Reactive nitrogen in Germany

Causes and effects – measures and recommendations

For our Environment

Umwelt Bundesamt

Summary

- Nitrogen and its compounds behave very differently in the environment. While atmospheric nitrogen is practically inert, the oxidised compounds (e.g. nitrogen oxide or nitrous oxide) and reduced compounds (e.g. ammonia) are reactive. Depending on the nature of the compound and the concentration, they can either be life-supporting nutrients or harmful pollutants. Therefore, these compounds are also referred to as reactive nitrogen in the environmental discussion.

- Human activity has led to massive changes to the natural nitrogen cycle over the past century and a drastic increase has been seen in the amounts of reactive nitrogen in the environment. However, the levels vary considerably worldwide, e.g. in tropical Africa, nutrient-poor soils represent a serious problem which leads to agricultural yields remaining well below the potential levels.

- In Germany, some 4.2 million tonnes of reactive nitrogen enter into the nitrogen cycle annually, corresponding to some 50 kg per person. About 6 kg per person per year is consumed in food. The remainder is contained in products, or finds it way unused into the environment.

- The excessive release of reactive nitrogen compounds into the environment leads to a series of problems which must be urgently addressed. These include the loss of aquatic and terrestrial biodiversity, the impairment of air quality, the increased release of greenhouse gases, and constraints on the use of groundwater as drinking water.

- In Germany, considerable reductions have been achieved in nitrogen emissions from the manufacturing sector, the energy industry, traffic and transport, and also from wastewater management.

- However, reductions have been much less successful in the agricultural sector, which meanwhile accounts for more than 60 per cent of Germany's nitrogen emissions.

- In order to stimulate a significant improvement for the environment, the levels set in the German government's sustainability strategy for the nitrogen surplus should be revised. UBA recommends setting a target for the nitrogen surplus of 50 kg per hectare per year by 2040.

- The Fertiliser Ordinance (DüV) is a key instrument for the reduction of nitrogen losses from farming into the environment. It is currently being reformulated in order to meet ecological requirements. By means of additional measures in the agricultural sector, further reductions are possible.

- An important contribution to achieve a balance in the nitrogen cycle can be made by changes in consumer behaviour, e.g. by reducing consumption of animal protein, or by avoiding the waste of food.

Contents

1. Reactive nitrogen – too much of a good thing?

Nitrogen (N) can take various forms. Mostly it occurs in its molecular form as a relatively inactive gas in the atmosphere. However, it also occurs as reactive nitrogen in various compounds. Paradoxically, these reactive nitrogen compounds can be both essential nutrients and harmful pollutants (Box 1).

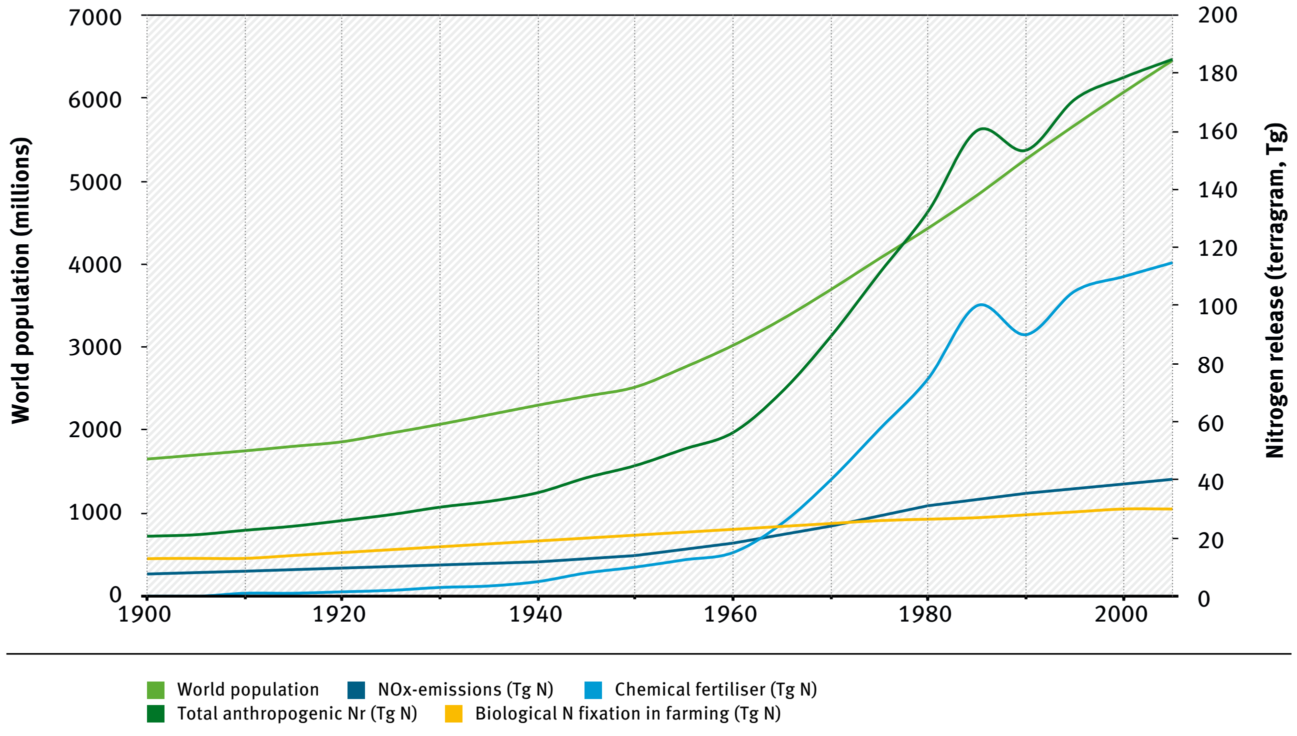
Over the past century, human activities have more than doubled the amounts of inactive atmospheric nitrogen being converted every year into reactive nitrogen (Fig. 1a), and in Europe the amount has quadrupled. This was either intentional, e.g. in order to produce artificial fertilisers and thus ensure the food production for the growing world population, or was an unintended by-product from the combustion of fuels.

