A new UK Nitrogen Balance Sheet (UK-NBS)

Methodology overview

Ulli Dragosits, Clare Pearson

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1. Introduction

A nitrogen balance sheet is a way to understand and quantify flows of nitrogen across all aspects of a country's environment and economy, as well as import and exports to and from other countries or regions. This quantification gives an indication of the absolute and relative importance of key processes and industries in terms of nitrogen usage and helps identify areas of potential waste. The quantified losses of nitrogen to the environment can also be used to relate to international targets, such as Target 7 (at least 50% reduction in excess nutrient losses) recently announced by the Convention on Biodiversity[1] under the Kunming-Montreal Global Biodiversity Framework.

The new UK Nitrogen Balance Sheet (UK-NBS) presented in this methodology document outlines the main nitrogen flows in the UK. These are summarised in the flow diagram in alance Sheet

[1] https://www.cbd.int/gbf/targets/

, with the calculation steps and data sources for each value summarised in Table 1.

2. Definitions

The terms nitrogen balance sheet and nitrogen budget are often used interchangeably. In this report, we cite previous work using the terminology it is published under. However, we are aware of WWF-UK's intention to refer to balance sheets in the context of this work, and nitrogen budgeting more akin to the carbon budgeting process led by the Climate Change Committee. In this sense, nitrogen budgets could be used to make detailed targeting recommendations as part of a pathway towards overall long-term targets and objectives (for nutrient losses/waste, GHG emissions, water quality, air quality and pollutant emissions, a prosperous agri-food and seafood sector, a sustainable, nature-positive, affordable food system, etc.). A N balance sheet could be used as a tool to understand how flows of nitrogen could change under different projections or scenarios of future policy, business of societal change. Crucially, the process would need to combine the predicted impact of interacting changes across the economy and environment on the nitrogen cycle in order to maximise synergies and manage trade-offs.

3. Methodology for estimating nitrogen flows

The methodology for estimating the nitrogen (N) flows summarised for the UK is based on collaborative international work under the UN Economic Commission for Europe (ECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP), often referred to as the Air Convention. Within CLRTAP, the Task Force on Reactive Nitrogen (TFRN) and specifically its Expert Panel on Nitrogen Budgets (EPNB) (UN ECE TFRN) has established international reporting guidance for country-scale nitrogen budgets (also referred to as nitrogen balances elsewhere). The EPNB guidance document on national nitrogen budgets (UN ECE, 2013) contains detailed draft annexes that outline a recommended methodology (UN ECE, 2021) for quantifying nitrogen flows. The recommended approach builds on existing national data collections wherever possible, including the widely available international greenhouse gas and air quality pollutant emission inventory reports and the OECD/Eurostat methodology (Eurostat, 2013) for Gross Nutrient Budgets (GNB, previously called Gross Nitrogen Balances).

The new UK nitrogen budget presented here builds on UN ECE guidance documents where possible, and also on methodologies used for the Scottish Nitrogen Balance Sheet (SNBS) (Scottish Government, 2021) and German nitrogen budget (Umweltbundesamt, 2020) which are both largely, but not entirely, based on the UN ECE guidance. The SNBS is the first nitrogen budget to be enshrined in law globally, to our knowledge, and the published report and underlying data spreadsheet, in particular, have been utilised for the new UK data compilation carried out for the WWF, to create a UK-wide summary Nitrogen Balance Sheet (UK-NBS).

As recommended by the guidance documents, the UK-NBS re-uses existing published statistics where available, including the latest GHG and air quality emission inventories (NAEI) and the UK soil nutrient balance report (DEFRA, 2022a). The SNBS methodology incorporates data and information provided by key expert institutions such as Scotland's Rural College (SRUC), SEPA, Forest Research, the UK Centre for Ecology & Hydrology (UKCEH), and Rothamsted Research, and the same methods have been applied where possible, to enable direct comparisons. All relevant data sources are listed in Table 1 below. For some less well understood nitrogen flows, the default values recommended in the guidance documents were applied to relevant activity data, as is common for Tier 1 emission inventory methodologies (i.e. the use of simple emission factors).

For import/export of the N content of materials to and from the UK, a new methodology was developed by the University of York in a parallel small project (Hicks, O'Neill, Simpson and Croft, 2023). This type of work was not possible for the SNBS for Scotland, as sufficiently detailed and complete statistics for import/export from Scotland to the rest of the UK and internationally do not currently exist. By contrast, there are very detailed itemised quantities of imported and exported materials available from FAOSTAT. These were compiled and combined with appropriate N content values taken largely from the same guidance documents and data sources as for the SNBS, matching those used in the compilation of the other N flows in the UK-NBS.

