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Integrated nitrogen indicator, national nitrogen target and the current situation in Germany (DESTINO Report 1)

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Integrated nitrogen indicator, national nitrogen target and the current situation in Germany (DESTINO Report 1)

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Abstract

The excessive release of reactive nitrogen into the environment by agricultural production, energy conversion, and mobility leads to problems which have to be urgently addressed, including the loss of aquatic and terrestrial biodiversity, increasing air pollution, the release of greenhouse gases, and the increased difficulties faced when treating groundwater to provide drinking water. The planetary boundary for nitrogen has clearly been crossed.

In 2017, the German Federal Government drew attention to these problems in its first Nitrogen Report and established the need for inter-departmental action, and since then the German Environment Agency (UBA) has launched a number of projects. These include this DESTINO project, which has two objectives: firstly to derive an integrated nitrogen indicator across all sectors and for all media characterising the current situation, together with a national nitrogen target (Report 1), and secondly to update the National Nitrogen Budget in line with the requirements of the Gothenburg Protocol (Report 2).

Report 1 of the DESTINO project documents the process of deriving the integrated nitrogen indicator. This is oriented on nitrogen-sensitive environmental sectors: Maintaining biodiversity, avoiding eutrophication of ecosystems, preserving the quality of groundwater, surface waters, and air, and meeting climate action objectives. The national nitrogen target quantifies the limits which must not be exceeded if the objectives are to be met. This effect-based national nitrogen target is the first to be proposed for Germany which is complementary to the planetary boundary.

Starting from data for the exceedance of target values and for current nitrogen releases (e.g. emissions), back-calculations are used to quantify the maximum DESTINO target values as a spatial mean for the environmental sectors.

The value of the integrated nitrogen indicator for Germany (corresponding to the total annual nitrogen losses into the environment) is currently 1574 kt N a^{-1} (1 kt = 1000 tonnes), which is equivalent to ~19 kg N per person per year. Adding together the critical loads for the environmental sectors gives a total value of 1059 kt N a^{-1} for the national nitrogen target. Some of the sectoral targets are only valid for the next stage, but the long-term targets for the protection of human health and the environment, which would be more ambitious, have not yet been specified. If they were known, then the national nitrogen target would be even lower. Because of the methods used, the target values also represent minimum values, applicable for the national spatial average. In order to be able to meet the target values everywhere in Germany, greater reductions in nitrogen losses would be necessary. With the calculated national nitrogen target of 1059 kt N a^{-1}, the nitrogen losses must be reduced by at least a third. The national nitrogen target serves to augment existing sector-specific indicators and targets, showing the direction in which Germany should proceed with regard to reactive nitrogen. For communicative and political purposes, a rounded figure of 1000 kt N a^{-1} can be used. It is essential that the existing indicators for environmental sectors are supervised and updated in parallel, including the monitoring of the spatial components.

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Abbreviations and acronyms

a	Year (annum)
a^{-1}	per annum
AA	Agricultural area
BMEL	Federal Ministry of Food and Agriculture
BMU	Federal Ministry for Environment, Nature Conservation and Nuclear Safety
BMUB	Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO_2	Carbon dioxide
CLev	Critical Level: A concentration of a pollutant in the atmosphere above which direct adverse effects may occur to human beings, plants, ecosystems or materials
CL	Critical Load: a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.
CTM	Chemicals transport model
D	Deposition
DE	Germany
DESTINO	DEutsche STickstoffflüsse, INdikatoren und Objectives
DFG	German Research Foundation
DIN	Dissolved inorganic nitrogen
DON	Dissolved organic nitrogen
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
EU	European Union
GW	Groundwater
BGW	Body of groundwater. A distinct volume of groundwater within an aquifer or aquifers in accordance with the EU Water Framework Directive (WFD)
ha	Hectare
kt	Kilotonne
LAWA	German Working Group on Water Issues (*Länder-Arbeitsgemeinschaft Wasser*)
m^3	Cubic metre
MAK	Maximum workplace concentration (DFG)
mg	Milligram
µg	Microgram (millionth of a gram)
$\mu g\ m^{-3}$	Microgram per cubic metre
MONERIS	Modelling Nutrient Emissions into River Systems

MoRE	Modelling regional emissions
MSFD	Marine Strategy Framework Directive (2008/56/EC)
N	Nitrogen
NEC	National Emission Ceilings
NERC	National Emission Reduction Commitments
NH_3	Ammonia
NH_4^+	Ammonium ion
NH_y	Reduced nitrogen species
NLRP	National Clean Air Programme
NMVOC	Non-methane volatile organic compounds
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NO_3^-	Nitrate
N_2O	Dinitrogen oxide
OI	Optimum interpolation
PM2.5	Particulate matter with an aerodynamic diameter of less than 2.5 micrometres
RCG	REM/CALGRID: Chemicals' transport model
RT	Response threshold (WHO)
TN	Total nitrogen
UBA	German Environment Agency
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization
WFD	EU Water Framework Directive

Summary

DESTINO Project (Chapter 1)

The excessive release of reactive nitrogen into the environment by agricultural production, energy conversion, and mobility has led to problems that must be solved as a matter of urgency, such as the loss of aquatic and terrestrial biodiversity, air pollution, the release of greenhouse gases, and the increased difficulties faced when treating groundwater to provide drinking water.

In January 2015, the German Advisory Council on the Environment proposed strategies for resolving the urgent environmental problem of nitrogen (SRU 2015). However, little or no progress has been made in tackling many of the environmental problems faced in Germany, as UBA has shown (UBA 2017).

The German federal government is intensifying its efforts with regard to nitrogen. In “Nitrogen input in the biosphere” (BMUB 2017), attention was drawn to the urgent need for inter-departmental action. The first governmental nitrogen report was produced on the initiative of the Federal Environment Ministry and following this the German Environment Agency (UBA) launched a number of initiatives. One of these was this **DESTINO** project, which has had the remit of answering scientific questions relating to the development of an integrated strategy for the reduction of reactive nitrogen emissions. The results of are documented in two reports:

- **Deriving an integrated indicator for nitrogen**: A cross-sector and cross-media value for the total emissions of reactive nitrogen at the national level should mark the critical level for Germany or the limits of safe activity (Report 1).
- **Updating the national nitrogen budget:** A national nitrogen budget was drawn up in 2015 by the German Environment Agency using data for the period 2005 – 2010 (UBA 2015). The Gothenburg Protocol, which was revised in 2012, recommends that the signatory states should regularly update the national nitrogen budgets and report on developments. The “Guidance document on national nitrogen budgets” provides guidelines for producing such a budget (ECE 2013). In the DESTINO Project, the national nitrogen budget has been updated using this methodology (Report 2; UBA 2020).

This DESTINO Report 1 documents the derivation of the integrated nitrogen indicator and presents the data for the current situation. The national nitrogen target is calculated and compared with the current level.

The German Environment Agency monitors various environmental indicators relating to reactive nitrogen. A selection of the results is published annually in the “Data on the Environment – Indicator report” (UBA 2017). The DESTINO Project does not aim to replace such indicators, but rather to generate a set of compatible indicators and target values from which to derive an integrated nitrogen indicator with a corresponding (total) target value. The integrated nitrogen indicator combines indicators for various sectors. It represents an attempt to integrate the many impacts of reactive nitrogen species. It aims to synthesise the individual aspects, which has not previously been done in this form at the national level in Germany.

The project team presented its methodology and the provisional results for an integrated nitrogen indicator to a group of national and international experts in Berlin (6 September 2017). Various suggestions were made which contributed to the improvement of the approach.

Environmental sectors, targets, and DESTINO indicators (Chapter 2)

Table 1 shows the nitrogen-sensitive environmental sectors which have been allocated quantitative sectoral targets and for which DESTINO indicators and target values have been determined in this project.

Table 1: Environmental sectors, targets, and DESTINO indicators as components of the integrated nitrogen indicator

Sector	Target values	Basis	DESTINO indicators
Terrestrial ecosystems/Biodiversity	NH_3 ambient pollution level: Critical Level for vascular plants [a] 3 µg m^{-3} NH_3	Gothenburg Protocol [b]	NH_3 emissions
Terrestrial ecosystems/ Eutrophication	Nitrogen deposition: Critical Load N_{total} (values are ecosystem specific)	NEC Directive [c]	Total NH_3 and NO_x emissions
Surface waters	Nitrate concentration North Sea 2.8 mg N_{total} l^{-1} and Baltic Sea: 2.6 mg N_{total} l^{-1}	Ordinance on the Protection of Surface Waters [d]	N-load
Groundwater	Nitrate concentration in groundwater: 50 mg l^{-1}	Groundwater Ordinance [e]	Nitrate inputs (N-surplus)
Climate	N_2O emission: Climate Action Plan long-term goal	Climate action plan [f]	N_2O emissions
Human health	NO_2 ambient pollution level in air: WHO-Background response threshold 20 µg m^{-3}	HRAPIE Study of WHO [g]	NO_x emissions

[a] There is also a critical level for non-vascular plants (1 µg NH_3 m^{-3}). On the use of the critical level for vascular plants see Section 3.1.5
[b] http://www.unece.org/environmental-policy/conventions/envlrtapwelcome/guidance-documents-and-other-methodological-materials/gothenburg-protocol.html [31.08.2018]
[c] Directive (EU) 2016/2284 of the European Parliament and the Council, 14.12.2016
[d] German Surface Waters Ordinance (OGewV), 20.06.2016
[e] German Groundwater Ordinance (GrwV), 09.11.2010
[f] Climate Action Plan 2050, Principles and goals of the German government's climate policy. Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). November 2016
[g] Recommendations for concentration response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide (WHO 2013)

DESTINO indicators and targets (Chapter 3)

For each environmental sector and its associated target, a back calculation is developed with which the maximum permitted nitrogen losses (emissions, exceedances, inputs) can be calculated for each nitrogen species. Wherever the nitrogen losses exceed maximum permitted values then there is a need for action.

For each sector, we first investigated what data were available for the calculation of the maximum permissible nitrogen losses for the relevant nitrogen species or DESTINO-indicator. Specific methods were then developed for the environmental sectors, and the appropriate values were determined. The details are explained in the relevant chapters.

National nitrogen target (Chapter 4)

UBA has formulated a list of requirements for the integrated nitrogen indicator. Among other things, the national nitrogen target should be affect-based, and should treat the various environmental sectors equally. It should also be possible to upgrade the integrated nitrogen indicator periodically.

Figure 1 shows the selected environmental sectors with the DESTINO indicators (see also Table 1). These are presented relative to the six DESTINO-target values (100 %).

In order to derive the national nitrogen target, only the DESTINO-indicator is chosen which has the lowest target value for each specific nitrogen species. This means that the targets for NH_3 and NO_x emissions are adopted from the more sensitive of the two environmental sectors to which two indicators were allocated. The total for all nitrogen species gives the national nitrogen target value for the integrated nitrogen indicator (Table 2 and Figure 2):

- The national nitrogen target is the sum of the calculated, maximum permitted NO_x, NH_3, N_2O emissions, and nitrate exceedances, in order to remain below the target values or critical levels for the six nitrogen sensitive environmental sectors.
- The current value for the integrated nitrogen indicator is 1574 kt N a^{-1}, compared with the national nitrogen target of 1059 kt N a^{-1}. For the German population, this is equivalent in 2015 to nitrogen losses of 19.2 kg N per person per year. Achieving the target would have required a reduction to 12.9 kg N per person per year or lower.
- For communicative and political purposes, a rounded figure of 1000 kt N a^{-1} can be used.

Figure 1: The six environmental sectors and the current status of the DESTINO-indicators relative to the target values (100 %)

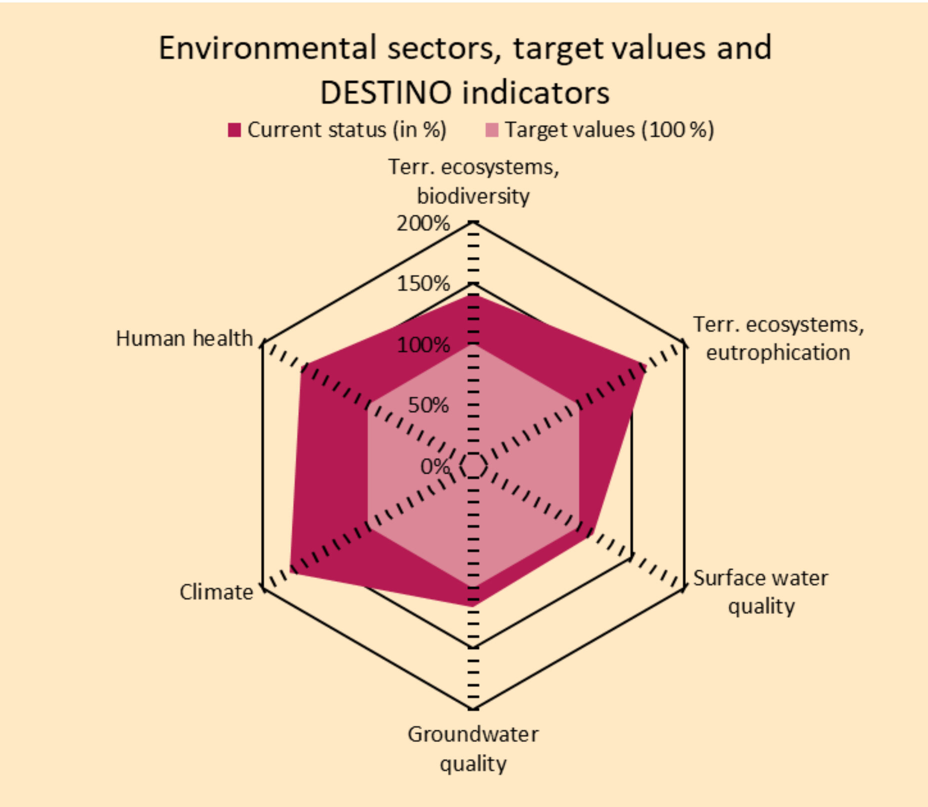
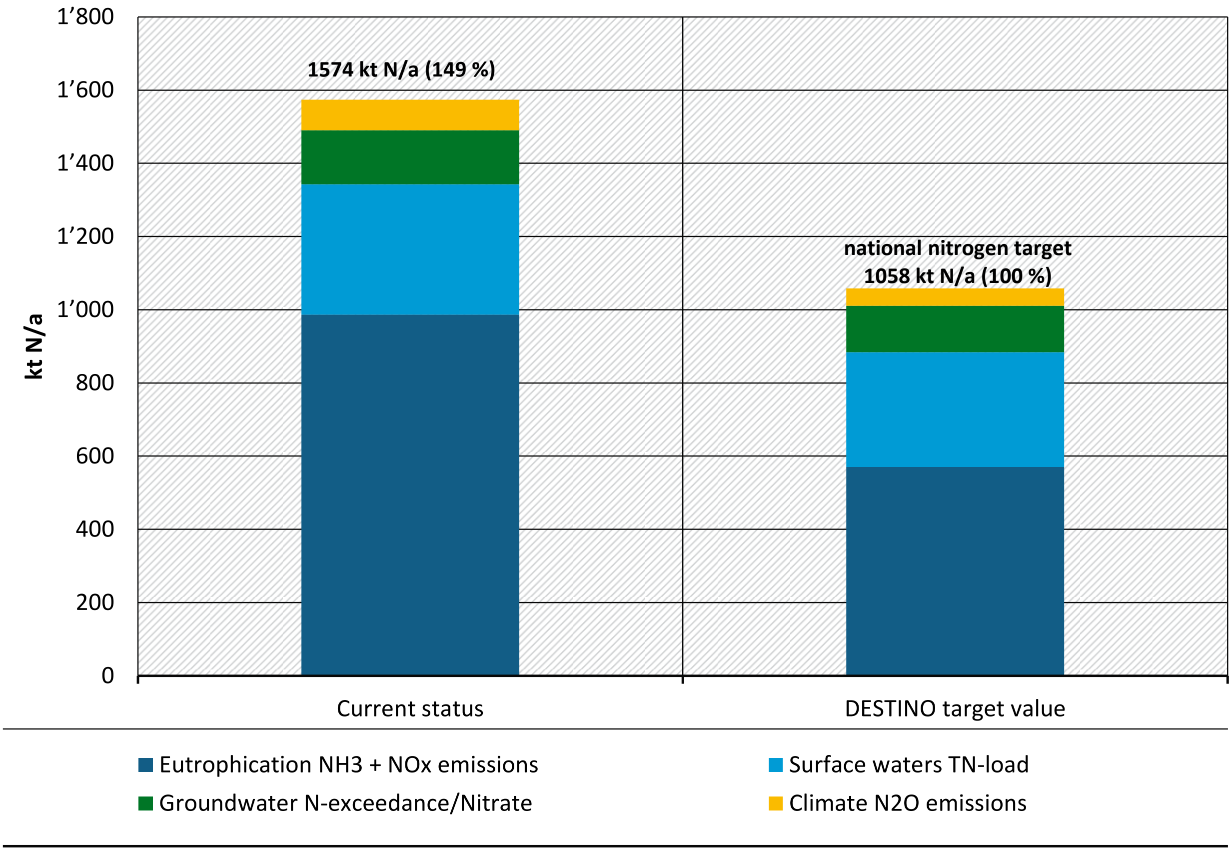


Table 2: The four DESTINO-indicators with the most demanding target values for each nitrogen species are used to calculate the integrated nitrogen indicator. Terrestrial ecosystems / biodiversity (NH_3 emissions) and Human health (NO_x emissions) are not taken into consideration because their target values are higher than for Terrestrial ecosystems / Eutrophication.

Sector	DESTINO-indicators		
	Nitrogen species	Current status (in kt N)	Lowest target value (in kt N)
Terrestrial ecosystems / eutrophication	NH_3 and NO_x emissions	625.3 kt NH_3-N a^{-1} 361.4 kt NO_x-N a^{-1}	402.0 kt NH_3-N a^{-1} 168.0 kt NO_x-N a^{-1}
Surface waters	Total nitrogen load	356.2 kt TN a^{-1}	314.0 kt TN a^{-1}
Groundwater	N-surplus / Nitrate	147.6 kt N a^{-1}	126.6 kt N a^{-1}
Climate	N_2O emissions	83.4 kt N_2O-N a^{-1}	47.8 kt N_2O-N a^{-1}
Integrated nitrogen indicator		**1574 kt N a^{-1}** (149 %)	**1059 kt N a^{-1}** (100 %)

Figure 2: Integrated nitrogen indicator current status and target value (national nitrogen target): in absolute terms (kt N a^{-1}) and as a percentage.



Source: Our calculations

The methods and results in this report represent a first attempt to create an integrated nitrogen indicator which describes the current situation and with which a national target for the total nitrogen-losses can be specified. The result shows that such an integrated nitrogen indicator is feasible. The proposed methods are relatively straightforward, but they require suitable data (measurements, modelling results). No ad-hoc data need to be collected to update the integrated nitrogen indicator, because all the necessary information is collected in the course of on-going environmental observations. Additional measurements or modelling will be required in order to check or refine the target value, but this work is being carried out or commissioned by the relevant public authorities and agencies. In our analyses, possible influences of imports and exports of pollutants are not taken into consideration. The methods are then simpler and the calculations are not dependent on measurements and model calculations from other countries. In Section 4.3.2 we discuss possible consequences of this for the DESTINO indicators.

For the most part, the results we obtained corresponded to our expectations: in short, nitrogen losses are currently much too high. On the basis of the calculated target values, a general reduction of at least one third is required. However, such a reduction is insufficient for two reasons: 1) The calculated target values are based on sectoral targets which are in turn only specified for an initial stage and fall short of the long-term goals for the protection of human health and the environment. This means that the **national nitrogen target is an interim target**. 2) The majority of the sectoral targets are calculated using spatial data and expressed as mean values or totals which no longer have a spatial dimension. With this concept, emissions constellations are still conceivable in which the national nitrogen target could be met in general, but at the same time the levels over (larger) areas of Germany levels were still in excess of the target values for some or all of the sectoral indicators. In other words, the target value for the integrated nitrogen indicator, as a spatial mean, represents a necessary but not sufficient condition for meeting the sectoral targets at every location. Further reductions will be needed if all sectoral targets are to be met everywhere. Therefore, the national nitrogen target can only augment existing, sector-specific spatial indicators and targets. It is essential that the existing indicators for environmental sectors are supervised and updated in parallel, including the monitoring of the spatial components. An integrated nitrogen indicator serves to express the complexities of the environmental problems posed by nitrogen in a single parameter, supporting the urgently necessary communications on reducing the losses of reactive nitrogen.

Reference is made in the report to planetary boundaries (Chapter 4.4), one of which is a planetary boundary for nitrogen. It is possible to scale these down to the German level, but the result is very highly dependent on the frame of reference used (e.g. per capita, per utilised agricultural areas, per capita consumption), so that the results have a correspondingly large uncertainty. The concept is limited to “intentionally fixed” nitrogen, so that environmental sectors and targets on which the integrated nitrogen indicator focusses are not taken into consideration.

1 DESTINO: German nitrogen flows, indicators and objectives

1.1 Project objectives and Work packages

Human activities have led to massive changes in the natural nitrogen cycle over the past century, and as a result the amounts of reactive nitrogen in the environment have increased dramatically (UBA 2015). The excessive release of reactive nitrogen into the environment through numerous anthropogenic processes – above all agriculture, energy conversion and mobility –has caused a range of problems that must be urgently addressed. These include the loss of aquatic and terrestrial biodiversity, increased air pollution and impaired human health, the increased release of greenhouse gases, which contribute to global climate change, and the increased difficulties posed by nitrate pollution when treating groundwater to provide drinking water. In January 2015, the German Advisory Council on the Environment published a special report with the title “Nitrogen: Strategies for resolving an urgent environmental problem”, calling for the development and implementation of a nitrogen reduction strategy for Germany (SRU 2015). As shown by UBA (2017), few or no positive developments can be identified in Germany with regard to these environmental problems. According to the German Advisory Council on the Environment:

“Nitrogen related objectives should be bundled, and the target system further developed. As an orientation, an overarching target for the total acceptable level of reactive nitrogen input into the environment in Germany should be defined. This overarching target should be based on ecosystem resilience and should be established via an interactive process involving the scientific community and the relevant sectors of society. This process should be based on cross-media modelling of inputs and the environmental impact of reactive nitrogen compounds. The overarching target should be supported by targets for nitrogen inputs in the agricultural sector, as well as for nitrogen emissions in the transport and energy sectors.” (SRU 2015a)

The German Federal Government has also intensified its activities with regard to the nitrogen problem. In Spring 2017, it published “Nitrogen input in the biosphere – First nitrogen report of the Federal Government” (Bundesregierung 2017) and drew attention to the urgent need for inter-departmental activities. Following this, the German Environment Agency (UBA) launched various projects, including one with the goal of answering scientific questions relating to the development of an integrated strategy for the reduction of nitrogen emissions. UBA had already called for tenders for a project in 2016 under the acronym DESTINO (**DE**utsche **ST**ickstoffflüsse, **IN**dikatoren und **O**bjectives), which was to provide two important contributions to a nitrogen reduction strategy:

Contributions:

1: Deriving an integrated nitrogen indicator.
A target value for the total depositions or the total emissions of reactive nitrogen at the national level in Germany was to mark the critical levels or the boundaries for safe activities across sectors and media. There are a number of individual indicators for the nitrogen problem, but no integrated nitrogen indicator. Such a general indicator is used in the discussion about climate change, namely the increase in the average global temperature in comparison with the pre-industrial level, with the aim of limiting the increase to well below 2 °C. This indicator has proved valuable because it bundles together all the complex heating and cooling effects and can describe the aggregate impact in a single quantity. It has played an important role in the political communication of the problem of climate change. The goal of the DESTINO project is the development of a comparable nitrogen indicator which could support the communication of the equally complex environmental problem posed by nitrogen. This **integrated nitrogen indicator** should describe the current situation, the target value, positive or negative trends, and the effects of technical instruments and political measures over time. The target value is referred to in the following as the **national nitrogen target**.

2: Updating the national nitrogen budget

In Article 7, “Reporting”, of the Gothenburg Protocol (“Multicomponent Protocol”) of the CLRTAP (UNECE 2012) the Parties are called on to report on their nitrogen budget and developments. Such nitrogen budgets are also a central element of the national nitrogen strategy. National nitrogen budgets highlight problematic areas and options for action within the complex nitrogen cycle by integrating nitrogen flows for all environmental media. The national nitrogen budget can be used to derive recommended actions for policy-makers, the business sector, and consumers. The current national nitrogen budget was compiled in 2015 by the German Environment Agency (UBA, 2015) on the basis of data for the period 2005 – 2010. As part of the national nitrogen strategy, this dataset must be updated to take into account further developments in the emissions inventory. For example, current agricultural ammonia emissions reflect new information about emission factors and new source groups and differ substantially from values reported in earlier years. Also, the previous national nitrogen budget did not fully take transboundary nitrogen flows into account, in particular imports and exports of agricultural products. This study aims to address these deficits, because the national nitrogen strategy should be based on the latest available data and relevant transboundary nitrogen flows.

The DESTINO Project is structured in four work packages:

1. Deriving an “integrated nitrogen indicator” together with a target value (“national nitrogen target”).
2. Characterising the indicators that are necessary to derive and update the integrated nitrogen indicator.
3. Updating the national nitrogen budget for Germany, as described in the Guidance Document for the revised Gothenburg Protocol and its annexes (UNECE 2013).
4. Conducting two consultation meetings with external experts on Work packages 1, 2 and 3. One meeting on the sectoral indicators took place on 6 September 2017 in the Federal Press Office in Berlin, the other on nitrogen flow analysis took place on 2 May 2018 in UBA, also in Berlin.

This report covers Points 1 and 2, as well as the conclusions drawn from the consultations on the integrated nitrogen indicator (Point 4). The results for Point 3 are published separately (UBA 2020).

1.2 DESTINO activities

The work packages were discussed at a Kick-off meeting in UBA in Dessau (INFRAS 2016a) and developed in further detail in a strategy paper (INFRAS 2017).

In May 2017, a discussion meeting took place at the UBA offices in Berlin which considered ways to derive the integrated nitrogen indicator (INFRAS 2017a). This was followed by a meeting of experts on 6 September 2017, again in Berlin (INFRAS 2017a). Methods and proposals for the integrated nitrogen indicator were discussed and guidelines formulated. Results already obtained at this stage were documented in an interim report (UBA 2017f). In December 2017, a further meeting was held at UBA in Dessau at which the methods were refined.

This report documents the following DESTINO activities:

- Chapter 2 gives an overview of the environmental sectors considered, the targets for these, and the DESTINO indicators.
- Chapter 3 describes how maximum emissions of nitrogenous substances and the current levels of the emissions were estimated for the environmental sectors and for the current levels of the emissions.

- Chapter 0 shows how a suitable integrated nitrogen indicator can be constructed, how the current status can be calculated, and how this can be compared with the target value.
- Chapter 5 contains annexes with background data and methodological additions, with an overview of the nitrogen indicators that must be drawn on in order to periodically update the integrated nitrogen indicator.

The details of the national nitrogen budget and the results are documented in a separate report (UBA 2020).

2 Environmental sectors, targets, and DESTINO indicators

2.1 Overview

In the detailed concept for the DESTINO Project (INFRAS 2017), six environmental sectors were specified which were to be taken into account to derive an integrated nitrogen indicator. These are the environmental sectors most affected by the losses of nitrogenous substances into the environment. Each environmental sector has a target value based on critical levels defined in environmental legislation or a binding government document. Environmental sectors and targets are listed in Table 3.

Table 3: Environmental sectors, target values and DESTINO-indicators as components of the integrated nitrogen indicator.

Environmental sectors	Target values	Basis	DESTINO-indicators
Terrestrial ecosystems/biodiversity	NH_3 ambient pollution level: Critical level for vascular plants [a] 3 µg m^{-3} NH_3	Gothenburg Protocol [b]	NH_3 emissions
Terrestrial ecosystems/ Eutrophication	Nitrogen deposition: Critical Load N_{tot} (values are ecosystem-specific)	NEC Directive [c]	Total NH_3 and NO_x emissions
Surface waters	Nitrate concentration North Sea 2.8 mg N_{tot} l^{-1} and Baltic Sea: 2.6 mg N_{tot} l^{-1}	Surface water Ordinance [d]	N-load
Groundwater	Nitrate concentration in groundwater: 50 mg l^{-1}	Groundwater Ordinance [e]	Nitrate input (N-surplus)
Climate	N_2O emission: Long-term goal Climate action plan	Climate Action Plan [f]	N_2O emissions
Human health	NO_2 ambient pollution level in air: WHO-Background response threshold 20 µg m^{-3}	HRAPIE Study of WHO [g]	NO_x emissions

[a] There is also a critical level for non-vascular plants (1 µg NH_3 m^{-3}). On the use of the critical level for vascular plants see Section 3.1.5
[b] http://www.unece.org/environmental-policy/conventions/envlrtapwelcome/guidance-documents-and-other-methodological-materials/gothenburg-protocol.html [31.08.2018]
[c] Directive (EU) 2016/2284 of the European Parliament and the Council, 14.12.2016
[d] German Surface Waters Ordinance (OGewV), 20.06.2016
[e] German Groundwater Ordinance (GrwV), 09.11.2010
[f] Climate Action Plan 2050, Principles and goals of the German government's climate policy. Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). November 2016
[g] Recommendations for concentration response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide (WHO 2013)

For each environmental sector, maximum permitted nitrogen losses (emissions, exceedances, inputs) were derived from the target values by back-calculation[1]. The relevant parameters, referred to in this report as "DESTINO-indicators", are also specified in Table 3.

[1] Emissions cause ambient pollution, expressed mathematically as c = f(E). In the DESTINO-Project, we have used the inverse function $E = f^{-1}(c)$ – a method referred to as 'back-calculation'.

The target values for the DESTINO-indicators are derived in Chapter 3. The approach adopted depends on the environmental sector in question. Various options were tested in the DESTINO project, and evaluated in terms of the following criteria:

- Readily available input data
- No spatial simulations required
- Robust results

For Terrestrial ecosystems and Health, the DESTINO indicators correspond to the NO_x and NH_3 emissions for which the NEC Directive (EU 2016/2284) has specified reduction commitments to be achieved by 2020 and 2030. The DESTINO target values are compared with the NEC targets in Sections 3.2.5and 3.6.5.

2.2 Methodology

2.2.1 The temporal and spatial dependence of the DESTINO indicators

The nature of the integrated nitrogen indicator (Section 4.1.1) requires that it should be periodically updated and compared with the target value. The integrated nitrogen indicator is thus dependent on the reference year and can be regarded as a function of time (time as an independent and discrete variable). The integrated nitrogen indicator relates to the total area of Germany and is not dependent on any particular location within Germany (i.e. it is an 'extensive' quantity). Otherwise, it would vary from place to place and could no longer be expressed as a single value.

Section 4.1 describes how the integrated nitrogen indicator is formed as a composite of selected sectoral indicators. These DESTINO sectoral indicators are determined in the same units as the integrated nitrogen indicator and are also only dependent on the reference year (as extensive quantities). In some cases, they are derived from spatial data, but the DESTINO-indicators and their target values are not themselves spatially differentiated. The consequences of this are discussed in Section 4.3.2.

2.2.2 Conversion factors and units

All the DESTINO-indicators involve reactive nitrogen species (NO_x, NH_3, N_2O, nitrate ions [2]), which in contrast to molecular nitrogen (N_2) can react with organic and inorganic substances to form new compounds. In order to be able to combine the various compounds to form the integrated nitrogen indicator (Section 4.1), they are expressed in terms of the proportion of nitrogen by mass. The following conversion factors are used:

Table 4: Conversion factors for N-compounds

Conversion factors	Inverse factors
1 t NO_x = 0.304 t NO_x-N	1 t NO_x-N = 3.29 t NO_x
1 t NH_3 = 0.824 t NH_3-N	1 t NH_3-N = 1.22 t NH_3
1 t N_2O = 0.636 t N_2O -N	1 t N_2O -N = 1.57 t N_2O
1 t NO_3 = 0.226 t NO_3-N	1 t NO_3-N = 4.43 t NO_3

NO_x emissions are expressed as an NO_2-equivalent.

2 In the case of surface waters, the N-burden includes other ions (e.g. nitrite), but these are only in negligible quantities.

DESTINO-indicators and the integrated nitrogen indicator are expressed in terms of annual loads of nitrogen in kilotonnes (kt):

1000 tonnes nitrogen = 1 kilotonne nitrogen = 1 kt N

The DESTINO-indicators and the target values are compared both in absolute terms (in kt N a^{-1}) and also as relative percentages, with the target values set at 100 %.

Consider as an example the DESTINO-indicator Climate (Section 3.5.4). At present, this indicator has a value of 83.4 kt N_2O-N a^{-1}. The target value is 47.8 kt N_2O-N a^{-1}, which for a relative comparison is set at 100 %, so that the indicator currently has the relative value of 174 % (= 83.4/47.8 x 100 %). To achieve the target value will require a reduction[3] of 74 percentage points. It might seem more usual to set the current level at 100 %, in which case the target value would be 57 % in relative terms and a reduction by 43 percentage points would be required. However, this would have the serious drawback that any future up-date of the DESTINO-indicator would change the expression of the target values in relative terms. The convention we have chosen means that the target values remain constant in terms of both absolute values and relative comparisons.

2.2.3 DESTINO-indicators compared with other nitrogen indicators

UBA monitoring of the state of the environment includes various reactive nitrogen indicators. Those which are particularly relevant for German and international environmental policies are published on its web site[4]. Every two years, UBA issues an indicator report entitled Data on the Environment (cf. UBA 2017). Many of the 50 environmental indicators relate to the undesired effects of reactive nitrogen and are therefore also relevant for the DESTINO Project. The indicators target the status of environmental sectors or Germany's undertakings on maximum emissions made in international agreements. The DESTINO Project drew on these environmental sectors and their indicators and used back calculation to determine the maximum permitted emissions. Depending on the environmental sector, the maximum emissions were higher or lower than the critical levels in the international agreements. Therefore, the target values for the DESTINO-indicators should be regarded **as additions** to the other target values. The goal of the DESTINO Project is not to replace other nitrogen target values, but to generate a set of compatible sectoral values from which a single target value can be derived for the integrated nitrogen indicator.

The variety of impacts of reactive nitrogen make it more difficult to express the entire nitrogen problem in one go. The integrated nitrogen indicator and its target value are intended to resolve this problem.

3 Note that an x % <u>reduction</u> corresponds to a <u>change</u> of -x %.

4 https://www.umweltbundesamt.de/daten/umweltindikatoren [31.08.2018]

3 DESTINO-indicators and the target values

3.1 Terrestrial ecosystems: Impacts due to ammonia

3.1.1 Impact mechanism

Ammonia emissions lead to acidification and eutrophication, impacting on terrestrial and aquatic ecosystems. In natural and near-natural ecosystems, excessive levels of ammonia in the air can affect biodiversity; increased ammonia concentrations can also directly damage vegetation.

