UK Centre for Ecology & Hydrology

2018 Estimates of nitrogen deposition in Northern Ireland and import/export of N deposition across the UK

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Issue Number 1

Date 22/08/2022

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Client Department of Agriculture, Environment and Rural Affairs (DAERA) Northern Ireland Environment Agency (NIEA)

UKCEH reference 07102 / Issue number 1

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1 Introduction

Atmospheric nitrogen (N) deposition represents a significant threat to sensitive habitats and species in the United Kingdom, with excessive N supply leading to declines in many important species of high conservation value, at the expense of fast growing species that can exploit the additional nitrogen supply. Atmospheric N deposition originates from emissions of ammonia (NH_3, mainly from agricultural sources) and nitrogen oxides (NO_x, mainly from transport, industry, power generation and other combustion sources).

This short report aims to update the import and export estimates of atmospheric nitrogen to/from Northern Ireland by Carnell et al. (2020). The atmospheric nitrogen (N) estimates presented in the 2020 report were based on FRAME source attribution model output for the emission year 2012 (Bealey and Dore 2017), which was the most recent dataset available at the time of writing. Although more up to date estimates of N deposition existed in early 2020 (when the last report was written), the source attribution dataset (for the emission year 2012) was the most up to date dataset providing estimates of N deposition by devolved administration and source type. This is because the source attribution modelling is only updated periodically, unlike the N deposition modelling, which is carried out annually.

More up to date estimates of N deposition to/from Northern Ireland now exist for the emission year 2018, which were developed under the Air Pollution Information System (APIS http://www.apis.ac.uk/) project and funded by the UK government agencies (SEPA, SNH, JNCC, EA, NE, NRW, NIEA). In addition to updated emission estimates used as model input, the model has also been updated and improved substantially, with important developments including the differentiation of deposition from sources within the Republic of Ireland, which were previously included with European sources. More recent model input data (such as improved land cover estimates and meteorology) were also used in this work which better reflect the present.

In Northern Ireland (NI), agricultural NH_3 emissions are estimated at 25.7 kt N $year^{-1}$ (31.84 kt NH_3 $year^{-1}$) in 2019 (https://naei.beis.gov.uk/, 2021). Overall agricultural NH_3 emissions in NI have increased in recent years, with a ~7 % increase in ammonia emissions reported between 2015 and 2019. Approximately 63 % of agricultural NH_3 emissions produced from livestock in NI are associated with cattle farming (Misselbrook and Gilhespy, 2022). Non-agricultural NH_3 emissions contribute ~3% of total NH_3 emissions inNI (1.02 kt NH_3). Emissions of nitrogen oxides (NO_x) in NI were estimated at 10.7 kt N $year^{-1}$ (35.0 kt NO_x as NO_2 $year^{-1}$) in 2019. This is 4 % of the total NO_x emissions produced in the UK (240.0 kt NO_x-N or 787.3 kt NO_x expressed as NO_2), with 26 % of NI NO_x emissions originating from road transport, 14 % from all other transport, 9 % from power generation and the remaining coming from industrial processing and other sources.

This report aims to quantify and compare N deposition to land in NI from sources within NI and beyond (in the UK, Republic of Ireland, Shipping and mainland Europe) to the amount of N deposition produced from NI sources that is deposited to the rest of the

UK. Estimating the likely source of N deposition received by NI will enable policy makers to assess how effective national N mitigation measures are likely to be.

2 Methodology

The amount of atmospheric N produced and deposited within Northern Ireland and imported/exported from outside of NI has been estimated using FRAME (Fine Resolution Multi-pollutant Exchange) source attribution modelling output. FRAME is a Lagrangian atmospheric transport model used to assess the annual mean deposition of reduced (NH_x) and oxidised (NO_y) nitrogen and sulfur over the United Kingdom. The domain of the source attribution model covers the British Isles with a grid resolution of 5km.

Source attribution data using FRAME are estimated by performing multiple model runs, with each source category removed in turn, in order to determine the proportion of N deposition (or "footprint") that is attributed to each individual emission source category. Regional land masks were applied to the emission maps to separate sources by each country of the United Kingdom (i.e. England, Scotland, Wales and Northern Ireland) to quantify the import and export of N deposition to NI from each. Emissions of ammonia (NH_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) were separated into 163 different sub-sectoral emission categories. This included three additional categories to the 160 UK/European sources used in the previous iteration (see Bealey & Dore 2017 for details), to allow for the separation of emission sources from the Republic of Ireland (which were previously included with European emissions).