In addition to the desirable effect of increasing agricultural production, the intensified nitrogen cycle today leads to many negative environmental impacts (Galloway et al., 2003). According to Rockström et al. (2009), the global boundaries of ecosystems have been exceeded by anthropogenous impacts on these cycles (Fig. 1b). International scientists therefore recommend a marked reduction in the conversion of atmospheric nitrogen into reactive nitrogen (Rockström et al., 2009, Fowler et al., 2013). Discussions are ongoing to establish a target value which would ensure nutrition and at the same time remain within environmental boundaries. Recent contributions state that the global conversion of atmospheric nitrogen to reactive nitrogen should be limited to about half the current level (De Vries et al., 2013). In its final

Figure 1a

Global trends in the production of reactive nitrogen by human activities

(as fertiliser, biological fixation or in the form of nitrogen oxides from combustion processes)



after Galloway et al., 2003

report, the Commission of Enquiry of the German Parliament on "Growth, Welfare, Quality of Life" names a sustainable, less-intensive nitrogen cycle as an essential objective (Deutscher Bundestag, 2013).

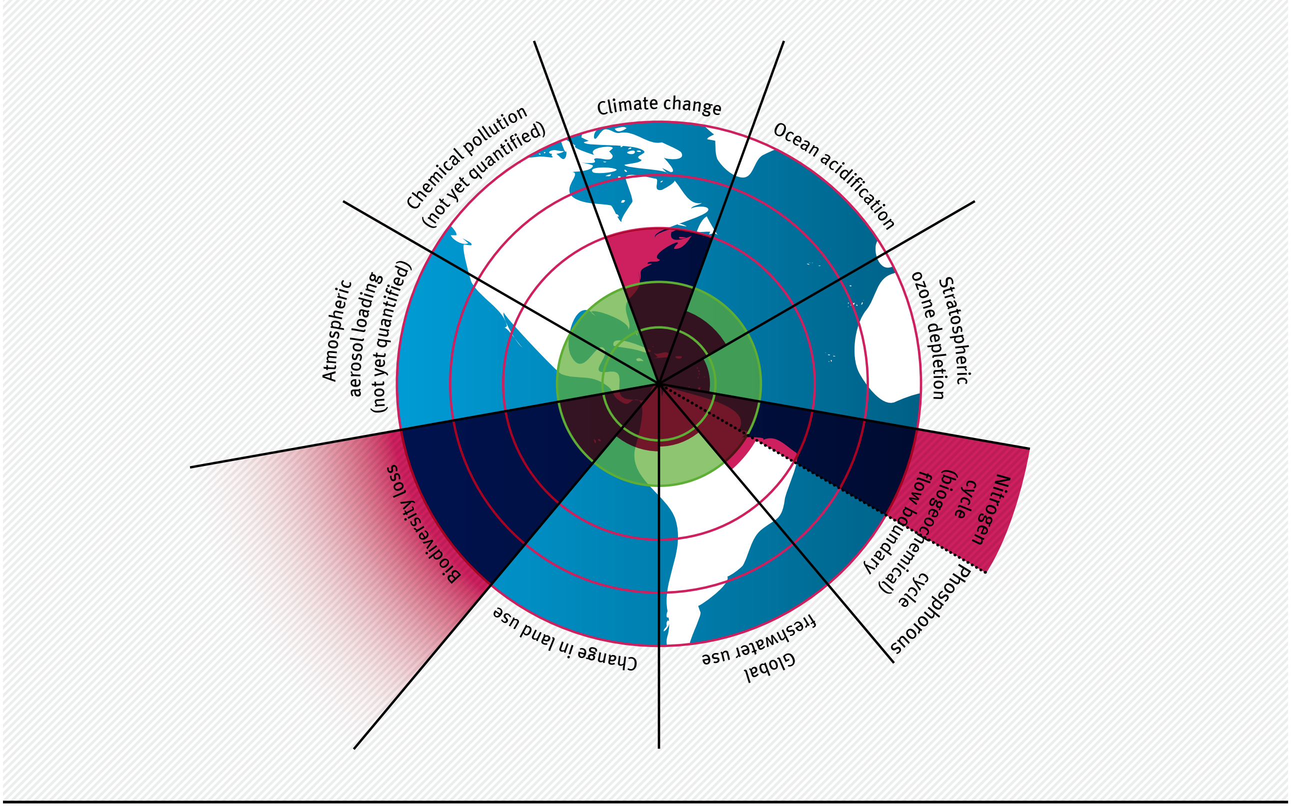
In the following chapters, the nitrogen cycle in Germany is analysed. On the basis of the results, options are outlined for reducing the negative effects.