Ammonia is released primarily by the degradation of urea or uric acid from the excretions of farm animals, and by the application of synthetic nitrogen fertilisers. The soil pH value and the temperature influence whether the reactive nitrogen takes the form of ammonia (NH_3) or ammonium-ions (NH_4^+) and how much finds its way as NH_3 into the atmosphere.

For these reasons, the Terrestrial ecosystems were chosen as environmental sectors for the DESTINO Project. The impact mechanism leads from the ammonia emissions as cause to the excessive ammonia pollution levels as effect. Using a simplified back calculation, the maximum annual load of ammonia emissions can be estimated which allow compliance with the target values for the ambient ammonia concentrations in Germany.

3.1.2 Sectoral target and the DESTINO target value

The ambient concentration of ammonia in the atmosphere is not limited under EU air quality provisions, or under German legislation. However, on the basis of studies of ammonia concentrations in the air required for the protection of sensitive vegetation, the Convention on Long-Range Transboundary Air Pollution (CLRTAP) recommends the following mean annual “Critical Levels” (ICP MODELLING & MAPPING 2017, Table 3.3):

C_{Lev} = 3 µg NH_3 m^{-3} for vascular plants

C_{Lev} = 1 µg NH_3 m^{-3} for non-vascular plants (e.g. lichen and mosses)

When determining the national DESTINO target value, only the critical level for vascular plants is considered. Since ammonia concentrations are affected mainly by local emissions, compliance with the critical levels for non-vascular plants would require a spatially differentiated approach.

The CLRTAP also includes Critical Loads for nitrogen inputs which correspond to the sum of oxidised nitrogen compounds (NO_x) and reduced nitrogen compounds (NH_y; e.g. ammonia). A limit on the ammonia emissions to comply with the Critical Loads is discussed in Section 3.2.

3.1.3 Method for calculating maximum ammonia emissions

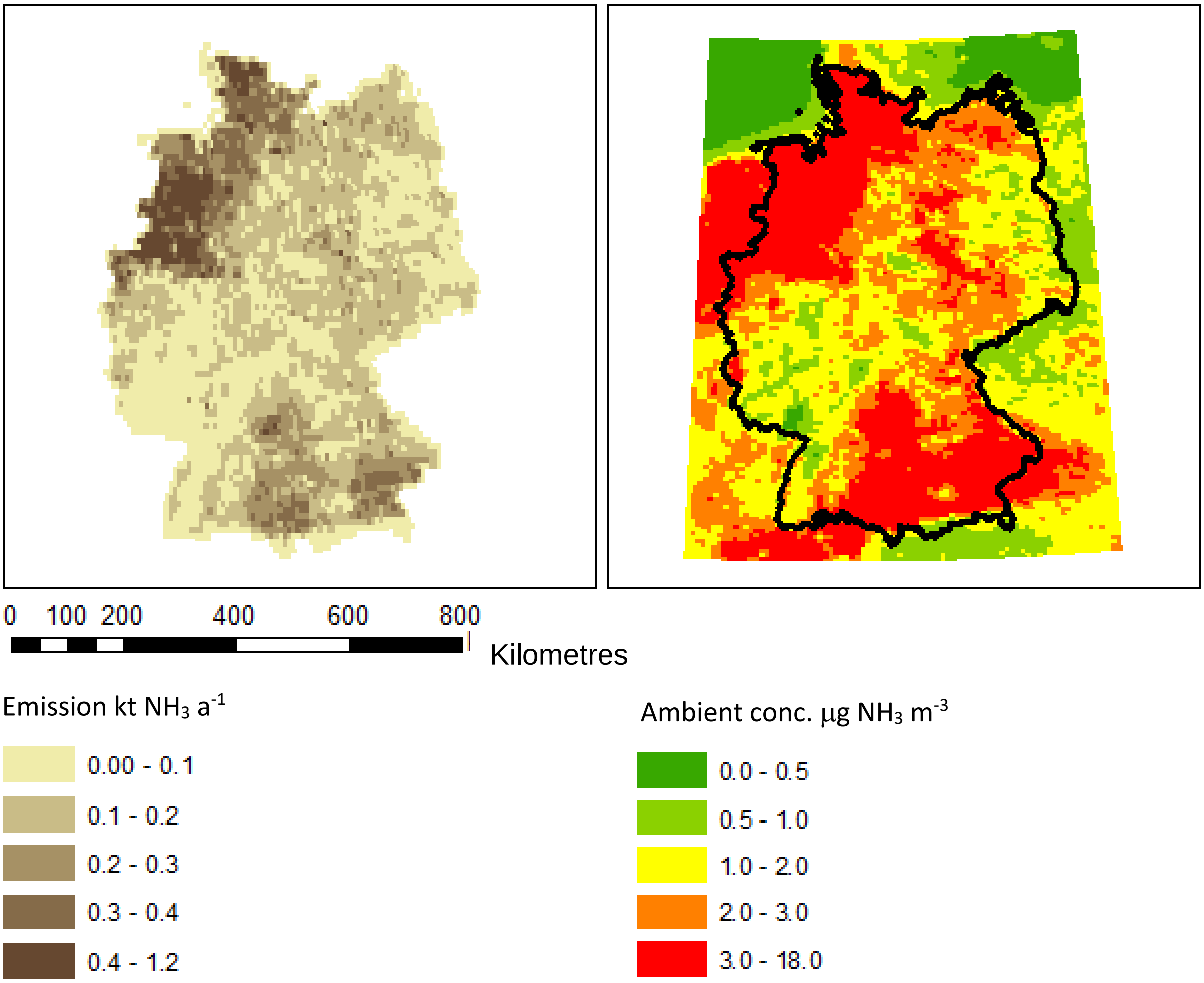
The maximum permissible ammonia emissions are calculated on the basis of spatially resolved data for emissions and ambient concentration levels (Figure 3). The national total emissions are reported annually to the CLRTAP. The total amount is made up of emissions from various sources. For each type of source, the specific proportions of emissions are distributed by means of suitable parameters to individual area, point, and line sources, allocated to the cells of a grid, and mapped (UBA 2016, Figure 3, left).

Using the REM-CALGRID model[5], the emissions can also be presented cartographically (UBA 2015a). The ambient ammonia concentrations are based on the results of the RCG chemical transport model. The temporal resolution of this data is 1 hour, with a spatial resolution of 0.03125° longitude and 0.015625° latitude. Using this, maps are generated with a spatial resolution of 2 km x 2 km (Figure 3, right).

Over wide areas, the ambient ammonia concentrations in Germany exceed the critical level for non-vascular plants (1 mg NH_3 m^{-3}). The critical level for vascular plants is also exceeded in many places, in particular in north-west and south-east Germany. These are also the regions with the highest emissions (Figure 3).

Figure 3: Maps of ammonia emissions and ambient concentrations 2015

a) ammonia emissions b) ambient ammonia concentrations



Spatial distribution of (a) ammonia emissions and (b) ambient ammonia concentrations
(a) based on the data for 15.02.2017[6] and the spatial distribution with GRETA (EMEP Grid) Data source: UBA (2017a).
(b) modelled with the CTM-Model RCG

In order to achieve compliance with the Critical Level for the ambient ammonia concentrations, it is necessary to derive a corresponding maximum value for the ammonia emissions. The spatially

[5] RCG: REM/CALGRID chemical transport model

[6] https://www.umweltbundesamt.de/daten/luftbelastung/luftschadstoff-emissionen-in-deutschland [31.08.2018]

resolved ambient concentrations and emissions show a strong correlation (Figure 4). The maximum permissible emissions per grid cell can therefore be derived from a linear regression of the spatially-resolved data.

The following equation can be used to calculate the ambient ammonia concentrations on the basis of the emissions:

$$Am_{NH3} = a\ Em_{NH3} + \mathrm{b} \qquad [\mu g\ m^{-3}] \qquad \text{(Eq. 1)}$$

where Am_{NH3} is the ambient ammonia concentration and Em_{NH3} is the ammonia emissions. The parameter a is the slope of the regression line and b is the intercept.

Substituting the Critical Level for vascular plants (C_{Lev}) into this regression equation as the ambient concentration, it is possible to derive the maximum permissible emission ($Em_{NH3,max}$).

$$Em_{NH3,max} = \frac{C_{Lev} - b}{a} \qquad [kt\ a^{-1}] \qquad \text{(Eq. 2)}$$

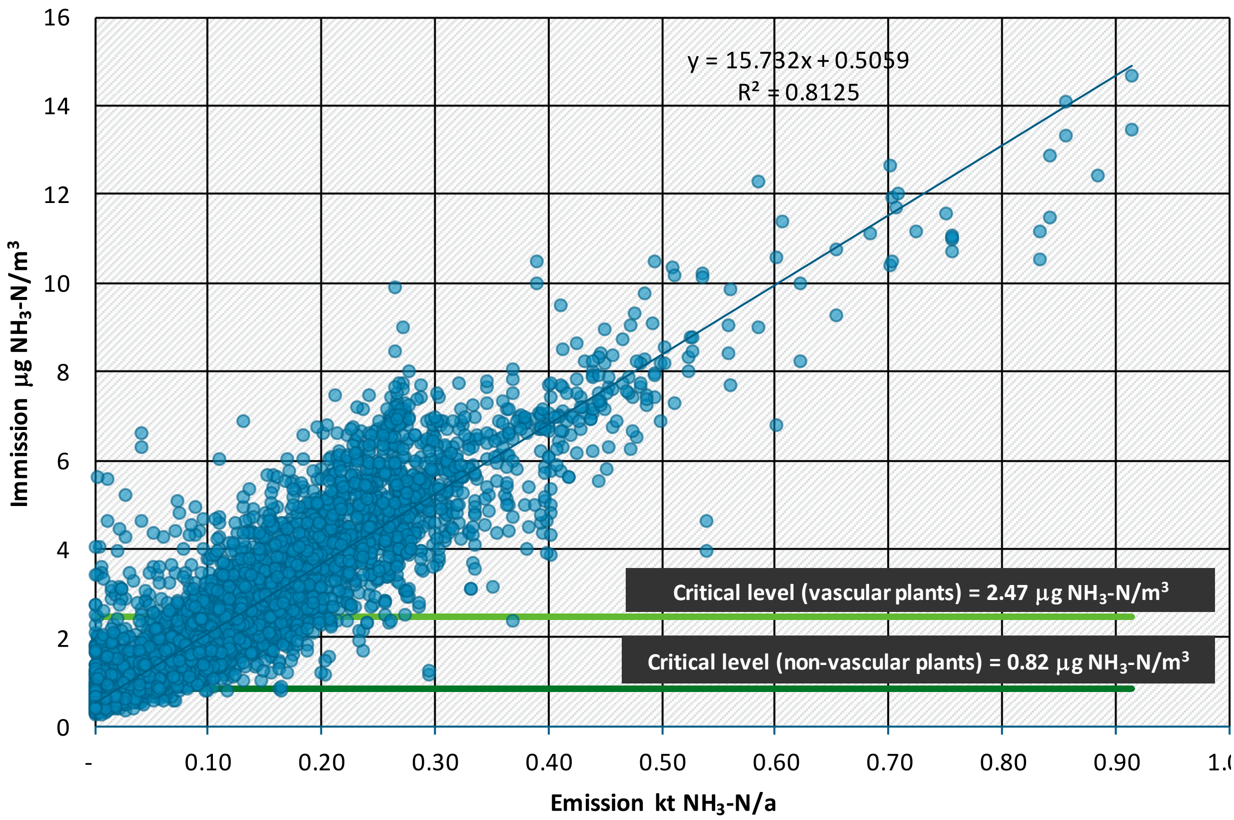
The total over all N grid cells of the positive differences between the emissions per grid cell (Em_{NH3}) and the maximum permissible emissions quantity ($Em_{NH3,max}$) corresponds to the reduction of the total emissions (R_{NH3}) that is required in order to remain below the critical level.

$$R_{NH3} = \sum_{i=1}^{N} (Em_{NH3,i} - Em_{NH3,max}) \ \ \forall \{i | Em_{NH3,i} - Em_{NH3,max} > 0\}, \qquad [kt\ a^{-1}] \qquad \text{(Eq. 3)}$$

Total no. of grid cells, N = 6314

However, a reduction of the total emissions by R_{NH3} can only ensure that the average value is not above the critical level. It remains very likely that the critical level will still be exceeded in certain locations, for example in the vicinity of larger point sources. Therefore, the spatial differentiation of the maximum permissible emissions must be taken into consideration.

Figure 4: Deriving the maximum ammonia emissions (Data for 2015, as of 2017)



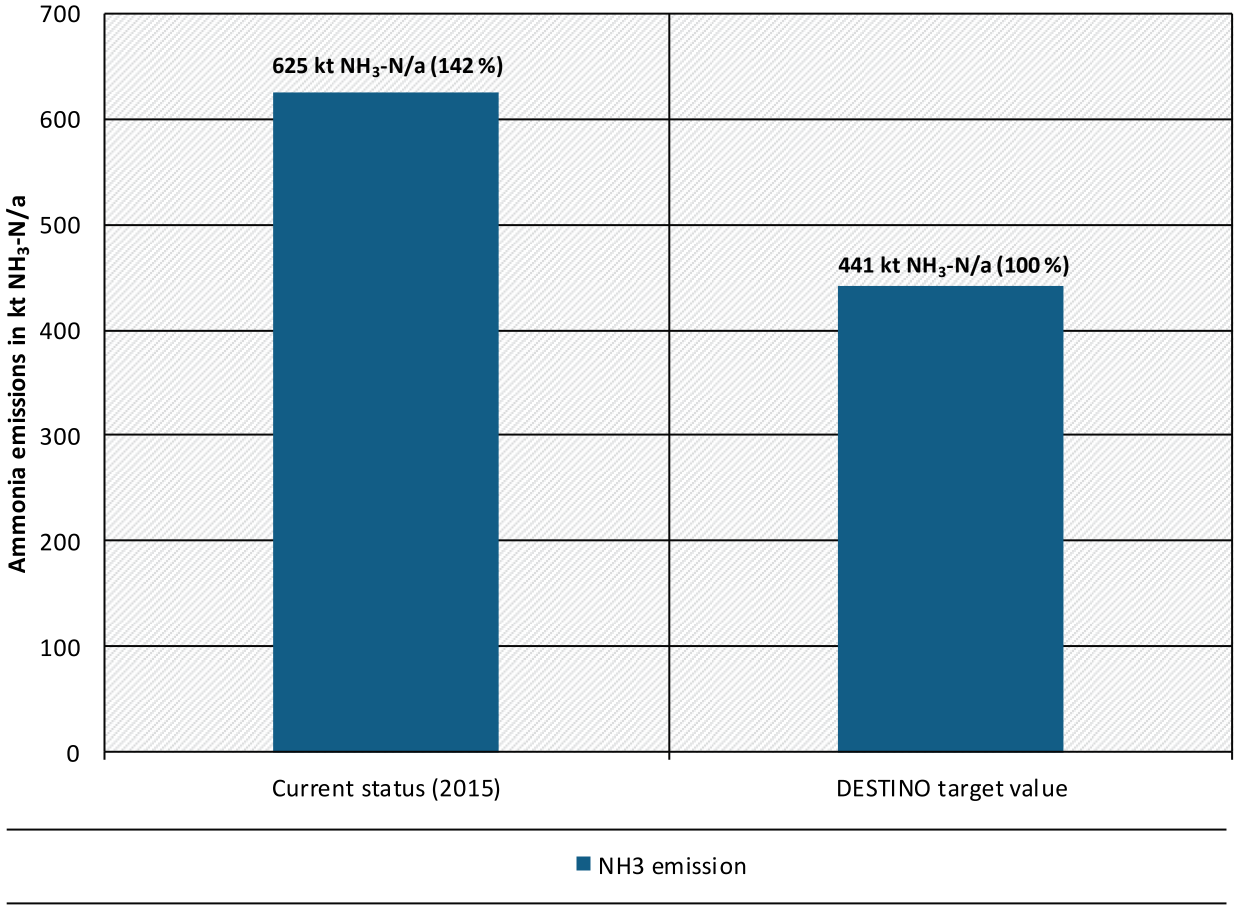
Source: UBA 2017a

The maximum permissible NH_3 emissions for compliance with the Critical Level can be derived from a linear regression between ambient ammonia concentrations and ammonia emissions per grid cell. Data source: UBA 2017a. Only the critical level of 3 µg NH_3 m^{-3} for vascular plants is considered, corresponding to 2.47 µg NH_3-N m^{-3}.

3.1.4 Results for the DESTINO indicator and target value for Terrestrial ecosystems / Critical Level

The DESTINO-target value is derived on the basis of the Critical Level for vascular plants (Figure 4). In order to meet the critical level of 3 µg NH_3 m^{-3} (=2.47 µg NH_3-N m^{-3}), the annual NH_3 emissions per grid cell must be a maximum of 0.12 kt NH_3-N a^{-1}. The DESTINO target value is therefore 441 kt NH_3-N a^{-1}. In 2015, the ammonia emissions were 625 kt NH_3-N, which is 42 % above the DESTINO target value (Figure 5).

Figure 5: DESTINO-indicator terrestrial ecosystems / Critical Level (biodiversity) for NH_3 emissions for 2015 and the DESTINO target value.



Source: Our calculations

NH_3 emissions in 2015 and DESTINO target value. Data source: Our calculations, see Figure 25.

3.1.5 Interpretation and assessment

1) We recommend updating the concentration modelling at intervals and checking the effect on the emission target. The February 2018 CLRTAP submission of the German air pollutant inventory updated the time series of NH_3 emissions (UBA 2018). As the result of changes in the methodology, the NH_3 emissions for 2015 were 11.7 % lower than in the February 2017 submission (UBA 2017b). This is a considerable difference, which can have an appreciable effect on the ambient concentration modelling and thus also on the calculation of the emission target (i.e. this is a “moving target”). It is also necessary to test how the continued reduction in the emissions affects the statistical relationship between the emissions and the ambient concentrations.

2) With the methods used, it is only possible to guarantee compliance with the national target value as a mean for all the grid cells considered. If the value in a future year reaches the target, then the mean NH_3 concentration over all the grid cells combined will be below the Critical Level, but it is highly probable that in some grid cells the value will be higher than this, while at the same time in other cells the value will be lower. Complying with the target value is therefore a necessary but not a sufficient criterion.

3) The calculation of the DESTINO-target value based on the critical level for vascular plants gives a value of 441 kt NH_3-N a^{-1}. Compliance with the critical level for non-vascular plants (1 mg NH_3 m^{-3}) would require a much greater reduction of ammonia emissions, namely to 96 kt NH_3-N a^{-1}. The

current status would then be 653 % relative to this critical level. The reduction target would be considerably lower than the target for ammonia emissions in the NEC Directive (cf. Section 3.2.4). However, since the ambient NH_3 concentrations are closely linked to local NH_3 emissions, a spatially aggregated application of the critical level for non-vascular plants is not appropriate. Reductions would be required in the direct vicinity of the locations with exceedances. The critical level of 1 µg NH_3 m^{-3} is therefore not an appropriate basis for a reduction target at the level of the national ammonia emissions.

4) In order to test how robust the method is, it would be necessary to investigate the sensitivity with regard to the size of the grid cells. Such in-depth spatial examinations were outside the current remit of the DESTINO project, but should be included in the future updating of the indicator.
5) An area-related indicator for the impacts on terrestrial ecosystems can be derived on the basis of the number of grid cells of the NH_3 concentration maps (Section 4.3.5). However, the area-related indicator does not allow conclusions to be drawn about the extent of reductions in emissions and is therefore not suitable for the construction of an integrated nitrogen indicator.
6) In the UBA indicator report Data on the Environment 2017 (UBA 2017), ammonia emissions are included as an indicator for eutrophication (under “Emission of air pollutants”). Since 1995, ammonia emissions have increased by 12 %. The targets for the indicator are the reduction targets specified in the NEC Directive. The quantification of the indicator is based on the indexed development of the air pollutants in question. The indicator “Emission of air pollutants” is expressed as the mean value of five air pollutants (sulphur dioxide, nitrogen oxides, ammonia, NMVOCs, particulate matter PM2.5). But this aggregate indicator, which does not consider spatial differences, is not directly comparable with the DESTINO-indicator for Terrestrial ecosystems / Critical Level (biodiversity). The UBA indicator report does not include an appropriate indicator for the direct impact of ammonia on vegetation.

3.2 Terrestrial ecosystems: Impacts of nitrogen inputs

3.2.1 Impact mechanisms

Air pollutants can be transported over long distances in the atmosphere. In the course of the transport, they can be removed from the atmosphere, either as a gas, as particles, or dissolved in precipitation and air humidity and deposited in ecosystems, where they can have unwanted or harmful impacts on soils, or flora and fauna. For near-natural, unfertilised terrestrial ecosystems, pollutant depositions from the atmosphere frequently constitute the most important pollution pathway. In particular, the eutrophying effects of the reactive nitrogen species NH_3 and NO_x threaten biodiversity. High levels of nitrogen depositions over longer periods change the balance between reactive nitrogen and other nutrients in soils (e.g. magnesium, phosphorus, and potassium). Unbalanced nutritional status in an ecosystem can reduce the capacity to withstand short-term disturbances or stress (frost, drought, pests)[7]. Current depositions are assessed by comparison with the ecosystem-specific critical loads.

3.2.2 Sectoral target and the DESTINO target value

There are no legal limits on the nitrogen inputs, as such. However, the German federal government has ratified the CLRTAP and its protocols and has thus committed itself to comply with the recommended critical loads for nitrogen depositions in the long term. Long-term compliance with the critical loads

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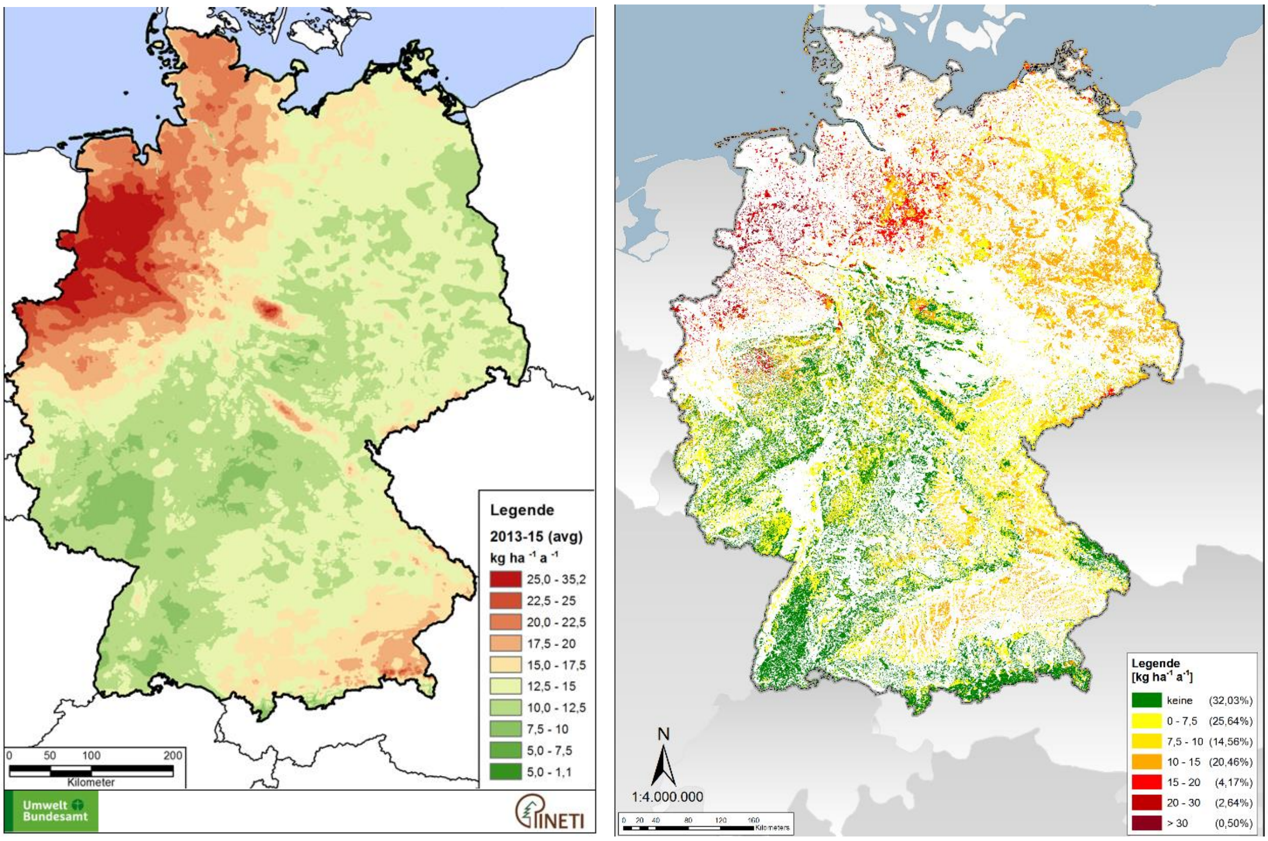
7 https://www.umweltbundesamt.de/themen/luft/wirkungen-von-luftschadstoffen/wirkungen-auf-oekosysteme#text-part-2 [31.08.2018]

for eutrophying nitrogen depositions is also the target of the German Sustainability Strategy of 2016 and the Biodiversity Strategy of 2007.

A critical load is the amount of estimated nitrogen depositions below which there are no harmful effects for sensitive elements; the load can be modelled using a simple mass balance (SMB) or determined empirically by experiment. The empirical critical loads or ranges can be determined on the basis of impact studies (ICP MODELLING & MAPPING 2017, Table V.1). The critical load for temperate and boreal forests, for example is in the range 10-20 kg N per hectare and year, and for moorland is 5-10 kg N per hectare and year.

Figure 6 shows the mean nitrogen deposition for 2013-2015 (left) and the regional distribution of the exceedances of the SMB-Critical Loads for nitrogen (right) (Schaap et al. 2018).

Figure 6: Regional distribution of the total nitrogen depositions (left) and exceedances of simple mass balance Critical Loads for eutrophying nitrogen (right).



Data source: PINETI-III (Schaap et al. 2018)

3.2.3 Methods for calculating the maximum ammonia and nitrogen oxide emissions

3.2.3.1 Determining the nitrogen inputs into soils

The inputs into terrestrial ecosystems take various forms and are quantified in different ways:

- Wet deposition (via precipitation) is determined by measuring the pollutant concentrations in precipitation at sampling points from various measuring networks. Measured concentrations in precipitation are combined with the concentrations calculated with the LOTOS-EUROS model by *kriging* (Gaussian process regression) and linked with annual precipitation data (1 km x 1 km) to produce a map of wet deposition (UBA 2014).

- Dry deposition on soils and vegetation depends on the nature of ground surfaces. It is only determined at a few sampling stations. Maps with a resolution of 1 km x 1 km are produced with model calculations.
- Occult deposition by direct contact with mist or clouds also depends on the nature of the ground surfaces. Land use data and meteorological data are used in combination with ambient concentrations of pollutants.
- The total depositions are determined by a combination of the spatially interpolated measurements of wet depositions with the modelled dry and occult depositions. They are available in a high spatial resolution (1 km x 1 km), dependent on land use.

Data for N-depositions is available from various sources. In the PINETI-III Project (Schaap et al. 2018), the depositions are modelled separately for oxidised and reduced nitrogen compounds, and the exceedances above the critical load are calculated. These data are available as a time series from 2000 to 2015 and are used here to calculate our indicator.

Data from an earlier sub-project of PINETI-III (Schaap et al. 2017a) can also be used to estimate the required indicator.

3.2.3.2 Calculating the emissions target on the basis of deposition data

The PINETI-III Project (Schaap et al. 2018) provides time series from 2000 to 2015 for deposition D(t). In line with the descriptions in Section 3.2.3.1, depositions were modelled separately for reduced and oxidised N-compounds. Exceedances were also modelled.

When determining the targets for nitrogenous emissions, the following approximation is made: The sum of the N-depositions is proportional to the sum of the nitrogenous emissions. Linearity is assumed between emissions E(t) and depositions at the national level, but this may not apply at the local level. The difference between the total deposition and the exceedances above the critical loads corresponds to the maximum permissible deposition.

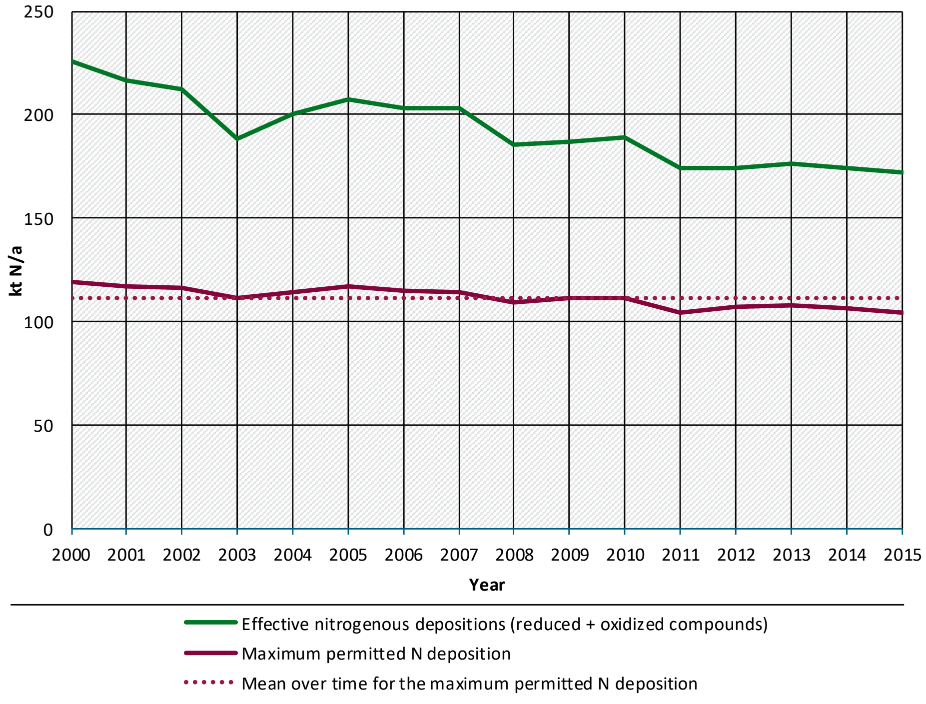
$$\frac{D(t)}{D_{\max(t)}} = \frac{E(t)}{E_{\max(t)}} \quad \text{where} \quad D_{max}(t) = D(t) - Exc(t) \qquad [\text{kt N a}^{-1}] \qquad (\text{Eq. 4})$$

Drawing on the figures in Table 5, this can be used to determine the maximum permitted emission E_{max} for each year of the time series:

$$E_{\max(2015)} = \frac{D(2015) - Exc(2015)}{D(2015)} \cdot E(2015) = 598\ kt\ N \qquad [\text{kt N a}^{-1}] \qquad (\text{Eq. 5})$$

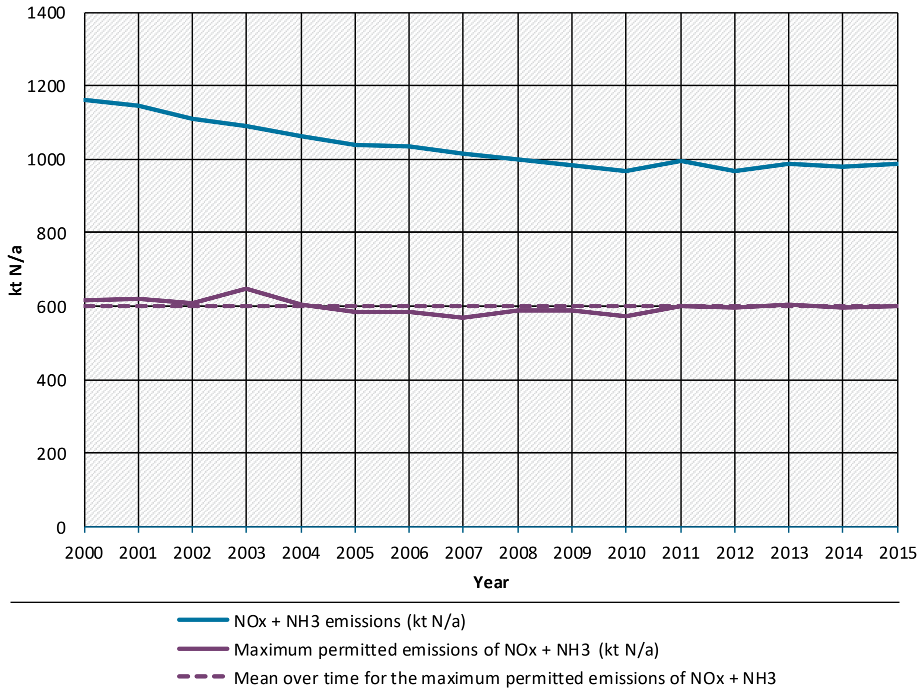
Figure 7 shows the modelled N-depositions and the maximum permitted N-depositions $D_{max}(t)$.

Figure 7: Nitrogenous depositions on areas of Germany with defined critical load (green) and maximum permitted deposition (D_{max}), so that as a spatial mean there are no exceedances (red). The mean over time for the maximum permitted deposition D_{max} is ~105 kt N a^{-1} (dotted line).



Source: PINETI-3 (Schaap et al. 2018)

Figure 8: Sum of emissions of NO_x and NH_3 for Germany (blue) and maximum permitted emissions (violet). The mean over time for the maximum permitted emission is ~598 kt N a^{-1} (dotted line).



Source: UBA 2017d

Table 5: Deposition of reduced and oxidised N-compounds on areas for which the critical loads are specified; exceedances of the critical loads on these areas, and NH_3 and NO_x emissions in Germany.

Year	Depositions D(t)			Exceedances Exc(t)			Emissions E(t)		
	N_{total}	NH_4^+	NO_3^-	N_{total}	NH_4^+	NO_3^-	N_{total}	NH_3	NO_x
	kt N a^{-1}								
2000	225	133	93	106	63	43	1161	575	587
2001	216	128	89	99	59	41	1144	581	563
2002	213	123	90	96	56	40	1109	570	539
2003	188	111	77	77	46	31	1091	569	522
2004	200	121	80	86	52	34	1064	562	502
2005	207	126	82	91	55	35	1038	558	479
2006	203	126	77	89	55	33	1036	562	474
2007	203	126	77	90	56	34	1015	562	452
2008	186	117	68	77	49	28	1000	570	430
2009	187	120	67	76	49	27	984	585	399
2010	189	120	69	78	50	28	967	561	406
2011	174	116	58	69	47	23	995	596	400
2012	174	115	59	67	45	22	967	580	387
2013	176	115	61	69	45	24	986	601	385
2014	174	119	56	68	47	22	978	607	371
2015	172	119	54	68	47	21	986	625	361

Data sources: Deposition data: PINETI-III, Schaap (2018). Emissions data UBA (2017d)

A PINETI-III Project scenario report (Schaap et al. 2017a) provides values for depositions and exceedances for various emissions scenarios determined using the LOTOS-EUROS model. For our purposes, the results for 2010 were of particular interest because they also show the proportions of depositions caused by foreign emissions. These are not taken into consideration in the approach previously described. Although this additional consideration would be of interest, it has the disadvantage that in order to determine the reduction of domestic emissions it is necessary to make assumptions about the future development of foreign emissions and the pollutions loads that will be exported from Germany. But the result for the emissions target would then be dependent on the transboundary exchange of pollutant loads, which would complicate the DESTINO approach (see Section 3.2.4). Discounting the imported and exported pollutant loads involves the implicit assumption that the neighbouring countries have a comparable development of emissions. This is plausible because all of Germany's neighbours are also parties to the Gothenburg Protocol, and the NEC Directive specifies emission reduction commitments for all Member States for 2020 and 2030.

