS	EF	AG	Digestate	N_{org}	EC	EF.EC_WS	Residues from biofuel production that are incinerated in waste incineration plants or transferred to landfills or composting sites	Annex EF
		Atmosphere						
EF_AT	EF	AT	Emissions	NH_3, NO_x, N_2O	EC, IC, TR, OE	EF.EC_AT EF.IC_AT EF.TR_AT EF.OE_AT	Release of reactive nitrogen species during fuel combustion processes	Annex EF
AT_EF	AT	EF	N fixation	N_2	EC, IC, TR, OE	AT_EF.EC AT_EF.IC AT_EF.TR AT_EF.OE	Technical Fixation of nitrogen during fuel combustion processes	Annex EF
		Rest of World						
RW_EF	RW	EF	fuel import	N fuel	EC, IC, TR, OE	RW_EF.EC RW_EF.IC RW_EF.TR RW_EF.OE	Import of fuels	Annex EF
EF_RW	EF	RW	fuel export	N fuel	EC, IC, TR, OE	EF.EC_RW EF.IC_RW EF.TR_RW EF.OE_RW	Export of fuels	Annex EF

Energy and fuels – Material and products (EF_MP)

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 and therefore this flow is not estimated in this report.

Energy and fuels – Agriculture (AG_EF, EF_AG)

Fuel combustion in the agricultural sector itself is covered in the sub-pool EF.OE (and the Nr ends up in AT).

The total amount of N in agricultural products used for energy generation and fuel production in Sweden was not estimated in the report on Agriculture (Stadmark et al. 2019). The production of biogas belongs to the Waste pool of the NNB and has not been estimated yet. In Annex 1 (EF) there is a flow described as *Residues from biofuel production that are used as animal feed*, this flow is not indicated in Annex3 (AG) and was not estimated in Stadmark et al. (2019). However, below we make a rough estimate of the N-flows related to biofuel production. The total energy production from the products below constitutes approximately 1% of the energy inflow to the Swedish energy market.

Biofuel production (biodiesel and ethanol) results in flow of N into and out of the EF pool. In 2015 production of ethanol from crops primarily took place in the Lantmännen Agroetanol facility in Norrköping. This facility can produce 230 000 m^3 of ethanol per year https://www.lantmannen.se/forskning-och-innovation/var-forskning/agroetanol/. If all this ethanol is made from wheat (domestic and imported) and 2.6 kg wheat is needed to produce 1 l of ethanol and the nitrogen content of the grains is 1.7% (https://www.livsmedelsverket.se/livsmedel-och-innehall/naringsamne/livsmedelsdatabasen) a total flow of N into and out of the EF pool estimates to 10 kt per year. The exact split of the origin of the 10 kt N (between AG and RoW) is uncertain, but not essential here. We have arbitrarily set the origin to 100% from AG.

Biodiesel was primarily produced from imported rape seeds in Perstorp BioProducts' facility in Stenungsund and to a lower extent with domestic material in Ecobränsle in Karlshamn. The N flow for biodiesel production in 2015 has not been estimated, but the principle is the same as for bioethanol, the inflow and outflow of N are of equal size. The residues are mainly considered to flow back to the AG pool as animal feed.

Other sources of bioenergy from cropland are energy wood, such as *Salix*, that was harvested from 11726 ha of agricultural land in 2015 https://statistik.sjv.se/PXWeb/pxweb/sv/Jordbruksverkets%20statistikdatabas/Jordbruksverkets%20statistikdatabas__Arealer__1%20Riket%20l%c3%a4n%20kommun/JO0104B1.px/table/tableViewLayout1/, and grains and straw. The flows of N from these sources have not been estimated.

EF_AG: ≥ 10 kt N

AG_EF: ≥ 10 kt N

Energy and fuels – Forest and semi-natural vegetation (FS_EF)

This flow was in the Swedish NNB estimated for the FS-pool (Annex 4) but not as a flow to EF. In Jutterström et al. (2020) the direct use of wood fuel was allocated to the pool Humans and settlements (HS) and not to the Energy & Fuel pool. Here we include the same estimate but ask the readers to avoid double-counting when an entire NNB is constructed.

For calculating the flow of N due to the production of Fuel wood (including wood for charcoal) excluding wood for export, the same density as for the roundwood is used (Jutterström et al. 2020) but with the N-content for the whole tree from Table 16 in Annex 4 (Forest and Semi-natural vegetation). Here we assume that the bark is also used as fuel and so the calculation uses the reported volumes over bark.