A comprehensive overview of the nitrogen flows in Germany, their effects, and possible reduction measures is provided in the report of the German Federal Environment Agency (UBA) "Integrated Strategy for the reduction of nitrogen emissions" (UBA, 2009a and b), on which this publication is based. Further important sources are the final reports on the international assessment of the nitrogen cycle at European and global levels (Sutton et al., 2011, Sutton et al., 2013).

Figure 1b

Planetary boundaries in nine sectors

For loss of biodiversity, climate change, and the nitrogen cycle (which also impacts on the other sectors) the authors find that the boundaries have been exceeded beyond the level of uncertainty (Azote Images/Stockholm Resilience Centre)



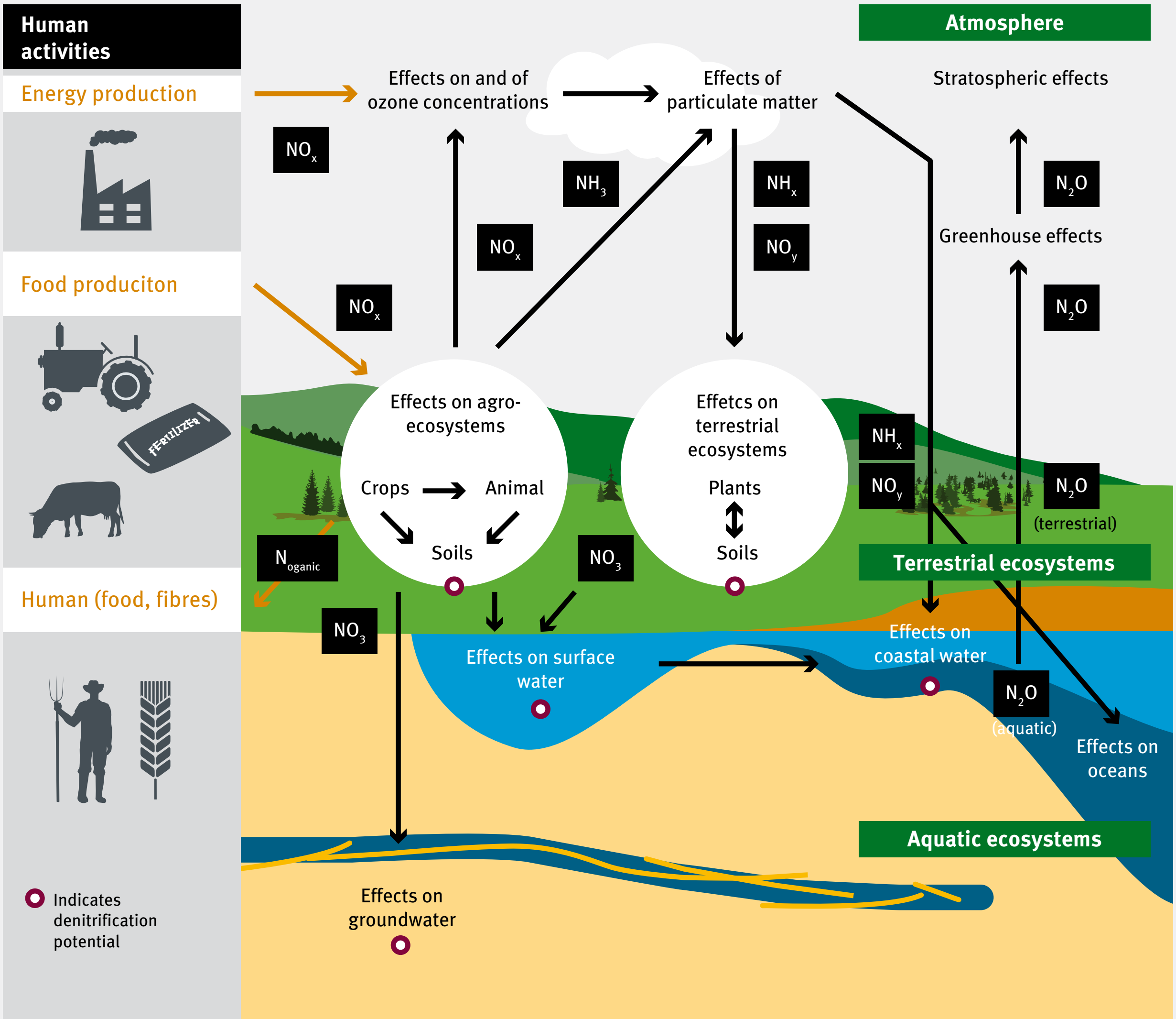
Rockström et al. (2009)

Box 1

Reactive nitrogen and the nitrogen cascade

Reactive nitrogen includes the following compounds:
Oxidised inorganic nitrogen compounds: Nitrates (NO_3^-), nitrites (NO_2^-) and nitrous oxide (N_2O)
Reduced inorganic nitrogen compounds: Ammonia (NH_3) and ammonium (NH_4^+)
Organic compounds containing nitrogen (N_{org}): Mainly in proteins (amino acids) in organisms and their remains.