Using a Box-Model for the atmosphere, the sum of imports and emissions equals the depositions plus exports (balance of the nitrogen flows). If the imports, exports and depositions are known, then the emissions can be calculated. Imports and exports can be obtained from the EMEP Model data (Source-

Receptor Relationships[8]). If a maximum permitted value is introduced for the depositions, it is possible to derive an emissions target. This approach was used over a decade ago by the Swiss Federal Office for the Environment to derive an environmental target for ammonia emissions from agriculture which still applies for Switzerland (BAFU 2007). In principle, the method could also be adopted for Germany, but it has disadvantages. Firstly, it again requires assumptions to be made about the development of transboundary air pollutants, and secondly, a single theoretical critical load must be assumed for all of Germany. This rules out regional ecosystem-specific critical loads, and the result is very dependent on the choice of the maximum permitted value for a critical load. The method was therefore not adopted for application in Germany.

3.2.4 Result for the DESTINO-indicator and target value for Terrestrial ecosystems / eutrophication

The time series for the emissions and the maximum permitted emissions calculated using Eq. 5 are presented in Figure 8. The mean value is 598 kt N a^{-1}; the individual values vary only slightly from year to year (variation coefficient of 3 %). This mean value is taken as the target value for the integrated nitrogen indicator. Introducing the emissions value for 2015 (986 kt N a^{-1}, see Table 5) gives the following indicator value 2015 for the eutrophication

$$I(2015) = \frac{E(2015)}{<E_{max}(t)>} \cdot 100\,\% = \frac{986\ kt\frac{N}{a}}{598\ kt\frac{N}{a}} \cdot 100\,\% = 165\,\% \qquad [\%] \qquad \text{(Eq. 6)}$$

Relative to 2015, a reduction of emissions by 40% is necessary.

A combined reduction in emissions of oxidised and reduced N-compounds by 388 kt N a^{-1} is necessary relative to the year 2015, but how this is to be achieved is not further specified. The method described above leads to a maximum emission that is calculated as the sum of the NO_x and NH_3 emissions. The target value could be achieved by reducing both components by the same rate (40 %), but other reduction rates would be possible as long as the combined effect remained the same.

Table 6: How the reduction target of 388 kt N a^{-1} can be achieved in various ways. All values relate to emissions in 2015 (361 kt NO_x-N a^{-1}, 625 kt NH_3-N a^{-1}, Total 986 kt N a^{-1}), and are rounded.

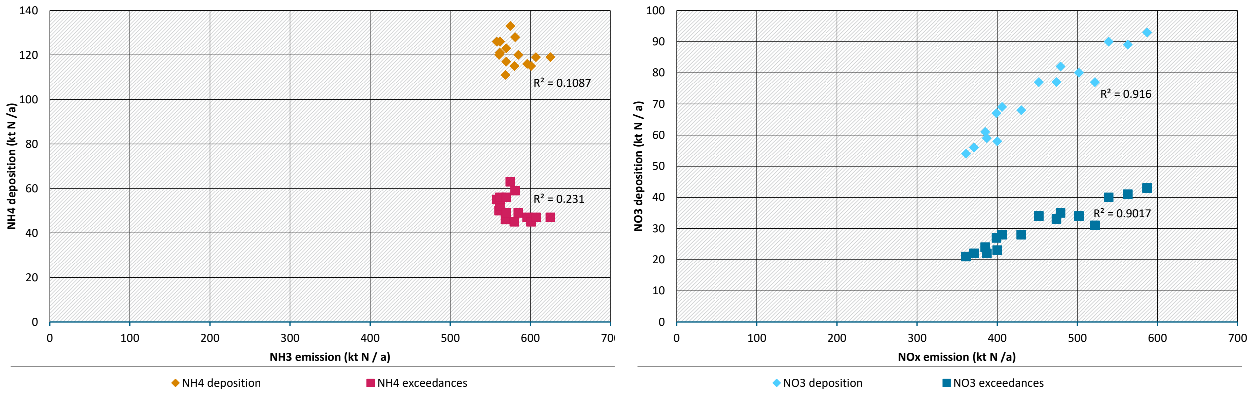
Reduction of NO_x by…		Reduction of NH_3 by …		Reduction of NO_x + NH_3 by…	
kt NO_x-N a^{-1}	%	kt NH_3-N a^{-1}	%	kt N a^{-1}	%
108	30 %	280	45 %	388	40 %
144	40 %	244	39 %	388	40 %
181	50 %	208	33 %	388	40 %

The method described in Section 3.2.3.2 with the result for the DESTINO target value in (eq. 6) gives a plausible result as long as both the NH_4^+ and NO_3^- ions are included in the total. However, if the two components are considered individually the results for the reduced components are implausible. The depositions of NH_4^+ on the areas with defined Critical Load and also the exceedances on these areas showed unexpected decreases in the period 2000 to 2015, because over the same period the NH_3

[8] http://www.emep.int/mscw/sr_main.html [31.08.2018]

emissions had increased. In contrast, the behaviour of the oxidised components is plausible. The NO_3^- depositions and the NO_x emissions both decrease (coefficient of determination $R^2 = 0.92$, correlation coefficient $R = 0.96$). Figure 9 shows that the NH_3 emissions hardly changed over this period and that the changes in the depositions and the exceedances are both small and practically uncorrelated with the NH_3 emissions (coefficient of determination $R^2 = 0.23$, the correlation coefficient is even negative, $R = -0.50$). This means that (Eq. 4) applies for the sum of reduced and oxidised depositions, and for the oxidised proportion alone (NO_x/NO_3^-). However, when considering the reduced proportion (NH_3/NH_4^+), overlying effects obscure the proportionality between the depositions and emissions.

Figure 9: Depositions and exceedances on CL areas: Left: reduced components (NH_4^+ deposition vs. NH_3 emission), right: Oxidised components (NO_3- depositions vs. NO_x emissions). Each dot represents one year in the period 2000-2015.



The phenomenon can be interpreted spatially. Ammonia gas is highly soluble in water and is therefore efficiently deposited by rain, mist and dew. The deposition will take place to a large extent near the place of emission, with only a small proportion being transported over large distances. (The "Source-receptor tables for 2016" show that 26 % of Germany's NH_3 emissions were exported, EMEP 2018.) The situation is different with nitrogen oxides. Gaseous NO_x is only washed out of the atmosphere in smaller quantities, and the NO_x is transported over longer distances. (The "Source-receptor tables for 2016" show that 53 % of Germany's NO_x emissions were exported, EMEP 2018.) There are clearly two regions in Germany with different spatial constellations and differing developments of the NH_3 emissions:

- Regions in which NH_3 emissions declined in the period 2000-2015 which have a relatively large number of areas in the vicinity with defined CL. Here the correlation between emissions and depositions is positive (both decline).
- Regions in which NH_3 emissions have increased and which have few areas in the vicinity with defined CL. Here too, developments of the emissions and depositions are positively correlated (both increase). Because only a small number of areas have a defined CL, the increase contributes little to the national statistics for depositions on CL-areas.
- Viewed nationally, the increase in NH_3 emissions of the second group of regions dominate, whereas for the depositions the large proportion of CL-areas in the first group dominate. This can explain the increase in the national NH_3 emissions and at the same time a decrease in NH_4^+ depositions on areas with defined CL. (If all NH_4^+depositions in Germany are considered, including those on areas without defined CL, then these increase parallel to the NH_3 emissions, and for these datasets the correlation is also positive.) The apparently implausible phenomenon is therefore explained by the spatial distribution of the CL-areas and sources of emissions.

What are the consequences of this? The method described in Section 3.2.3 can be applied to the sum of reduced and oxidised components, but this limits the accuracy of the calculated target value for the N-emissions or increases the uncertainty involved. This can be shown with regard to the choice of the time window: If instead of 2000-2015, we consider only the period 2005-2015, then the emissions target sinks from 598 kt N a^{-1} (eq. 5) to 352 kt N a^{-1} and therefore the DESTINO Indicator rises from 165 % to 280 %. In contrast, if the period 2000-2010 is considered, then the target level increases to 754 kt N a^{-1} and the DESTINO Indicator sinks to 130 %. The target value is therefore highly dependent on the choice of time window. This is undesirable and does not comply with the requirements for the integrated nitrogen indicator.

The observed spatial effects therefore call into question the suitability of a method that is without any spatial reference. In consultation with UBA, the authors of the method concluded that the method described in Section 3.2.3, namely the sum of the NH_3 and NO_x emissions, is not robust enough for the determination of the sectoral indicator for Terrestrial ecosystems/Eutrophication.

An extension of the method was tested, but this was also found to be unsuitable, cf. Annex 5.2.

Therefore, the target values here were determined using the politically binding reduction targets of the NEC Directive for Member States of the European Union until 2030. The national reduction commitments made in accordance with the NEC Directive (EU 2016) are based on IIASA model calculations using the GAINS Model (IIASA 2012). These emission reductions should lead to a 35 % improvement in the status of ecosystems with regard to eutrophication impacts (COM, 2013). The targets which Germany should meet by 2030 are given in Table 7. The figures in the first line relate to 2005, which is the reference year used in the NEC Directive, while the percentages below this relate to the emissions in 2015, which is the reference year in this report. In order to meet the target value, the total of NO_x und NH_3 emissions should be reduced by 42 % compared with the values for 2015. Coincidentally, this is very close to the value of 40 % obtained in Section 3.2.2 using the original method. However, the targets for the individual components differ. An advantage of using the NEC targets compared with the previous method (Section 3.2.3) is that the NEC directive gives individual targets for NO_x and NH_3, leaving no scope for choosing the distribution, as implied in Table 6. The previous proposal envisaged applying the necessary relative (not absolute) reduction of 40 % to each of the two components. But the NEC-target for NO_x is 54 %, whereas the NEC-target for NH_3 is a smaller reduction of 36 %. As discussed below, meeting the targets of the NEC directive does not guarantee that loads for all CL areas will be below the critical level (cf. the comments in Section 3.2.5).

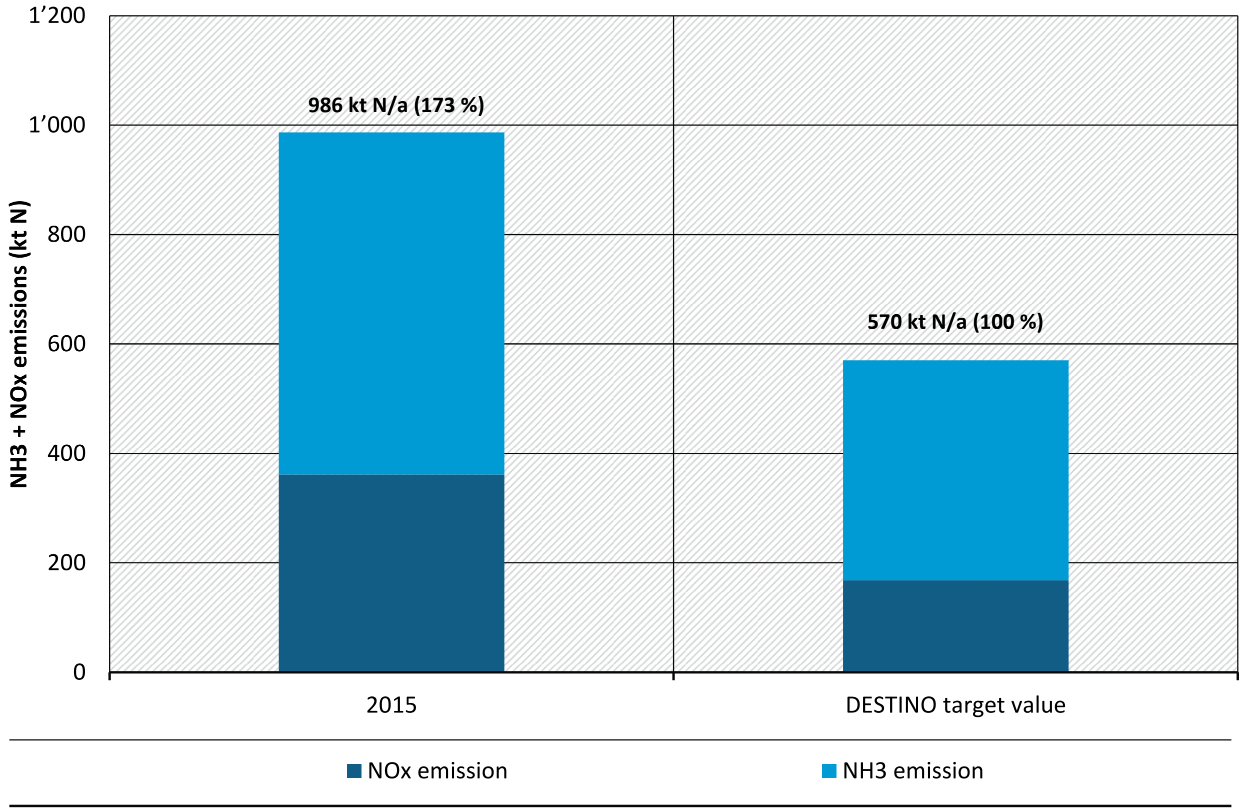
Table 7: Separate reduction targets and target values for nitrogenous air pollution emissions in accordance with the NEC directive for 2030. An "N total" is added in italics.

Basis	NO_x	NH_3	*N total*
NEC Directive (EU 2016/2284), to be achieved by 2030 compared with 2005 Absolute target value (calculated using data as of 2017)	65 % 168 kt NO_x-N a^{-1}	29 % 402 kt NH_3-N a^{-1}	*(43 %)* *570 kt N a^{-1}*
Necessary % reduction relative to emissions in 2015 (Data as of 2017, UBA 2017d)	54 %	36 %	*42 %*

Absolute target value (based on data from UBA 2017)

The DESTINO sectoral indicator, the sum of NO_x and NH_3 emissions, had a value of 986 kt N a^{-1} in 2015, or 173 % of the target value.

Figure 10: DESTINO-indicator terrestrial ecosystems / critical load, sum of NH_3 and NO_x emissions. Current status (2015) and DESTINO target value.



3.2.5 Interpretation and assessment

1) Various methods were tested, in order to use the deposition data and exceedances to derive a maximum load of NO_x and NH_3 emissions. The simplest method was initially chosen for use in the integrated nitrogen indicator (assuming a linear relationship between N-depositions on CL-areas and the national N-emissions). The sum of NO_x and NH_3 emissions would need to be reduced from 986 kt N a^{-1} (2015) to 598 kt N a^{-1} in order to meet the target for eutrophication of terrestrial ecosystems. This would require a reduction of the emission by 40 % of the value for 2015 and the DESTINO sectoral indicator would be 165 % in 2015. However, a more detailed analysis showed that because there have so far been hardly any reductions in NH_3 emissions and therefore only slight reductions in NH_4^+ depositions (see Figure 9), the method is very dependent on the choice of time window, so that it is not possible to determine a target value robustly with the method. Adaptations of the method did not change this fact. Therefore, a DESTINO target value was used which was based on the politically binding commitments for NO_x and NH_3 emissions in line with the NEC Directive. As a consequence, the sum of the NO_x and NH_3 emissions will have to be reduced by 42% compared with 2015, and the indicator value is 173 %.
2) It is important to note that the preamble to the NEC directive states: “The revised TSAP sets out new strategic objectives for the period up to 2030 with a view to moving further towards the Union's long-term objective on air quality.” Even when the NEC target values are achieved, the long-term goal will not yet have been reached. The simulations of IIASA (IIASA, 2012) show that for an MTFR scenario 2030 (Maximum Technically Feasible Reduction) with a reduction of N-emissions by 50 % in comparison with 2015 (58 % compared with 2005, the negotiated value was 43 %), some 30 % of the CL-areas in Germany would not meet the CL requirement. This means that the

target value under the NEC directive for N-emissions must be regarded as an intermediate target. Meeting the target values does not guarantee that levels will be sub-critical for all CL-areas.

3) As with Terrestrial ecosystems / Biodiversity, we recommend regularly updating the deposition modelling and checking the emissions targets. The latest German air pollutant inventories submitted under the CLRTAP (February 2018 and 2019) included an updated time series for NO_x and NH_3 emissions as a result of changes to the methodology (UBA 2018). For the year 2015, the NO_x emissions are 4.5 % higher than in the submission made in February 2017, but the NH_3 emissions are 11.2 % lower (UBA 2017b). These differences directly affect the DESTINO sectoral indicator. If there are larger changes, then the consequences for the depositions should also be determined, because among other things the target values of the NEC directive are intended to ensure compliance with the Critical Loads.
4) Meeting the sectoral target: The NO_x emissions were already reduced by ~40 % from 2000 to 2015, whereas NH_3 emissions increased by 9 % over the same period (Table 5). It will not be a simple task to reduce the NO_x emissions by a further 54 %, but a 36% reduction in NH_3 emissions is likely to prove much harder. Achieving the sectoral target for Terrestrial ecosystems / Eutrophication must therefore be recognised as a major challenge.
5) In its indicator report Data on the Environment 2017, UBA comments on nitrogen eutrophication: "The National Strategy on Biological Diversity includes the target of not exceeding the critical loads by 2020 (BMU 2007[9])). This target is no longer feasible, but in the German Environment Agency's view it should remain a long-term goal." In the DESTINO project, this goal is targeted. The UBA indicator report goes on to cite the new interim goal for the German federal government: "The proportion of land affected by excess nitrogen deposition should fall by 35 % between 2005 and 2030 (Federal Government 2016)." The two scenarios in the IIASA report (Baseline and MTFR), involve reductions in N-emissions by 26 % and 58 % respectively relative to 2005. This would leave 48 % or 30 % of CL-areas respectively with excessive levels of deposition. Under the Baseline Scenario the new interim target would be achieved. The UBA indicator report includes an indicator for air pollutants: "Germany must reduce emissions of the five air pollutants by an average of 45 % between 2005 and 2030", and it also says: "Reaching the commitments of the European NERC (national emission reduction commitments) Directive for 2030, is a major challenge for the German environmental policy. Ammonia emissions in particular …. must be reduced to achieve this." (p. 44, UBA 2017). The results calculated for the integrated nitrogen indicator (42 % reduction of NO_x and NH_3 emissions in comparison with 2015) are in a comparable range, even though the group of pollutants is not identical and the time horizon is not the same.
6) For the sectoral targets Terrestrial ecosystems / Impacts due to ammonia and Eutrophication, Groundwater quality, and Health, an alternative indicator could be chosen which relates to the areas affected (see also Section 4.1.3). Such an indicator for the environmental sector Terrestrial ecosystems / Eutrophication is included in the report of Schaap et al. (2018). In 2015, 68 % of all areas had levels above the critical load. A simple area-related indicator in 2015 would therefore have a value of 312 % (= $[1 - 0.68]^{-1}$ %), relative to a target value of 100 %, which would be much higher than the load-related indicator. (However, the area-based value has the disadvantage that it does not correlate with the national emissions and is therefore not compatible with the emissions load approach chosen here.)

9 "By the year 2020, the critical loads and levels for acidification, heavy metal and nutrient discharges (eutrophication) and for ozone will be met, so that even sensitive ecosystems will enjoy lasting protection." BMU (2007), p. 54

3.3 Surface waters quality: Effects of nitrogen inputs

3.3.1 Impact mechanisms

The eutrophication of surface waters (watercourses, water bodies, transitional and coastal waters), that is the enrichment of the water with nutrients (nitrogen and phosphorus), accelerates the growth of phytoplankton and macrophytes and disturbs aquatic communities. Increased algal growth leads to changes in the species spectrum, and the bacterial degradation of algal detritus depletes oxygen levels, which impacts in particular on the zoobenthos. In extreme cases, fish populations can be decimated and harmful sulphur dioxide can be formed (UBA 2013).

3.3.2 Sectoral target and the DESTINO target value

The quality standards and target concentrations of reactive N-compounds for the various types of surface water are specified in the Ordinance on the Protection of Surface Waters (OGewV).

A) Surface waters (excluding transitional and coastal waters)

In the German Ordinance on the Protection of Surface Waters (OGewV) (Annexes 7 and 8), the following critical levels or environmental quality standards are given for nitrogen compounds:

Nitrate	$NO_3^- \leq 50$ mg l^{-1}
Nitrite-nitrogen	NO_2-N ≤ 10 µg l^{-1}
Ammonium-nitrogen	NH_4^+-N ≤ 0.04 mg l^{-1}
Ammonia-nitrogen	NH_3-N < 2 or < 1 µg l^{-1} (depending on the type of flowing water);

all values determined as annual means.

The environmental quality standards of the EU WFD of 50 mg NO_3^- l^{-1} as an annual mean was not exceeded in the period 2011 - 2014 at any of the 256 watercourse monitoring stations of the EEA network. With regard to the ecological quality of inland waters, nitrate levels are therefore not considered as a component of an indicator.

As far as is known, the limit values for ammonia and nitrites not exceeded in any surface waters in Germany. Ammonium concentrations for 2011 exceeded limits at fewer than 3 % of the measuring points of the LAWA network (our evaluation on the basis of Fig. 33 in UBA 2013). The loads of these three N-compounds in surface water systems are very low, and make only a negligible contribution when calculating a quantitative N-target value.

Therefore, when determining a surface waters indicator, inland waters (rivers and lakes) are not taken into consideration.

B) Transitional and coastal waters

North Sea and Baltic Sea

Some 80 % of the reactive nitrogen in German coastal areas is anthropogenic in origin (Fuchs et al. 2010). For the North Sea and the Baltic Sea, target values are not given as species-specific nitrogen concentrations, but as follows (OGewV, Article 7):

North Sea: Total nitrogen concentration (TN) ≤ 0.21 to ≤ 0.67 mg l^{-1} (annual mean) and dissolved inorganic nitrogen concentration ≤ 0.17 to ≤ 0.53 mg l^{-1} (the winter average, 01.11. to 28.02.), depending on the type of coastal water.

Baltic Sea: Total nitrogen concentration ≤ 0.13 to ≤ 0.36 mg l^{-1} (annual average), depending on the type of coastal water.

These marine-ecological target values are converted to permissible total nitrogen concentrations (as an annual average) for the German watercourses flowing into coastal waters (Ordinance on the Protection of Surface Waters (OGewV) Article 14):

North Sea: Total nitrogen concentration (TN) ≤ 2.8 mg l^{-1}

Baltic Sea: Total nitrogen concentration (TN) ≤ 2.6 mg l^{-1}

in each case, as mean annual concentration at the limnic/marine transition point (for rivers entering into the North Sea or Baltic Sea in German territorial waters) or the place on the border where a river leaves German territory. (Note: The Rhine is treated as a transitional watercourse to the Netherlands). No international agreement has yet been reached regarding the nitrogen concentration in the River Oder (which marks the border with Poland). This reduction requirement could therefore not yet be included in the calculation, which leads to a (slight) underestimation.

It is assumed that the marine-ecological target values are sufficient to meet the nitrogen reduction of the EU Marine Strategy Framework Directive and the Baltic Sea Action Plan for the open North Sea and Baltic Sea. For the Baltic Sea, this is contingent on the atmospheric nitrogen depositions falling by at least 20% with the implementation of the Gothenburg Protocol and the EU NEC Directive. In addition, the marine ecological target values are based only in part on the indicators used to describe the good status regarding eutrophication. It is therefore possible that there will still be eutrophication effects even after reaching the target values, and that the target values will have to be lowered even further. Furthermore, the effects of climate change will very probably also make necessary a revision of the target values for the marine ecology.

Black Sea (Danube basin)

The Danube catchment basin in Germany covers 17 % of German territory and accounts for some 7 % of the total Danube basin. Due to the long-time of travel of the River Danube from the German border to the Black Sea, degradation and retention play a very important role. The nutrient exports from Germany are therefore of secondary importance for achieving the marine-ecological targets in the Black Sea (LAWA 2016). The German Working Group on Water Issues notes that with regard to the marine-ecological requirements, no further reduction of the total nitrogen concentration in the German catchment areas of the River Danube is required.

3.3.3 Methods for calculating the maximum N-loads

For a river basin *k*, the necessary relative reduction of the total N-concentration $\Delta c_k(\%)$ can be calculated from the current concentration and the relevant target value:

$$\Delta c_k(\%) = (c_k - c_k(target\ value))/c_k \cdot 100 \quad \text{for all } c_k > c_k(target\ value) \qquad [\%] \qquad \text{(Eq. 7)}$$

The annual mean total N concentration c_k is proportional to the total annual N-load $M_{N,k}$ in surface waters. Assuming that the annual load is not correlated to the outflow quantity, the necessary change in the annual N-load $\Delta M_{N,k}$ for a river basin corresponds to the relative change in concentration:

$$\Delta M_{N,k} = M_{N,k} * \Delta c_k(\%) \qquad [\text{kg N a}^{-1}] \qquad (\text{Eq. 8})$$

The total necessary reduction in the N-inflow $\Delta M_N(DE)$ into the North Sea and Baltic Sea in German territorial waters then corresponds to the sum of reductions in N-inflows for all river basins:

$$\Delta M_N(DE) = \sum_{DE} M_{N,k} \qquad [\text{kg N a}^{-1}] \qquad (\text{Eq. 9})$$

Indicator I is now defined as the current value of the annual N-load $M_N(DE)$ divided by the target value (N-inflow minus the necessary reduction in the N-inflows $\Delta M_N(DE)$), and expressed as a percentage:

$$\text{I} = \frac{M_N(DE) \cdot 100\,\%}{[M_N(DE) - \Delta M_N(DE)]} = \frac{100\,\%}{[1 - \Delta M_N(DE)/M_N(DE)]} \qquad [\%] \qquad (\text{Eq. 10})$$

When the target value of 2.6 or 2.8 mg N l^{-1} (respectively) has been achieved at all limnic/marine transition points (or at borders), then I = 100 %. Until the target values have been achieved, I > 100 %.

3.3.4 Result for the DESTINO indicator and target value for Surface water quality

The starting point for calculations is the total nitrogen concentrations and loads in the German watercourses flowing into the North and Baltic Seas (Table 8). The report on the implementation of the Marine Strategy Framework Directive gives the following values:

Table 8: Nitrogen reduction requirement in German watercourses flowing into the North Sea and Baltic Sea, various time periods (LAWA, 2018)

River basin	Current load[a] kt N a^{-1}	Target load[a] kt N a^{-1}	Reduction [a] kt N a^{-1}
	North Sea – Target concentration 2.8 mg N l^{-1}		
Rhine	198.3[b]	196.6	-1.7
Elbe	78.8[b]	66.6	-12.2
Ems	15.1[c]	7.8	-7.3
Weser	44.4[b]	28.5	-15.9
Eider	5.7[b]	4.7	-1.0
Sub-total North Sea	**342.3**	**304.2**	**-38.1**
	Baltic Sea – Target concentration 2.6 mg N l^{-1}		
Schlei / Trave	6.3[b]	4.0	-2.3
Warnow / Peene	7.6[d]	5.8	-1.8
Sub-total Baltic Sea	**13.9**	**9.8**	**-4.1**
Total	**356.2**	**314.0**	**-42.2**

[a] Source: Reports of the river basin associations (FGG) Eider, Elbe, Weser, Ems, Rhine, Schlei/Trave, and Warnow/Peene, as of: March 2018 (LAWA, 2018)

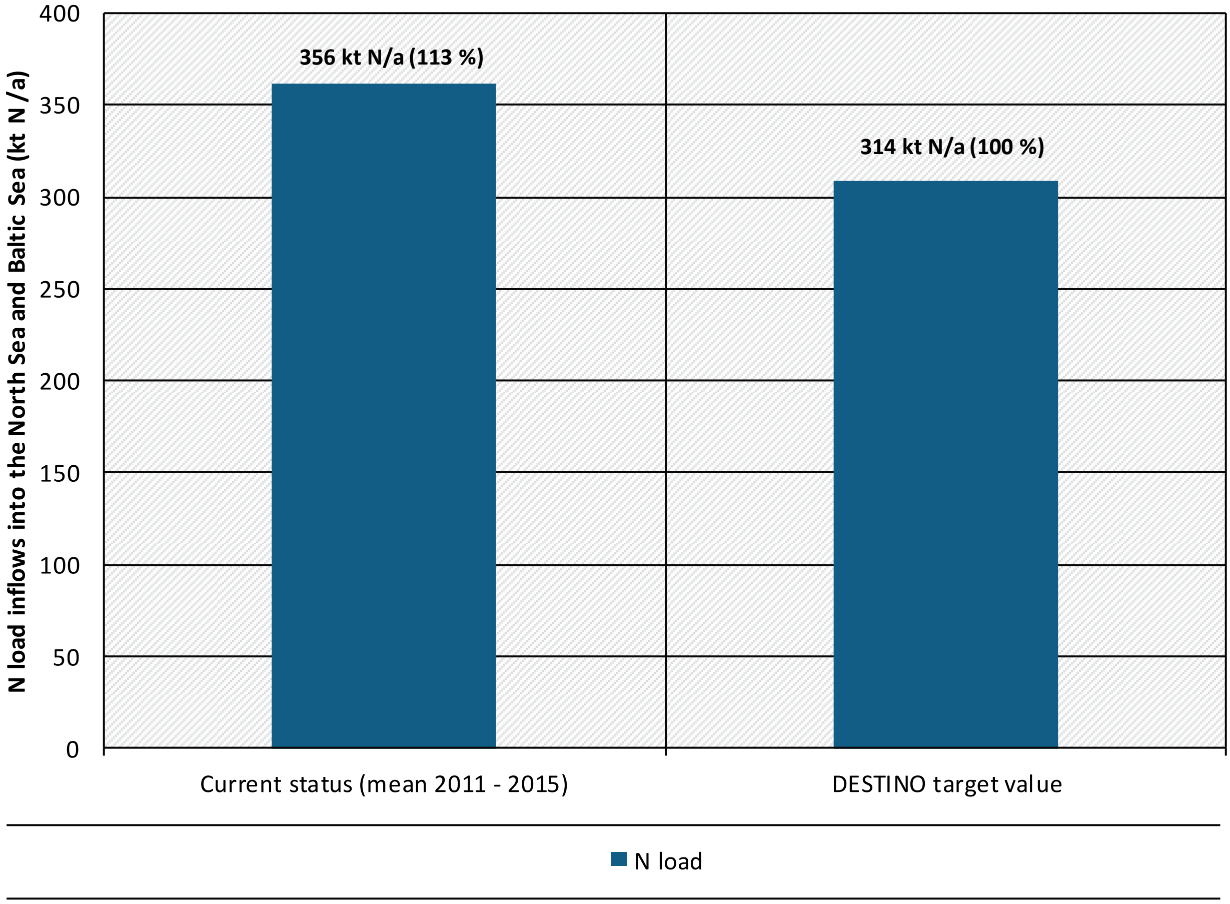
[b] Normalised mean nitrogen load 2012 - 2016.

[c] Mean nitrogen load 2008 – 2012.

[d] Mean nitrogen load 2012 – 2015.

Table 8 shows a total annual N-load of 356.2 kt N a^{-1} from the inflows from Germany into the North Sea and Baltic Sea and the outflow of the Rhine into the Netherlands (different reference periods for the individual river basins). To comply with the target values at the limnic/marine transition points and at the Bimmen/Lobith border point, the annual N-load would have to be reduced by 42.2 kt N a^{-1} or 11.8 % to the target load of 314.0 kt N a^{-1}. This gives the value of I = 113.4 % for the DESTINO indicator for Surface waters (see Figure 11). However, the loads can fluctuate depending on the outflow, so that the reduction requirement can vary considerably depending on the period under consideration. In order to minimise such fluctuations, future calculations of the reduction requirement should be based on outflow-normalised nitrogen loads, and should also consider the statistical uncertainty.

Figure 11: DESTINO-indicator Surface waters, N-load in inflows into the North Sea and Baltic Sea. Current status (annual mean 2011 - 2015) and DESTINO target value.



Source: Our calculations

3.3.5 Interpretation and assessment

1) The indicator for Surface waters includes transitional, coastal and marine waters of the North and Baltic Seas. If the other surface waters were also to be taken into consideration, then the list of sectoral targets would have to be extended correspondingly.
2) The approach used to calculate the indicator is based on the premise that the annual N-load and outflow, and thus also the mean annual N-concentration in the flows are not correlated with one another. This was investigated and confirmed for the River Rhine, Bimmen/Lobith station, for the time series 1991 – 2016.
3) Due to the relatively slow exchange of the body of water, there is a delay in the reaction of coastal and marine waters to reduced N-inflows (as with bodies of groundwater, see 3.4.5). Even after the inflows into North Sea and Baltic Sea have reached or are below the target value for the N-concentration, it will still take a long time until the coastal waters as a whole reach the target value. A model-based estimate for the implementation of the HELCOM Baltic Sea Action Plan shows that even if nutrient reduction measures were implemented immediately, it could take up to 100 years before the nutrient target values for the open waters of the Baltic Sea were achieved (HELCOM 2013).
4) In principle, another approach could be used to determine the necessary reduction which relates to the watercourses feeding into the river basins. Using modelling systems such as MONERIS (Modelling Nutrient Emissions in River Systems, Venohr et al. 2011) or MoRE (Modelling Regionalized Emissions, Fuchs et al. 2017) the total N-concentrations in a river basin above the transitional or border point could be calculated that must be complied with in order to avoid exceeding the target value of 2.6 or 2.8 mg TN l^{-1} at the limnic/marine transition point or at the border crossing point. The key factor is the level of N-retention in the surface water system, which depends primarily on the time of travel from the point where the N-inflow enters the surface water system through to the transition point (other factors such as the C-contents and pH-value of the body of water are neglected here). LAWA (2016) has already presented a map of permissible annual total N-concentrations for the planning units of the WFD derived using this approach. However, not all the necessary data is currently available, so that we did not pursue this approach further here.
5) The N-load in surface waters comes from a number of sources. The indicator Surface waters only quantifies the necessary overall reduction. The contributions of the various sources (e.g. agriculture, settlement water management) or the individual input pathways is a matter for the WFD planning measures. The contributions were estimated at the national level for specific sources and pathways using the MoRE model (Fuchs et al. 2017). The annual inputs into surface waters from inland sources according to the Model results amount to nearly 500,000 t N, of which ~54 % is attributable to the outflows of groundwater (Table 8).