In summary, the use of existing long-term statistics and the established methodology from the SNBS enabled a relatively quick compilation of the key national nitrogen flows, as far as possible given the limited resources and time frame available. Additional resources would allow for more detailed data to be collated, nitrogen use efficiencies to be calculated and time series to be compiled to visualise trends over time and identify cross-economy and cross-environment opportunities for more efficient and less wasteful use of nitrogen, reducing nitrogen losses to the environment.

4. UK N Balance Sheet

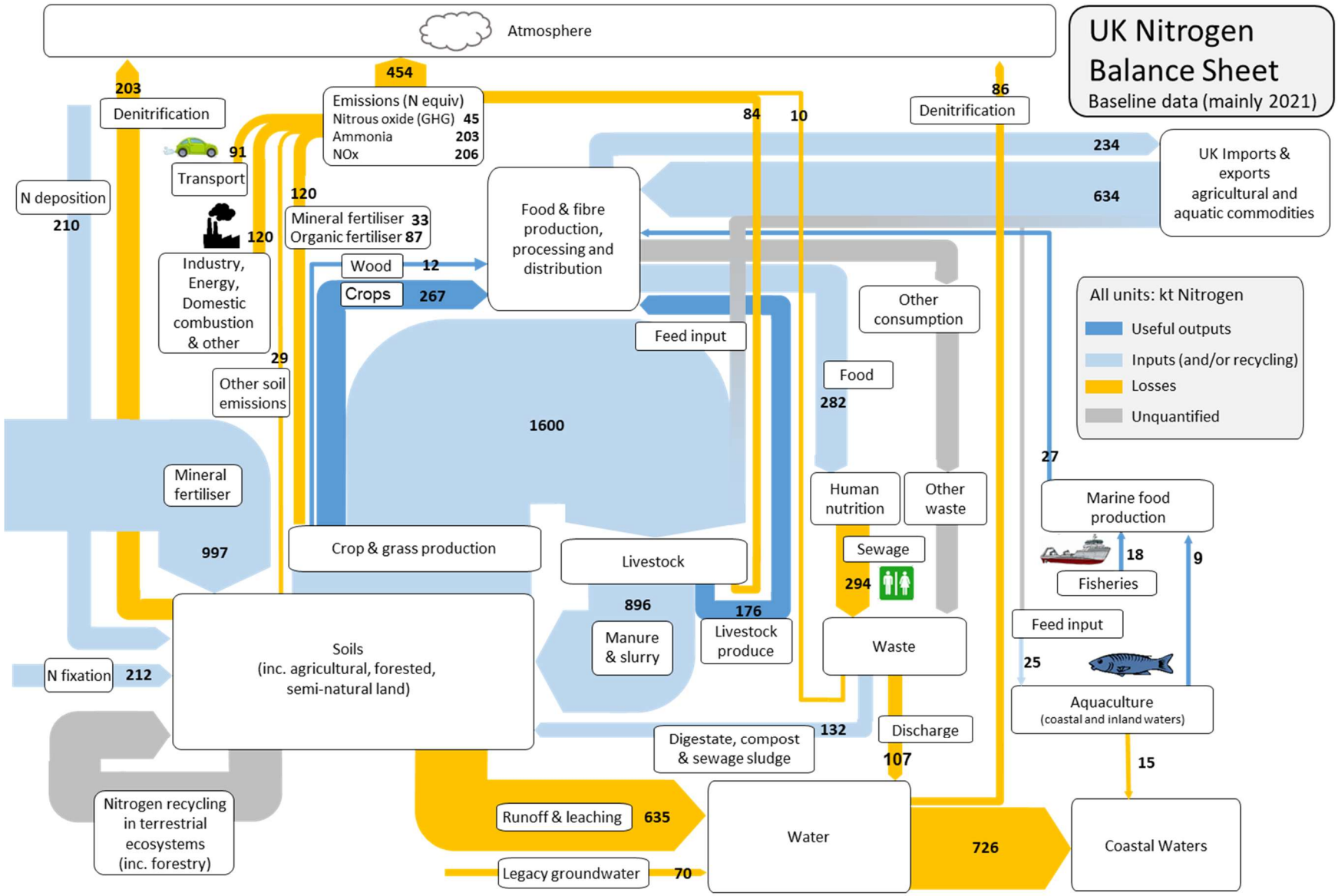

Figure 1: UK N Balance, details of flows and data sources in Table 1 below.