Aside from the separation of emissions from the Republic of Ireland, the model footprint definitions were kept consistent with the previous source attribution model run (for the year 2012). This included 22 individual point sources and background 'area source' emissions of SO_2, NO_x and NH_3 split into 11 SNAP sectors (Selected Nomenclature for Air Pollution, European Environment Agency, 2013), international shipping and European emissions. The 11 SNAP sectors are: energy production and transformation; commercial institutional and residential combustion; industrial combustion; industrial processes; solvent use; road transport; other transport; waste treatment and disposal; agriculture; and natural. The top 22 point sources were isolated as they are of interest to regulators. They were made up of power stations (12), refineries (5), steel works (3), auto generators (1), and other industrial combustion (1).

It should be noted that, for this type of modelling, i.e. the estimation of atmospheric N input to the whole land area of Northern Ireland, a "grid square average" version of the N deposition model output is used. This takes account of the vegetation and land cover types present across each individual grid square, using the appropriate deposition velocity for each surface type, i.e. summing up the total N deposition in each 5 km by 5 km grid square, depending on vegetation/land surface types (low-growing semi-natural vegetation, woodland, improved grassland, arable, urban, water). This N deposition dataset is distinct from the vegetation-specific versions that are used for assessing atmospheric N input to sensitive semi-natural habitats, where the emphasis

is on estimating the amount of N deposition received by individual woodland habitats or low-growing semi-natural habitats (such as bogs), to quantify the threat to each habitat.

3 Results

3.1 Source Attribution Estimates for 2018

The total amount of atmospheric N deposition that is received in Northern Ireland (NI) is estimated at 11.7 kt N yr^{-1} (Table 1).

The data show that NI exports more N deposition to the rest of the UK than it receives (from the UK and elsewhere), in terms of total N (Figure 1). Missing parameters (expressed with "?" in Table 1) are the amount of N deposition exported from Northern Ireland and imported to the Republic of Ireland, and also the amount of N exported from Northern Ireland to the rest of Europe/outside the domain. These terms are not available from the model outputs.

Table 1: *Modelled estimates of nitrogen deposition received by Northern Ireland (NI) and deposition originating from sources within NI.*

Country/area of origin	Total N deposited to land in NI (kt N yr^{-1})	Deposition originating from sources in NI to elsewhere (kt N yr^{-1})
Northern Ireland	6.3	NA
Republic of Ireland	1.9	?
England	1.1	1.8
Wales	0.2	0.5
Scotland	0.4	5.4
Europe	0.9	?
Offshore & International Shipping	0.9	NA
Total	11.7	Incomplete without additional modelling

"?" *refers to information that cannot currently be quantified without additional modelling*