Table 9: Sources and fate of nitrogen inputs into surface waters in Germany according to MoRE model calculations, annual mean 2010 – 2014 (Fuchs et al. 2017; summarised in DESTINO Report 2, UBA 2020).

Sources and fate	kt N a^{-1}
Nitrate inputs into surface waters due to groundwater outflows	268.2
Inflows into surface waters from settlement water management	114.3
Runoff, erosion and drainage from agricultural areas	112.0
Atmospheric N-deposition on surface waters r	4.8
Total annual inputs into surface waters in German territories	**499.3**
plus N-load in transboundary inflows (from upstream neighbours)	67.3
minus N-retention in the surface water system	-66.0
N-load in outflows into North Sea and Baltic Sea or to downstream neighbours	**500.6** [a]

[a] N-load differs from the figure in Table 8, because (i) the N-loads in Danube, Maas, and the German portion in the river Oder are not included in Table 8, and (ii) the values in Table 9 are based on model calculations for all areas including minor watercourses.

Due to the relatively large contribution of groundwater to the N-load in surface waters, an improvement in the indicator “Groundwater quality” could in theory also lead to a corresponding improvement in the indicator “Surface waters”, i.e. there would be an additive effect between the two indicators. Practically, however, this is not likely to play much of a role: as will be discussed in Section 3.4.5, the indicator “Groundwater” does not evaluate the actual NO_3^- concentration in groundwater, but for pragmatic reasons the N-surplus from the agricultural area. Due to the long reaction time of the NO_3^- concentration in groundwater after changes in nitrate leaching from agriculture, it can be assumed that changes to the N-surplus and thus to the Groundwater indicator can be much more rapid than a change in the nitrate load of the groundwater flowing into the surface waters.

3.4 Groundwater quality: Nitrate pollution

3.4.1 Impact mechanism

Drinking water is essential for human life. A large proportion of drinking water in Germany is derived from groundwater (61 %), so that the protection of groundwater is a key environmental consideration. Nitrate itself is not a direct health threat, but in the stomach, it can be converted into nitrite, which blocks haemoglobin and thus oxygen transport in the blood. An excessive intake of nitrate by infants can lead to “blue baby syndrome”. In the stomach, nitrites react with other food constituents to form nitrosamines, which are carcinogenic. It is therefore recommended as little nitrate as possible should be ingested in drinking water and foodstuffs.

3.4.2 Sectoral target and the DESTINO target value

Germany’s Drinking Water Ordinance specifies a limit value of 50 mg NO_3^- l^{-1} for drinking water. For the precautionary protection of groundwater reserves abstracted for producing drinking water, this concentration was adopted as the threshold for “good” groundwater quality (Groundwater Ordinance, 09.11.2010). The assessment of groundwater pollution by nitrates as components of an integrated nitrogen indicator is based on this threshold value of 50 mg NO_3^- l^{-1}.

The Groundwater Ordinance also specifies thresholds for ammonium and nitrite of 0.5 mg l^{-1} in each case. However, there is no evidence that these threshold values are exceeded in a body of groundwater in Germany; therefore, these N-compounds are not taken into consideration when determining a groundwater indicator.

3.4.3 Method to calculate the maximum N-surplus

The sectoral indicator for Groundwater quality is defined as the ratio of the current N-surplus (as an area balance) to a reduced N-surplus, for which there would theoretically not be any further exceedance of the nitrate quality threshold of 50 mg NO_3^- l^{-1} in groundwater, summed over all areas for which the quality standard is currently exceeded. The starting point is the nationwide presentation of nitrate concentrations in groundwater (1 km x 1 km grid, Figure 31 in Section 5.4.2). As part of this project, such a uniform presentation over all of Germany was developed for the first time. The map is based on nitrate concentrations from some 8,100 GW federal state monitoring stations, regionalised using the “Random Forest” classification method based on spatial data (maps) for hydrogeology, land use, etc. (cf. Section 5.4).

For each grid cell j with $c_j > 50$ mg NO_3^- l^{-1}, the relative NO_3^- concentration reduction $\Delta c_j(\%)$ can be calculated which is required to comply with the quality standard of 50 mg NO_3 l^{-1}:

$$\Delta c_j(\%) = (c_j - 50)/c_j \cdot 100 \qquad \text{for all grid cells j with } c_j > 50 \text{ mg } NO_3^- \, l^{-1} \qquad [\%] \qquad \text{(Eq.11)}$$

From the calculation of the balance N-surpluses for agriculture in Germany using regional structures (Häußermann et al. 2019), the annual nitrogen surplus on the agricultural area (AA) is known for each grid cell (in kg N ha^{-1} AA a^{-1}, annual mean 2011 – 2014).

For the calculation of the sectoral indicator it is assumed as a simplification that the nitrate concentration in GW is predominantly due to nitrates in leachate from agricultural areas, i.e. that the contributions of forests, settlements and other areas are negligible. This simplification seems justifiable in view of the fact that farming – the impact of which on groundwater is characterised by the N-surplus indicator – offers the only viable opportunity for measures to reduce the NO_3^- concentration in BGWs.

The N-surplus for the agricultural areas is regarded as a potential nitrate input into the GW, but as a rule only a certain proportion of this surplus actually finds its way into the groundwater or reaches a sampling point. The size of this proportion depends on numerous factors, such as the type of soil, weather conditions, denitrification in the unsaturated zone and in the aquifer, as well as N-fixing in the soil humus. The nitrate concentration in the groundwater is also affected by dilution, i.e. the volume of leachate. For a grid cell with $c_j > 50$ mg NO_3^- l^{-1} it is assumed that the potential nitrate input and thus the N-surplus of the agricultural area NS_j in the relevant grid cell must be reduced by the same percentage as the concentration c_j, i.e. that, with a delay, the reduction in the nitrate concentration in the GW is proportional to the reduction in the N-surplus of the agricultural area (Eq. 12):

$$\Delta NS_j(\%) = \Delta c_j(\%) \qquad [\%] \qquad \text{(Eq. 12)}$$

The reduction in the absolute N-surplus $\Delta M_{N,j}$ (in kg N a^{-1}) for each grid cell j can then be calculated from the reduction of the N-surplus NS_j on the AA (kg N ha^{-1} AA a^{-1}) and the agricultural area AA_j (ha AA) in the grid cell:

$$\Delta M_{N,j} = NSj * \Delta c_j(\%)/100 * AAj \qquad [\text{kg N a}^{-1}] \qquad (\text{Eq. 13})$$

The nationwide reduction required for the N-surplus $\Delta M_N(DE)$ is the sum of the reduction of the N-surplus for all grid cells *j* with $c_j > 50$ mg NO_3^- l^{-1}.

$$\Delta M_N(DE) = \sum_j \Delta M_{N,j} \quad \text{for all grid cells } j \text{ with } c_j > 50 \text{ mg } NO_3^- \, l^{-1} \qquad [\text{kg N a}^{-1}] \qquad (\text{Eq. 14})$$

The DESTINO-indicator I is defined as the ratio of the current value of the N-surplus M_N(DE) to the target value (surplus minus the national reduction in the N-surplus ΔM_N(DE)).

$$I = \frac{M_N(DE) \cdot 100\ \%}{[M_N(DE) - \Delta M_N(DE)]} = \frac{100\ \%}{[1 - \Delta M_N(DE)/M_N(DE)]} \qquad [\%] \qquad (\text{Eq. 15})$$

When the target “all grid cells $c_j \leq 50$ mg NO_3 l^{-1}” has been achieved, then $I = 100$ %, but until this is the case, $I > 100$ %.

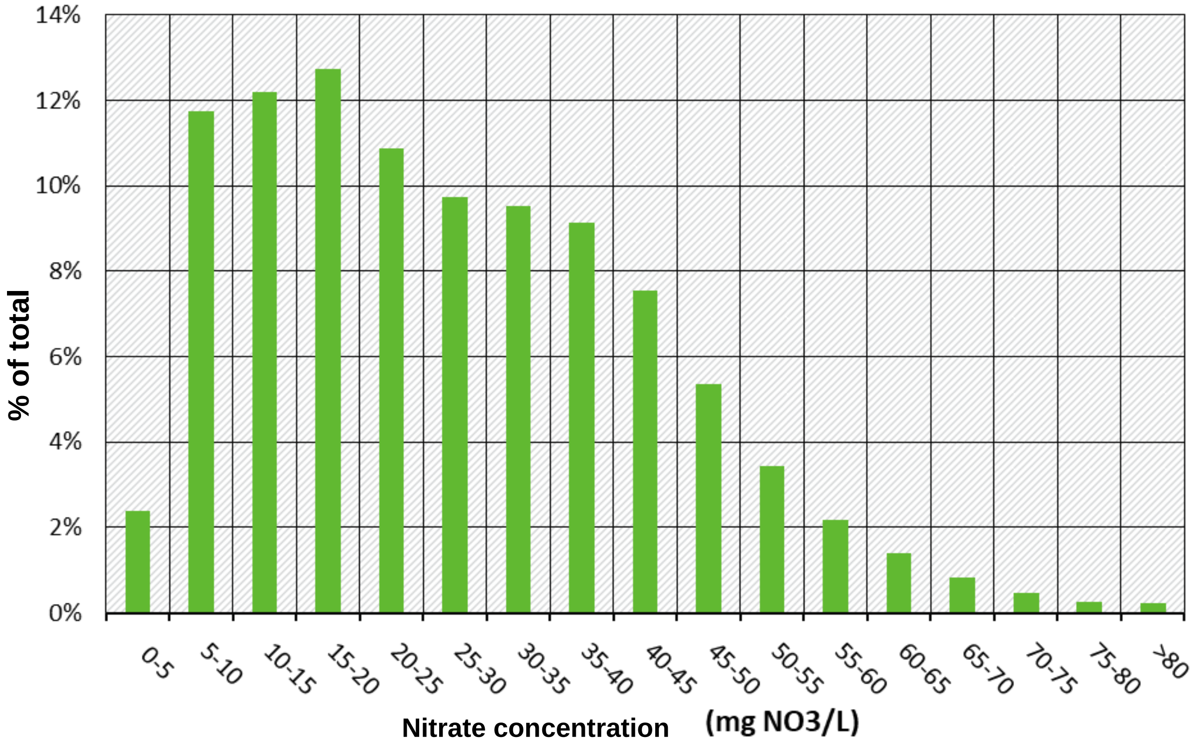
To calculate the DESTINO indicator we used the following data (1 km x 1 km grids):

- Map “Nitrate concentration in groundwater”, estimates with Random-Forest classification (Figure 31)
- Map “N-surplus on agricultural area (AA)”, mean 2011 - 2014 (unpublished, for methodology see Häußermann et al. 2019)
- Map “Proportion of agricultural area in the grid”, based on the land cover model map DE2012 (LBM-DE), 2012, Codes 211 and 231 (BKG 2016).

3.4.4 Result for the DESTINO indicator and target value Groundwater quality

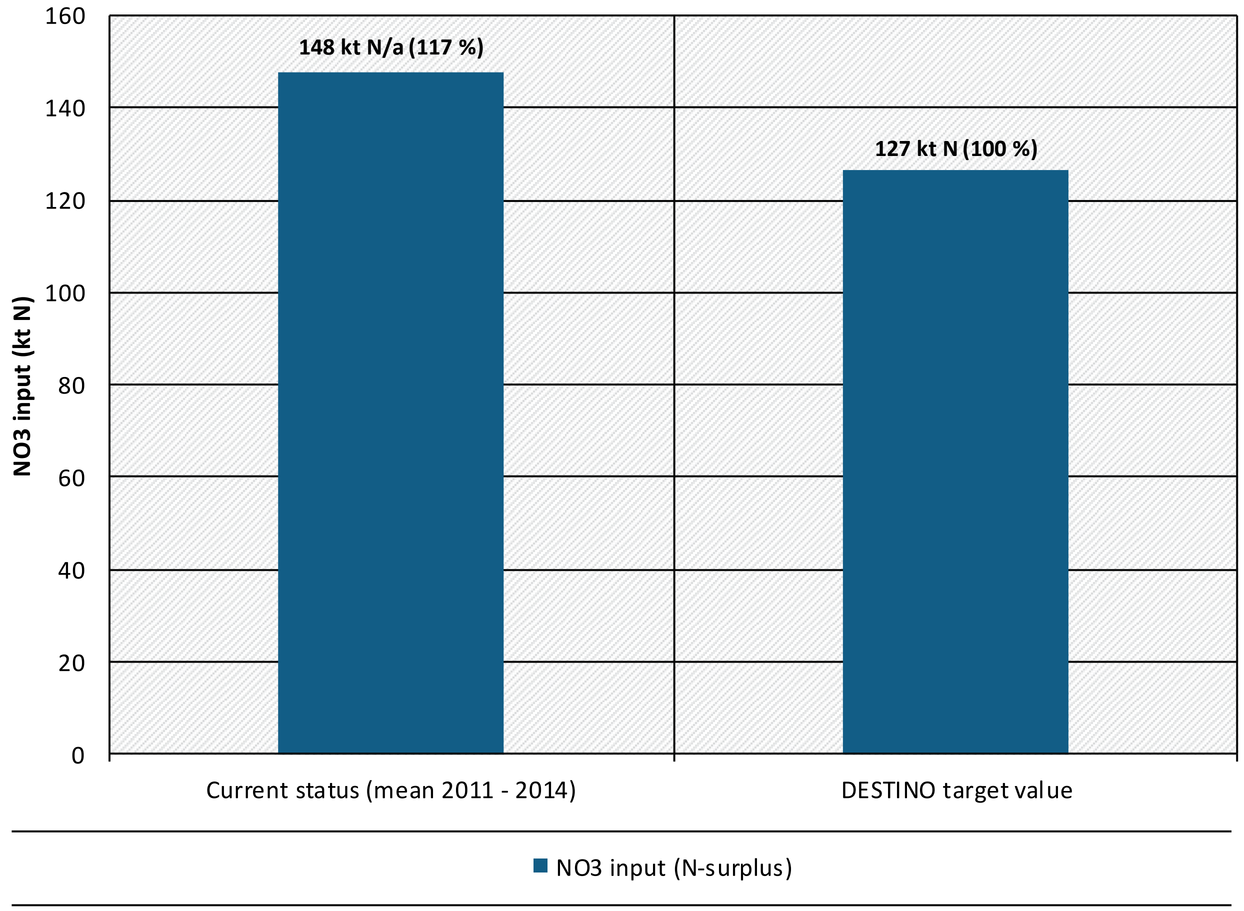
The frequency distribution of the grid map of nitrate concentration in groundwater in Germany (Figure 31, Section 5.4.2) shows that 8.8 % of the area (grid cells) have $c(NO_3^-) > 50$ mg l^{-1}. This proportion is much lower than results of other maps or measurement networks, which show between 18.2 % and 28 % (see Section 3.4.5). If only grid cells are evaluated with mainly agricultural use (50 % and more AA), then 14.4 % of these grid cells have nitrate concentrations above quality threshold.

Figure 12 Distribution according to the Random-Forest classification, estimated nitrate concentration in groundwater in Germany (see Figure 31)



The mean NO_3^- concentration in grid cells which exceed the threshold is 59.4 mg NO_3^- l^{-1}. For these cells with $c(NO_3)$ > 50 mg l^{-1}, the mean necessary reduction of the N-surplus is 15.8 % or 9.1 kg N ha^{-1} AA a^{-1}. The sum for all these grid cells gives a necessary reduction of the N-surplus in Germany of 21,046 t N a^{-1}. Relative to the total area balance N-surplus (annual mean 2011 - 14) of 147,638 t N a^{-1} in the grid cells with $c(NO_3^-)$ > 50 mg l^{-1} this corresponds to 14.3 %. The value for the sectoral indicator is thus I = 116.6 % (see Figure 13).

Figure 13: DESTINO-indicator Groundwater, N-surplus of the agricultural area in grid cells exceeding the threshold concentration. Current status (mean 2011 - 2014) and DESTINO-target value.



Source: Our calculations

3.4.5 Interpretation and assessment

A number of comments and reservations have to be made with regard to the DESTINO-indicator “Groundwater quality”.

1) In principle, an indicator "Exceeding the nitrate quality norm in GW" should express how much nitrate (mass) is currently in all bodies of groundwater (BGWs) in Germany (as the total of the product of the mean nitrate concentration c_{BGW} and the volume V_{BGW} of groundwater in all BGW_i) and the amount by which this would have to be reduced so that in all cases: $c_{BGW} \leq 50$ mg NO_3^- l^{-1}. However, it is not possible to calculate the quantity of nitrate in the BGWs nationwide for two reasons: (i) The volumes are not known for most of the bodies of groundwater (except in a few hydrologically well-documented cases). (ii) NO_3^- concentrations are mainly measured in groundwater near the surface, so that the results are not representative of the concentrations over the whole depth of the BGW.
   - The indicator “Reduction of the area-related N-surplus” therefore does not evaluate the progress in meeting the target for the environmental sector (how many BGWs or what proportion of the areas have a “good status” with regard to nitrates). Rather it assesses the reduction of the (potential) nitrate pollution entering the groundwater. By the reduction of the N-surplus of the agricultural area, the quality standard will initially only theoretically

be met in the leachate or in the newly recharged groundwater. When the groundwater in an aquifer will reach the quality standard depends on how long it takes for the groundwater to be exchanged more or less completely, and whether there is any additional nitrate degradation in the groundwater.

- ► Nevertheless, this approach is preferred because as a rule the groundwater reserves as a rule only react very slowly to changes in the inputs dissolved in the inflowing leachate. In aquifers in fissured rock (central upland regions) groundwater may spend several years underground, in porous rock aquifers (Northern Germany, upper Rhine plain) several decades and more. It is therefore likely to take this long before a reduction of the nitrate inputs in leachate is also reflected in the nitrate concentration in the groundwater – "groundwater has a long memory". Since the integrated nitrogen indicator is intended to have a practical influence on policy making, it seems more appropriate to base the evaluations on the (potential) nitrate inputs.
- ► The sectoral indicator describes the effect of measures adopted to implement EU WFD provisions, or the EU Nitrate Directive and with which the (potential) nitrate inputs into groundwater are to be reduced to an acceptable level. The long delay before the effects can actually be measured in the environmental sector "Groundwater" is due to the long hydrogeological reaction time of the groundwater system and should not be blamed on present or future policy actors. At the same time, this does highlight the great responsibility of current environmental policies for the long-term protection and improvement of the groundwater quality for coming generations.

2) As long as the GW databases in Germany's federal states do not have a uniform structure, updating the sectoral indicator will only be practicable at intervals, since enquiries currently have to be sent to sixteen different databases and the responses then have to be collated manually.

3) The reduction of the nitrate inflows into the groundwater or the reduction of the nitrate concentrations in GW has an influence on two environmental sectors: Surface waters and Groundwater. Measures to reduce the N-surplus in agriculture could therefore in principle also benefit the DESTINO indicator for Surface waters. However, the additive effect between the two indicators is in fact small, as outlined in Section 3.3.5.

4) The approach used in Section 3.4.3 can in principle also be applied for any other quality standard, e.g. for a precautionary value of 40 mg NO_3^- l^{-1} or 37.5 mg NO_3^- l^{-1}, which a number of federal states have already introduced in their WFD planning as a threshold above which measures are to be taken.

5) In the discussion on the extent of the nitrate pollution of groundwater in Germany, data from various sources and measurements from various networks are used for evaluations, leading to different conclusions.

- ► The nitrate report of the German federal government (BMU/BMEL 2016) draws on data from 697 measuring stations of the EU nitrate monitoring network. Over the period 2012 to 2014, 28.0 % of the stations reported a mean nitrate concentration in excess of 50 mg NO_3^- l-^{1}.
- ► The "Data on the Environment 2017 – Indicator report" of UBA (2017) includes the indicator "Nitrate in groundwater". This draws on data from some1200 sampling sites of the EEA groundwater measurement network; the values for Germany are reported to the European Environment Agency (EEA). In 2014, 18.2 % of the monitoring stations reported nitrate concentrations above 50 mg NO_3 l^{-1}.
- ► An area-based evaluation of the map "Chemical status of the bodies of groundwater in Germany with regard to the parameter nitrate" (Figure 32, Section 5.4.2) shows 29.9 % "red" areas, i.e. BGWs that do not have a good status for nitrate according to the EU WFD. From a

total of 1168 BGWs, 313 BGWs (or 26.8 %) do not have a good status. Among other things, the discrepancy may be due to the following reason: In most cases, the WFD classification of a BGW is made with reference to more than one measuring station. It is usual for a BGW to be rated with a “poor” status if measurements from a single station exceed the nitrate quality standard. This means that a BGW may be classed as not having a good status even though some of its measuring stations meet the quality standards.

- In earlier publications, including previous Nitrate Reports of the German Federal Government (e.g. BMELV 2012), reference was often made to the “old” nitrate measuring network. In 2012 this consisted of only 162 measuring stations, of which ~50 % had nitrate concentrations above 50 mg l^{-1}. The goal of this measurement network was to register the pollution situation in agricultural areas and the effects of measures adopted in this sector. For the most part, sampling stations were selected with high nitrate levels. The network is therefore completely unrepresentative of the overall situation of the bodies of groundwater.
- Clearly, it is not possible to say with any certainty what proportion of the groundwater in Germany has nitrate concentrations that are too high. Depending on whether an area-based approach is chosen or one based on measuring stations, and on the measuring network that is used, very different results will be obtained for the proportion of groundwater that is polluted by nitrates.
- Due to the inadequate documentation, it will probably not be possible for a single institution drawing on the point measurements of the federal states, to produce a map in the foreseeable future which exactly corresponds to the area distribution pattern of the “red” BGW map in Figure 32.

6) As an alternative to an area-based evaluation based on the map of estimated NO_3^- concentrations (Figure 31), it would in principle also be possible to adopt a measuring station-related approach. However, this approach was not pursued further, for two main reasons:
Firstly, the distribution of the monitoring stations varies considerably in the federal states (see Section 5.4.1.2, Table 28). This problem could in part be redressed by making use of the EEA monitoring network, which would also mean that the data for the indicator would be consistent with the measurements for the presentation in the “Data on the Environment”. However, this network has some 1,200 stations, which corresponds to only one station per 300 km².
Secondly, there is the question of which approach should be used to determine the area represented by each measuring station (of either network), in order to be able to quantify the required reduction in the N-surplus.
We find the method described in Section 5.4 is better suited to generating a nationwide presentation of the NO_3^- concentrations in groundwater.

3.5 Climate: Global warming due to nitrous oxide emissions

3.5.1 Impact mechanism

As a greenhouse gas, nitrous oxide (N_2O) contributes to global warming. The greenhouse gas potential is 298-times[10] that of CO_2. The radiative forcing of nitrous oxide is about 0.2 W/m², which represents some 7 % of the RF caused by all greenhouse gases, and this is contributing to global warming (Myhre et al. 2013). This is expected to lead to direct, local impacts, e.g. more frequent extreme weather events, increased periods of drought and heat waves, and negative impacts on biodiversity and various

[10] Cf. IPCC Fourth Assessment Report in the 100-year horizon.

ecosystem services. In addition to direct, climate-related changes, there will also be indirect consequences, e.g. climate-related changes in other parts of the world will affect the availability of import goods (resources, foodstuffs, etc.) and the demand for exports.

In addition to its effect as a greenhouse gas, nitrous oxide also contributes to the depletion of stratospheric ozone. Since it has meanwhile been possible to reduce emissions of other ozone-depleting chemicals, N_2O is now the most important contributor to stratospheric ozone depletion (UNEP 2013).

In 1990, 52 % of N_2O emissions in Germany were from the agricultural application of nitrogenous fertiliser, and from agricultural land use. Further relevant sources of N_2O were the chemical industry (36 %) and combustion processes (10 %). In 2015, agriculture accounted for 81%, the energy sector 14 %, and industry for 2% (UNFCCC 2017). For agriculture, it is important to distinguish between direct and indirect nitrous oxide emissions. Direct emissions are from organic and mineral fertilisers, atmospheric N-depositions, and reactive nitrogen in soils from plant residues and biological N-fixing from legumes. Indirect N_2O emissions are produced in soil by the microbial transformation of nitrogen compounds such as nitrates and ammonia[11].

3.5.2 Sectoral target and the DESTINO target value

There are currently no legal limits on greenhouse gas emissions. The Climate Action Plan 2050 of the German Federal Environment Ministry (BMUB 2016) does contain a long-term objective for 2050 and interim targets for 2030.

- Long-term objective: By 2050, total greenhouse gas emissions are to be reduced by 80 % to 95 % in comparison with 1990 levels.
- Interim goal for 2030: Total greenhouse gas emissions in Germany must be reduced by at least 55 % compared with 1990 levels. The sectoral interim values are shown in Table 10.

Table 10: Climate Action Plan, Interim goals for 2030

Sector	1990 (in million tonnes CO_2-eq.)	2014 (in million tonnes CO_2-eq.)	2030 (in million tonnes CO_2-eq.)	2030 (% reduction compared with 1990)
Energy sector	446	358	175 – 183	62 – 61 %
Building	209	119	70 – 72	67 – 66 %
Transport	163	160	95 – 98	42 – 40 %
Industry	283	181	140 – 143	51 – 49 %
Agriculture	88	72	58 – 61	34 – 34 %
Interim total	**1209**	**890**	**538 – 557**	**56 – 54 %**
Others	39	12	5	87 %
Overall total	1248	902	543 – 562	56 – 55 %

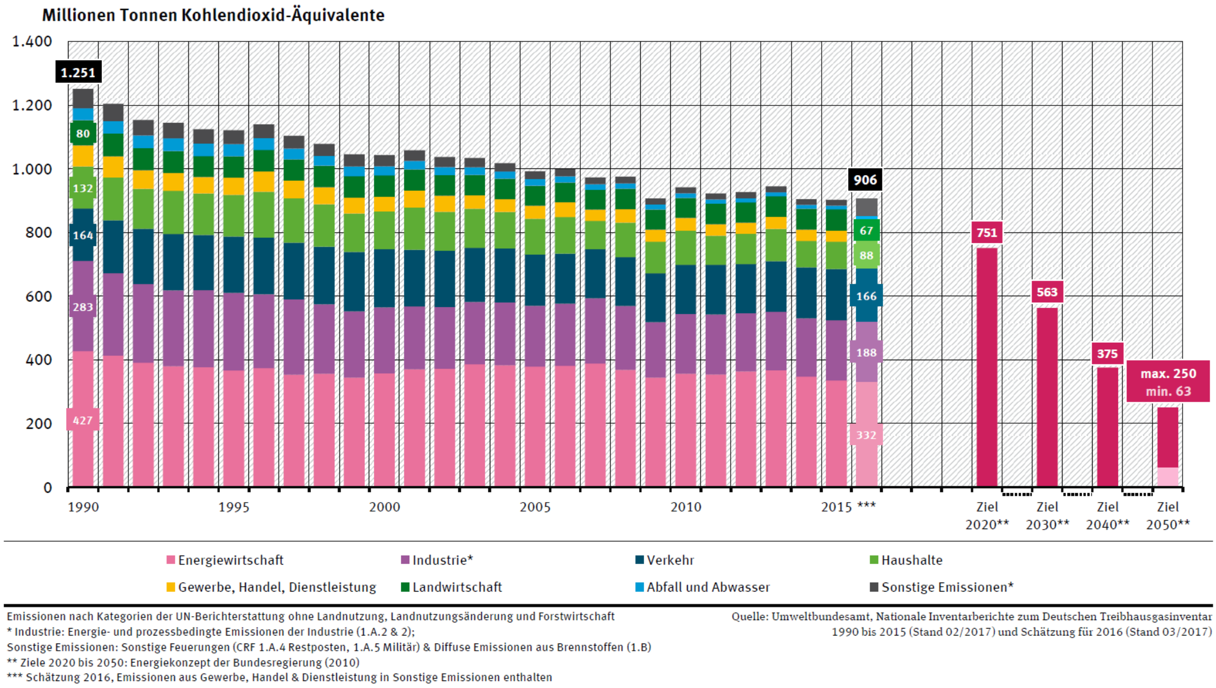
Source: German Climate Action Plan 2050 (BMUB 2016)

The development of greenhouse gas emissions since 1990 shows that reductions could be achieved in particular in the energy sector, in industry, in private households, and in trade, commerce, and

11 https://www.umweltbundesamt.de/themen/boden-landwirtschaft/umweltbelastungen-der-landwirtschaft/lachgas-methan [31.08.2018]

services (Figure 14). The greenhouse gas emissions from agriculture have only declined slightly over this period.

Figure 14: Germany's greenhouse gas emissions, with targets 2020 to 2050 (red)



Source: UBA[12]

The German Climate Action Plan only refers to total greenhouse gas emissions in CO_2-equivalents. Therefore, it was necessary to develop a long-term objective for nitrous oxide emissions for the DESTINO Project. The basis for deriving the target values for the nitrous oxide emissions per sector are the historical data on nitrous oxide emissions according to the national greenhouse gas inventory (UNFCCC 2017), the sectoral interim targets for 2030 and the long-term objective for 2050 in the German Climate Action Plan (BMUB 2016), see Table 10. The DESTINO-target for the nitrous oxide emissions is based on the long-term objective for 2050.

No sectoral targets are defined for 2050, but only an overall reduction target of 80 to 95 %. In order to derive the sectoral long-term objectives for the nitrous oxide emissions, we made the following assumptions:

- For the nitrous oxide emissions in the **Energy sector**, a long-term objective is a mean reduction of 87.5 % compared with 1990. This reduction target is thus consistent with the long-term objective for all greenhouse gas emissions.
- It is assumed for nitrous oxide emissions from **Agriculture** that the sectoral reduction target for 2030 can be extrapolated linearly to 2050[13]. With the sectoral reduction target of 32.5 % by 2030 compared with 1990, giving a reduction for 2050 of some 40 % compared with 1990.
- By 2015, the nitrous oxide emissions from **Industry** had been reduced by 95 % compared with 1990, so that emissions were already at a very low level and accounted for ~2 % of

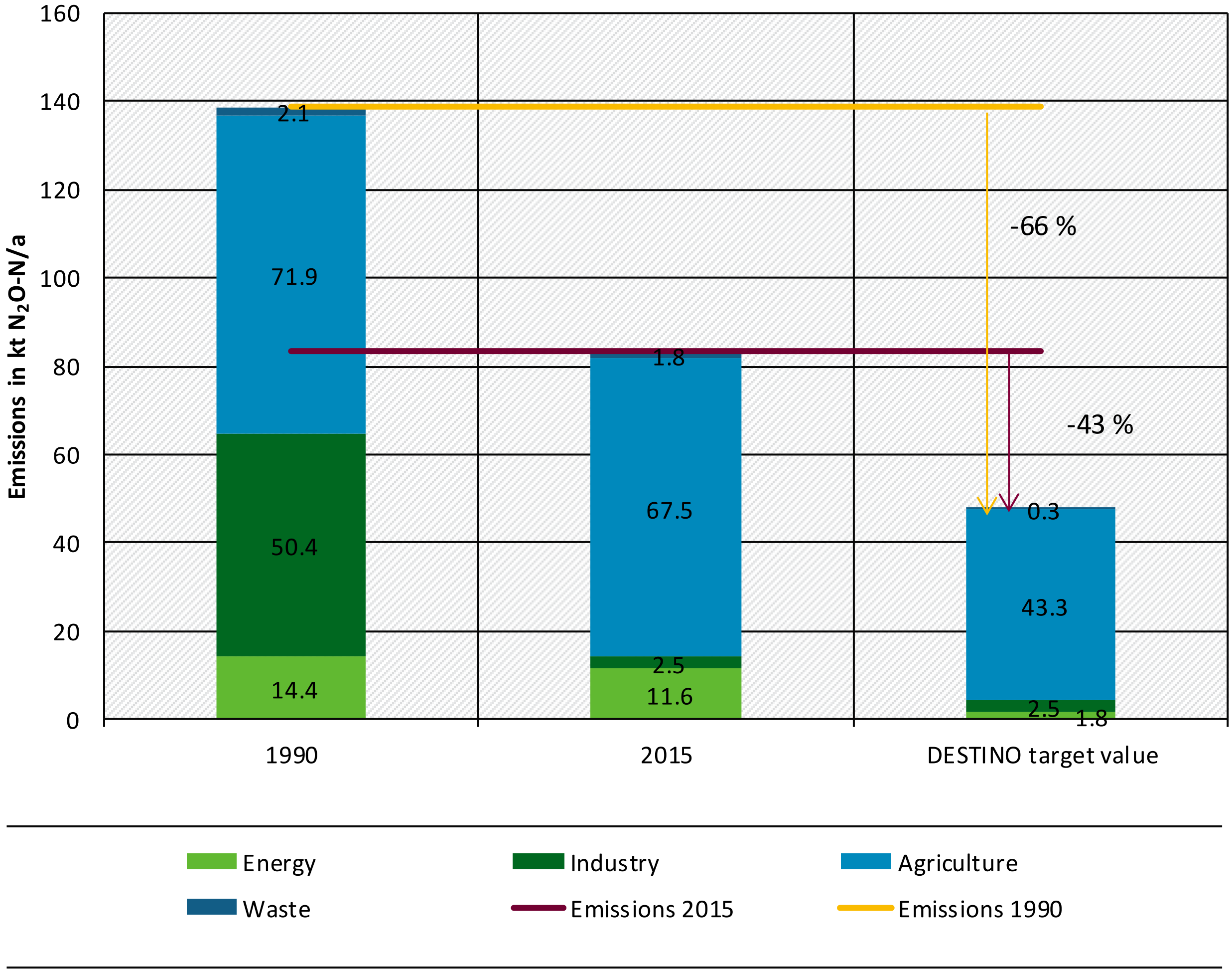
12 https://www.umweltbundesamt.de/en/indicator-greenhouse-gas-emissions [5.7.2019]

13 The validity of the assumptions will have to be discussed in connection with the long-term strategy for agriculture and nutritional security in Germany.

total nitrous oxide emissions. Industry has already made its contribution to achieving the sector reduction target of 50% by 2030 compared with 1990 and we therefore assume that there will be no further reduction from 2015 onwards and the nitrous oxide emissions from Industry will remain constant.

- For nitrous oxide emissions from the **Waste** sector, the reduction path for the “Others” category of the Climate Action Plan is assumed. This corresponds to an 87 % reduction by 2050 compared with 1990.
- Over all sectors, the result is a 66 %reduction of nitrous oxide emissions compared with 1990 levels. Relative to the nitrous oxide emissions in 2015, this corresponds to a reduction of 43 %. This reduction target is adopted as the DESTINO target value.

Figure 15: Nitrous oxide emissions according to sectors and DESTINO target value for the Climate sector.



Source: Our calculations, UNFCCC 2017

Historical data of the nitrous oxide emissions (1990, 2015) and DESTINO target value.