Once nitrogen is in a reactive form, it can lead to effects in a variety of further chemical forms (NO_x,NH_y, N_{org}) in various places and with differing environmental impacts (air, soil, water, vegetation, fauna including humans). This is called the nitrogen cascade (Galloway et al., 2003).



after Galloway et al., 2003

2. Negative impacts of the intensified nitrogen cycle

The intensified nitrogen cycle leads to negative impacts in various sectors of the environment (UBA, 2011). This chapter gives a short overview of these threats and impacts. (More detailed information about the individual aspects is provided in the the corresponding references) In addition, an outlook is provided, showing the situation that is expected to develop by 2020 or 2030 if no further measures are introduced.

2.1 Threats to biological diversity

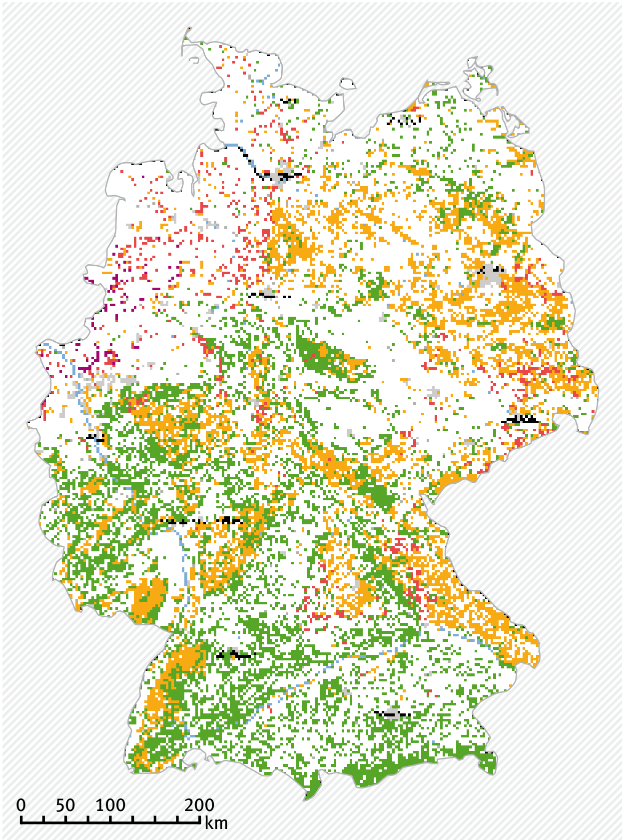
The increased deposition of reactive nitrogen can lead to the destabilisation of ecosystems and the displacement of sensitive species. Rapidly growing, nitrophilous plant species may out-compete other plant species. In many cases, such changes are not immediate, but can only be observed over time. Nearly half the species on the "Red List" are threatened by increased nutrient depositions (Federal Agency for Nature Conservation [BfN], 2004 and 2012). In addition, increased availability of nitrogen can make many plant species more susceptible to other stress factors, e.g. frost, drought or herbivory (Bobbink et al., 2010).

Worldwide, nitrogen depositions represent one of the five main threats to biological diversity (Sala et al., 2000). A negative impact can only be excluded with certainty if the depositions remain below ecological limit values (critical loads) for eutrophication (Fig. 2). Furthermore, acidification of ecosystems in Europe is meanwhile caused primarily by the deposition of reactive nitrogen compounds. Under the German Government's National Strategy on Biological Diversity (BMU, 2007) it was therefore agreed that, by 2020, the deposition levels of nutrients should be below the critical loads for all sensitive areas. This is currently only the case for about half of these sites.

Figure 2

Exceeding critical loads for eutrophication by nitrogen depositions in rural ecosystems for 2009

According to current knowledge no long-term negative effects are expected for terrestrial biodiversity below these values



Exceeding $CL_{out}N$ [kg N ha^{-1} yr^{-1}]