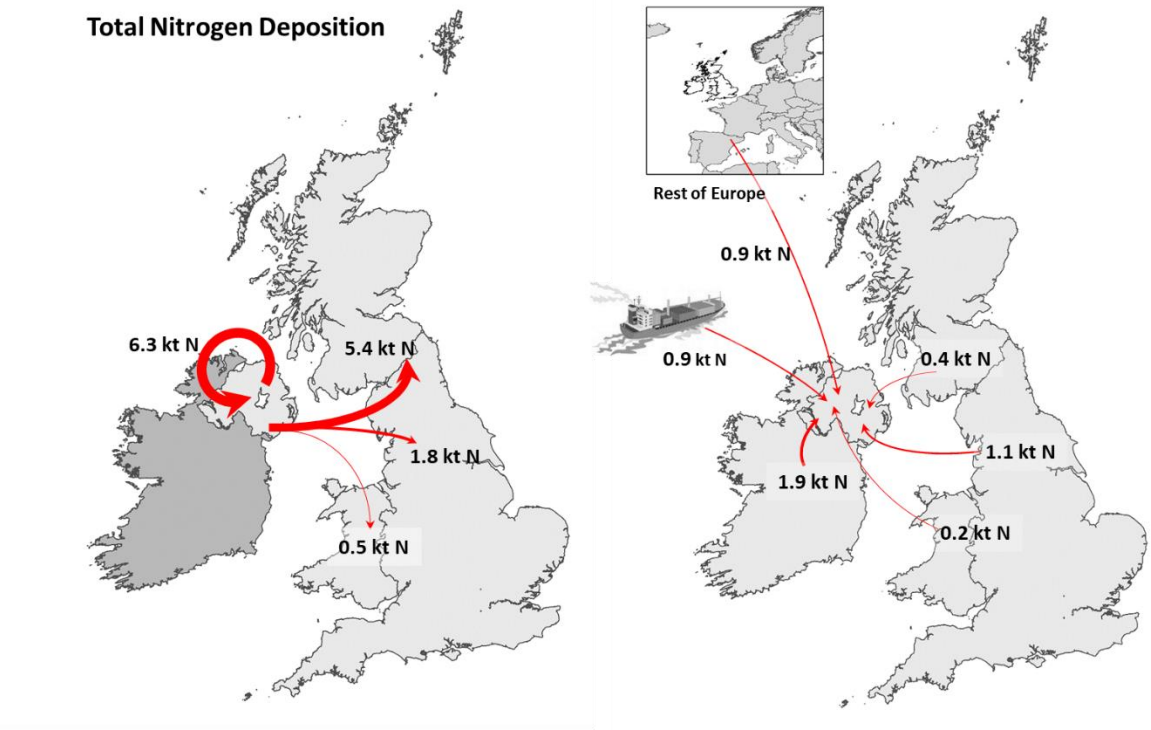

***Figure 1**: Total N deposition estimates to UK land from emission sources within Northern Ireland (left) and estimated input to NI from sources outside of NI (right). N.B. values may not add up to totals in Table 1 due to rounding.*

3.2 Source of N deposition

The amount of reduced N (NH_x) that Northern Ireland exports to the rest of the UK (6.3 kt N) is much greater than it receives from UK, Republic of Ireland and Europe (2.4 kt N). The amount of oxidised N (NO_y) that is produced and exported from Northern Ireland to the rest of UK is 1.4 kt N, which is less than it receives from the UK, Republic of Ireland and Europe (3.0 kt N, Table 2).

The total estimated amount of N deposition that both originates in NI and is deposited within NI, at ~6.3 kt N yr^{-1}, is mostly due to NH_3 emissions from within NI (92%), with only 8% due to NO_x emissions from within NI (Table 2). These atmospheric N inputs which originate from within Northern Ireland sources are the fraction that can be tackled with internal NI policy development. When taking into account atmospheric N input from all sources (NI-internal and beyond), the majority (70 %) of the N deposition received by NI overall originates from reduced N (NH_x) sources (Figure 2), with 71 % of the emissions from these sources located within NI. However, N deposition from NO_y sources is largely (86 %) produced by sources outside NI (Figure 3). Of the NO_y deposition received by NI, 33 % is from sources located in the rest of the UK, 4 % from the Republic of Ireland, 24% from the rest of Europe and remaining ~26 % comes from offshore sources and international shipping.

***Table 2**: Modelled estimates of oxidised (NO_y) and reduced (NH_x) nitrogen deposition received by Northern Ireland and deposition originating from sources within Northern Ireland. **N.B.** totals may not add up due to rounding to 2 significant figures.*

Country/area of origin	Deposition to land in NI (kt N yr^{-1})			Deposition originating from sources in NI to elsewhere (kt N yr^{-1})		
	NH_x deposition	NO_y deposition	Total N deposition	NH_x deposition	NO_y deposition	Total Deposition
Northern Ireland	5.8	0.48	6.3	-	-	-
Republic of Ireland	1.8	0.1	1.9	?	?	?
England	0.21	0.87	1.1	1.3	0.52	1.8
Wales	0.05	0.11	0.2	0.33	0.15	0.48
Scotland	0.20	0.17	0.38	4.7	0.7	5.4
Europe	0.09	0.83	0.92	?	?	?
Shipping	0.00	0.92	0.92	-	-	-
Total	**8.1**	**3.5**	**11.7**	**incomplete**		

"?" *refers to information that cannot currently be quantified without additional modelling*