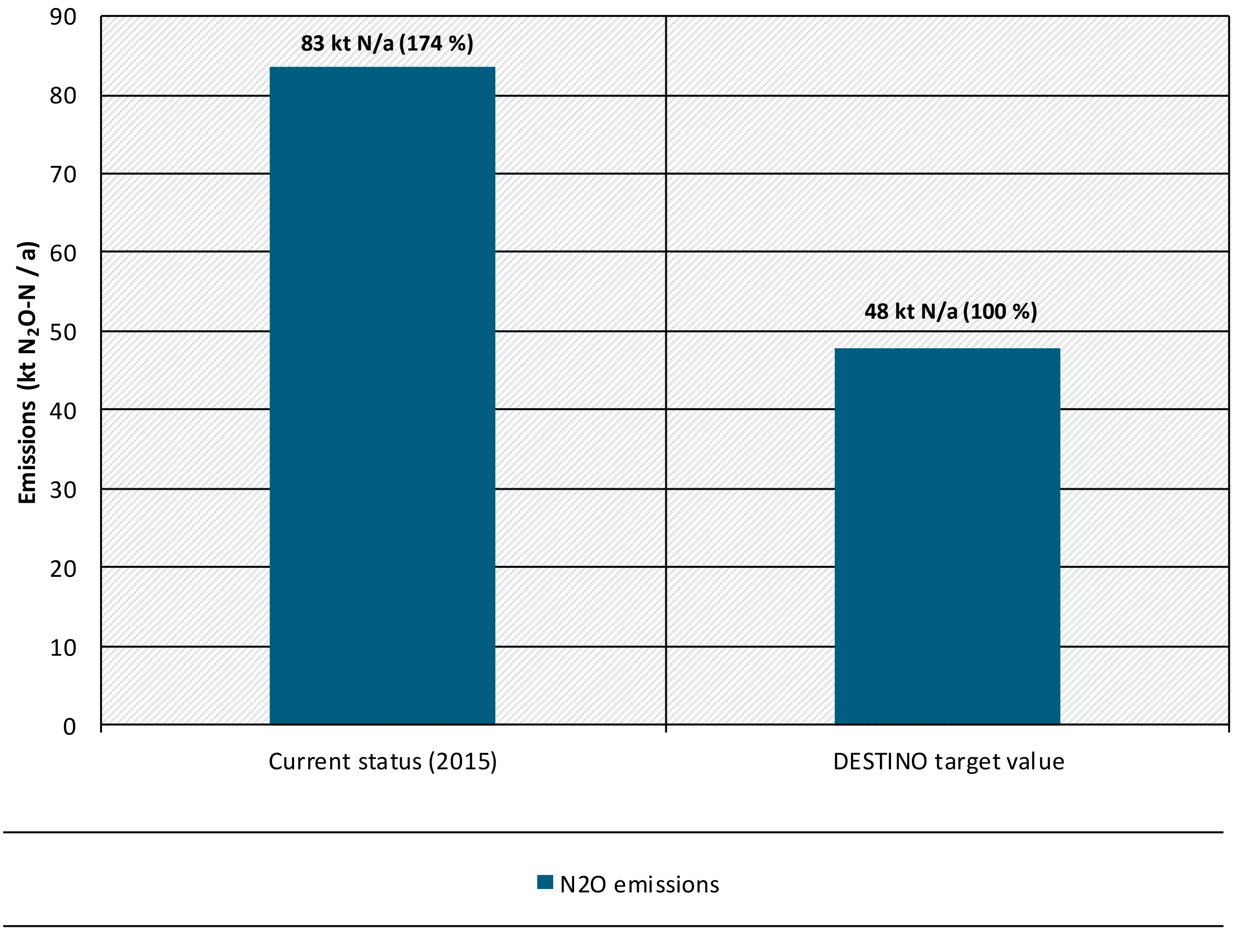
3.5.3 Methods for calculating the maximum nitrous oxide emissions

Back calculation is not needed to derive the maximum permissible nitrous oxide emissions, because the sectoral target for Climate is already expressed in terms of N_2O emissions.

3.5.4 Result for the DESTINO-indicator and the target value for the Climate sector

In 2015, nitrous oxide emissions amounted to 83.4 kt N_2O-N a^{-1}. The DESTINO target value is 47.8 kt N_2O-N a^{-1}. The emissions in 2015 were therefore 35.6 kt N_2O-N a^{-1} too high, and a corresponding reduction is necessary in order to achieve the Climate sector target for nitrous oxide emissions. The value for the DESTINO indicator for Climate is 174 % (83.4/47.8 x 100 %, see Figure 16).

Figure 16: DESTINO-indicator Climate, nitrous oxide emissions (N_2O). current status (2015) and DESTINO-target value.



Source: Our calculations UNFCCC 2017

Historical data for nitrous oxide emissions (2015) and DESTINO-target value.

3.5.5 Interpretation and assessment

1) Since the reduction target for the environmental sector Climate is already formulated in terms of N_2O emissions, no back calculation is necessary. But because there is no long-term objective for the individual greenhouse gases, reference has to be made to historical data in combination with assumptions about future developments. The approach proposed here will have to be discussed with UBA. The method takes into account that emissions from the management of living systems (agriculture) cannot be reduced to the same extent as may be possible with technical systems. Whether the assumptions we have made (see Section 3.5.2) are justified is difficult to decide. But the

method can only be discussed in the context of a long-term strategy on agriculture and nutritional security in Germany[14].

2) The UBA indicator report Data on the Environment 2017 (UBA 2017) sets total emissions of greenhouse gases in relation to the national targets for all greenhouse gases. Since nitrous oxide emissions only account for some 4 % of total greenhouse gas emissions, this indicator is not directly comparable with the DESTINO target value for the Climate sector.
3) No spatial differentiation is necessary for the Climate sector, since the impacts only depend on total global greenhouse gas emissions.
4) The February 2018 submission of the German greenhouse gas inventory involved changes in methodology and an updating of the time series for N_2O emissions (UNFCCC 2018). The revised N_2O emissions figures for 2015 are lower by 0.7 % and for 1990 are higher by 0.1 % than those in the February 2017 submission (UNFCCC 2017b), although this difference has a negligible effect for the calculation of the emissions target for nitrous oxide. For future submissions we recommend checking whether there have been significant changes in the emissions figures for 1990 or 2015. If necessary, the target value would then have to be updated.

3.6 Human health: Impairments and threats due to nitrogen dioxide pollution

3.6.1 Impact mechanism

An increased concentration of nitrogen oxides can have both direct and indirect impacts on human health. It can lead to inflammation and damage to the respiratory organs and has been shown to increase the effects of allergens. Asthmatics are particularly affected because they can suffer bronchial constriction, exacerbating their symptoms. A study of the German Environment Agency (UBA 2018e) shows that increased NO_2 pollution in Germany is having harmful effects on human health[15]. In 2014, some 6000 premature deaths due to cardio-vascular diseases were attributable to ambient NO_2 pollution in rural and urban areas. Other publications are cited that have shown a link between exposure to nitrogen dioxide and diseases such as diabetes mellitus, hypertension, strokes, chronic obstructive pulmonary disease (COPD), and asthma (UBA 2018e).

In addition, under UV radiation, ozone can be formed from nitrogen oxides and volatile organic compounds. Increased ozone concentrations impair lung functions and can lead to inflammation of the airways and respiratory problems. These effects are exacerbated by strenuous physical activity. The 'MAK' Commission (MAK = maximum workplace concentrations) of the German Research Foundation (DFG) assesses ozone as a substance suspected of causing cancer in humans[16].

Furthermore, ammonia and nitrogen dioxide emissions also contribute to the formation of secondary particulates in the atmosphere. These particles are not only released directly by combustion in vehicles, wood stoves, or power stations, but are also formed by the reaction of the two (precursor) gases with one another to form particular ammonium nitrate or with further precursor substances such as sulphur dioxide and hydrocarbons (forming particular ammonium sulphate and organic material). Airborne particulate matter is a health risk in Germany. These small particles can cause inflammation in

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14 We are not aware of such a discussion to date.

15 https://www.umweltbundesamt.de/no2-krankheitslasten [31.08.2018]

16 https://www.umweltbundesamt.de/themen/luft/wirkungen-von-luftschadstoffen/wirkungen-auf-die-gesundheit#text-part-2 [31.08.2018]

the airways, increase allergic respiratory diseases and can play a part in the development of chronic lung diseases, lung cancer and cardiovascular diseases[17].

In the following, we consider only the direct impacts of NO_2 pollution on human health. Depending on the environmental conditions, the ozone formation is limited by nitrogen monoxide or volatile hydrocarbons. However, the effects of low-level ozone concentrations cannot be considered as part of the integrated nitrogen indicator (for further comments on ozone see Section 3.6.5.). Nor can the contribution of nitrates and ammonium to particulate matter be readily incorporated in the concept.

3.6.2 Sectoral target and DESTINO target value

The NO_2 limit value for the protection of human health specified in the EU Ambient Air Quality Directive is 40 µg NO_2 m^{-3} as an annual mean. The limit value for one hour of 200 µg NO_2/m^3 is not to be exceeded more than 18 times in a calendar year. However, this limit value is not suitable for deriving a target value for NO_x emissions, because concentration peaks above the limit values may occur in the direct vicinity of local emission sources (e.g. traffic) and the measurements from stations in such locations will not correlate well with the national NO_x emissions. However, the background concentration of NO_2 does correlate very well with the national NO_x emissions. Therefore, the target value is derived on the basis of data on the background concentration of NO_2.

The World Health Organization recommended a response threshold of 20 µg NO_2 m^{-3} for background concentrations (WHO 2013). This response threshold is used when calculating the DESTINO-target value for NO_x emissions.

3.6.3 Methods for calculating maximum NO_2 emissions

The DESTINO target value for the national NO_x emissions is calculated on the basis of NO_2 ambient pollution data. The NO_x pollution is only measured at a few locations and the data would therefore not be suitable for obtaining a robust target value. In addition, the sectoral target has already been formulated for NO_2 ambient pollution levels. Therefore, the method used to derive the DESTINO target value for the national NO_x emissions is based on the NO_2 levels rather than NO_x levels.

When determining the target for NO_x emissions, the following approximation is made: The 98th percentile value of NO_2 pollution measurements from all background measuring stations is proportional to the sum of all national NO_x emissions. The 98th percentile value is chosen for the following reasons. All locations should have a background concentration which is below the response threshold of 20 µg NO_2 m^{-3}. At the same time, the national target value should as far as possible be unaffected by local influences. Since the monitoring stations cannot always be clearly allocated to a specific category, it must be assumed that some of the background measuring stations will also be affected by local emission sources. The evaluation of the data from the background measurement stations shows that the same stations had the highest measurements in all the years considered. In the course of a future update of the target value, the classification of these stations should be checked in order to ensure that stations at all locations only register the background pollution levels.

Assuming that the 98th percentile value for the NO_2 ambient pollution levels at all background pollution measurement stations is proportional to the total national NO_x emissions, then a linearity exists between NO_x emissions E(t) and NO_2 ambient pollution levels c(t) for Germany. This may not apply at the local level. In order to determine the target value ($E_{\max}$) as robustly as possible, the chosen

17 https://www.umweltbundesamt.de/publikationen/umweltschutz-in-der-landwirtschaft

method is based on a mean ratio of NO_x emissions to NO_2 ambient pollution levels over a number of years.

$$E_{\max} = c_{max} \langle \frac{E(t)}{c(t)} \rangle \;\; with\; c_{max} = 20\, \mu g\; NO_2/m^3 \qquad [-] \qquad \text{(Eq. 16)}$$

With a mean ratio of NO_x emissions to NO_2 ambient pollution levels of 11.8 (kt N · m³)/(µg NO_2 · a) for the selected period.

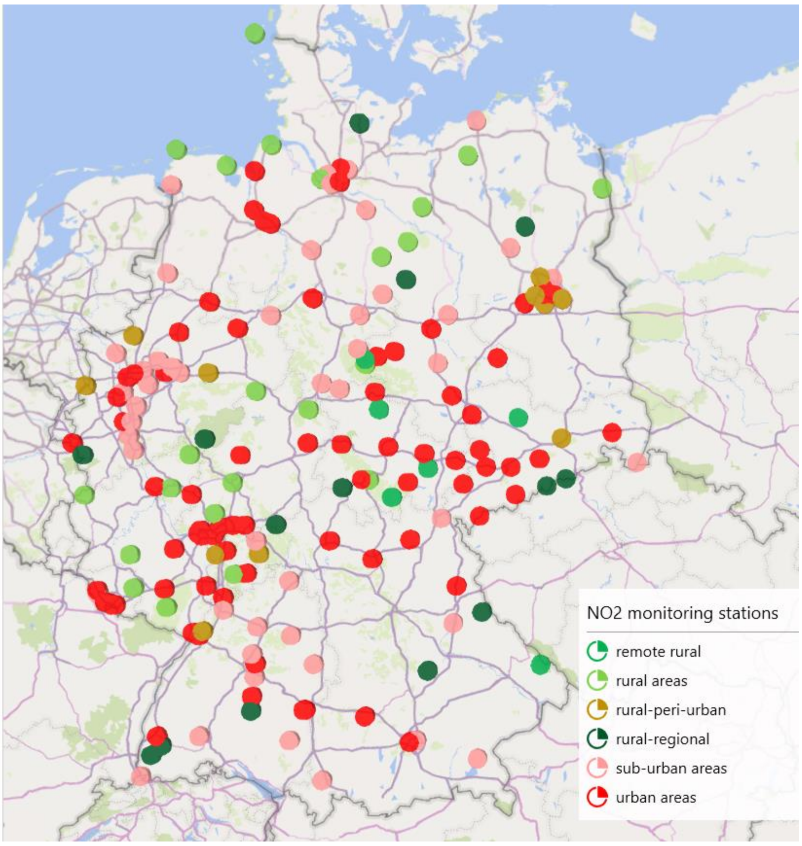
The maximum permitted NO_x emission E_{max} can then be determined:

$$E_{\max} = c_{max} \langle \frac{E(t)}{c(t)} \rangle = 20\, \mu g\; NO_2/m^3 \cdot 11.8\, \frac{\text{kt N} \cdot m^3}{\text{a} \cdot \mu\text{g}\, NO_2} = 235.8\, kt\; N/a \qquad [\text{kt N a}^{-1}] \qquad \text{(Eq. 17)}$$

In Germany, ambient NO_2 levels were measured at some 500 stations[18]. The lengths of the time series differ from location to location. In order to derive the target value, we attempted to find continuous time series for the largest number of stations measuring background pollution levels. We reviewed the available data and identified a total of 179 stations with continuous time series for background NO_2 pollution levels for the period 2002 to 2015 (Figure 17).

18 http://www.umweltbundesamt.de/daten/luftbelastung/stickstoffdioxid-belastung#textpart-5 [31.08.2018]

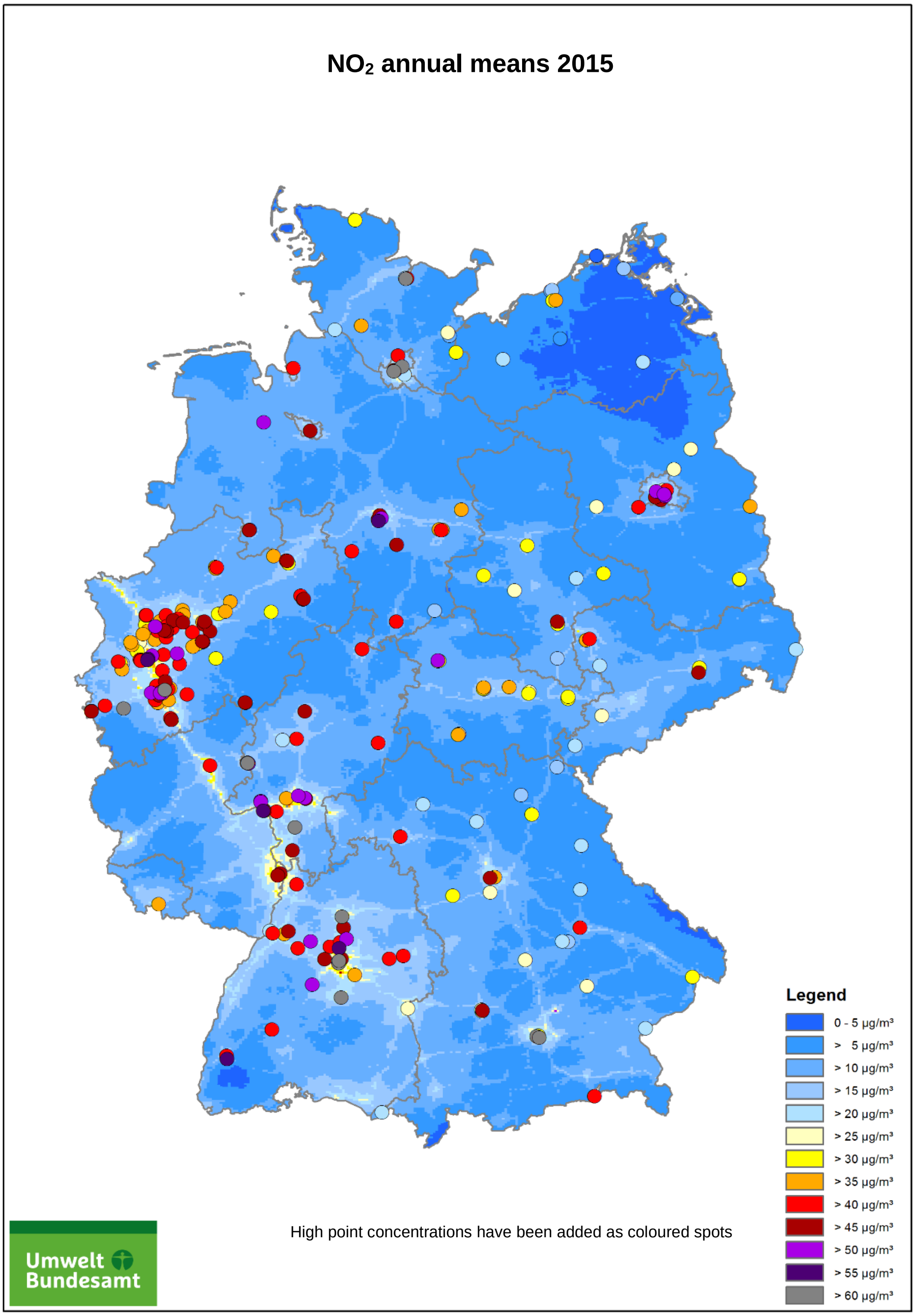
Figure 17: Locations of NO_2 background measurement stations with continuous data for 2002 - 2015



The 179 background NO_2 monitoring stations are shown with complete data from 2002 to 2015. Of these, 78 stations are in urban areas, 47 in sub-urban areas, 23 in rural areas, 11 stations are rural-peri-urban, 14 stations are rural-regional and 6 stations are remote rural. Data source: UBA (2017b)

The NO_2 ambient concentrations maps show widespread compliance with the annual limit value (40 µg m^{-3}), except at exposed locations, where values are still too high (Figure 18).

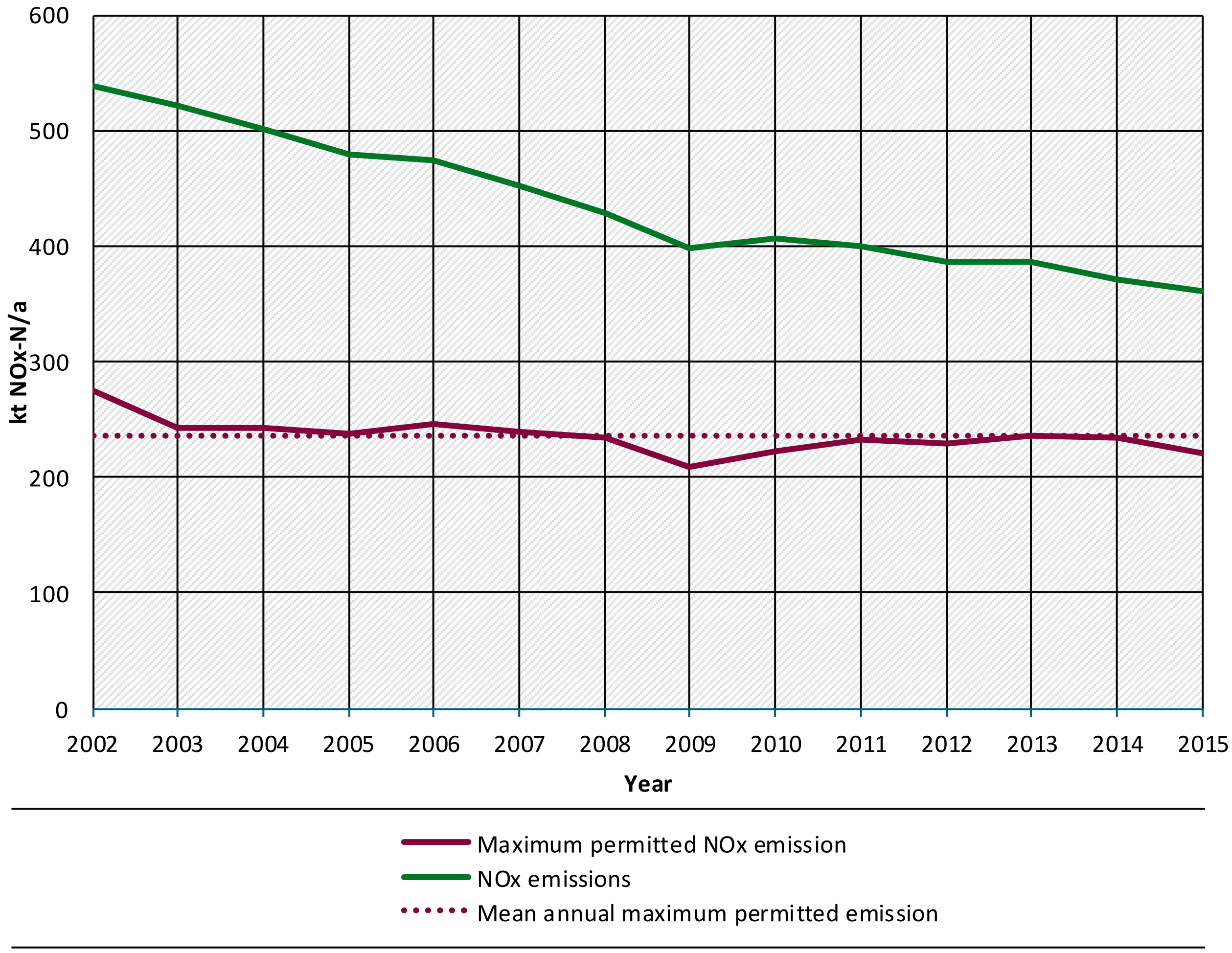
Figure 18: Map of the modelled NO_2 ambient concentrations 2015 (combination of measurements and distribution model). Circles mark measurements from stations that are only locally representative (annual means). The annual limit value is 40 µg NO_2 m^{-3}. The WHO response threshold for background concentrations is 20 µg NO_2 m^{-3}. Data source UBA [19]



[19] https://www.umweltbundesamt.de/themen/luft/luftschadstoffe/stickstoffoxide [31.08.2018]

Figure 19 shows the time series of annual NO_x emissions and maximum permitted NO_x emissions E_{max} derived using the method described above (Eq. 16).

Figure 19: NO_x emissions (green line) and the maximum permitted NO_x emission (red line) for compliance with the WHO response threshold for the NO_2-background concentration. The mean annual maximum permitted emission is 236 kt NO_x-N a^{-1} (dotted line).

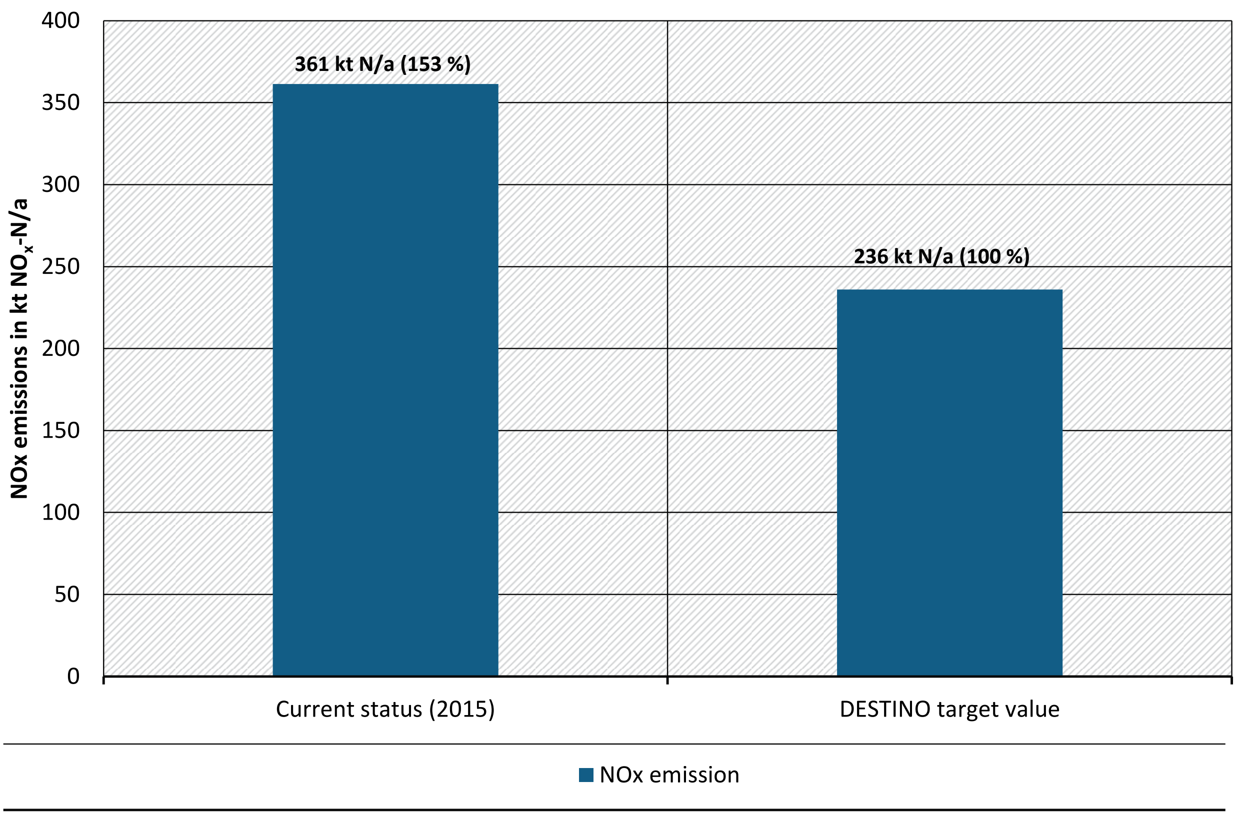


Source: UBA 2017b, Our calculations

3.6.4 Result for the DESTINO-indicator and the target value for Human health

The DESTINO target value for NO_x emissions is 235.8 kt NO_x-N a^{-1}. In 2015, the NO_x emissions were 361.4 kt NO_x-N a^{-1}, which is 125.6 kt N a^{-1} above the DESTINO target value. This is the reduction in NO_x emissions required to reach the sectoral target value for Human health. The DESTINO indicator for Health is 153 % (361.4/235.8 x 100 %, see Figure 20).

Figure 20: DESTINO-indicator Human health, nitrogen oxide emissions (NO_x). Current status (2015) and DESTINO target value



DESTINO target value for nitrogen oxide emissions compared with the emissions in 2015.

3.6.5 Interpretation and assessment

1) The method presented is limited to the direct impacts of NO_2 pollution on human health. However, as mentioned in Section 3.6.1, there is also an indirect impact, because nitrogen oxides are important precursors of **ozone**, which can harm human health. A simulation of ambient ozone concentrations for various emissions scenarios by Aksoyoglu et al. (2008) can be used to simulate the effects. For DESTINO, Scenario 6 (Table 1 in Aksoyoglu et al. 2008) is particularly relevant. This assumes that in 2010 all parties to the Gothenburg Protocol had reduced their NO_x, NMVOC, NH_3, and SO_2 emissions to 50 % of the target values. In Switzerland the ozone peaks would have been reduced by 10 - 20 % (in the publication in Section 3.4.3), and the number of hours with mean values of more than 120 µg m^{-3} would have been reduced to 0 - 6. In southern German, in contrast, where the maximum 8-hour mean is most frequently exceeded (see UBA 2017a), there would still have been 18 such peak hours. According to the EU Air Quality Directive, the long-term objective would not yet have been achieved[20]. The Gothenburg target value for NO_x emissions in Germany in 2010 was 1051 kt NO_x a^{-1} [21], 50 % of which would be 525 kt NO_x a^{-1} (or 160 kt NO_x-N a^{-1}). Interpreted as maximum emissions, this value is much lower than the value 361 kt NO_x-N a^{-1} given above, and it is even lower than the NEC Directive target of 550 kt NO_x a^{-1} (or 167 kt NO_x-N a^{-1}). But

[20] Directive 2008/50/EC, Annex VII/B: 120 µg m^{-3} not to be exceeded on more than 25 days per calendar year averaged over three years. Annex VII/C Long-term objective: 120 µg m^{-3} as maximum daily 8-hour mean within a calendar year.

[21] https://de.wikipedia.org/wiki/Luftreinhaltung

it should be noted that the results are dependent not only on the NO_x emissions, but also on the other emissions with Gothenburg targets. The maximum NO_x emissions should be analysed at least with regard to the NMVOC emissions. For Germany there are currently no specific ozone simulations which would allow quantitative conclusions about maximum NO_x emissions.

2) The UBA's indicator report Data on the Environment 2017 (UBA 2017) includes the indicator Air quality in agglomerations. This is based on data from all monitoring stations in conurbations for urban and suburban background pollution levels. Among other things, the deviations from the WHO response threshold of 20 µg NO_2 m^{-3} for NO_2 were calculated for these stations. For each agglomeration, the mean differences of the values for all background measurement stations to the WHO response threshold were calculated. These values were then averaged for all agglomerations and compared with the WHO recommendation. For NO_2, the indicator for 2015 was 9.2 % above the WHO response threshold. The DESTINO target value for Human health, in contrast, is based on the 98th percentile of the ambient concentration data and thus sets much more demanding reduction targets, with a value for 2015 that is 63 % above the target.
3) As an alternative, another way of deriving the target value was also tested (Section 5.3). This is based on a linear regression between the 98th percentile of ambient NO_2 concentrations and the national NO_x emissions. However, the results show that a very extensive extrapolation would be required, and the results obtained would involve considerable uncertainties. This approach is therefore not sufficiently robust and is judged unsuitable for deriving a target value for Human health.
4) The extent to which public health is impaired by NO_2 pollution depends to a large extent on the spatial distribution of the pollution and the population density. In order to get a realistic depiction of the exposure situation it is necessary to quantify the exposure of the public to elevated nitrogen dioxide concentrations. In the DESTINO Project area-differentiated approaches were not used for the indicators. A possible approach is outlined in Section 4.3.5.
5) We recommend that the ambient concentration models should be updated at intervals. After changes in the methodology, the February 2018 submission of the German air pollutant inventory for the CLRTAP updated the time series of NO_x emissions (UBA 2018). For 2015, the NO_x emissions were higher by 4.5 % than in the February 2017 submission (UBA 2017b). This is a considerable difference, which can have an appreciable effect on the ambient concentration modelling and thus also on the calculation of the emission target (i.e. this is a moving target). It is also necessary to test how the continued reduction in the emissions affects the statistical relationship between the NO_x emissions and the ambient NO_2 concentrations.
6) The emissions targets could in future be made more robust by using a Monte Carlo simulation. This offers some flexibility in the choice of stations, in the timeframe, and the choice of percentile values. It could be use in order to take a large number of random samples from the available measurements, also selecting various percentile values between 95 % and 100 %. The emissions target could be calculated for each random sample. From the resultant emissions targets, the value is selected which is most probable, is statistically robust and is no longer dependent on a specific parameter (stations, time window, percentile value).

4 Integrated nitrogen indicator and national nitrogen target

4.1 Construction of an integrated nitrogen indicator and its target value

4.1.1 Requirements for the integrated nitrogen indicator

The integrated nitrogen indicator should meet the following requirements:

- It should be derived on the basis of effects, and thus relate to the sectoral values.
- When it reaches its target value, then the sectoral values should be met in Germany as spatial means.
- The environmental sectors should be treated equally.
- As far as possible there should not be overlapping (double counting).
- It should be possible to carry out updates periodically, so that the development over time can be demonstrated.
- The integrated nitrogen indicator should only reach the target value when all sectoral indicators have reached their individual targets.

4.1.2 Construction of the integrated nitrogen indicator

In Sections 3.1 to 3.6, we showed how back calculation can be used to derive critical loads for reactive nitrogen in various environmental media. The integrated nitrogen indicator and its target value should be constructed using these results. The requirements mentioned in the previous section can be taken into account with the following construction:

1. For all environmental sectors the relevant DESTINO-indicators were identified and their current values and target values were quantified (Chapter 3). These include air pollutant and greenhouse gas emissions (NH_3, NO_x, N_2O), the total nitrogen load in watercourses leaving Germany, and the amount of reactive nitrogen in the form of nitrates leaching into groundwater (mainly due to N-surpluses from agriculture).
2. The derived target values ensure for each sectoral indicator with spatial components (only the GHG N_2O emissions are independent of where they are emitted) that the national spatial means do not exceed the critical load. However, this is not sufficient to ensure that the same applies everywhere at a regional level.
3. The NH_3 and NO_x are both emitted in two environmental sectors[22] so that two target values are derived for the same nitrogen species. In the integrated nitrogen indicator, however, each nitrogen species is only included once, using the lower target value.
4. The target value of the integrated nitrogen indicator is determined as the sum of the strictest target values per N-species (the sum is taken across N- species, not across the environmental sectors[23]). It is expressed in the units kt N a^{-1}.
5. Similarly, the individual DESTINO indicators are added to give the current value of the integrated nitrogen indicator (units kt N a^{-1}), including each N-species only once (not including the DESTINO indicators with N-species with less strict target values).
6. Although different terms are used for Groundwater and Surface waters (N-surplus and N-load), in fact the N-load is in part a consequence of the N-surplus. The total nitrogen load in watercourse outflows and the N-surpluses (nitrate inputs) are mostly caused by the application of fertiliser, but they also include depositions of nitrogenous air pollutants (included in Biodiversity and

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22 The required mean reduction in NO_x emissions for Germany is greater for Terrestrial ecosystems than for Human health. To protect Human health, the loads must primarily be reduced at hotspots (measuring stations near to dense traffic).

23 For a given nitrogen species, the target values of environmental sectors that are less severe than those of the other environmental sectors do not flow into the target value for the integrated nitrogen indicator.