FS.FO – EF: 7.3 kt N

Energy and fuels – Waste (WS_EF, EF_WS)

According to the Annex 1, WS_EF is the flow of nitrogen contained in waste fuels used as fuel in industrial combustion processes (e.g. cement production). The flow EF_WS accounts for nitrogen contained in the digestate and residues of biofuel production that is generated as a by-product in the sub-pool ´Energy conversion´ and transferred to the pool Waste, e.g. to waste incineration plants, landfills or composting sites. The Annex 5 (waste) is , however, not available at the time of finalizing this report (January 2023). In general, the Nr flows between EF and WS are expected to be in order of individual kt N. For comparison, the DESTINO project in Germany quantified EF to WS flow to 1.6 kt N. Furthermore, waste incineration plants are not included in the pool EF, independent of whether the energy produced in the waste incineration process is recovered or not. Instead, all waste incineration plants are accounted for in the pool Waste. Therefore, we at this point do not attempt to quantify WS_EF and EF_WS flows. This will be amended once the EPNB provides the completed Annex 5 and the WS pool is reported.

Energy and fuels – Rest of the world (RW_EF, EF_RW)

In 2015 Sweden imported 23 million m^3 of crude oil and 7 million m^3 of fuels (primarily diesel, petrol and jet fuel) (https://drivkraftsverige.se/statistik/import-export, data retrieved 20 January 2022). Assuming densities of crude oil (0.85 ton m^{-3}), diesel (0.82 ton m^{-3}), petrol (0.75 ton m^{-3}), jet fuel and other fuel types (0.80 ton m^{-3}) (https://www.energihandbok.se/branslen) and a N content of 0.25% in crude oil (http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_feedback.pdf), 0.02% in diesel, 0.1% in petrol and jet fuel (UBA 2020) the imported N in fuel 2015 was estimated to 53.5 kt N, of which 49.7 kt were in crude oil. These amounts are not emitted during the combustion of the fuels, as has also been found in Germany (UBA, 2020). In the German report they discuss the oxidation and reduction steps of N in crude oil and further oil products in the refineries and that the wastewater treatment at the refineries finally denitrify the produced N-compounds.

RW_EF: 53.5 kt N

In 2015 Sweden exported diesel, petrol, and other oil-based products (https://drivkraftsverige.se/statistik/import-export, data retrieved 20 January 2022) with a total N content of 8.8 kt N, according to the calculations made for import above. For year 2015 the export of aviation fuel, crude oil and light petrol were reported as 0 m^3.

EF_RW: 8.8 kt N

These flows are considered to comprise only inactive nitrogen compounds, but they are included in the NNB to achieve a more complete balance.

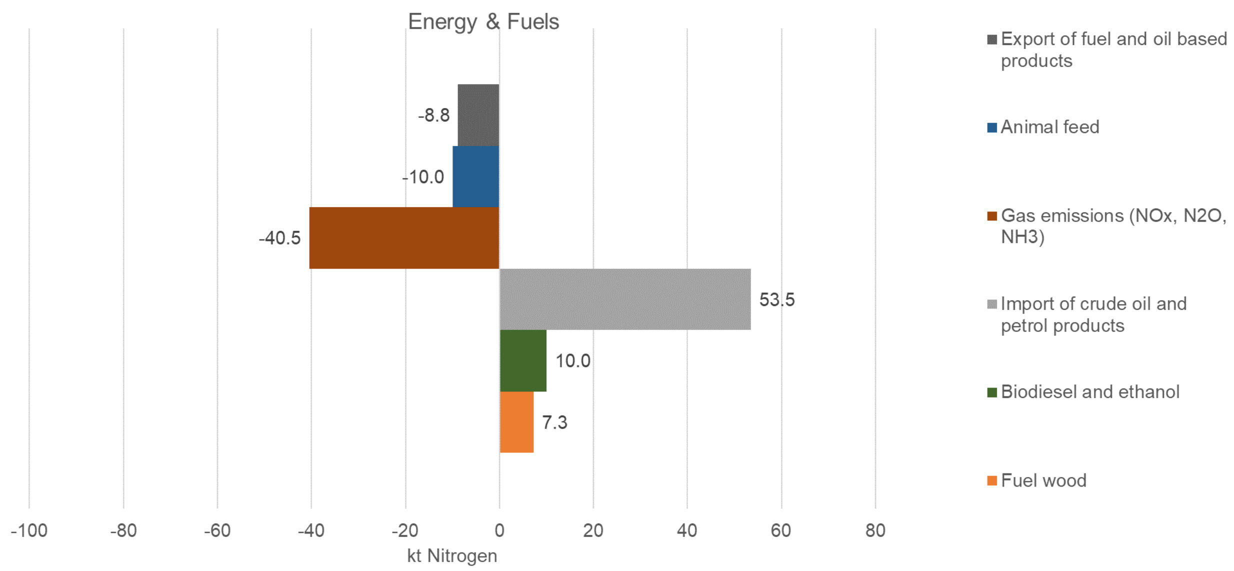

Figure 3 Inflows and outflows of Nr to and from the EF pool (kt N).