No exceedance: 52.4% | ≤ 10: 41.0% | 10–20: 6.0% | › 20: 0.6%

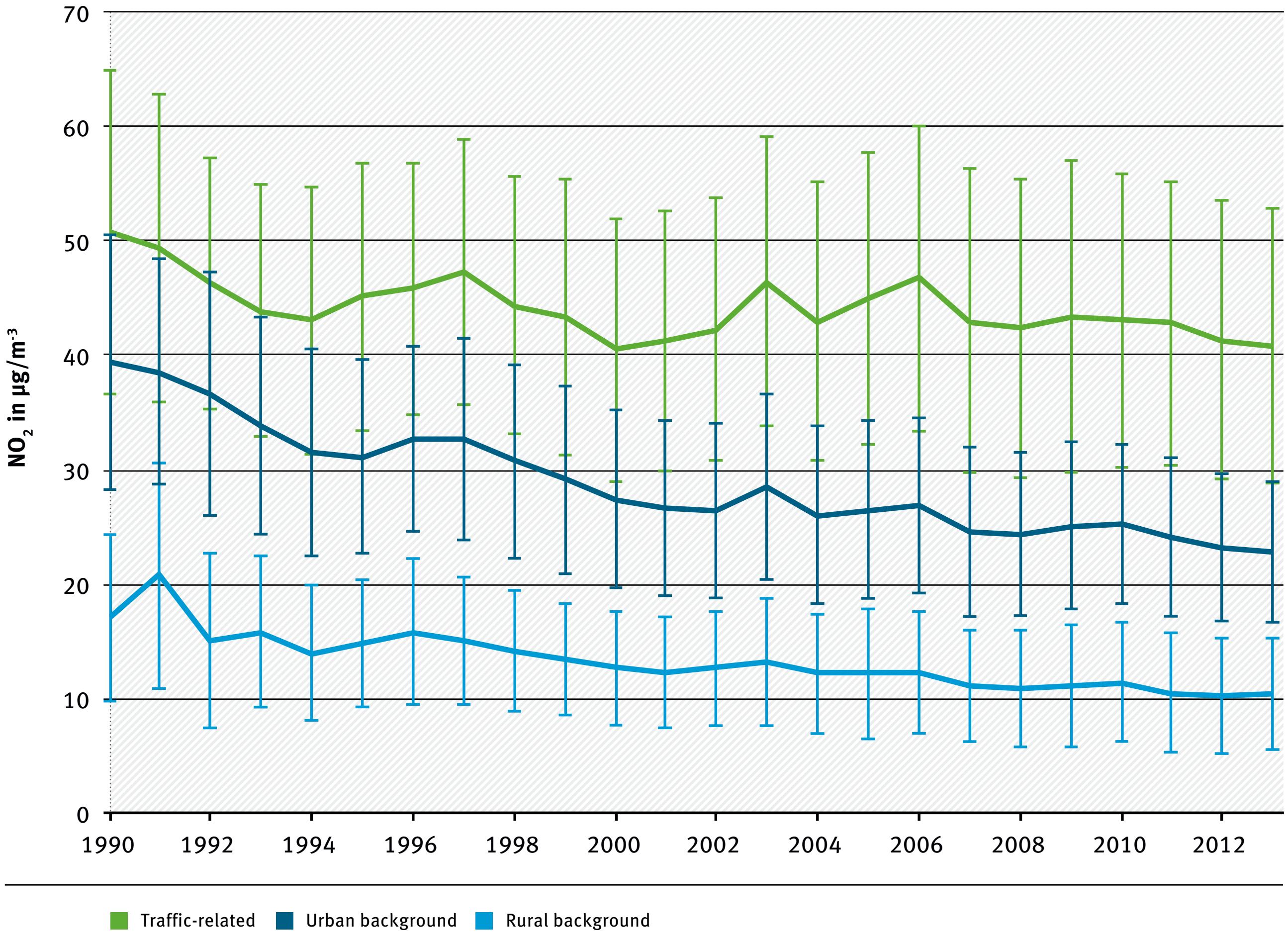
UBA-Projekt PINETI-2, FKZ 3712 63 240

Reactive nitrogen compounds are also responsible for the development of ground-level ozone. In Germany and large parts of Europe, ground-level ozone represents a considerable stress factor for plants, leading to decreased crop yields (Mills and Harmens, 2011) and the possible impairment of biological diversity.

Figure 3

Mean-annual trends of NO2 in Germany for rural background, urban background, and traffic-related measuring stations

For the period 1990 to 2013 (for stations that have measured over at least 9 years)



Outlook: Without further measures, the exceedance of critical loads for eutrophying nitrogen in Germany will only decline by about 25 per cent by 2030 in comparison with the levels for 2005 (International Institute for Applied Systems Analysis (IIASA), 2014).

2.2 Threats to air quality

Nitrogen dioxide (NO2), which finds its way into the atmosphere mainly as a result of combustion processes, has negative effects for human health. It can lead to inflammation of the airways, among other things, and can also increase the harmful effects of other atmospheric pollutants. In the European Union the limit value is 40 µg m^{-3} (annual mean), but many cities have considerable problems when trying to comply with this (Fig. 3). In addition, reactive nitrogen compounds contribute to the formation of secondary particulate matter, which can also be harmful to human health. Models show that agricultural emissions in Germany (in particular of ammonia) are related to about a quarter of PM10 particulate matter depositions (Stern, 2013a). Nitrogen oxides play a part in the formation of ground-level ozone, which is harmful not only for ecosystems but also for human health. Ozone concentrations are still exceeding the target value for the protection of human health at about 10 per cent of the measuring stations in Germany (UBA, 2014c).

Outlook: The emission reductions anticipated by 2020 will lead to a further reduction in air pollution levels. Nevertheless, without additional measures the current target levels for NO_2, ozone, and particulate matter concentrations will still not be met at all stations (Jörss et al., 2014, Stern, 2013b).