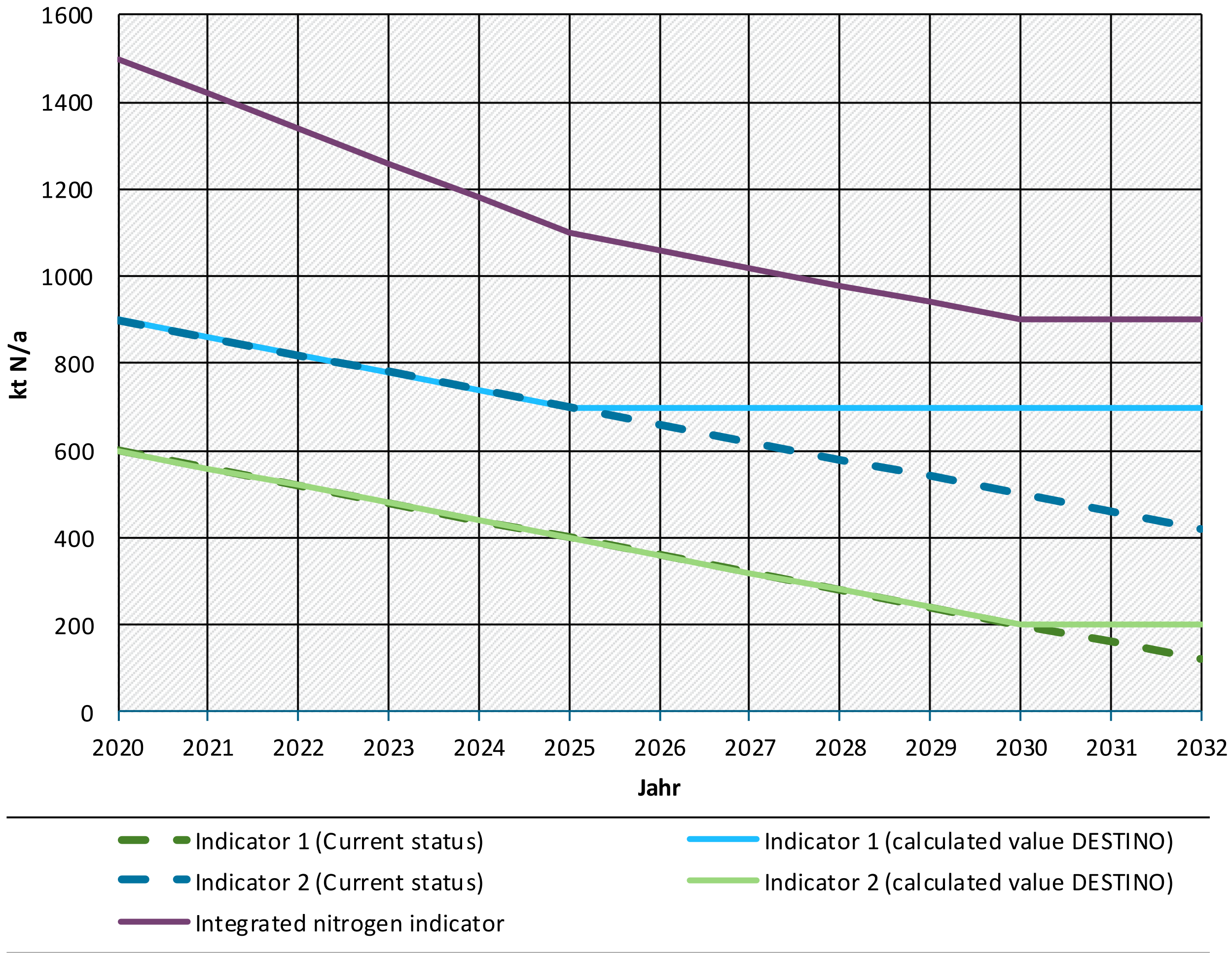
Eutrophication), which in turn are caused by nitrogenous emissions. However, these slight overlaps do not interfere with the dynamics of the integrated nitrogen indicator. A reduction of NH_3 emissions, for example, would express itself in the value of the integrated nitrogen indicator not only through the contribution from depositions, but also to a much lesser extent through the N-load in surface water, as well as with a time delay through nitrate in groundwater. The corresponding reductions are expressed in the individual DESTINO indicators and contribute to the reduction in the integrated nitrogen indicator (cf. Section 3.4.3.).

Implementing the reduction strategy will lead to reductions in N-losses. A DESTINO-indicator may then reach and sink below its target value. In this case, an additional rule applies:

7. When a sector indicator falls below its target value, then the calculation of the integrated nitrogen indicator is subsequently based on the target value, rather than the (lower) current value. This will avoid compensation effects between one environmental sector and another, (which would otherwise contradict the intention of the integrated nitrogen indicator, namely to achieve the target values for **all** environmental sectors).

This final rule will slow down the dynamic of the integrated nitrogen indicator in future, if all relevant DESTINO-indicators decline. Figure 21 illustrates the case for two sectoral indicators. As the first reaches its target value the integrated nitrogen indicator decreases less quickly, and only reaches the target level when **both** DESTINO-indicators have reached their target value.

Figure 21: A fictive example of the slowed dynamics of the integrated nitrogen indicator, with the possible development of values for two sectoral indicators (broken line, current value). After the target value has been reached (Indicator 1 in 2025, Indicator 2 in 2030), the target value continues to be used to calculate the integrated indicator (extended horizontal lines). The value of the integrated indicator (extended violet line) declines less quickly than the real development



4.1.3 Area-related DESTINO-indicators

Other ways of forming the integrated nitrogen indicator were also considered. For example, we tested whether area-related sectoral indicators could be used. For some indicators there were such options, and the results are summarised in Section 4.3.5. However, this is not the case for all environmental sectors, so that the construction of an integrated nitrogen indicator using only area-related indicators is not possible for technical reasons. This option also has an important disadvantage: the relation to areas does not provide information about the extent to which the driving nitrogen flows (emissions, N-surpluses) have to be reduced in order to achieve the target value. The integrated nitrogen indicator would therefore give no guidance about the (quantitative) reduction targets of measures.

4.2 Results for the integrated nitrogen indicator and for the national nitrogen target

4.2.1 DESTINO indicators current status and target values

The DESTINO indicators, as derived in Sections 3.1 to 3.6 are presented in Table 11.

Table 11: DESTINO-indicators and their target values

Environmental sector	DESTINO-indicators			
	Nitrogen species	Current status - absolute	- relative	Target value (100 %)
Terr. ecosystems / Biodiversity	NH_3 emissions	625.3 kt NH_3-N a^{-1}	142 %	441.1 kt NH_3-N a^{-1}
Terr. ecosystems / Eutrophication	Total NH_3 and NO_x emissions	625.3 kt NH_3-N a^{-1} 361.4 kt NO_x-N a^{-1}	173 %	402.0 kt NH_3-N a^{-1} 168.0 kt NO_x-N a^{-1}
Surface waters	Total nitrogen load	356.2kt TN a^{-1}	113%	314.0 kt TN a^{-1}
Groundwater	N-surplus/ Nitrate	147.6 kt NO_3-N a^{-1}	117 %	126.6 kt NO_3-N a^{-1}
Climate	N_2O emissions	83.4 kt N_2O-N a^{-1}	174 %	47.8 kt N_2O-N a^{-1}
Human health	NO_x emissions	361.4 kt NO_x-N a^{-1}	153 %	235.8 kt NO_x-N a^{-1}

The results can be visualised as a web presentation, see Figure 22 and Figure 23.

Figure 22: The six environmental sectors and the current status of the DESTINO-indicators relative to the target values (100 %)

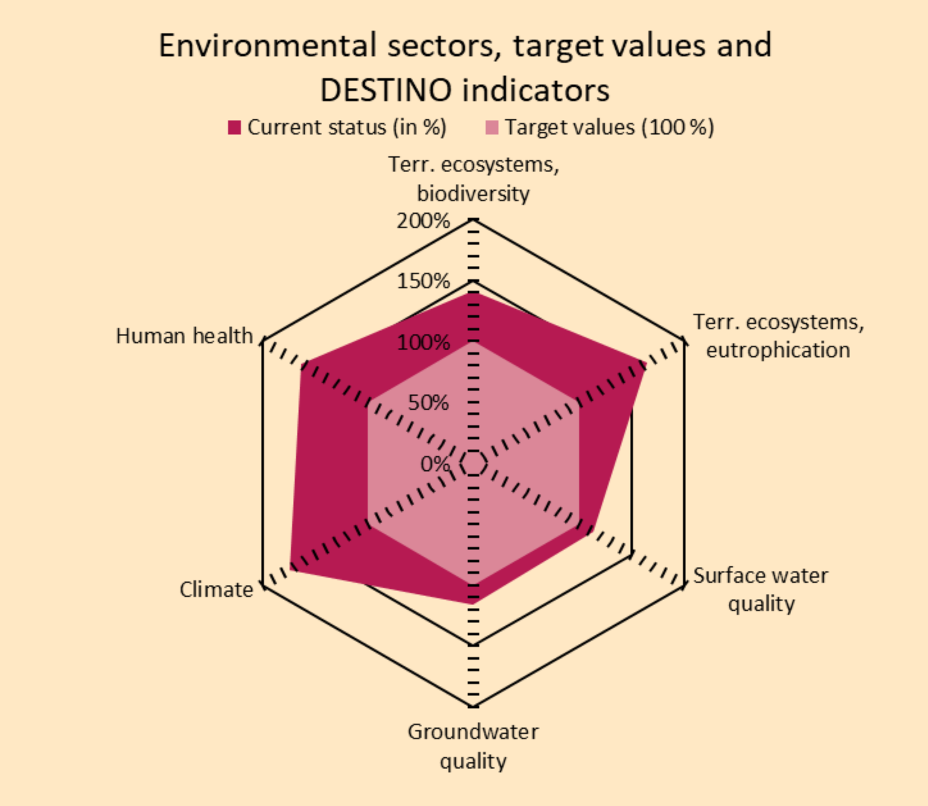


Figure 23: The six environmental sectors and the current status of the DESTINO-indicators and their target values in absolute terms (emissions, depositions, loads in kt N a^{-1}).

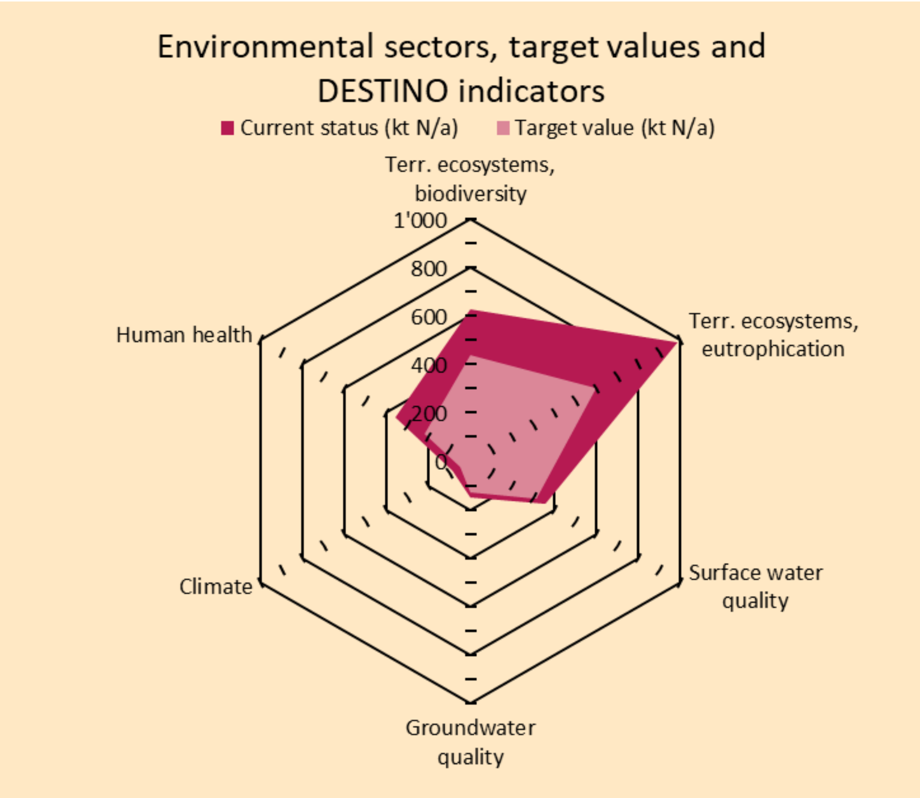


Figure 22 shows the relative values of the DESTINO-indicators, with the target values set at 100 % for all six sectors. This presentation demonstrates that both the greatest relative exceedances are currently in the environmental sectors Climate (174 %), and Terrestrial ecosystems / Eutrophication (173 %). For Human health (153 %) and Terrestrial ecosystems/ Biodiversity (142 %) the exceedances are also very high, with lower values for Groundwater (117 %) and Surface waters (113 %)

In Figure 23, the values of the DESTINO-indicators are given in absolute terms (in kt N a^{-1}). This shows that by far the greatest quantitative reduction is required for Terrestrial ecosystems / Eutrophication (417 kt N a^{-1}), followed by Terrestrial ecosystems / Biodiversity (184 kt N a^{-1}) and Human health (125 kt N a^{-1}), with lower reductions required for Surface waters (42 kt N a^{-1}), Climate (36 kt N a^{-1}) and Groundwater (21 kt N a^{-1}).

An interpretation and assessment of these values and their applicability is provided in Sections 3.1 to 3.6. **Note that the intention is to augment other existing indicators and not replace these** (see Sections 1.1 and 2.2.3).

4.2.2 National nitrogen target

In accordance with the rules formulated in Section 4.1.2, when nitrogen species (e.g. NH_3 and NO_x emissions) affect two environmental sectors and their DESTINO indicators, the more sensitive of the DESTINO indicators is identified. The less sensitive indicators will not be considered further: this is the case for the environmental sectors Terrestrial ecosystems / Biodiversity, and Human health:

- The target value for Terrestrial ecosystems / Biodiversity is 441 kt NH_3-N a^{-1}, which is higher than for Terrestrial ecosystems / Eutrophication (402 kt NH_3-N a^{-1}).
- The target value for Human health is 235.8 kt NO_x-N a^{-1}. This is higher than that of Terrestrial ecosystems / Eutrophication (168 kt NO_x-N a^{-1}).

The sectoral indicators and target values of the other environmental sectors are used to calculate the integrated nitrogen indicator and its target value (Table 12).

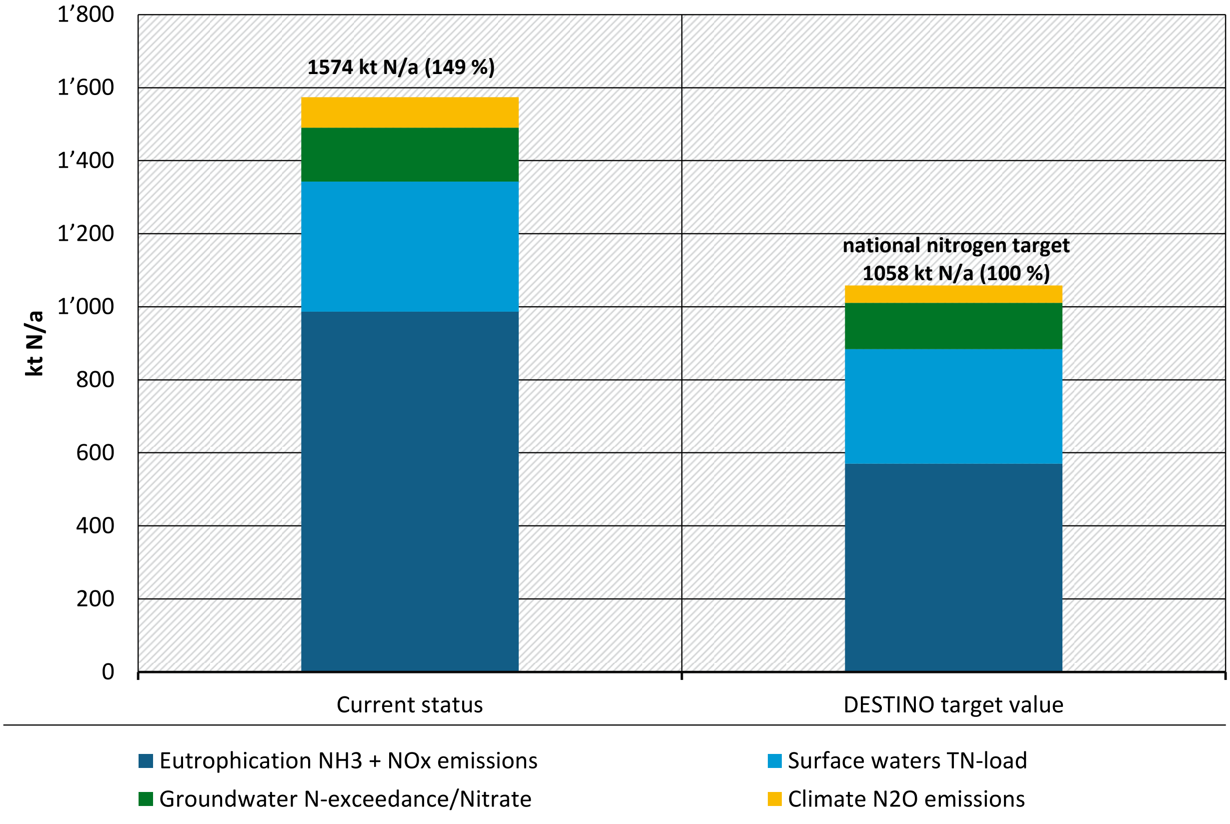
Table 12: The DESTINO indicators with the strictest target values for nitrogen species contribute to the calculation of the integrated nitrogen indicator. (Two sectoral indicators are not included.)

Environmental sector	DESTINO indicators		
	Nitrogen species	Current value (in kt N)	Lowest target value (in kt N)
Terrestrial ecosystems / Eutrophication	Sum of NH_3 and NO_x emissions	625.3 kt NH_3-N a^{-1} 361.4 kt NO_x-N a^{-1}	402.0 kt NH_3-N a^{-1} 168.0 kt NO_x-N a^{-1}
Surface waters	TN-load	356.2 kt TN a^{-1}	314.0 kt TN a^{-1}
Groundwater	N-surplus / Nitrate	147.6 kt N a^{-1}	126.6 kt N a^{-1}
Climate	N_2O emissions	83.4 kt N_2O-N a^{-1}	47.8 kt N_2O-N a^{-1}
Integrated nitrogen indicator		**1574 kt N a^{-1}** (149 %)	**1059 kt N a^{-1}** (100 %)
Not included (higher target values!)			
Terrestrial ecosystems / Biodiversity	NH_3 emissions	625.3 kt NH_3-N a^{-1}	441.1 kt NH_3-N a^{-1}
Human health	NO_x emissions	361.4 kt NO_x-N a^{-1}	235.8 kt NO_x-N a^{-1}

Integrated nitrogen indicator and target value (national nitrogen target) are presented in Figure 23. The integrated nitrogen indicator has a value of 1574 kt N a^{-1}. This represents the total nitrogen losses in Germany in the various environmental media. With a population of ca. 82.18 million in 2015, it corresponds to 19.2 kg N per person per year. The DESTINO-target value of the integrated nitrogen indicator is 1059 kt N a^{-1} or 12.9 kg N per person for 2015. Setting this at 100 %, then the integrated nitrogen indicator is currently at 149 %. In order to achieve the target value, the N-losses must be reduced by 49 percentage points or 516 kt N a^{-1}. Compared with the current status (1574 kt N a^{-1}), the indicator will have to be reduced by about one third in order to reach the target.

In Section 4.2.3, the uncertainties are considered. These show that it is sufficient to express the integrated nitrogen indicator and the national nitrogen target accurate to two significant digits. Communications could therefore express the current value of the **integrated nitrogen indicator as 1600 kt N a^{-1} and the national nitrogen target as 1000 kt a^{-1}**.

Figure 24: Integrated nitrogen indicator: Current value and target value (national nitrogen target): absolute (in kt N a^{-1}) and relative (%).



Source: Our calculations

Some two-thirds of the integrated nitrogen indicator and the DESTINO target value is accounted for by NH_3 and NO_x emissions. The N-losses in soils and surface waters account for about a quarter (current value) or a third (target value), while the proportion of nitrous oxide emissions (N_2O) is in comparison small.

A relative comparison (Table 11 and Figure 22) shows that the highest reduction rate is required for nitrous oxide, followed by NH_3 and NO_x emissions. The necessary reduction rates for the water system are comparatively small.

4.2.3 Uncertainties of the DESTINO-indicators

An uncertainty analysis was not carried out in the DESTINO Project. However, uncertainty estimates for the sectoral indicators are available from other sources:

- NH_3, NO_x emissions: The uncertainties are estimated in the air pollutant reporting for the CLRTAP. For the national emissions totals they are 15 % for NH_3 and 27 % for NO_x (UBA 2018)
- N_2O emissions: The uncertainties in agriculture and for forests and land use are very large; they are lower for the national total, but still considerable (UBA 2018a).
- N-load in inflows into North Sea and Baltic Sea, nitrate input into groundwater: In the national nitrogen budget (DESTINO Report 2, UBA 2020) the N-flows are assigned to semi-

quantitative uncertainty levels. Both N-flows are rated “Level 3”, with uncertainties between 50 % and 200 %.

A simple uncertainty estimate (propagation of uncertainty) for the integrated nitrogen indicator (sum over the sector indicators) gives an uncertainty range of ±25 % to ±30 %. The uncertainty of the target value will be somewhat greater because the determination of the sector target values involves further (uncertain) assumptions.

If both uncertainties are known, the uncertainty can also be estimated as the difference between the current value and target value, i.e. the uncertainty of the required measures. It should be borne in mind that the uncertainties of the current value and the target value are positively correlated. Depending the strength of the correlation, the uncertainty is then ±20 % to ±30 %.

These figures indicate the magnitude of the uncertainties. However, a robust, quantitative estimate of the uncertainties of the integrated nitrogen indicator (both current value and target value) would require a Monte Carlo simulation, because the prerequisite for simple propagation of error is not fulfilled in this case (uncertainties are not small in comparison with the means).

4.2.4 Comparison with the data in the national nitrogen budget (DESTINO Report 2)

The DESTINO sectoral indicators for current values are also included in the national nitrogen budget developed in the work package AP3 of the DESTINO Project and documented in Report 2 (UBA 2020). Table 13 shows how DESTINO indicators are linked to nitrogen flows. There are some differences between values, because the nitrogen budget is based on the mean nitrogen flows over the period 2010 to 2014, whereas for the integrated nitrogen indicator as far as possible the annual values for 2015 are used (with the exception of Surface waters and Groundwater).

Table 13: Comparison of the DESTINO-indicators with the data of the national nitrogen budget.

Environmental sector	Nitrogen species	Report 1 Integrated nitrogen indicator	Report 2 National nitrogen budget	
		Current status	Current status	Ref. UBA 2020
Terr. ecosystems / Biodiversity [a]	NH_3 emissions	625 kt NH_3-N a^{-1} (2015)	589 kt NH_3-N a^{-1} (2010-2014)	Tab. 3-5 ("Sum")
Human health [a]	NO_x emissions	361 kt NO_x-N a^{-1} (2015)	380 kt NO_x-N a^{-1} (2010-2014)	Tab. 3-4 ("Sum")
Surface waters	TN-load	356 kt TN a^{-1} (2011-2015)	334 [b] kt TN a^{-1} (2010-2014)	Tab 10-5 (Sub-Pool HY.SW)
Groundwater	N-surplus / Nitrate	148 kt N a^{-1} (2011-2014)	*1091* [c] kt N a^{-1} (2010-2014)	Tab. 7-5 (Sub-Pool AG.SM)
Climate	N_2O emissions	83 kt N_2O-N a^{-1} (2015)	83 kt N_2O-N a^{-1} (2010-2014)	Tab. 3-4 ("Sum")

[a]) For the NH_3 and NO_x emissions for Terr. ecosystems / Eutrophication (which is not shown in the table) the references to UBA 2020 apply that are given for Terr. ecosystems /Biodiversity, and Human health.
[b]) Sum of N(tot) in outflow minus N(tot) in inflow minus N(tot) in outflow of the River Danube (=334 kt Na^{-1}). Differences to 356 kt N a^{-1} are: Different timeframes, different data sources (the DESTINO-indicator draws on LAWA (2018), but the nitrogen budget uses loads calculated with the MoRE-Model).
[c]) The values for Groundwater (in italics) are not comparable: The N-surplus according to the nitrogen budget relates to the total agricultural area in Germany, but the DESTINO-indicator adds together only the N-surpluses in the grid cells with values above the critical nitrate concentration in groundwater.

4.2.5 Tracking the DESTINO-indicators

The DESTINO-indicator values change from year to year (Figure 8, Figure 14, Figure 19), and this in turn changes the current value of the integrated nitrogen indicator. As with greenhouse gas emissions, for which the development towards the goals of the Kyoto Protocol and the Paris Agreement are observed at intervals, the development of the integrated nitrogen indicator to its target value can also be studied. In the interests of environmental protection, the goal should be reached as soon as possible. If the development is slow or stagnating, then legislators and public authorities are called on to plan and implement further measures. Therefore, it is important to update the total nitrogen indicator periodically and to communicate its value.

Annex 5.1.1 shows the environmental data required for the updating. Almost all the data needed for the DESTINO Project are collected as part of on-going environmental monitoring programmes, but these are updated at different intervals:

- Emissions of NH_3, NO_x and N_2O are updated annually (in accordance with CLRTAP and UNFCCC).
- Total nitrogen loads in German inflows into the North Sea and Baltic Sea are registered every 6 years.
- The agricultural statistics for calculating the N-surpluses are updated annually on the basis of random samples, and in a full survey every five years.

Greater changes are to be expected with NO_x emissions. They currently account for 23 % of the integrated nitrogen indicator, so that a reduction of the annual NO_x emissions by 5 %[24] would lead to a reduction of the integrated nitrogen indicator by 1 %. The other indicators are likely to change less. This small reduction of the integrated nitrogen indicator suggests that updates need not be carried out annually, but rather at less frequent intervals, e.g. every five years.

The national inventories for air pollutants and greenhouse gas emissions are submitted annually under the CLRTAP and UNFCCC conventions. Each submission covers the entire emissions series from the basis year (1990), and where improvements are made to the model calculations then the values for all the past years also have to be recalculated. In particular for Germany's NH_3 emissions there have been significant recalculations in the recent past (see Section 3.1.5). Such changes have consequences for the modelling of ambient concentrations and depositions, and these in turn are important when determining the DESTINO-target values (in Section 3.1.5 this is referred to as a "Moving Target"). In this case it is necessary to recalculate not only the current value DESTINO indicator, but also the target values. **Annex 5.1.2 shows the data needed for such a recalculation**. These include the maps of NH_3 emissions and ambient NH_3 concentrations (regular modelling by UBA), ambient NO_2 concentration measurements (permanent follow-up by UBA), NO_x and NH_y depositions (regular modelling by UBA). A longer period also seems appropriate for these revision steps (e.g. five years).

In addition to the regular revisions of the DESTINO-indicators and their target values, it is also advisable to carry out additional updates if individual indicators show particularly remarkable changes or if there is a change in the direction of development.

4.3 Assessment of the integrated nitrogen indicator

4.3.1 General assessment

Generating an integrated nitrogen indicator

The methods and results in this report represent a first attempt to create an integrated nitrogen indicator which describes the current situation and with which a national target for the total nitrogen-losses can be specified. The result shows that such an integrated nitrogen indicator is feasible. The methods we propose are relatively easy to apply, but they require a series of individual indicators. With the exception of groundwater and surface water systems, the data requirements are relatively modest. However, if the target value has to be checked or refined, additional measurements and modelling will have to be carried out or commissioned by the relevant public authorities and agencies. Some of these are time-consuming and are not carried out regularly (see Section 5.1).

An important advantage of the DESTINO-indicators and the integrated nitrogen indicator is that their values relate to the "driving" nitrogen flows, i.e. those that can be influenced by reduction measures.[25] In this way it is possible to estimate the development of the integrated nitrogen indicator for various emission scenarios.

It is to be expected that the discussions of the procedures adopted and the results so far obtained will lead to further developments of the methods and thus also of the integrated nitrogen indicator and the target value. It would be desirable for other countries to adopt the idea of an integrated nitrogen indicator. This would offer the opportunity to develop standardised methods.

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[24] This is roughly the annual reduction in NO_x emissions required to meet the target of the NEC Directive for 2020.

[25] In contrast to induced nitrogen flows, which are a consequence of the driving flows and cannot be directly influenced.

The initial results show that far too much reactive nitrogen is currently being released. While the target value is 1059 kt N a^{-1} (100 %), the current level is 1574 kt N a^{-1} (149 %), so that a general reduction by at least a third is necessary. However, as has been emphasised, this reduction alone would not be sufficient to ensure that the targets and critical loads for the sectoral indicators are not exceeded at a regional level. This could require further reductions.

- Terrestrial ecosystems /Critical Level: Achieving the target value is a necessary but not sufficient condition for complying with the Critical Level everywhere. For a sufficient reduction the target value would have to be lowered (see 3.1.5).
- Terrestrial ecosystems / Eutrophication: As noted in Section 3.2.5 achieving the NEC target values would only improve the ecosystem status with regard to eutrophication by 35 % compared with 2005. The NEC Directive therefore explicitly refers to strategic targets for the period up to 2030 with a view to moving further towards the long-term objective on air quality (Preamble No. 3, NEC Directive 2016/2284).
- Surface waters: When determining target values for marine ecology it was assumed that the implementation of the Gothenburg Protocol and the commitments of the EU NEC directive would lead to a reduction of atmospheric nitrogen inputs by at least 20 %. If this were not the case, then the target values would have to be lowered further. And not least in view of changes to the climate the development of the marine ecological target values is not yet concluded. (see Section 3.3.2).
- Groundwater: The indicator “Reduction of the area-related N-surplus” therefore does not evaluate the progress in meeting the target for the environmental sector (how many bodies of groundwater or what proportion of the areas have a “good status” with regard to nitrates). Rather it assesses the reduction of the (potential) nitrate pollution entering the groundwater (see Section 3.4.5). If the indicator reaches the target value it is not guaranteed that the levels will be below the threshold of 50 mg $NO_3^- l^{-1}$. in all bodies of groundwater.
- Human health: The target value was determined using the threshold of 20 µg/m³ recommended by WHO (2016). In their recommendation, they write: “…evidence is lacking on the possible threshold for quantification of effects for the other outcomes associated with NO_2” (WHO 2016). If the WHO recommendation is changed in the light of further studies, then the DESTINO target value would have to be adapted.

Conclusion: The national nitrogen target derived in this investigation must be understood as an **interim target**. It does not yet guarantee that sectoral targets will be met everywhere.

Assessment with reference to the “Nitrogen” special report of the German Advisory Council on the Environment

In its special report, the Advisory Council (SRU) commented on the necessary reduction as follows: “In Germany, this will presumably require that current nitrogen levels be at least halved, in order to meet existing national and European quality objectives.” (SRU 2015, Summary, p. 7). It is not possible to make a direct comparison with the statements in the Special Report of the Advisory Council, but if nitrogen inputs are set equal to nitrogen losses, then the DESTINO target value represents an interim step on the way to achieving the long-term goals of the SRU. Among other things, the difference between SRU and DESTINO is due to the fact that the SRU calls for sectoral target values to be met across the board, and not only as spatial means.

4.3.2 Spatial aspects

In the consultations held in the course of developing the integrated nitrogen indicator, it was rightly pointed out that the target value might be reached before all the sectoral target values have been met **everywhere** (in all spatial units).

As already mentioned in Section 1.1, the remit for the integrated nitrogen indicator is to express a mean annual load of reactive nitrogen for Germany as a whole. It is derived from spatial data, but integrates these so that it no longer contains any specific spatial references (extensive quantity). Two examples highlight the limitations of the integrated nitrogen indicator:

- In the case of Terrestrial ecosystems / Critical Level (NH_3), reduction measures could lead to some regions reaching values below the Critical Level, while levels in others parts of the country remain above it. Reductions in a sufficient number of regions could lead to a situation in which national reduction target was met, despite the fact the individual regions remained above the Critical Level.
- Surface waters: If the target load for total nitrogen were achieved thanks to particularly effective reduction measures implemented in the Rhine river basin, then the outcome for the North Sea would be well below the target value (2.8 mg l^{-1} TN). However, if the reduction measures did not extend to the Rivers Schlei/Trave and Warnow/Peene then the inflows into the Baltic Sea would remain far above the target level of 2.6 mg l^{-1} TN.

If the sectoral target values are to be met all over Germany, then achieving the target value for the integrated nitrogen indicator represents a necessary but not a sufficient condition.

In principle, it would be possible to construct the integrated nitrogen indicator using complicated spatial models in such a way that the target value would only be reached when the sectoral targets were met everywhere. Germany would have to be subdivided into numerous spatial units (e.g. grid cells) and each unit would have to be examined separately to determine when the reduction targets were met. The target could be met in various ways. With regard to Human health, for example, a reduction of the ambient NO_2 concentrations in rural locations below 20 µg m^{-3} could be achieved by emission reductions in a number of sectors (transport, industry, trade, households). For an individual cell, it would only make sense to regard the inputs into this cell as being caused by a corresponding portion of the national emissions. For each possible realisation of a target status, the result would be a unique emissions scenario giving different national totals. Such an approach was not possible within the remit of the DESTINO Project.

This is one reason why the integrated nitrogen indicator cannot replace the existing N-indicators – it is only able to **augment** these. The concept of an integrated nitrogen indicator represents the attempt to integrate the complex problems of reactive nitrogen in the environment in a single parameter, with the aim of simplifying communications about this urgent environmental problem. **At present, the national nitrogen target should only be regarded as showing the direction in which Germany should proceed with regard to reactive nitrogen. It is essential that the existing indicators for environmental sectors are supervised and updated in parallel, including the monitoring of the spatial components.**

4.3.3 Loads in coastal and marine waters

As mentioned in Section 3.3.4, the N-loads can fluctuate depending on the outflow, so that the reduction requirement can vary considerably depending on the period under consideration. In order to minimise such fluctuations, future calculations should be based on outflow-normalised nitrogen loads and should also consider the statistical uncertainty.

4.3.4 Imports and exports of reactive nitrogen

Nitrogenous pollutants are imported and exported by transboundary transport (atmosphere, rivers, groundwater flows). The imports increase the nitrogen load in Germany, whereas exports reduce it, while increasing loads elsewhere. Imports cannot be affected by domestic emissions reductions and if they remain unchanged, they form a base level for pollution. In this case, the domestic emissions have to be reduced even more, the greater this base level pollution is. In this first version of the integrated nitrogen indicator, the methods used do not take imports and exports into consideration. This implies that the necessary reductions apply for the imported contributions, and also the exports. Imports and exports in the case of Terrestrial ecosystems / Eutrophication have already been considered (IIASA 2012). Ways to allow for the possible influence of imports and exports on Surface waters, and Human health are considered.