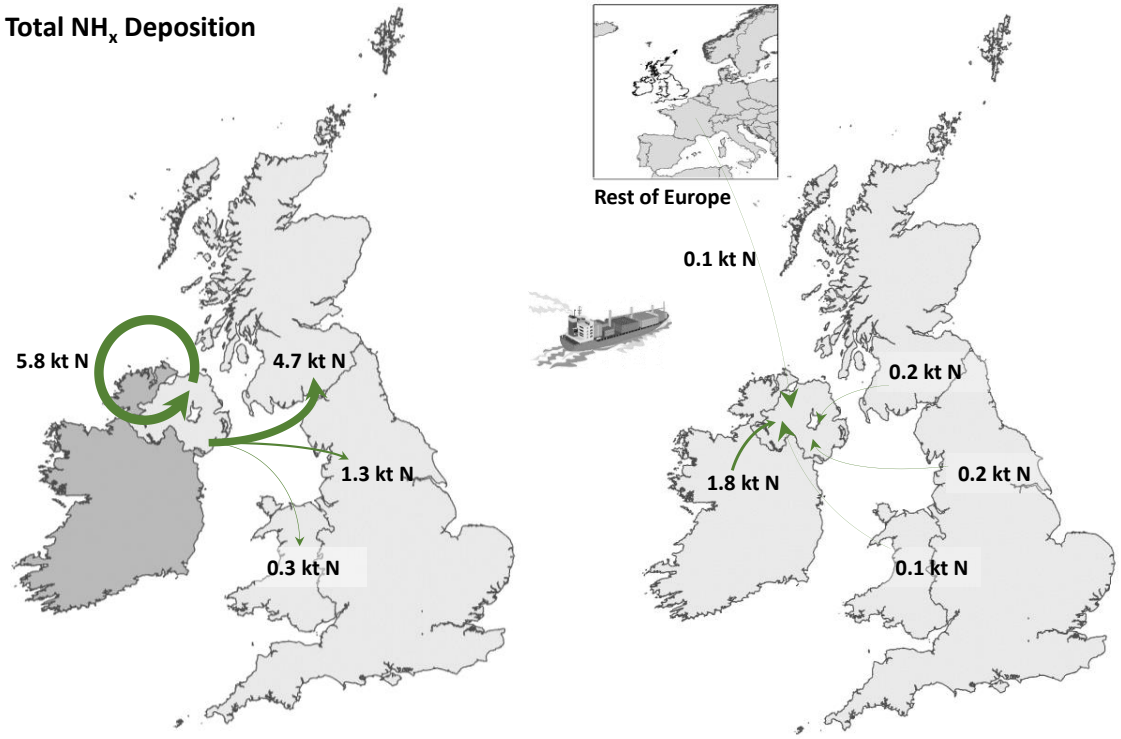

***Figure 3**: N deposition estimates to UK land from reduced nitrogen (NH_x) emission sources within Northern Ireland (left) and estimated input to NI from sources outside of NI (right). N.B. values may not add up to totals in Table 2 due to rounding.*