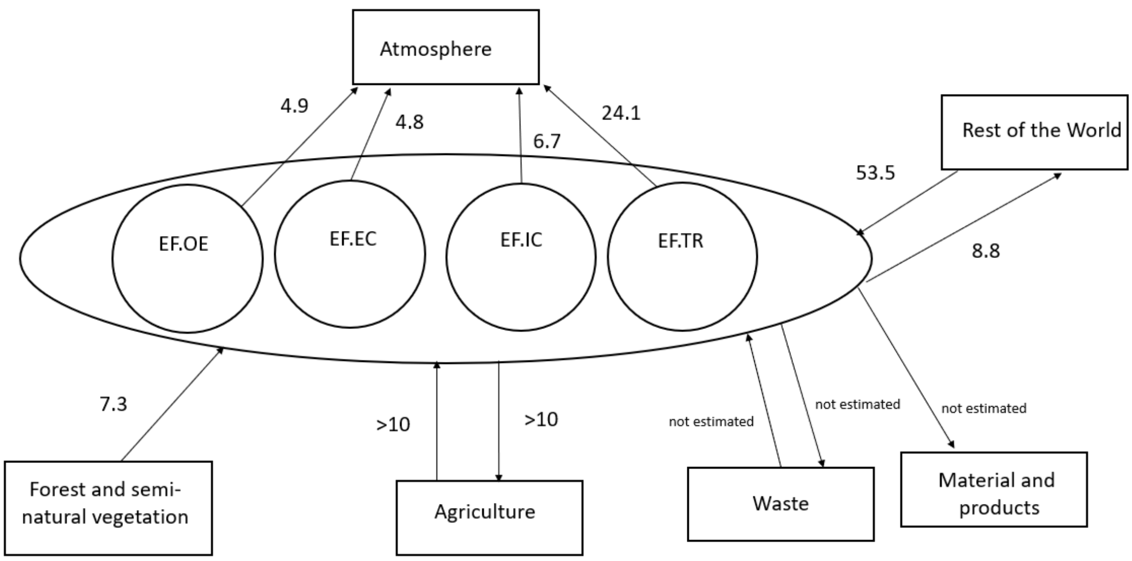

Figure 4 Flows of reactive nitrogen (kt) between the Energy pool and the other pools and the rest of the world. Emissions to the atmosphere are divided into four sub pools; EF.EC = Energy conversion, EF.IC = Manufacturing industries and construction, EF.TR = Transport, EF.OE = Other energy and fuels.

Conclusion

The overall flows of Nr in 2015 connected to the Energy and fuel pool of the NNB for Sweden are summarized in Figures 3 and 4. The largest flow of Nr to the EF pool is the import of fuels. The largest flow of reactive nitrogen from the EF pool is the emission of NO_x, N_2O and NH_3 to the Atmosphere (40.5 kt N). Flows to and from all other NNB pools were considered except for the interactions with WS since the Annex defining the methodology to quantify the flows to and from WS is not available yet. The Nr flows between EF and WS are, however, considered to be relatively unimportant.

The fact that the emissions to the atmosphere are lower than the Nr content in fuels indicates the efficiency of the measures deployed in refineries and at various levels of fuel combustion in both industrial plants and in combustion engines in vehicles. Considering that the majority of Nr in the emissions created during the combustion processes originates from N_2 in the air and from thermal production (rather than from Nr in the fuel), the amount of Nr converted to N_2 by catalytic conversion and other NO_x-emission reducing technologies is most likely in order of hundreds of kt N per year. Consequently, the quantification of Nr flows in the EF pool involves "hidden" flows of industrial N fixation in combustion processes which is, shortly after its creation, converted back to N_2 by NO_x control measures before it reaches the atmosphere. How balanced the Nr budget of the EF pool is will therefore be dependent on the efficiency of the air pollution controls and the balance could in theory lay anywhere between outflows exceeding inflows several times if no emissions controls are employed, or exports being only a small fraction of imports in case of (unlikely) 100% efficiency of the emission controls.

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