2.3 Threats to water quality

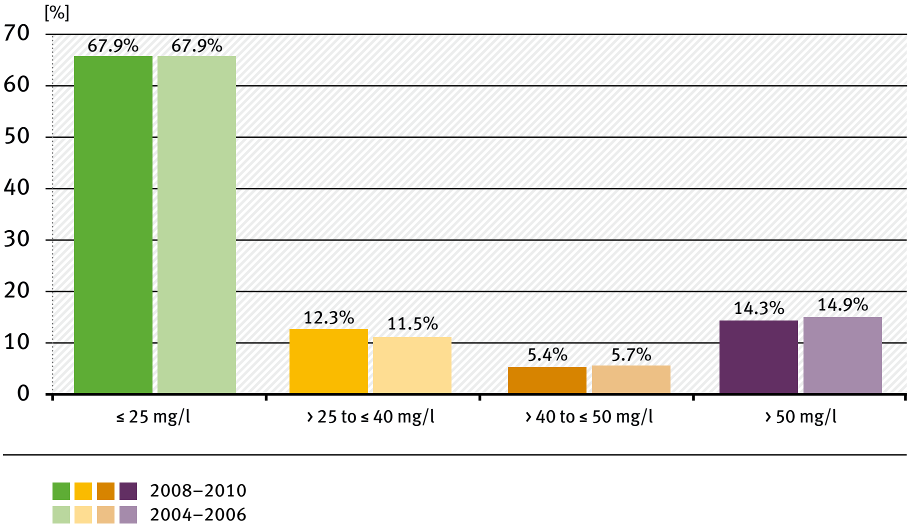
Pure water is vital for life, but nitrogen surpluses which are not used productively by plants can find their way into groundwater, and most of our drinking water is extracted from groundwater sources. A considerable proportion of groundwater reserves in Germany have excessive levels of nitrates. This is a cause for concern, because groundwater only reacts to changes very slowly, and current levels are the result of inputs over past years and decades.

The Nitrates Report of the German Government (Federal Ministries for the Environment, Nature Conservation and Nuclear Safety (BMU) and of Food, Agriculture and Consumer Protection (BMELV), 2012) shows that at some 14 per cent of the measuring stations of the national measuring network for reporting to the European Environment Agency still have concentrations above the nitrate critical load of 50 mg l[-1] (Fig. 4) and that the concentrations at 40 per cent of the measuring stations of the network have increased (Fig. 5).

Figure 4

Frequency distribution of the mean nitrate levels in groundwater as reported to the European Environment Agency