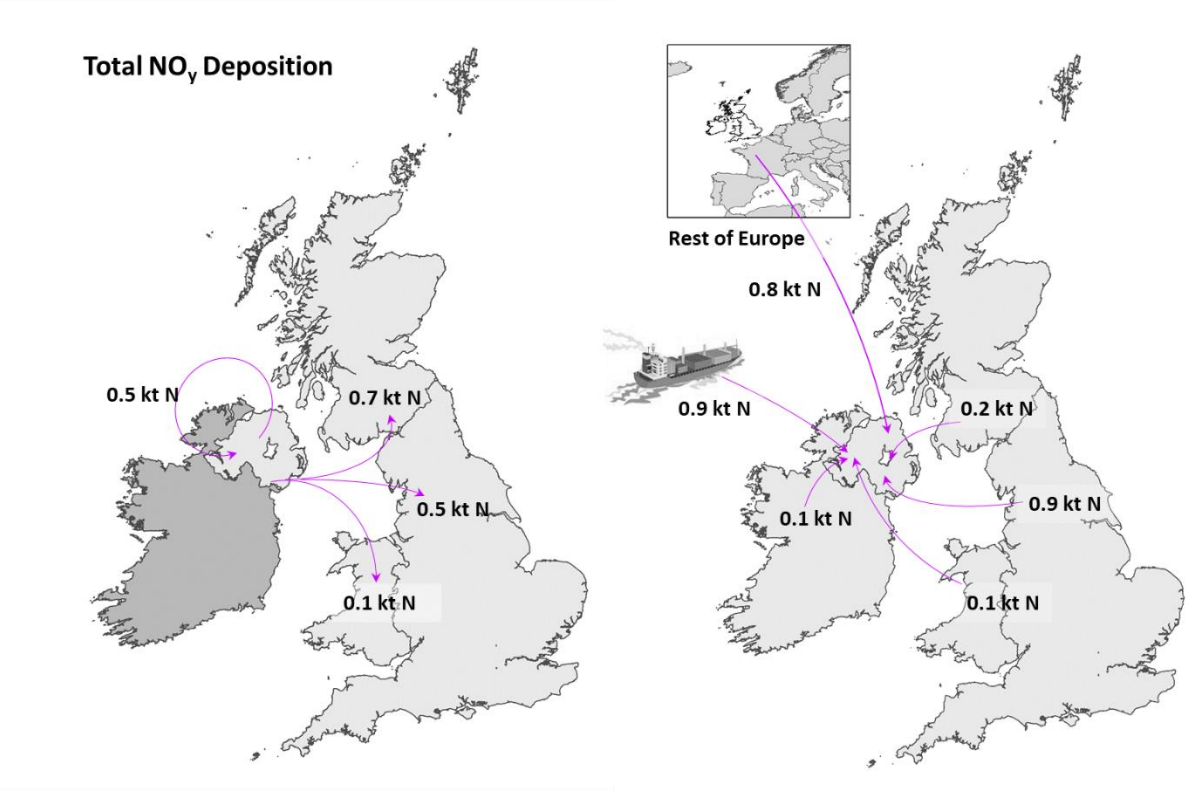

***Figure 4**: N deposition estimates to UK land from oxidised N (NO_y) emission sources within Northern Ireland (left) and estimated input to NI from sources outside of NI (right). N.B. values may not add up to totals in Table 2 due to rounding.*

3.3 Form of N deposition

Most of the dry deposition to land in Northern Ireland is from emission sources within NI (78 %). The majority (67 %) of the N deposition received by NI from sources outside of NI is in the form of wet deposition (Table 3). Similarly, most of the N deposition originating from NI being deposited in the rest of the UK is in the form of wet deposition (68 %). Figures 4 and 5 present the import/export terms of dry and wet deposition. The Figures show that NI exports more dry and wet deposition to the UK than it receives from the UK and Europe (inc RoI, offshore installations and international shipping). Dry deposition refers to the transfer of gases and aerosols and the gravitational settling of aerosols to the surface, whereas wet deposition occurs when aerosols are washed out and deposited to the surface through precipitation.

Table 3: *Modelled estimates of dry and wet nitrogen deposition received by Northern Ireland and deposition originating from sources within Northern Ireland.* ***N.B.*** *totals may not add up due to rounding to 2 significant figures.*

Country/area of origin	Deposition to land in NI (kt N yr^{-1})			Deposition originating from sources in NI to elsewhere (kt N yr^{-1})		
	Dry deposition	Wet deposition	Total N deposition	Dry deposition	Wet deposition	Total N deposition
Northern Ireland	4.1	2.1	6.3	-	-	-
Republic of Ireland	0.64	1.3	1.9	?	?	?
England	0.18	0.90	1.1	0.62	1.2	1.8
Wales	0.03	0.14	0.17	0.21	0.27	0.48
Scotland	0.07	0.30	0.38	1.7	3.7	5.4
Europe	0.09	0.83	0.92	?	?	?
Shipping	0.14	0.78	0.92	NA	NA	NA
Total	5.3	6.4	11.7	incomplete		

"?" *refers to information that cannot currently be quantified without additional modelling*