The influence of imported N-compounds on Surface waters

Of the N-load of 356.2 kt N a^{-1} in the outflow into the North Sea and Baltic Sea or to neighbouring downstream countries (see Table 8), some 84 % is due to inputs from domestic sources and ~16 % is from up-stream transboundary flows, above all in the Rhine and Elbe (derived from the details in Table 6). Since the imported (inflowing) N-load is not affected by measures adopted in Germany, the necessary N-load reduction of 42 kt N a^{-1} can only be achieved by reducing domestic inputs. The (domestic) target value is then 252.7 kt N a^{-1} and the current relative value of the DESTINO-indicator increases from 113.4 % to 138.6 %. As in the case of Human health, the DESTINO target value for the integrated nitrogen indicator would have to be lowered, i.e. the required reduction would be more demanding.

The influence of imported N-compounds on Human health

If imported NO_2 pollution is not reduced, then domestic emissions must be reduced even more in order to remain below the WHO response threshold of 20 µg NO_2 m^{-3}.

In order to examine the sensitivity, a national average imported proportion of 1 µg NO_2 m^{-3} was considered. The corresponding target value was calculated by reducing the maximum permissible NO_2 ambient concentration (A_{max}) by the imported contribution (A_{imp}). The corrected target value for the NO_x emissions (E_{max}) is now given by the following equation:

$$E_{\max} = (I_{\max} - I_{Imp}) \langle \frac{E(t)}{I(t)} \rangle \;\; mit\ I_{max} = 20\ \mu g\ NO_2/m^3\ where\ I_{Imp} = 1\ \mu g\ NO_2/m^3 \quad [-] \qquad \text{(Eq. 18)}$$

The result shows that an average import contribution of 1 µg m^{-3} to ambient NO_2 concentrations lowers the emissions target value and increases the relative DESTINO indicator value from 153 % to 161 %. The emissions target for Human health would then be less strict than for Terrestrial ecosystems / Eutrophication and would therefore not be included in the calculation of the national target value.

Table 14: Sensitivity analysis of the target value for Human health with and without imports of N-compounds.

	Assumption Imports of 0 µg NO_2 m^{-3}	Assumption Imports of 1 µg NO_2 m^{-3}
Target value, absolute	235.8 kt NO_x-N	224.0 kt NO_x-N
Current status relative to the target value (DESTINO indicator 2015)	153 %	161 %

No specific information is currently available about the contribution of imports to the ambient NO_2 concentrations. The reference above to falling NO_x emissions in Germany's key neighbouring countries in recent years and the associated reductions in imports shows that under the current circumstances the inclusion of imports is not a pressing issue.

Conclusions

If the integrated nitrogen indicator is updated at a later date, the quantitative influence of imported and exported pollution loads should be modelled and the sensitivity considered. As long as the effects remain small, and as long as the development of the nitrogenous emissions in other countries runs parallel to the development in Germany, then the methods for calculating the integrated nitrogen indicator and the national nitrogen target can be used without including imports and exports. This represents a convenient simplification.

4.3.5 Area-related indicators

Area-related indicators are not available for all environmental sectors, so that it would not be technically possible to use these for the construction of an integrated nitrogen indicator. In addition, the area-related information cannot be used to derive reduction amounts for emissions. An advantage of area-related indicators is that they would make it possible to consider small-scale differences. Even if national target values are met, there may be local values that are above the maximum permissible nitrogen inputs. These high local values are compensated for by lower values in other regions so that they are no longer apparent in the integrated nitrogen indicator. Where such local exceedances can be depicted by area-related indicators, this would be a useful supplement to the integrated nitrogen indicator.

Area-related indicators for the environmental sectors are:

a) Terrestrial ecosystems / Biodiversity: An area-related indicator for the pollution of terrestrial ecosystems can be derived on the basis of the number of grid cells of the ambient NH_3 concentration maps. The number of grid cells exceeding the critical levels compared with the total number of grid cells can be used to calculate the proportion of the total area nationwide with excessive ambient NH_3 concentrations. In 2015, the critical level of 3 µg NH_3 m^{-3} was exceeded for 38 % of all grid cells. The current area indicator relative to the target value is therefore 100% / [1 – 0.38] = 161 %, which is higher than the load indicator (142 %).
b) Terrestrial ecosystems / Eutrophication: An indicator can be developed on the basis of the areas of sensitive ecosystems for which a critical load is defined (see Section 3.2.5). Currently, N-inputs are above the critical load for 68 % of the areas. The area indicator for the current situation is therefore 100 % / [1 – 0.68] = 312 %, which is considerably larger than the load indicator (165 %).
c) Surface waters: There is no area-related indicator.

d) Groundwater: The calculation of the DESTINO-indicator already uses area data; the current value of the indicator is 117 %.
e) Climate: There is no area-related indicator.
f) Human health: In 2015, 39 % of the NO_2 monitoring stations reported values exceeding the WHO response threshold of 20 µg NO_2 m^{-3} (taking into account all stations with continuous measurements for the period 2000 – 2015). However, Human health is also dependent on the numbers of people exposed to the pollution. It is therefore necessary to quantify public exposure to elevated nitrogen dioxide concentrations. For Germany, data on exposure to nitrogen dioxide is available for the period 2007 - 2014 (UBA 2018e). In principle, this could be used to calculate the numbers of residents in areas with an NO_2 background concentration of 20 µg NO_2 m^{-3}. Such calculations could not be carried out as part of the DESTINO Project due to budget constraints. They would have to be investigated in a follow-up project.

4.3.6 Using the national nitrogen target in the context of political objectives and for public communications

The calculated value of the integrated nitrogen target is 1058 kt N a^{-1} (Table 12). This reflects the results calculated separately for six sectoral targets which have been combined to form the integrated nitrogen target. It takes into account all sources of nitrogen emissions and has the objective of achieving a certain level of protection for each sector. As explained previously (Section 4.2.3), the target value has a range of uncertainty of ±30 %.

For uses in a political context, it is necessary to convert the values calculated on the basis of the data for 2017 in order to take the updated figures into account[26] and to meet the requirements of the current policy framework. To simplify communications with the general public, it is also appropriate to round the calculated target value down slightly to 1000 kt N a^{-1}. In the following, the necessary adaptation steps are described:

1. Converting the integrated nitrogen target to the policy specifications of the National Clean Air Programme and thus also to the revised data
2. Converting the integrated nitrogen target according to the proposals in the draft "Action programme for nitrogen reduction"
3. Adapting the integrated nitrogen target to the requirements for communications

The resulting target value of 1000 kt N a^{-1} lies within the range of error of the calculated national target value. Therefore the recalculated values do not affect the basic thrust of the integrated nitrogen target.

4.3.6.1 Converting the integrated nitrogen target to meet the policy specifications of the National Clean Air Programme

The target for the sectoral indicator "Terrestrial ecosystems: Impacts of nitrogen inputs" (Section 3.2) is based on the percentage reduction requirements for NO_x and NH_3under the NEC Directive and the National Clean Air Programme (NLRP; BMU, 2019), which Germany has committed to achieve by 2030 in comparison with the levels in 2005. Using the NOx emissions data for 2005 and 2015 from the datasets of 2017 (UBA 2017d) and the obligation in accordance with the NEC Directive for a reduction of

[26] The Gothenburg Protocol calls on the Parties to the CLRTAP to submit updated national emissions data annually, and if necessary to update the entire time series. In the course of such updating, Germany's NH_3 and NO_x emissions have been amended since the submissions of 2017 (see also Section **Fehler! Verweisquelle konnte nicht gefunden werden.**)

65 % by 2030 compared with 2005, an absolute target value was calculated for NO_x in 2030. (Achieving the target would lead to a reduction in the areas affected by excessive atmospheric nitrogen deposition in Germany by 35 % compared with 2005.)

The National Clean Air Programme (NLRP) transposes the provisions of the NEC Directive into German law. This includes an undertaking for a 65 % reduction of NO_x emissions by 2030 compared with 2005. However, neither the NEC Directive nor the national clean air programme require the agricultural sector to reduce its NO_x emissions. As a result of this policy provision, the NO_x emissions from agriculture must be excluded from the calculations for the sectoral indicator "Terrestrial ecosystems: Impacts of nitrogen inputs". In addition, the National Clean Air Programme is based on a more recent dataset (2018), with slight deviations throughout for NO_x and NH_3 emissions in comparison with the data from 2017. An overview of the relevant emissions data and target values is given in Table 15 (NO_x) and Table 16 (NH_3). For policy-making and for calculations of the difference between current levels and the target (e.g. in the planned BMU Action Programme for Nitrogen Reduction) then the latest data for 2015 must be used (the bottom lines in Table 15 and Table 16).

Table 15: NO_x emissions 2005, 2015 and the 2030 emission reduction commitment with and without agriculture, depending on the reported data

	2005	2015	Target 2030	Units
Reduction of NO_x in accordance with the NEC Directive	0 %	-	65 %	Percentage
NO_x with agriculture (Table 12, data from 2017, UBA 2017d)	479	361	168	kt NO_x-N a^{-1}
NO_x without agriculture (data from 2017, UBA 2017d)	444	322	155	kt NO_x-N a^{-1}
NO_x without agriculture (data from 2018, BMU 2019)	444	337	156	kt NO_x-N a^{-1}

Table 16: NH_3 emissions 2005, 2015 and the emission reduction commitment for 2030, depending on the reported data

	2005	2015	Target 2030	Units
Reduction of NH_3 in accordance with the NEC Directive	0 %	-	29 %	Percentage
NH_3 (DESTINO, data from 2017, UBA 2017d)	558	625	402	kt NH_3-N a^{-1}
NH_3 (data from 2018, BMU, 2019)	515	552	366	kt NH_3-N a^{-1}

4.3.6.2 Converting the integrated nitrogen target according to the proposals in the draft "Action programme for nitrogen reduction"

In parallel to the DESTINO Project, BMU and UBA are developing an Action Programme for Nitrogen Reduction with a time horizon of 2030 for achieving the targets. The DESTINO target value for the sectoral indicator "Climate: Global warming due to nitrous oxide emissions" (Section 3.5) is oriented on the National Climate Action Plan and has previously been formulated for 2050. All other sectoral targets are either directly oriented on 2030 or can readily be used for this target year.

In order to use the sectoral target “nitrous oxide emissions” for the integrated nitrogen indicator, a value must be derived for 2030. Since the national climate action programme does not explicitly define a reduction target for nitrous oxide emissions, the value for 2030 was determined by linear interpolation between 2015 and 2050. An overview of the results obtained are shown in Table 17.

4.3.6.3 Adapting the integrated nitrogen target to the requirements for communications with policy-makers and the general public

For communication purposes, it is convenient to use a rounded, memorable value for the integrated nitrogen target. If the sectoral targets are rounded to whole numbers as a first step and then added together, this results in an integrated target value of 1059 kt N a^{-1}. As a precaution, it is appropriate to round this value down to 1000 kt N a^{-1}. The result is ~6 % lower than the calculated target value and is well within the uncertainty range of ±30 % (740 to 1380 kt N a^{-1}).

To ensure consistency between the overall target and the sectoral targets, it is necessary to adjust the sectoral targets correspondingly. In order to obtain a value of 1000 kt N a^{-1}, a scaling factor of 0.97 is applied to the adapted overall target of 1031 kt N a^{-1} for 2030 in accordance with Sections 4.3.6.1 and 4.3.6.2 (see Table 17). This factor is also used to provide scaled sectoral targets, as shown in the final column of Table 17. For the planned national action programme for nitrogen reduction, these scaled sectoral target values are applicable.

Table 17: Calculated target values, adaptations to NLRP, conversion to the time horizon 2030, and adaptations for communication purposes

Nitrogen species	DESTINO calculated (rounded to whole numbers)	DESTINO NH_3 and NO_x adapted to NLRP, without NO_x agriculture	DESTINO N_2O converted to time horizon 2030	DESTINO adapted for communications
	kt N a^{-1}	kt N a^{-1}	kt N a^{-1}	kt N a^{-1}
NH_3	402	366	366	355
NO_x	168	156	156	151
NO_3 (Surface waters + Marine waters)	314	314	314	305
NO_3 (Groundwater)	127	127	127	123
N_2O	48	48	68	66
N total	**1059**	**1011**	**1031**	**1000**

4.4 Other nitrogen indicators: Planetary boundaries and nitrogen efficiency

The idea of an overall indicator for nitrogen is not new. The work on Planetary Boundaries[27] already assigns one of the nine planetary boundaries to nitrogen. The Planetary Boundary concept is a popular way to communicate the need for action in a simplified form as a global aggregate for the nine environmental sectors. For nitrogen, efforts have been made to derive critical levels globally on the basis of indicator values (de Vries 2013). The Nitrogen Boundary currently being discussed is 62 million tonnes of intentional nitrogen fixation annually. As the term planetary boundary indicates, it applies for the whole planet, but breaking this total down to the level of individual nations is by no means straightforward. At a symposium "Total Reduction Target for Nitrogen" held in Berlin on 6 September 2017, H. Hoff from the Potsdam Institute for Climate Impact Research showed that depending on the reference parameter (e.g. per capita, agricultural area, per capita consumption, etc.[28]) the boundary for Germany would be between 500 kt N a^{-1} and 2800 kt N a^{-1}. The current value lies between 1700 and 2500 kt N a^{-1} (Hoff 2017)[29]. The discussion on the application of such a boundary for Germany is still on-going (Hoff et al. 2017). Such a value would complement the integrated nitrogen indicator, because the planetary boundary of intentionally fixed nitrogen is limited and does not take into consideration the environmental sectors and sectoral targets on which the integrated nitrogen indicator is focussed.

At the same meeting, Wim de Vries (de Vries 2017) presented a concept of the EU Nitrogen Expert Panel entitled "Nitrogen Use Efficiency (NUE) - an indicator for the utilization of nitrogen in agriculture and food systems" (EU Nitrogen Expert Panel 2015). The concept addresses nitrogen in agriculture. It is based on the idea of optimising the nitrogen input on utilised agricultural areas(fertiliser), not solely to minimise losses (as emissions into the air, or leachate into soils, groundwater, and surface waters), but in order to combine minimum losses with maximum yields. Depending on the soil type, there is an area in the diagram of N output (agricultural products) against N input (fertiliser) with optimum nitrogen use efficiency (NUE).

As with planetary boundaries, the results of this concept complement the integrated nitrogen indicator. The optimum nitrogen use efficiency in agriculture augments the integrated nitrogen indicator because in addition to nitrogen losses to the environment it also integrates agricultural production. On the other hand, the NUE indicator, being limited to nitrogen in agriculture, has a much narrower scope than the integrated nitrogen indicator, which covers all environmental sectors.

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27 As introduced by Johan Rockström and the Stockholm Resilience Center. Cf. Steffen (2015)

28 Hoff names the following principles for downscaling: equity, fair shares, environmental justice, historic resource use or emissions ("debt"), common but differentiated responsibility, capacity/ability, right to development, different resource endowment (Hoff 2017).

29 Corresponding to 20 to 30 kg N a^{-1} per capita.

5 Annexes

5.1 Nitrogen indicators

5.1.1 DESTINO-indicators required for updating the integrated nitrogen indicator

Table 18: Indicator NH_3 emissions

Specification	Description
Name	Ammonia emissions (NH_3 emissions)
Affected sectors	Terrestrial ecosystems / Biodiversity Terrestrial ecosystems / Eutrophication Groundwater Surface waters
Definition	The annual national ammonia emissions from all sources (energy sector, industry, and trade, households, agriculture, waste sector). System limits: Territorial principle (not point of emission)
Units	1000 tonnes NH_3-N
Background	Impacts of NH_3 emissions see Section 3.1.1, 3.2.1, 3.3.1, 3.4.1
Context	For example: Data on the Environment 2017 (UBA), Emission of air pollutants Eutrophication of North Sea and Baltic Sea due to nitrogen, Nitrate in groundwater
Data source	UBA https://www.umweltbundesamt.de/daten/luft/luftschadstoff-emissionen-in-deutschland [31.08.2018]
Process steps	The ammonia data are converted to NH_3-N units: 1 kt NH_3-N = 1 kt NH_3 x 14/17 = 1 kt NH_3 x 0.8235
Data owner, Contact	German Environment Agency (UBA), I 2.6 buergerservice@uba.de
Frequency of revision	Annual

Table 19: Indicator NO_x emissions

Specification	Description
Name	Nitrogen oxide emissions (NO_x emissions)
Affected sectors	Terrestrial ecosystems / Eutrophication Human health
Definition	The annual national NO_x emissions from all sources (energy sector, trade and industry, households, agriculture, waste management). Territorial principle (not point of emission)

Specification	Description
Units	Figures in 1000 tonnes NO_x-N
Background	Impacts of NO_x emissions see Sections 3.2.1, 3.6.1
Context	See: Data on the Environment 2017 (UBA), Emission von air pollutants Air quality in conurbations,
Data source	UBA https://www.umweltbundesamt.de/daten/luft/luftschadstoff-emissio-nen-in-deutschland [31.08.2018]
Process steps	The source gives data in 1000 tonnes NH_3. The data must be converted to NO_x-N: 1 kt NO_x-N = 1 kt NO_x x 14 / 46 = 1 kt NO_x x 0.3043
Data owner, Contact	German Environment Agency (UBA), I 2.6 buergerservice@uba.de
Frequency of revision	NO_x emissions are measured and reported annually

Table 20: Total nitrogen-loads in German watercourses ending in the North Sea or Baltic Sea

Specification	Description
Name	Total nitrogen-loads in German watercourses ending in the North Sea or Baltic Sea
Affected sectors	Transitional and coastal waters (North Sea and Baltic Sea) / N-eutroph-ication
Definition	Total-N load per annum (TN) or dissolved inorganic N load (DIN) in wa-tercourses at the limnic-marine transitional point or at boundaries and critical loads for compliance with the Marine Strategy Framework Di-rective (MSFD)
Units	Tonnes N a^{-1}
Background	Eutrophication of coastal waters by excessive N-inputs, see Section 3.3.1
Context	see e.g. Data on the Environment 20172017 (UBA), (Eutrophication of North Sea and Baltic Sea due to nitrogen
Data source	Report to MSFD (see Section 3.3.4)
Process steps	Evaluation of report to MSFD (see Section 3.3.4)
Data owner, Contact	LAWA, Federal States, UBA FG II 2.3 and II 2.4
Frequency of revision	Every six years (reporting period)

Table 21: Map of nitrate-concentration in groundwater

Specification	Description
Name	Nitrate concentration in groundwater
Affected sectors	Groundwater / nitrates; Human health (drinking water supplies)
Definition	Map "Nitrate concentration in groundwater", estimates with Random-Forest classification
Units	mg $NO_3^{-}l^{-1}$
Background	Health threat; failure to reach "good status" in accordance with Water Framework Directive, see Section 3.4.1
Context	see e.g. Data on the Environment 2017 (UBA), (Nitrate in groundwater UBA (2017g): additional costs for preparing drinking water due to agriculture Website WasserBLIck.net
Data source	a) Federal State authorities and agencies b) cf. Section 6.5.1.3 c) see Table 17.
Process steps	Map of estimated distribution of nitrate concentrations in groundwater determined using Random-Forest classification involving: a) Measurements of the nitrate concentration in groundwater from the measurement networks of the Federal States (s. Section 5.4.1.2) b) 10 digital maps of hydrogeological and other parameters (s. Section 5.4.1.3) c) Map of N-surplus on agricultural areas (s. Section 5.4.1.3 Random-Forest classification (s. Section 5.4.1)
Data owner, Contact	a) Federal States b) Sources as given for maps (s. Section 5.4.1.3) c) UBA (Map of N-surplus has been regularly updated by Univ. Giessen, Inst. of Landscape ecology and resource management). Map (1 km x 1 km grid) "Nitrate concentration in groundwater": Uni. Giessen, Inst. of Landscape ecology and resource management (Martin Bach); made available to UBA as part of this project.

Table 22: Map of N-surplus on agricultural areas

Specification	Description
Name	Surplus of the nitrogen area balance of agriculture
Affected sectors	Groundwater / nitrate and Transitional and coastal waters / N-load (Eutrophication)
Definition	Map "N-surplus on agricultural areas (AA)", mean 2011 – 2014, (unpublished); Methodology see Häußermann et al. 2019)
Units	kg N/(ha AA * a)
Background	Key parameter for calculating nitrate concentrations in groundwater and the indicator "Groundwater pollution by nitrate"
Context	see e.g. UBA (2016b): Assessment of methods to reduce nitrate inputs

Specification	Description
Data source	Agricultural statistics (Destatis) and other sources (cf. methodology description)
Process steps	Method description – Häußermann et al. (2019)
Data owner, Contact	Uni. Giessen, Inst. f. Landscape ecology and resource management (Martin Bach); results (maps) are freely available.
Frequency of revision	Agricultural statistics: annual; Updating of N-area balances: Project-based, typically every 2-3 years (time series currently 1995 – 2016)

Table 23: Indicator N_2O emissions

Specification	Description
Name	N_2O emissions
Affected sectors	Climate
Definition	Annual national N_2O emissions from all sources (energy sector, industry and commerce, households, agriculture, waste management). Territorial principle (not point of emission)
Units	1000 tonnes N_2O-N
Background	Impacts of N_2O emissions see Section 3.5.1
Context	see e.g. Data on the Environment 2017 (UBA), Emission of greenhouse gases
Data source	UBA https://www.umweltbundesamt.de/daten/klima/treibhausgas-emissionen-in-deutschland [31.08.2018]
Process steps	The data sources use units of 1000 tonnes N_2O. The data must be converted to N_2O-N units: 1 kt N_2O-N = 1 kt N_2O x 28 / 44 ≈ 1 kt N_2O x 0.6364
Data owner, Contact	German Environment Agency (UBA), I 2.6 buergerservice@uba.de
Frequency of revision	Annually

5.1.2 Further indicators required to update the DESTINO-target values

Table 24: Map of ambient NH_3 concentrations

Specification	Description
Name	Map of ambient NH_3 concentrations
Affected sectors	Terrestrial ecosystems / biodiversity
Definition	Spatially resolved NH_3 concentration data
Units	$\mu g\ NH_3\ m^{-3}$

Specification	Description
Background	The NH_3 target value is derived on the basis of a regression between NH_3 concentrations and emissions.
Context	see e.g. UBA Website on air pollutant emissions: https://www.umweltbundesamt.de/daten/luft/luftschadstoff-emissio-nen-in-deutschland [31.08.2018]
Data source	Data based on the results from the chemical transport model REM-CALGRID with a spatial resolution of 2 km x 2 km.
Process steps	1. Each grid cell has a concentration value. 2. Regression between NH_3 concentrations and NH_3 emissions per grid cell 3. Calculating the intersection point between the regression line and the critical level of 3 µg NH_3 a^{-1}
Data owner, Contact	German Environment Agency, II 4.2, Contact: Stefan Feigenspan
Frequency of revision	At regular intervals

Table 25: Map of NH_3 emissions

Specification	Description
Name	Map of NH_3 emissions
Affected sectors	Terrestrial ecosystems / biodiversity
Definition	Spatially resolved NH_3 emissions data
Units	kt NH_3 a^{-1}
Background	The NH_3-target value is derived on the basis of a regression between NH_3 concentrations and emissions. A map of current NH3 concentra-tions is essential for updating the DESTINO target value.
Context	See e.g. UBA-Website on air pollution emissions: https://www.umweltbundesamt.de/daten/luft/luftschadstoff-emissio-nen-in-deutschland [31.08.2018]
Data source	Annual submissions of national emissions to CLRTAP (UBA 2016).
Process steps	1. Each grid cell is allocated a concentration value. 2. Regression between concentration and emission per grid cell 3. Calculation of intersection between regression line and critical level of 3 µg NH3 a^{-1}
Data owner, Contact	German Environment Agency, II 4.2, Contact: Stefan Feigenspan
Frequency of revision	Regularly

Table 26: Measurement data for NO_2 ambient concentrations

Specification	Description
Name	Measurement data for ambient NO_2 concentrations
Affected sectors	Human health
Definition	Data from all locations which measure NO_2 background concentrations.
Units	µg NO_2 m^{-3}
Background	Updating the NO_x-target value requires an extended time series of data on ambient NO_2 concentrations.
Context	see e.g. UBA-Website on emissions of air pollutants: https://www.umweltbundesamt.de/daten/luft/luftschadstoff-emissionen-in-deutschland [31.08.2018]
Data source	Modelling with the CTM-Modell RCG: Results of the chemical transport model REM-CALGRID with a resolution of 2 km x 2 km.
Process steps	1. Identification of continuous measurement series 2. Determining the 98th percentile value 3. Calculating the relation between the 98th percentile value of measured NO_2-background concentrations and the WHO-response threshold of 20 µg NO_2 m^{-3}
Data owner, Contact	German Environment Agency, II 4.2, Contact: Stefan Feigenspan
Frequency of revision	Annually

Table 27: NO_x and NH_y depositions

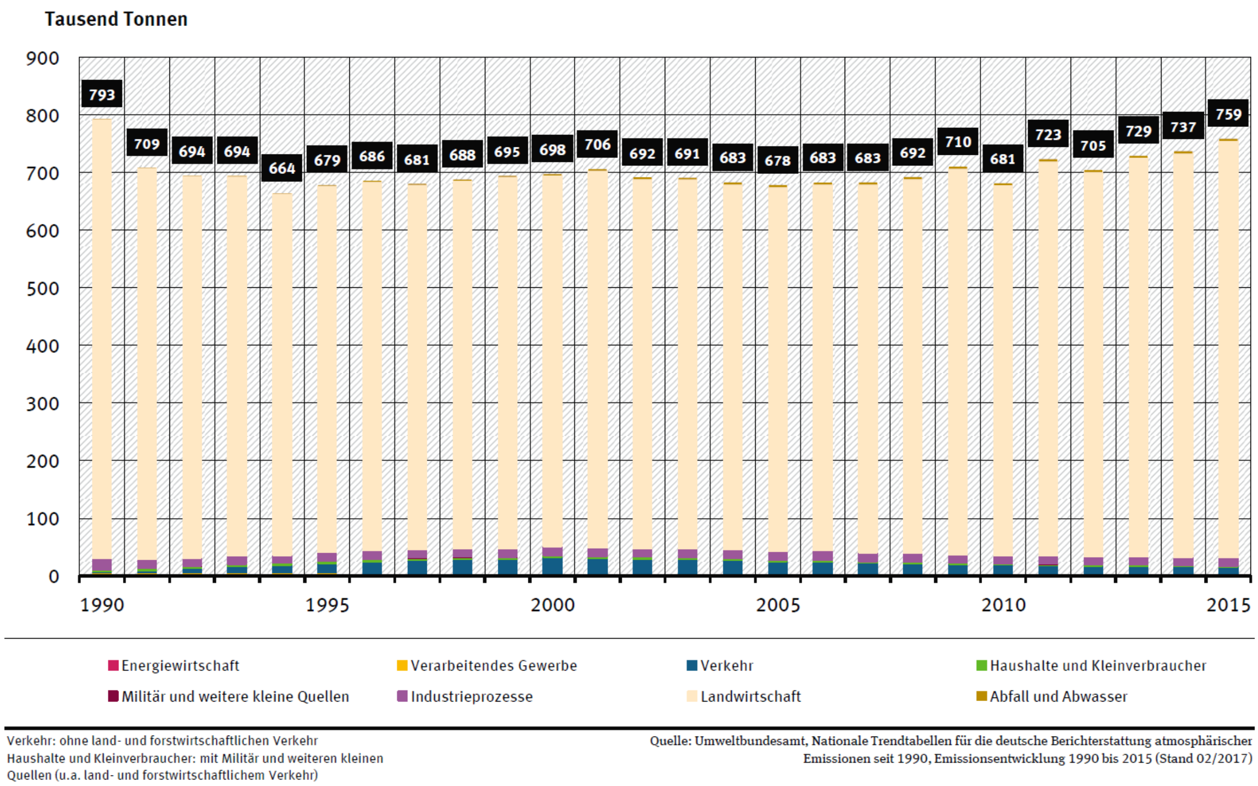
Specification	Description
Name	Atmospheric deposition of nitrogen
Affected sectors	Terrestrial ecosystems / Eutrophication
Definition	The annual deposition load, divided into oxidised NO_y and reduced NH_x nitrogen species on soils (total area of Germany) including levels of NO_y and NH_x that are above the critical loads. Further distribution of data would be desirable according to country of origin or at least division between domestic and imported emissions.
Units	kt N a^{-1}
Background	The deposition of nitrogen has various impacts on soils that are relevant for DESTINO, e.g. eutrophication, reducing the tolerance of ecosystems to frost, drought, pests, etc.
Context	see e.g. UBA-Websites on pollutant inputs: https://www.umweltbundesamt.de/daten/luft/luftschadstoff-emissionen-in-deutschland [31.08.2018] https://www.umweltbundesamt.de/themen/luft/wirkungen-von-luftschadstoffen/wirkungen-auf-oekosysteme/kartendienst-stickstoffdeposition-in-deutschland [31.08.2018]

Specification	Description
	Data on the Environment 2017 (UBA), Section Eutrophication of North Sea and Baltic Sea due to nitrogen.
Data source	PINETI-III: Modelling and mapping of atmospheric pollutant depositions from 2000 bis 2015 to assess ecosystem-specific threats to biodiversity in Germany Martijn Schaap, Carlijn Hendriks, Richard Kranenburg, Jeroen Kuenen, Arjo Segers TNO, Utrecht Angela Schlutow, Hans-Dieter Nagel, Anja Ritter ÖKO-DATA, Strausberg Sabine Banzhaf Free University Berlin, Berlin For the German Environment Agency. FKZ 3714 64 2010. July 2018.
Process steps	1. Calculation of deposition and concentration fields from emissions and meteorological data with the LOTOS-EUROS transport model. 2. Calculation of wet deposition fields on the basis of measurements 3. Use of a heuristic approach to estimate occult deposition 4. Use of a scavenging ratio approach to calculate the dry deposition 5. Transformation of results for dry and wet depositions to the higher resolution 1 km x 1 km grid, and combination to show the total deposition
Data owner, Contact	German Environment Agency, II 4.3, Contact: Markus Geupel
Frequency of revision	regularly

5.1.3 Time series for the emissions of NH_3, NO_x and N_2O

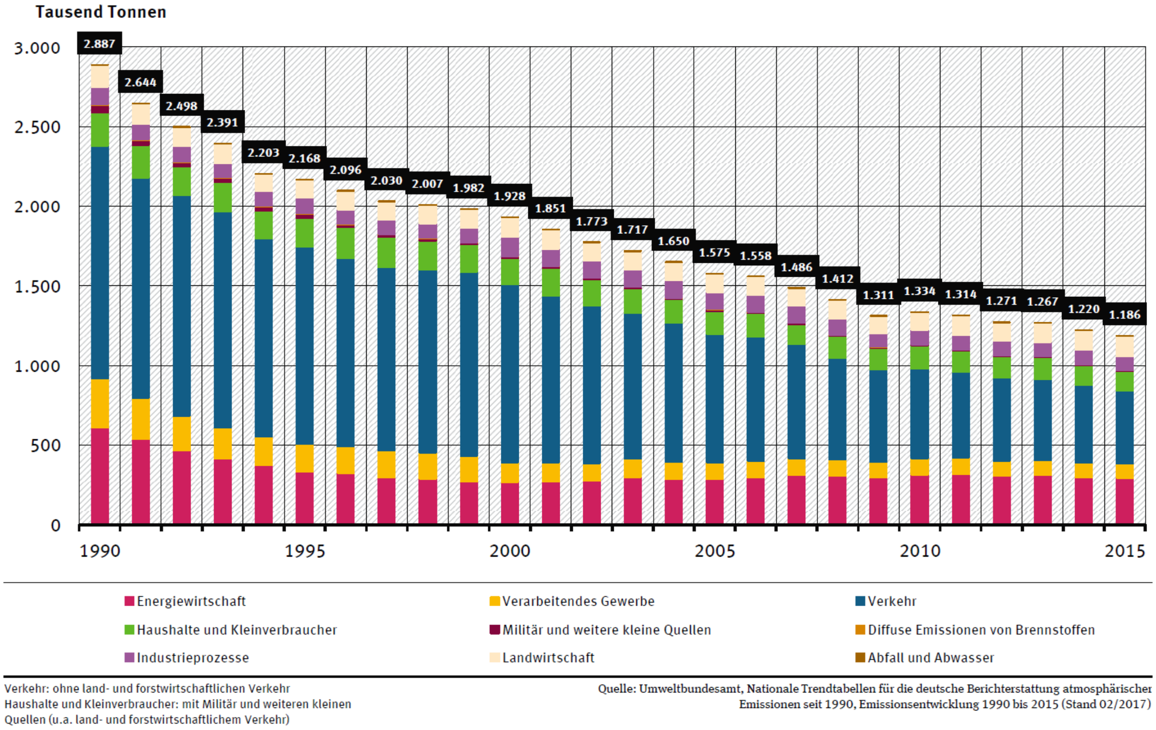
The emissions data we have used are taken from the UBA website.

Figure 25: NH_3 emissions according to source (in 1000 t NH_3), as of 2017.



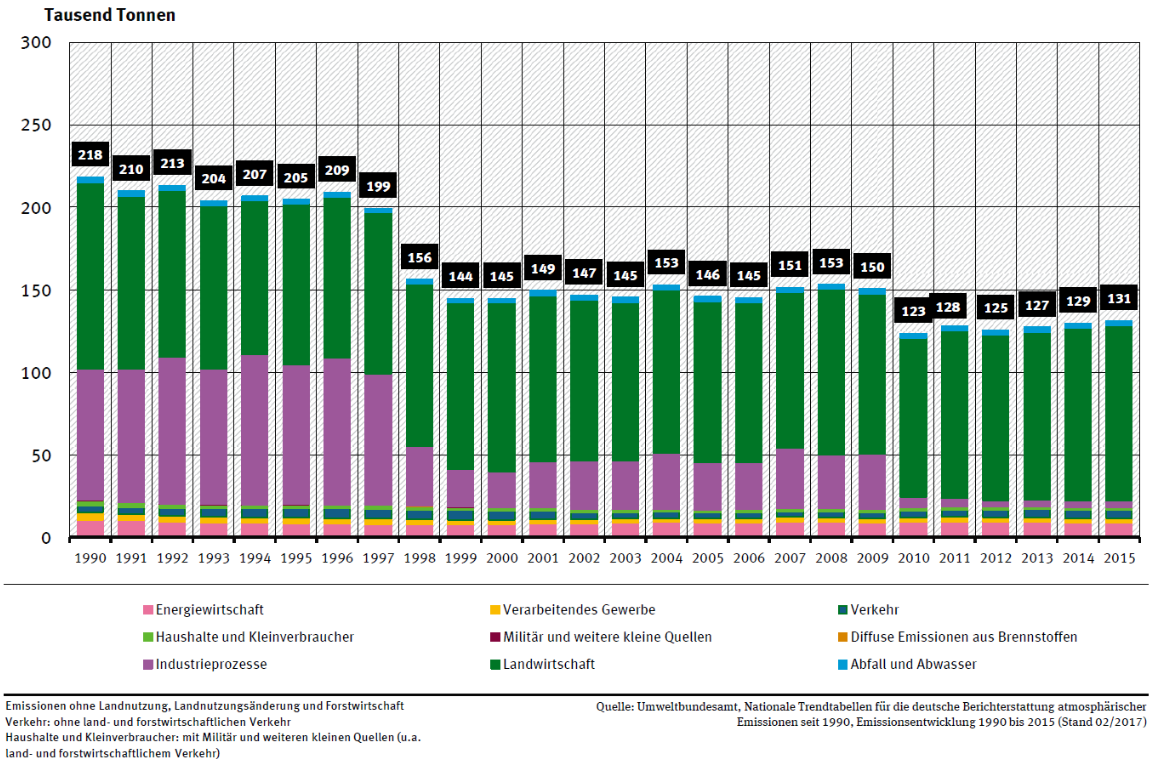
Source : https ://www.umweltbundesamt.de/sites/default/files/medien/361/dokumente/2017_02_15_em_ent-wicklung_in_d_trendtabelle_luft_v1.0.xlsx _[10.10.2018]

Figure 26: NOx (as NO_2 equivalent) emissions according to source (in 1000 t NO_x), as of 2017.