Table 1: Description of each flow in Figure 1, including data sources and calculation steps.

From	To	Description	N-species	Size of flow (kt N / yr)	Time period	Data source(s)/ reference(s)
	Soils	Mineral Fertiliser application to agricultural land	Total N	997	2021	Data underlying the UK agricultural emission inventory
Atmosphere	Soils	Biological Nitrogen Fixation	Total N	212	2021	Biological N fixation total derived for different land types as follows: For agriculture from UK and England soil nutrient balances 2021 (DEFRA, 2022a). For wetlands, EPNB guidance (Annex 4, Table 19) recommends 0-22 kg N / ha / yr for "peat bog"; average value of 11 kg / ha / year used; area of semi-natural vegetation (wetlands = saltmarsh, bog, fen marsh and swamp) from UKCEH Land Cover Map 2021: 6,800 km^2. For woodlands, the EPNB method for "temperate forests" as used, with biological nitrogen fixation values from a recent paper by Du and De Vries (2018), as recommended by experts from Forest Research, of 12.5 kg N / ha / yr and applied over "stocked area > 20 years old. According to Forest Research (2021), there are 2.645 million ha of total stocked woodland area in GB by age class (Table 1.6c: conifers + 1.7c: Broadleaf), of which: 2.003 million ha is over 20 years old. Scaled up to UK using relative proportions of total woodland area for each devolved administration in Table 1.1. For other semi-natural land (excluding wetlands and woodlands/forests), EPNB guidance (Annex 4, Table 5) recommends 2.3-3.1 kg N / ha / yr for semi-natural grass; average value of 2.7 kg N / ha / yr used; area of semi-natural vegetation types from UKCEH Land Cover Map 2021: 31,528 km^2. (Marston et al. 2022)
Atmosphere	Soils	N Deposition	NH_3 & NO_x	210	2021	UKCEH - CBED model output (model used for derivation of official UK N deposition trends and assessment of exceedances of critical loads and critical levels – see annual DEFRA reports by Ed Rowe et al. 2022)
Soils	Water	Runoff & leaching	Total N	635	2010	from LTLS-FM model (Bell et al. 2021)

	Water	Legacy groundwater	Total N	70	2010	from LTLS-FM model (Bell et al. 2021)
Waste	Water	Discharge	Total N	107	2010	from LTLS-FM model (Bell et al. 2021)
Water	Atmosphere	Denitrification	N_2	86	2010	from LTLS-FM model (Bell et al. 2021)
Water	Coastal Water	Runoff from UK land to UK coastal waters	Total N	726	2010	from LTLS-FM model (Bell et al. 2021)
Aquaculture	Coastal water	Aquaculture Excreta and feed waste to UK coastal waters	Total N	15	2019	Scottish aquaculture statistics and N flow calculation method adopted from SNBS (Scottish Government 2021) and scaled to UK, using 2017 aquaculture produce data in Table 1 of Future of the Sea: Trends in Aquaculture report (Government Office for Science, 2017).
	Aquaculture	Aquaculture feed input	Total N	25	2019	Scottish aquaculture statistics and N flow calculation adopted from SNBS (Scottish Government 2021) scaled p to UK using aquaculture produce data in Table 1 of Future of the Sea: Trends in Aquaculture report (Government Office for Science, 2017). Feed totals from amount of feed used by Scottish salmon producers x 8% N content
Aquaculture	Marine food production	Aquaculture produce	Total N	9	2019	Scottish aquaculture statistics and N flow calculation adopted from SNBS (Scottish Government 2021) scaled to UK using aquaculture produce data in Table 1 of Future of the Sea: Trends in Aquaculture report (Government Office for Science, 2017).
Fisheries	Marine food production	Produce from fisheries landing in UK	Total N	18	2021	UK sea fisheries annual statistics report 2021 (Marine Management Organisation), Section 2 Table 2.1, kt fish product multiplied by N content (UNECE Guidance, 2021. Annex 6, Table 12)
Marine food production	Food & fibre production/ processing/ distribution	Fishery and aquaculture produce	Total N	27	2019-2021	Sum of aquaculture and fishery production
Food & fibre production/ processing/ distribution	Human Nutrition	Food consumed by humans	Total N	282	2021	ONS 2021 Mid-year population estimates for 2021, human nutrition data from National Diet and Nutrition Survey (Whitton et al., 2011; British Journal of Nutrition, 106, 1899-1914) applied to relevant age groups.
Food & fibre production/	Other consumption	Other non-food consumption, such as clothing and other materials			Unquantified	