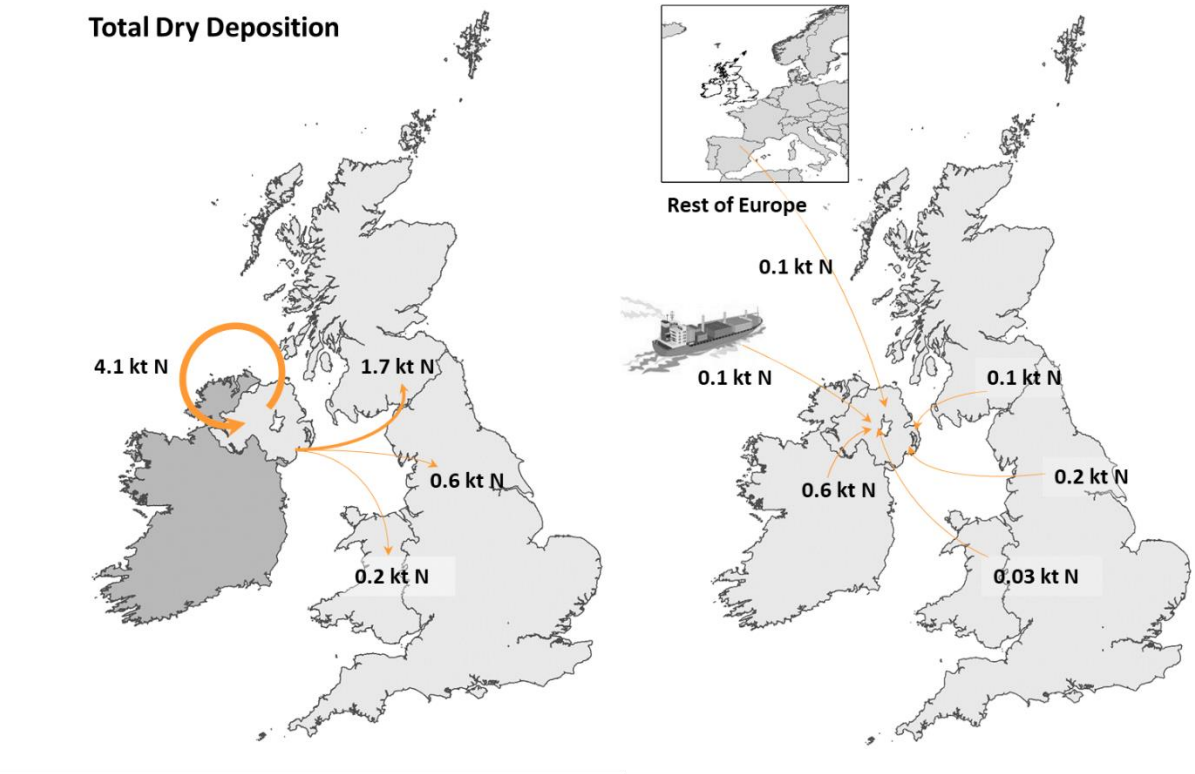

Figure 4*: Dry N deposition estimates to UK land from emission sources within Northern Ireland (left) and estimated inputs of dry deposition to NI from sources outside of NI (right). N.B. values may not add up to totals in Table 3 due to rounding.*