Source : https ://www.umweltbundesamt.de/sites/default/files/medien/361/dokumente/2017_02_15_em_entwicklung_in_d_trendtabelle_luft_v1.0.xlsx _[10.10.2018]

Figure 27: N_2O emissions according to source (in 1000 t N_2O), as of 2017.



Source : https ://www.umweltbundesamt.de/sites/default/files/medien/361/dokumente/2017_01_23_em_entwicklung_in_d_trendtabelle_thg_v1.0.xlsx [10.10.2018]

5.2 Additional comments on Terrestrial ecosystems / Eutrophication

Extending the method to calculate the emission targets from deposition data (Section 3.2.3.2)

a) Reducing the areas with Critical Load exceedance

According to the results of the method described in Section 3.2.3.2, the reduction of NO_x and NH_3 emissions by 40 % is a necessary condition for achieving the target. However, it is not a sufficient measure because the exceedance is only reduced to zero as a spatial mean.[30] In (Eq. 4) it would be possible to introduce a lower value instead of the maximum permitted deposition with the justification that this would make it possible to further reduce the number areas with exceedances. A simulation was carried out with the spatial deposition data (PINETI-III). As an example, if only half the CL value was used, the required reduction of the N emissions would be 56 % rather than 40 %. The target value would be reduced from 598 kt N a-1 to 433 kt N a-1 and the DESTINO indicator would be increased from 165 % to 227 %. With assumptions for an even lower value, there would be an even lower target value and the number of CL-areas with exceedance would be further reduced. The step-wise process could be continued until there was not a single area showing an exceedance. The elimination of the exceedance on the last hectare would be achieved with a reduction on the basis of the national N-emissions. But such an extreme application would of course be absurd. For a sensible application of the method, an arbitrary assumption would be necessary about the extent to which the CL-values should be lowered or what number of CL-areas with exceedances would be acceptable. This is also not in accordance with the requirements of the integrated nitrogen indicator. For this reason, such an extended application of the method was rejected.

b) Imports and exports of air pollutants

If imports and exports are to be considered, then Equation 5 (Eq. 5) has to be amended as follows:

$$E_{max} = \frac{D(t) - Exc(t) - Imp(t) + Exp'(t)}{D(t) - Imp(t) + Exp(t)} \cdot E(t) \qquad [\text{kt N a}^{-1}] \qquad \text{(Eq. 19)}$$

According to Schaap et al. (2017), imports in 2010 accounted for 33.7 % of exceedances above Critical Loads. In eq. 18, imports and exports of NO_x and NH_3 emissions are denoted by Imp(t) and Exp(t) respectively, and Exp'(t) indicates the exports under the condition $E = E_{max}$. The values are known from the new nitrogen balance for 2010 to 2014 (Report 2; UBA 2020), so that it would be possible to calculate the maximum emissions both including the imported proportions and without these. However, the data for 2015 on imports, exports and exceedance are lacking, so that no consistent evaluation is possible with Eq. 18 for 2015.

It should be noted that there have been positive changes, i.e. reductions, in nitrogenous emissions in the countries neighbouring Germany in recent years (2010 – 2015). An evaluation of the emissions inventories of Denmark, France, the Netherlands and Poland[31], shows that in the period 2010 – 2015 the total of their NO_x and NH_3 emissions fell by 10 %, so that there is a downward trend in imports to Germany. In the case of Terrestrial ecosystems / Eutrophication, these findings support the use of the simple method without the specific consideration of imports and exports.

[30] While there were exceedances in some areas, values in other places were well below the critical load,

[31] CLRTAP, Submissions 2018: http://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting/2018_submissions/ [31.08.2018]

5.3 Additional comments on Human health

An alternative for deriving the DESTINO-Target value for Human health was also considered. This was based on a regression of the 98th percentile of the measurements of the ambient NO_2 concentrations and the nationwide NO_x emissions. For comparability, the same data was used as described in Section 3.6, i.e. the data from monitoring stations with a continuous time series of measurements of background NO_2 concentrations covering the period 2002 to 2015.

The target value is calculated by means of a regression between the annual NO_x emissions and the 98th percentile of the ambient NO_2 concentrations. In order to ensure that as many locations as possible would be below the critical level, the 98th percentile of the measured NO_2 concentrations was used.

The annual NO_x emissions and the 98th percentile of the concentrations show a high level of correlation (Figure 28). The maximum permissible emissions can thus be derived by a regression of the 98th percentile of the NO_2 concentration series ($Am_{NO2,98th\ percentile}$) and the annual nitrogen oxide emissions (E_{NOx}). The best R^2 (or the highest correlation coefficient R) is achieved with a linear regression:

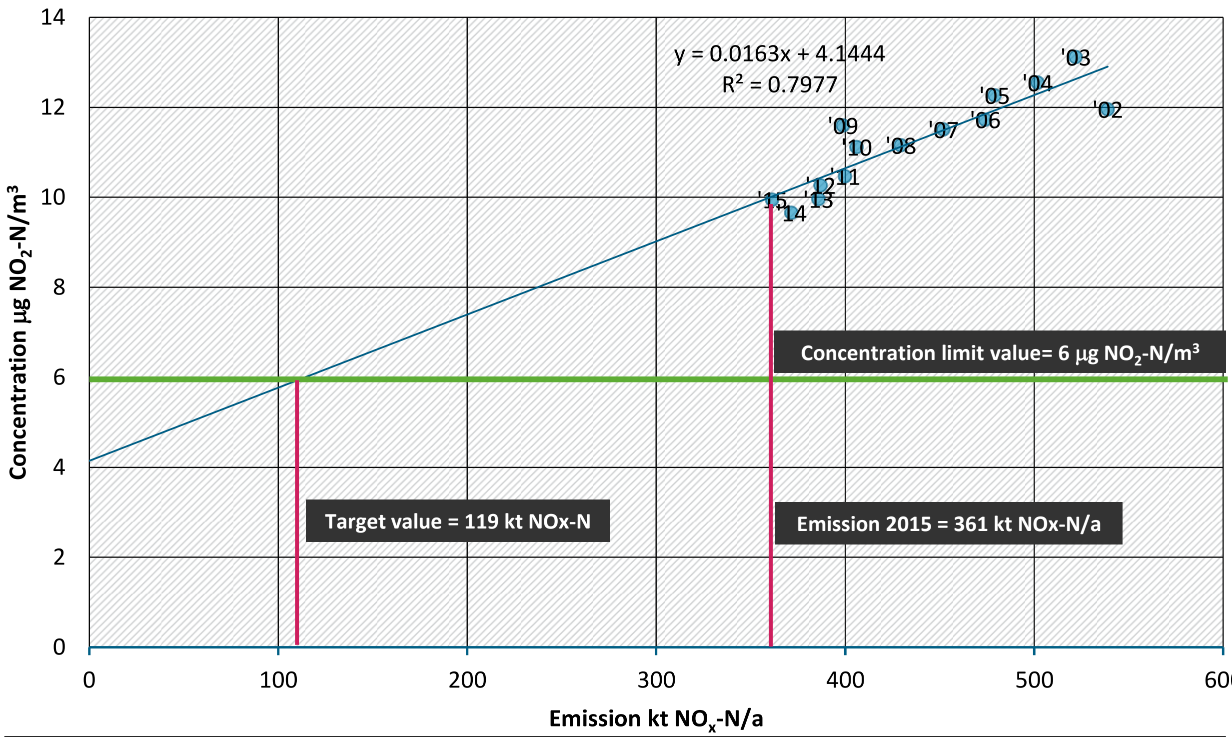
$$Am_{NO2,98th\ percentile} = a + b\ Em_{NOx} \qquad [\mu g\ NO_2\ m^{-3}] \qquad \text{(Eq. 20)}$$

The regression coefficients are determined using the least squares method. The equation (Eq. 20) can then be used to calculate how high the emissions maximum can be in order to ensure that 98 % of all stations have mean values below the WHO response threshold (RT) of 20 µg NO_2 m^{-3}. Expressed in terms of the maximum emissions ($E_{NO2,max}$) this gives the following equation:

$$Em_{NO2,max} = \frac{Am_{NO2,98thpercentile} - a}{b} = \frac{RT - a}{b} = \frac{6.087 - 4.1444}{0.0163} = 119\ kt\ NO_2 - N/a \qquad [kt\ NO_2\ a^{-1}] \qquad \text{(Eq. 21)}$$

The calculation of the maximum emissions is based on the assumption that the emissions imported from neighbouring countries are reduced to the same degree as the domestic emissions. The imported emissions are not taken into consideration in this method.

Figure 28: Regression of the 98th percentile of the measured NO_2 ambient concentrations and the NO_x emissions (national total) for the years 2002 to 2015



Regression analysis of the 98th percentile value of the measured background NO_2 concentrations and NO_x emissions. Data for background concentrations from all monitoring stations with a continuous time series for 2002 – 2015. Labels show the year of measurement. Data source: UBA 2017b

The regression analysis is based on the assumption that the error terms are not interdependent, i.e. the residues must not be autocorrelated. The analysis of the residues of the regression of ambient NO_2 concentrations vs. NO_x emissions (Durbin-Watson coefficient D = 1.57 < 2.0), shows that there is no auto-correlation.

Results

If we assume that the nitrogen oxide emissions in other countries are reduced to the same extent as in Germany, then the regression analysis gives a maximum for annual nitrogen oxide emissions ($Em_{NOx,max}$) of 119 kt NO_x-N a^{-1}. In 2015, emissions were 361 kt NO_x-N a^{-1}, which is more than 200 percentage points above the target value. The emissions would have to be reduced by 242 kt NO_x-N a^{-1}.

However, the extent of the extrapolation required to determine the target value means that the result involves a very high level of uncertainty. Therefore, this approach was not adopted.

We tested a further method for determining the maximum NO_x emissions. Using the RCG modelled NO_2 concentrations, a correlation analysis was carried out on the EMEP Grid for the NO_x concentrations and the NO_2 concentrations (RCD). As with the method for the Terrestrial ecosystems/Critical Levels for NH_3 (see Section 3.1), the intention was to show the extent to which the NO_x emissions of grid cells would have to be reduced so that no NO_2 concentrations exceeded the critical level. It was found that the model data are not suitable for such an analysis because the spatial resolution of 2 km x 2 km is too coarse, so that peak values are smoothed out and practically no exceedances are visible[32]. The method used in Section 3.6 has the advantage that it is based on measurements which represent the real ambient concentrations.

5.4 Area-based nitrate concentrations in groundwater

5.4.1 Materials and method

In order to present the spatial distribution of nitrate concentrations in groundwater in Germany (1 km x 1 km grid), the "Random Forest" classification method is used (Section 5.4.1.1). The development of the classification algorithm is based on some 8,100 point data on nitrate concentrations from groundwater monitoring stations (Section 5.4.1.2), with 13 predictor variables derived from cartographic data on hydrogeology, land use, etc. as the decision criteria (Section 5.4.1.3).

5.4.1.1 The Random Forest model

With a "Classification and Regression Tree" (CART) method, a number of objects (data) can automatically be classified on the basis of decision rules so that the objects within a class are as similar as possible to one another, while the classes are as different as possible (Breiman 1984). A training dataset of the classification tree is developed. This can be used to estimate the target value (here: NO_3^- concentration) for all objects for which the value of the predictor is known (here: spatial data, see Section 5.4.1.3). In contrast to most other linear regressions, CART methods are relatively robust and the classification can be based on either categorised or numerical variables. A disadvantage is the limited range of predicted values: it is only possible to give predictions that are within the range of the training dataset (Peterson 2005). Furthermore, the strength of the predictors (e.g. the slope in a linear regression model) is not apparent to the user – only the relative value is shown.

As a further development of the CART approach, which only forms a single tree, the "Random Forest" method (RF) generates multiple trees. Their predictive values are averaged to provide an ensemble-model prediction and continuous estimated values (Breiman 2001). RF also ranks the predictors in terms of their relative influence on the estimate. This ranking is determined by quantifying the improvement of the predictive accuracy with and without each of the predictors.

Cross-validation was carried out in order to estimate the predictive accuracy of the statistical model, the quality of the model was assessed with the coefficient of determination R^2. The calculations were carried out using the software R-4.4.1. For the development of the RF-model involved, a 10-fold cross-validation was carried out three times. For the RF-algorithm, definitions were introduced for the number of trees (n_{tree} = 1000) and the number of predictors randomly sampled at each split (mtry = 5).

5.4.1.2 Point data (groundwater measuring stations)

The federal states kindly provided data and time series of nitrate concentrations for groundwater monitoring stations (city states were not included). The data were prepared, entered into a database and selected on the basis of the following criteria:

[32] "The maps show the concentrations with the mean characteristic of the spatial resolution of ~2 km x 2 km. Hot spots that only occur at one station are not included in the area-based presentation for all of Germany. All stations classed as 'road' or 'road-extreme' were not used, in accordance with the Flemming classification. Measurements in locations impacted by roads with heavy traffic can therefore not be found in the presentation, since as a rule these measurements are excluded from the concentration levels of the surrounding stations." (UBA 2015a)

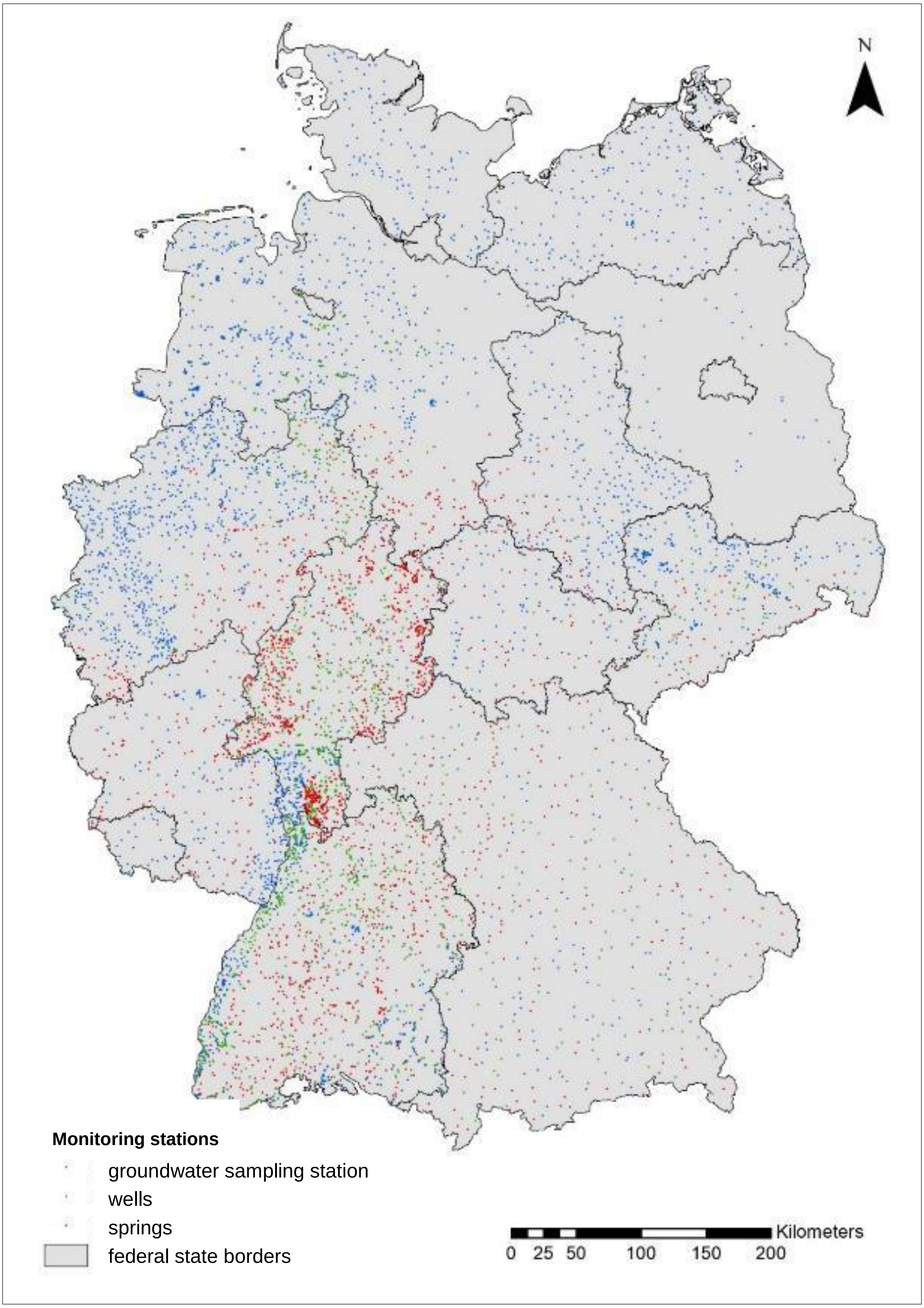
- Clear identification of type of measuring station: Groundwater measuring station (GWM), wells, or sources
- Availability of data on depth of measurement or nature of the filter pathway (exclusion factor)
- Depth of measurement <100 m
- At least two measurements in the period 2010 to 2017
- Nitrate concentration >0.5 mg l^{-1} as a mean over the time series
- If the median nitrate concentration for a station in the time series is >10 mg l^{-1}, then the variation coefficient must be less than 1
- For the modelling, the annual mean nitrate concentration for the period 2010 – 2017 was used.

Table 28 gives an overview of contributing sampling stations and stations used for modelling according to Federal States. Figure 29 shows the distribution of the measuring stations.

Table 28: Numbers of contributing sampling stations and stations used for modelling according to federal states (not including city states)

Federal state	No. of contributing sampling stations	No. of stations used for modelling
Total	**19,742**	**8,106**
Baden-Wurttemberg	2,205	1,668
Bavaria	574	493
Brandenburg	223	52
Hesse	5,793	2,113
Mecklenburg-West Pomerania	401	249
Lower Saxony	5,363	986
North Rhine-Westphalia	1,561	1,148
Rhineland Palatinate	2,194	379
Saarland	52	40
Saxony	472	382
Saxony-Anhalt	431	300
Schleswig-Holstein	258	126
Thuringia	214	170

Figure 29: Distribution of the sampling points used for modelling



5.4.1.3 Area data

As predictors for the RF-classification, we used the following area information (digital maps):

- Land cover model Germany (BKG 2016b), “Land use”, aggregated to five land-use classes (arable land, grassland, permanent crops, settlements, and forest)
- HYRAUM – Hydrogeological Spatial Structure of Germany (BGR 2015a, AD-HOC-AG HYDROGEOLOGIE 2016), 36 hydrogeological categories
- BÜK1000 – Overview map 1:1,000,000 (BGR 2018a), 38 categories
- Leaching rate (BGR 2003a)
- Groundwater regeneration (BGR 2003b)
- Water storage capacity (field capacity) of soils in Germany to 1 m depth (BGR 2015b)
- Humus contents – organic matter of soils in Germany (BGR 2016a, 2016b)
- Nitrogen surplus on agricultural areas, annual means 2011 – 2014 (Häußermann et al. 2019)
- Leachate concentration (calculated from leaching rate and N-surplus)
- NO_3^- concentration groundwater regeneration (calculated from the leaching rate and N-surplus).

For the development of the classification in the RF method, the point data of nitrate concentrations have to be linked to area values. For each of the 8,100 measuring stations, the value of the predictors is determined for a circular buffer with a radius of 1 km from the available maps (ArcGIS 10.2, Buffer Analysis – “Intersect Analysis” or “Spatial Join Analysis” and “Spatial Join – Largest Overlap Analysis”). For five land-use classes (arable land, grassland, permanent crops, settlements, and forest) the percentage of the area covered in the buffer was calculated; for the hydrogeological sphere and soil landscape, the value of the dominant area proportion was adopted; for the variables leaching rate, groundwater regeneration, field capacity, humus contents, and nitrogen-surplus the mean, area-weighted values were determined within the buffer.

The RF-classification method was then used to predict the distribution of the nitrate concentration in groundwater in Germany (for a 1 km x 1 km grid). As for the buffers, the values of the predictors were determined for each grid cell. The “GeoGitter Germany 1 km” was used as the mask for the evaluation of the area data and for the presentation of the results on NO_3^- concentrations (BKG 2017).

5.4.2 Results

Figure 30 shows the parameter ranking for the RF model. The predictor “Hydrogeological sphere” has by far the greatest importance for estimating the nitrate concentration, followed by “Soil landscape”, “Proportion of grassland” and “Proportion of arable land”. “Nitrogen-surplus on utilised agricultural area” is the only parameter that can be directly influenced by management measures (apart from the conversion of arable land or grassland to other forms of use). However, this parameter is of secondary importance compared with the factors related to topography, use-structure, or climate-related influences.

Figure 30: Ranking the predictors according to influence on the estimated nitrate concentration (relative to the highest ranking factor)

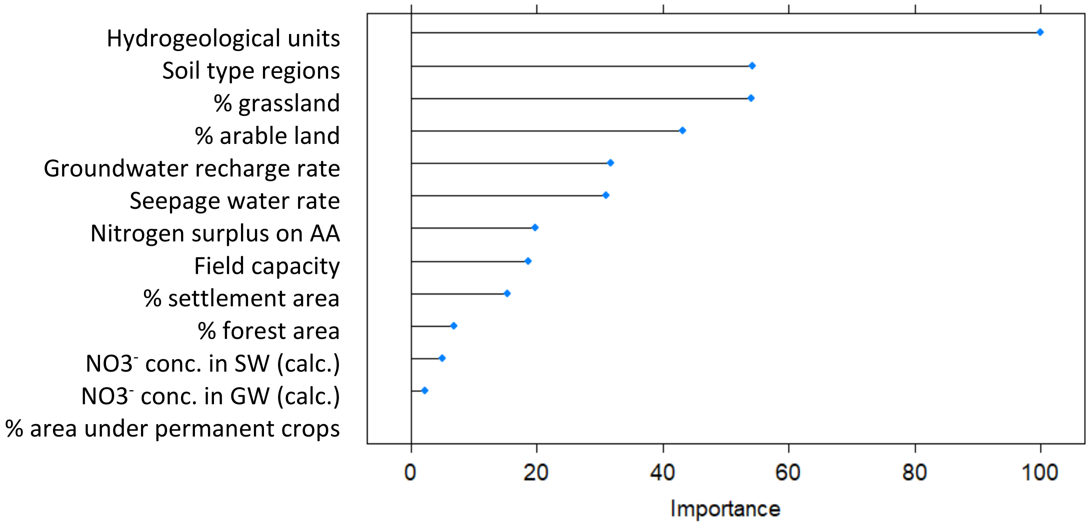
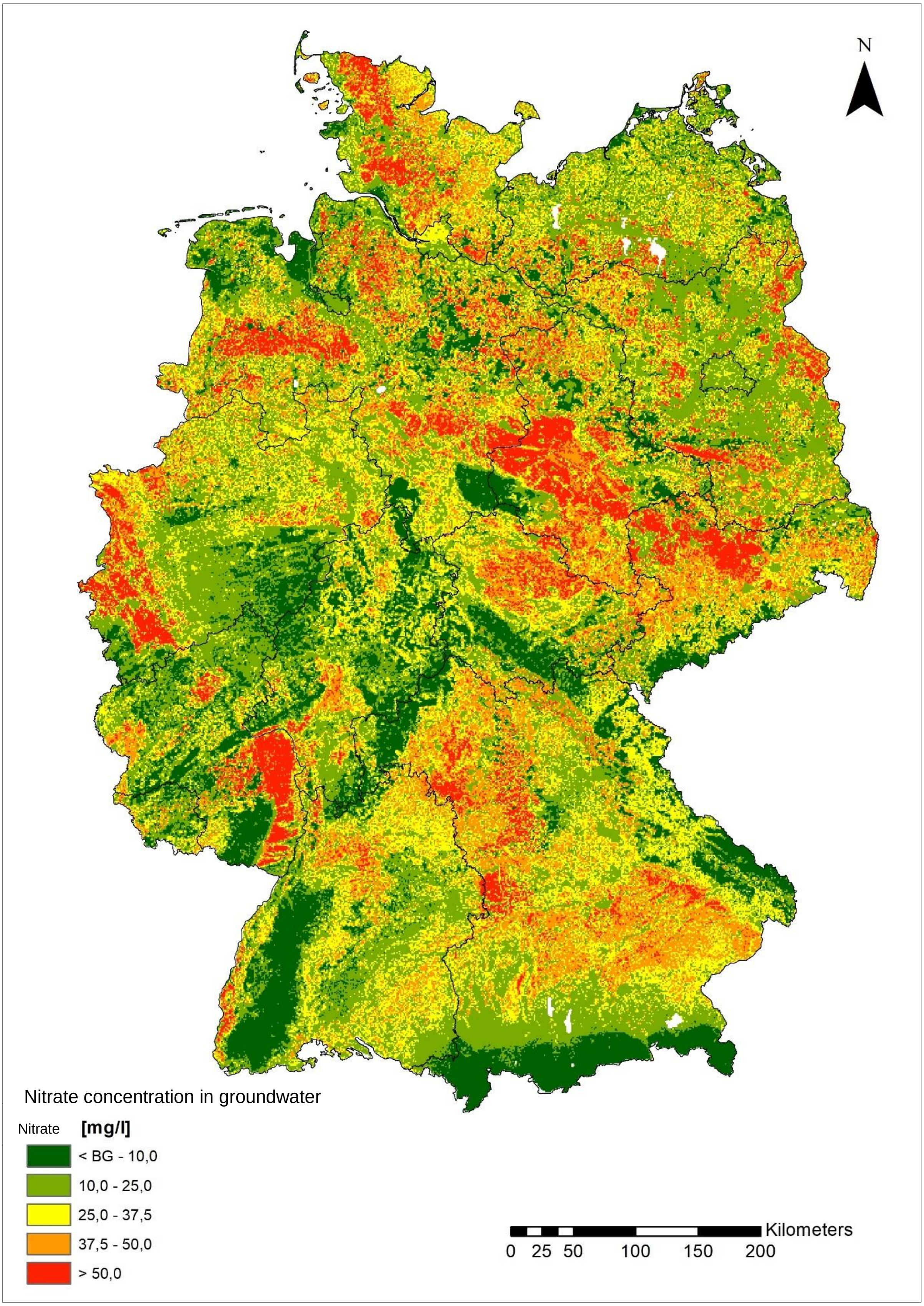


Figure 31 shows the distribution of the nitrate concentrations in Germany estimated with this method. The distribution pattern appears to fit well with the bodies of groundwater in Figure 32 which have a "poor status" because they exceed the nitrate quality limits according to the WFD classification (UBA 2017e).

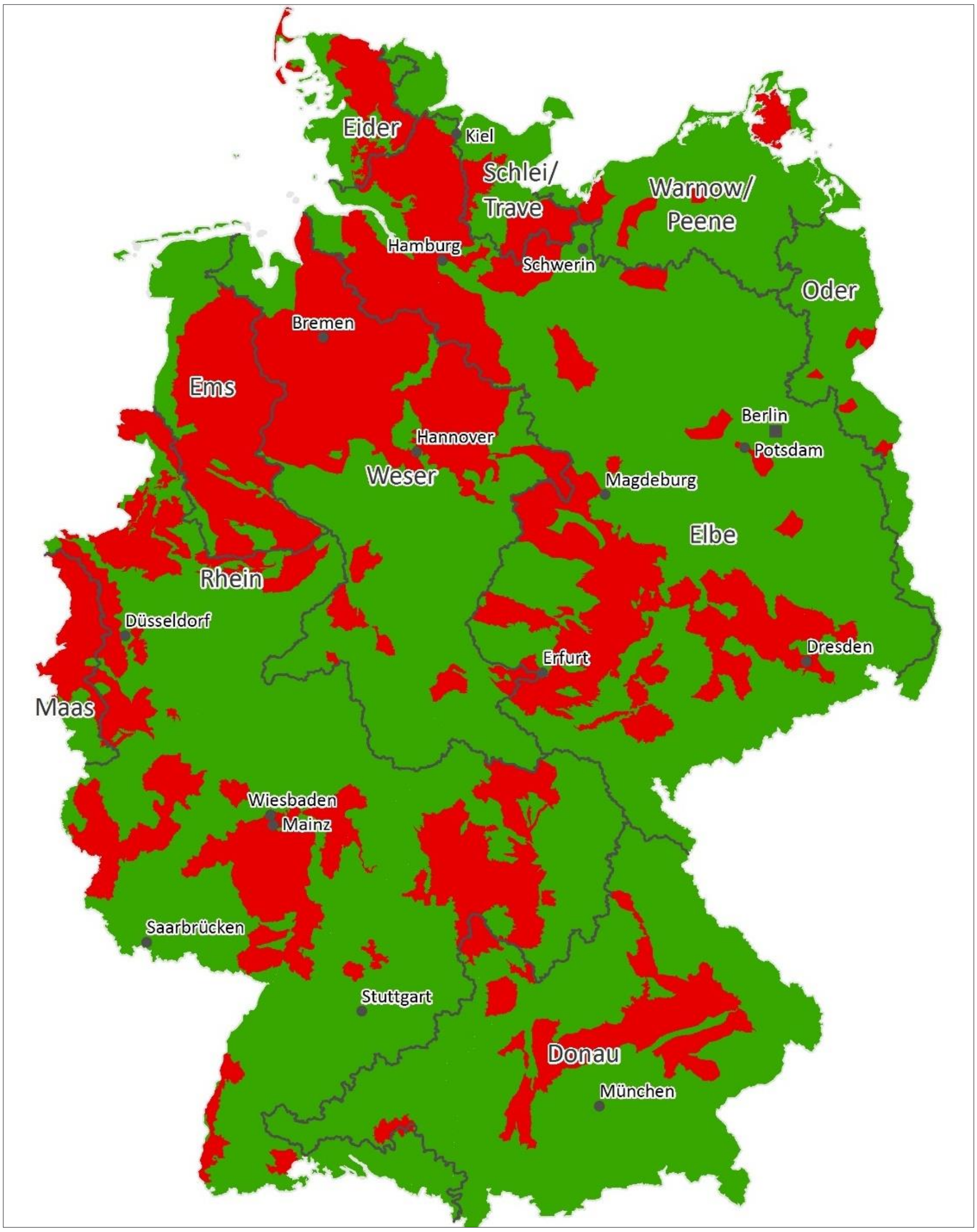
Figure 31: Distribution of the nitrate concentration in groundwater in Germany (1 km x 1 km grid), predicted using the Random Forest classification



Note: The map was generated using a model and provides a broad overview; the local nitrate concentrations in groundwater can vary.

Nitrate concentrations exceeded 50 mg l^{-1} primarily in the intensively farmed lowland plains of northern Germany, in the regions with high concentrations of livestock (in particular in north-western Germany), and in areas with a large proportion of permanent crops (e.g. Rhine-Hesse, upper Rhine plain). Low concentrations were estimated for the low mountain regions and the regions with mainly grassland. In addition to the visual assessment, the prediction can also be assessed quantitatively by comparison with maps of nitrate concentration in groundwater developed using other methods, e.g. the geostatistical interpolation method SIMIK (Bardossy et al. 2003, Usländer et al. 2003).

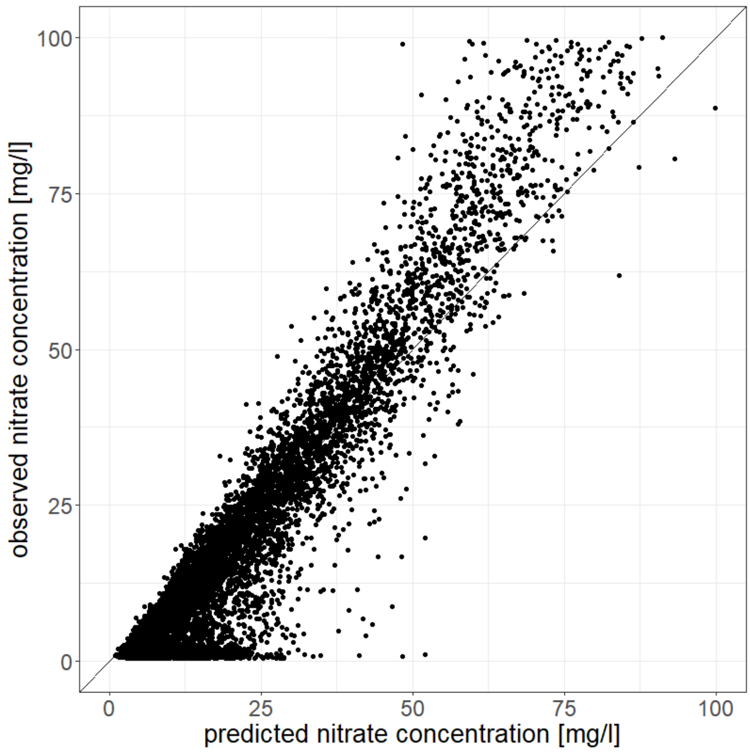
Figure 32: Bodies of groundwater in Germany with a "poor" status (red areas) with regard to nitrate (UBA 2017e)



Geodata basis: GeoBasis DE / BKG 2015; Data: WasserBLick/BfG, as of 23.3.2016; Processing: UBA, LAWA.
Federal states use varying assessment methods.

For the classification of some 8,100 reference values (i.e. measuring points) of the training dataset, an R^2 of 0.9 was obtained, which is very high (see Figure 33). However, for the application as a predictive model the coefficient of determination R^2 was only 0.3. A cross-validation was carried out with the training dataset, i.e. the dataset was divided at random into training data and test data. A prediction model was developed using the training data which was then applied to the test data, and the prediction quality is determined for this test data. This procedure is repeated a number of times and the mean coefficient of determination is finally determined across all cross-validations. The limited predictive quality must be borne in mind when interpreting Figure 31.

Figure 33: Observed nitrate concentrations in groundwater vs. Predicted values in accordance with the Random-Forest classification (n = 8106 measuring points, see 5.4.2)



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