For the periods 2008–2010 and 2004–2006

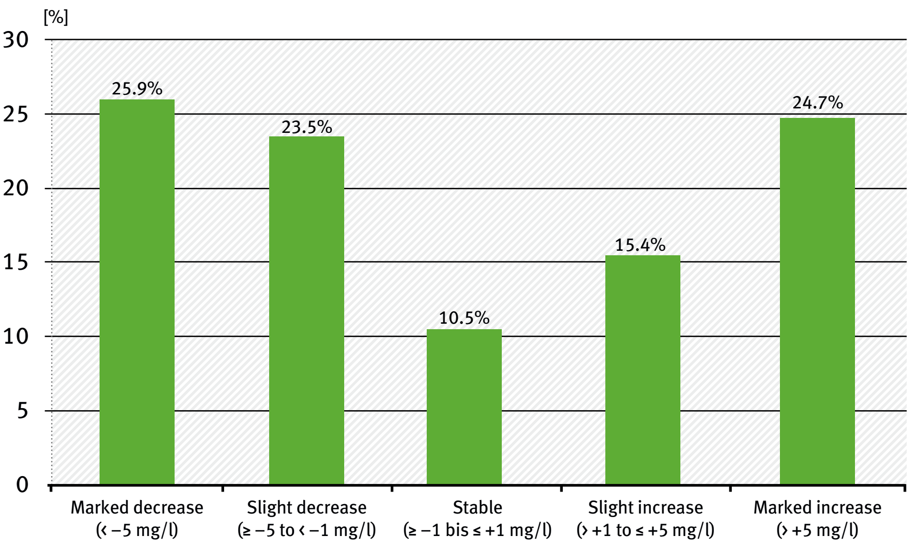


EEA Network: 739 joint measuring stations — BMU & BMELV, 2012

Figure 5

Changes in nitrate levels in groundwater for network stations

For the period 2008–2010 in comparison with 2004–2006

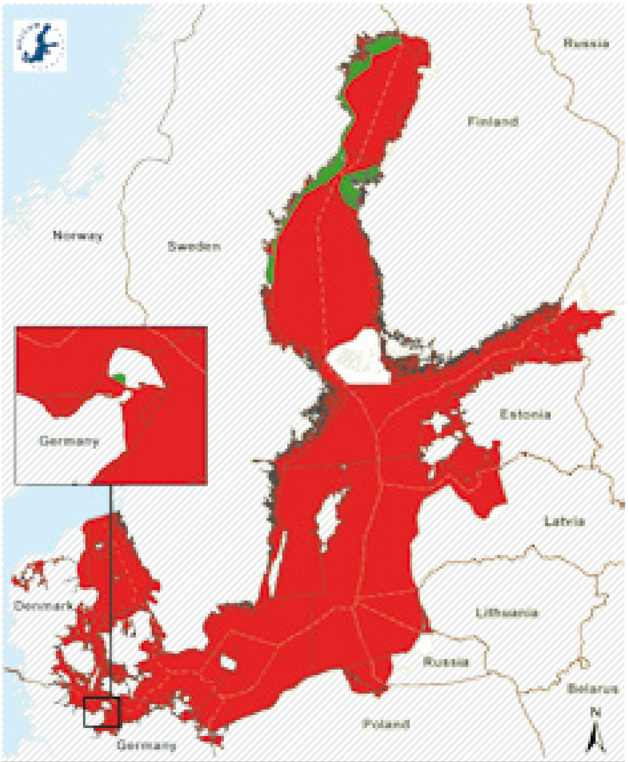


Total number of measuring stations: 162 — BMU & BMELV, 2012

Figure 6

Eutrophication status of the Baltic Sea

Red areas have a poor eutrophication status (SubGES), green areas have a good status (GES). Data was analysed using the HELCOM "Eutrophication Assessment Tool" HEAT 3.0 and data for 2007–2011. For coastal waters, the WRRL evaluation was used



GES SubGES --- Exclusive Economic Zone

Eutrophication status of the Baltic Sea 2007–2011 – A concise thematic assessment. Baltic Sea Environment Proceedings No. 143 — HELCOM (2014)

As a consequence of high nitrate levels, water utilities have already had to abandon some groundwater extraction points and access new, deeper-lying groundwater reserves. This strategy not only leads to additional costs but also faces limitations due to the finite groundwater reserves and the possibility of cross-contamination between pure and tainted aquifers. It is therefore urgently necessary to reduce inputs. Pro-active groundwater protection is much more cost-effective than a subsequent drinking-water treatment (UBA, 2014f and g). The European Commission has already noted the inadequate implementation of the measures of the Nitrates Directive in Germany and has initiated formal infringement proceedings against the Federal Republic of Germany, which could lead to the imposition of penalties.

Currently, excessive levels of phosphates and nitrates in marine waters represent – in addition to overfishing – the greatest ecological problem faced by the German areas of the North Sea and the Baltic Sea. Eutrophication leads to various negative impacts on marine ecosystems (UBA, 2013c). This is the main reason why the coastal waters currently fail to qualify for the "good ecological status" in accordance with the Framework Water Directive and "good environmental status" in accordance with the Marine Strategy Framework Directive (Fig. 6). The Nitrate Report of the German Government (BMU & BMELV, 2012) shows that many measuring stations near the coast have reported higher nitrate concentrations in comparison with the previous reporting period (2003–2006).

In addition, high nutrient loads are one of the reasons why many surface water bodies have no "good ecological status". This is mostly caused by phosphorous levels, which are the decisive factor for surface water bodies, but nitrogen limitation is also possible, in particular for lakes (Dolman et al., 2012).

Outlook: Germany will not meet the requirement of the Framework Water Directive to achieve good groundwater status for bodies of groundwater and good surface water status for all bodies of surface water by 2015. The requirement under the Marine Strategy Framework Directive to achieve a good environmental status for marine waters by 2020 will also not be met. The nitrate levels in some bodies of groundwater have meanwhile ceased to decline, and in some cases are even showing an upward trend.