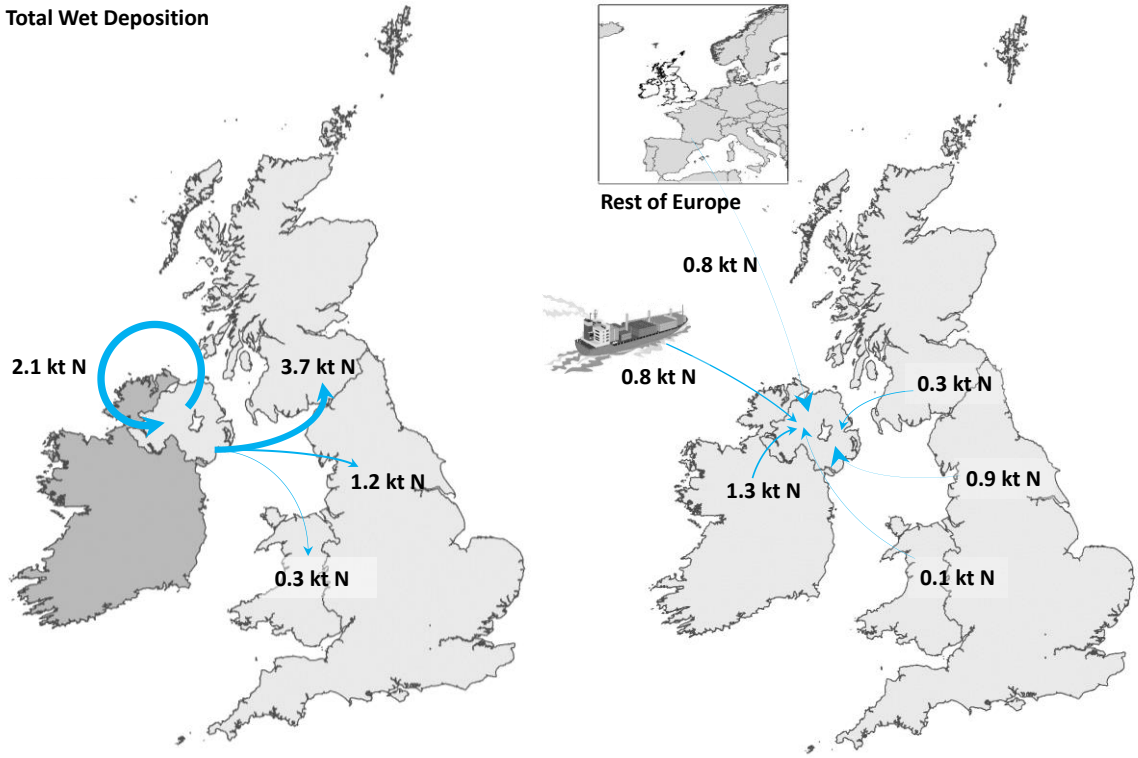

***Figure 5**: Wet N deposition estimates to UK land from emission sources within Northern Ireland (left) and estimated wet deposition input to NI from sources outside of NI (right). N.B. values may not add up to totals in Table 3 due to rounding.*

3.4 Comparison to previous source attribution estimates (for the year 2012)

3.4.1 Total N Deposition

Table 4 compares the import and export of N deposition to and from Northern Ireland estimated by the two most recent source attribution datasets (for the emission years 2012 and 2018). The most notable difference between the two datasets is the reduction in overall N deposition received by NI between the two datasets (18.0 kt N in 2012 to 11.7 kt N in 2018). In addition to using more up-to-date emission estimates, the 2018 version of the source attribution dataset also includes many improvements to the FRAME model; including improved land cover and meteorology estimates which better reflect the present. It is therefore difficult to directly compare the N deposition totals as the model versions are different. However, the decreased N deposition received by NI is likely to be predominantly due to methodological changes in emission estimates and emission reductions between the years (mainly from outside of NI). However other

changes to the model set up (including meteorology) may be a substantial contributor to these changes.

Table 4: *Comparison of the import and export of N deposition to and from Northern Ireland estimated by the two source attribution datasets (for the emission years 2012 and 2018).* ***N.B.*** *totals may not add up due to rounding to 2 significant figures.*

Country/area of origin	Deposition Type	Deposition to land in NI (kt N yr^{-1})			Deposition originating from sources in NI to elsewhere (kt N yr^{-1})		
		2012	2018	% change	2012	2018	% change
Northern Ireland	NH_x	9.1	5.8	-37%			
England		0.5	0.2	-56%	1.5	1.3	-14%
Wales		0.12	0.05	-53%	0.37	0.33	-11%
Scotland		0.47	0.22	-57%	4.3	4.7	8%
Republic of Ireland		-	*1.8*				
Europe (exc. RoI)		-	*0.1*				
Europe (inc. RoI)		3.1	1.9	-39%			
Northern Ireland	NO_y	0.77	0.48	-37%			
England		1.2	0.9	-26%	0.6	0.5	-8%
Wales		0.14	0.11	-17%	0.17	0.15	-14%
Scotland		0.22	0.17	-20%	0.67	0.71	6%
Republic of Ireland		-	*0.1*				
Europe (exc. RoI)		-	*0.8*				
Europe (inc. RoI)		1.2	1.0	-20%			
Offshore & International Shipping		1.2	0.9	-24%			
Total	NH_x	**13.3**	**8.1**	**-39%**	**6.2**	**6.3**	**2%**
Total	NO_y	**4.7**	**3.5**	**-25%**	**1.4**	**1.4**	**-2%**
Total	**Total N**	**18.0**	**11.7**	**-35%**	**7.6**	**7.7**	**1%**

4 Conclusion

This study and the previous report (Carnell and Dragosits, 2019) show that Northern Ireland exports more atmospheric N deposition to the rest of the UK (7.7 kt N) than it receives (from the UK and elsewhere, 5.4 kt N). The amount of N originating from sources within NI and deposited within NI is mostly from NH_3 emission sources (92%), with only 8% due to NO_y emissions, again this is similar to the results of the modelling for 2012 (Carnell and Dragosits, 2019). These atmospheric N inputs produced within the country are the fraction that can be tackled with NI-internal policy development. When taking into account atmospheric N input from all sources (NI-internal and beyond), a substantial proportion of the NH_x deposition is from sources within NI, while

NO_y deposition may be harder to tackle with a substantial proportion coming from the UK, Republic of Ireland and the rest of Europe, including shipping.

5 References

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