processing/ distribution						
Other consumption	Other waste	Other non-food waste from consumption, manufacturing, and distribution			Unquantified	
Human Nutrition	Waste	Sewage	Total N	294	2021	12 g N per person per day = 4.38 kg N yr^{-1}; mid-2021 population estimate (Office of National Statistics) for UK 67,026,292. N excretion rate from Naden et al, 2016.
Waste	Soils	Digestate, compost & sewage sludge	Total N	132	2021	Data underlying the UK agricultural emission inventory. Consisting of organic fertiliser input to soils (sewage sludge, manure-based digestate, crop-based digestate, food-based digestate and other digestate)
Waste	Atmosphere	Emissions from waste	Sum of NH_3-N, NO_x-N and N_2O-N	10	2021	National Atmospheric Emission Inventory, 2021 air pollutant data converted into N equivalent for each species.
Transport	Atmosphere	Emissions from transport	Sum of NH_3-N, NO_x-N and N_2O-N	91	2021	National Atmospheric Emission Inventory, 2021 air pollutant data converted into N equivalent for each species.
Industry, Energy, Domestic combustion & other	Atmosphere	Emissions from industry, energy, domestic combustion, and other sources such as public combustion	Sum of NH_3-N, NO_x-N and N_2O-N	120	2021	National Atmospheric Emission Inventory, 2021 air pollutant data converted into N equivalent for each species.
Soils	Atmosphere	Other emissions from soil, including land use change and soil management	N_2O-N	29	2021	National Atmospheric Emission Inventory, 2021 greenhouse gas data converted into N equivalent for each species.
Soils	Atmosphere	Denitrification	N_2	203	2021	For denitrification from agricultural lands, UK Utilised agricultural area (UAA) from Agricultural Land Use and Crop Areas in the UK (DEFRA) and associated Land use tables * 10 kg N ha^{-1} yr^{-1} (SRUC expert knowledge). For semi-natural and wetland area, used rates from German Nitrogen Budget (1 kg N ha^{-1} yr^{-1} for semi-natural land and used 20 kg N ha^{-1} yr^{-1} for wetlands) and land areas from 2021 UKCEH Land Cover map. For forests: used German Nitrogen Budget emission factor 1.1 kg N ha^{-1} yr^{-1}, across the area of "stocked woodland > 20 years old" (as per UNECE guidance document). There are 2.645 million ha of total stocked woodland

						area in GB by age class (Table 1.6c: conifers + 1.7c: Broadleaf, according to Forest Research (2021)), of which: 2.003 million ha is over 20 years old. Scaled up to UK using relative proportions of total woodland area for each devolved administration in Table 1.1.
Crop & grass production	Atmosphere	Emissions from mineral fertiliser	NH_3-N & NO_x-N	33	2021	National Atmospheric Emission Inventory, 2021 air pollutant data converted into N equivalent for each species. Includes manufactured urea, ammonium nitrate, etc.
Crop & grass production	Atmosphere	Emissions from organic fertiliser	NH_3-N & NO_x-N	87	2021	National Atmospheric Emission Inventory, 2021 air pollutant data converted into N equivalent for each species. Includes manures, digestate, sewage sludge etc.
Crop & grass production	Atmosphere	Emissions from Fertiliser (mineral & organic)	NH_3-N & NO_x-N	120	2021	Sum of mineral and organic fertiliser
	Atmosphere	Sum of all emissions to atmosphere from human activity	Total N	454	2021	Sum of all emissions to atmosphere from human activity
Crop & grass production	Food & fibre production/ processing/ distribution	Crops for human consumption	Total N	267	2021	N content of crops taken from Eurostat Nutrient Budgets Handbook (2013) guidance, crop yield/areas/production stats from Agriculture in the United Kingdom 2021 Report (DEFRA) data tables behind Chapter 7: Crops. Crop production multiplied by proportion of domestic use attributed to milling or specified as for human consumption. All milled cereals, fresh fruit and veg were assumed to be for human consumption. This figure includes remaining crop areas not attributed to seed, feed, distilling or human consumption. May include a small proportion for waste
Crop & grass production	Food & fibre production/ processing/ distribution	Wood production/ harvest	Total N	12	2020	N content from EPNB guidance and German N budget; sum of wood removals for energetic and materials use (using the same approach and UK Forestry statistics series as for the SNBS)
Crop & grass production	Livestock feed	Feed intake by UK livestock	Total N	1600	2021	Applying a process-based livestock model (Leinonen et al. 2019). This approach was applied using the annual Material Flow Accounts (MFA) for the SNBS (Scottish Government 2021). This same approach was applied to the UK-NBS using the national statistics in the Agriculture in the United Kingdom 2021 Report (DEFRA), Chapter 8 Livestock data tables. N in feed grown in UK is estimated by multiplying typical N content in feed (by feed type) with the feed intake estimated in the MFA dataset. Imported feed includes soya meal and fishmeal. Fish meal may contain UK-produced fish

						meal, but commodity market heavily influences use of imported vs UK-produced feed materials.
	Livestock feed	Feed import	Total N	Not Estimated		The application of the MFA methodology to calculate feed production needed for UK livestock populations meant that the proportion of required feedstock that was imported could not be calculated. While some livestock feed crops could be assumed to be imported (i.e. Soya), others such as cereals are likely a mixture of UK-grown and imported feed, the proportion of which is unknown and varies with commodity prices. Import/export data tables do not identify the usage of the crop.
Livestock	Atmosphere	Emissions from livestock	Sum of NH_3-N, NO_x-N and N_2O-N	84	2021	National Atmospheric Emission Inventory, 2021. Emissions from Livestock housing & storage of livestock manures
	Atmosphere	Total N_2O-N emitted to atmosphere from human activity	N_2O-N	45	2021	Sum of N_2O-N emissions from National Atmospheric Emission Inventory for greenhouse gases (2021) from: Transport, fertiliser, waste, livestock housing and manure, soil management, land use change and industry, power generation and manufacturing
	Atmosphere	Total NO_x-N emitted to atmosphere from human activity	NO_x-N	206	2021	Sum of NO_x-N from National Atmospheric Emission Inventory for air pollutants (2021) from: Transport, fertiliser, waste, livestock housing and industry, power generation and manufacturing
	Atmosphere	Total NH_3-N emitted to atmosphere from human activity	NH_3-N	203	2021	Sum of NH_3-N from National Atmospheric Emission Inventory for air pollutants (2021) for: Transport, fertiliser, waste, livestock housing and industry, power generation and manufacturing
Livestock	Livestock produce	Produce from livestock, including meat, eggs, milk and wool	Total N	176	2021	Production of N in meat, milk and eggs taken from Agriculture in the United Kingdom 2021 Report (DEFRA, 2022) data tables behind Chapter 8: Livestock. Wool production data for UK from British Wool report (2022) (table on page 11). Production volumes combined with N content from UNECE guidance (Annex 6, Table 12)
Livestock	Manure & Slurry	Livestock excreta	Total N	896	2021	Data underlying the UK agricultural emission inventory. Sum of livestock excreta to grazing, manure used for spreading, excreta for use in anaerobic digestion (after housing & storage losses).
Food & materials import	Food & fibre production/ processing/ distribution	Food & materials import	Total N	634	5-year avg 2017-2021	UK imports of agricultural and aquatic commodities (mass in tonnes from FAOSTAT, N content from guidance documents) see Hicks et al. 2023 for details

Food & fibre production/ processing/ distribution	Food & materials export	Food & materials export	Total N	234	5-year avg 2017-2021	UK imports of agricultural and aquatic commodities (mass in tonnes from FAOSTAT, N content from guidance documents) see Hicks et al. 2023 for details

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Contact

enquiries@ceh.ac.uk

@UK_CEH

ceh.ac.uk

Bangor

UK Centre for Ecology & Hydrology
Environment Centre Wales
Deiniol Road
Bangor
Gwynedd
LL57 2UW

+44 (0)1248 374500

Edinburgh

UK Centre for Ecology & Hydrology
Bush Estate
Penicuik
Midlothian
EH26 0QB

+44 (0)131 4454343

Lancaster

UK Centre for Ecology & Hydrology
Lancaster Environment Centre
Library Avenue
Bailrigg
Lancaster
LA1 4AP

+44 (0)1524 595800

Wallingford (Headquarters)

UK Centre for Ecology & Hydrology
Maclean Building
Benson Lane
Crowmarsh Gifford
Wallingford
Oxfordshire
OX10 8BB

+44 (0)1491 838800

UK Centre for Ecology & Hydrology