2.4 Climate change

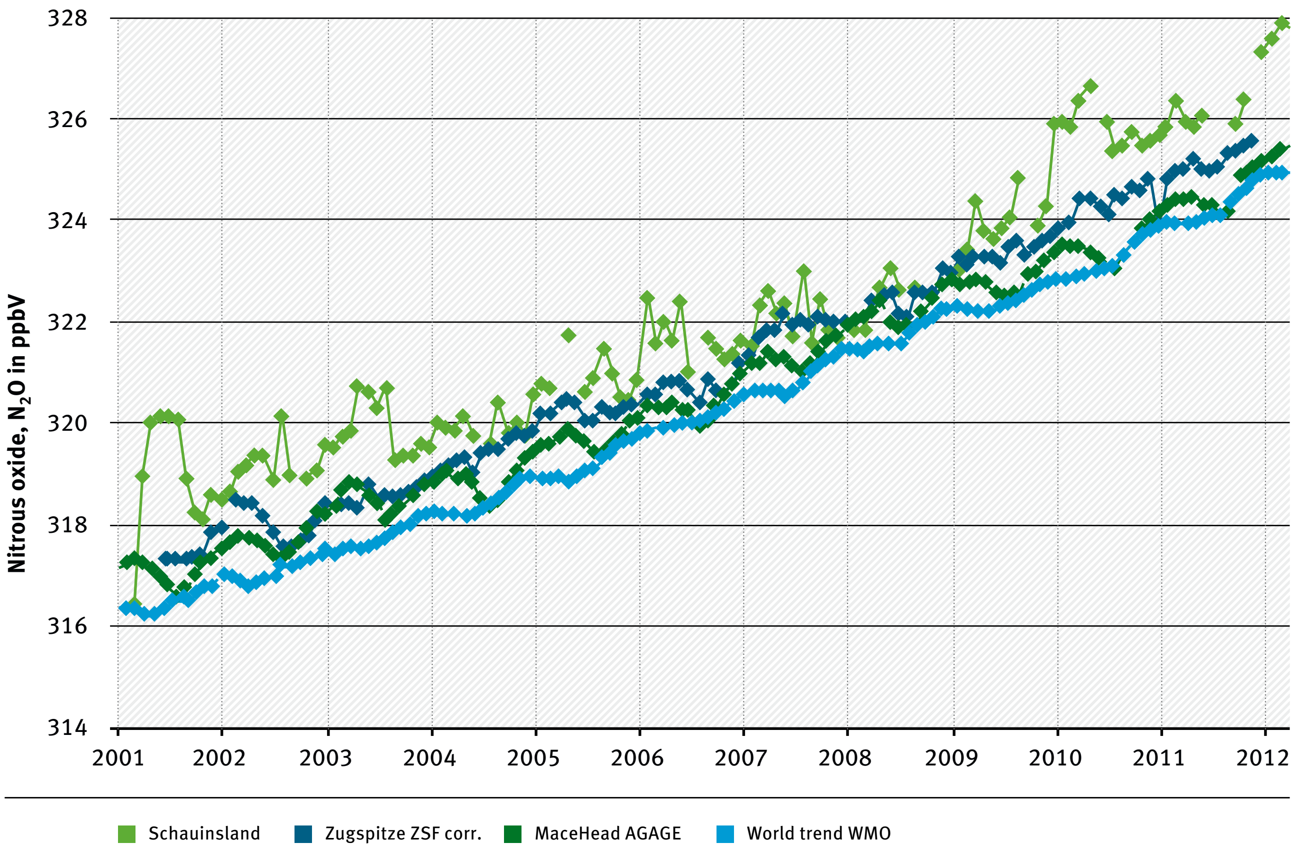
Nitrous oxide is a reactive nitrogen compound (Fig. 7). It is produced as a by-product of microbial activity in soil, in particular nitrification and denitrification. Nitrous oxide (dinitrogen monoxide, N_2O) is 265-times more effective as a greenhouse gas (per kilogram emission) than carbon dioxide (Stocker et al., 2013). In 2011, the radiative forcing of nitrous oxide (which is a measure of the climate impact of a greenhouse gas) account-

Nitrous oxide is released as a by-product of microbial processing of nitrogen in soil

Figure 7

Monthly mean concentrations of nitrous oxide (N_2O) in the atmosphere

Measuring data of UBA (Schauinsland, Zugspitze) and from Ireland (Mace Head) with the global trend from the World Data Centre for Greenhouse Gases (WDCGG, Tokyo)



ed for about 30 per cent of the overall anthropogenic radiative forcing. Reactive nitrogen contributes to the formation of ground-level ozone, which is also a greenhouse gas. On the other hand the intensified nitrogen cycle also has a cooling effect on the climate. The increased binding of carbon compounds, the formation of atmospheric particles that reflect incoming solar radiation back into space, as well as the shortening of methane's lifetime in the atmosphere are key processes for the cooling effect. It is currently estimated that the warming and cooling effects more or less balance out, and that at present the intensified nitrogen cycle has a slight overall cooling effect.

Outlook: Since the cooling effects typically act over a much shorter time scale than the warming effects, the intensified nitrogen cycle will probably contribute to global warming in the long term (Sutton et al., 2013). Possible climate impacts should therefore always be taken into consideration when assessing measures to reduce nitrogen emissions (Sutton et al., 2011).

2.5 Effects on materials

Every year, the weathering and corrosion of building materials and historical monuments makes costly repair and restoration work necessary. Nitrogen compounds play a large role in this, in particular nitric acid (HNO_3) and also particles consisting to varying degrees of nitrogen compounds.

Nitrogen oxide emissions lead to increased concentrations of atmospheric ozone which contributes to material damage. Ozone oxidises organic materials (polymer plastics, rubber, surface coatings) and makes these brittle; it also accelerate the ageing and weathering of metals. The increased risk of material damage by atmospheric pollutants (e.g. reactive nitrogen compounds) can be deduced from comparisons of the corrosion rates in regions with low and high levels of pollution (urban and industrial areas). In recent decades, overall rates of material damage in Germany have declined considerably, above all due to reductions in sulphur emissions. However, no comparable success has so far been achieved for emissions of nitrogen compounds. In the year 2000, the corrosion rates were still 1.5 to 5 times greater than the background corrosion rates, with the affected areas covering large parts of Germany. There has been no fundamental change in this situation since the year 2000.

Outlook: Due to the reduced levels of atmospheric pollution by 2020 (see 2.2), the weathering and corrosion rates of materials will decline further, but will remain well above background rates. As a result, society will continue to face high costs in future.

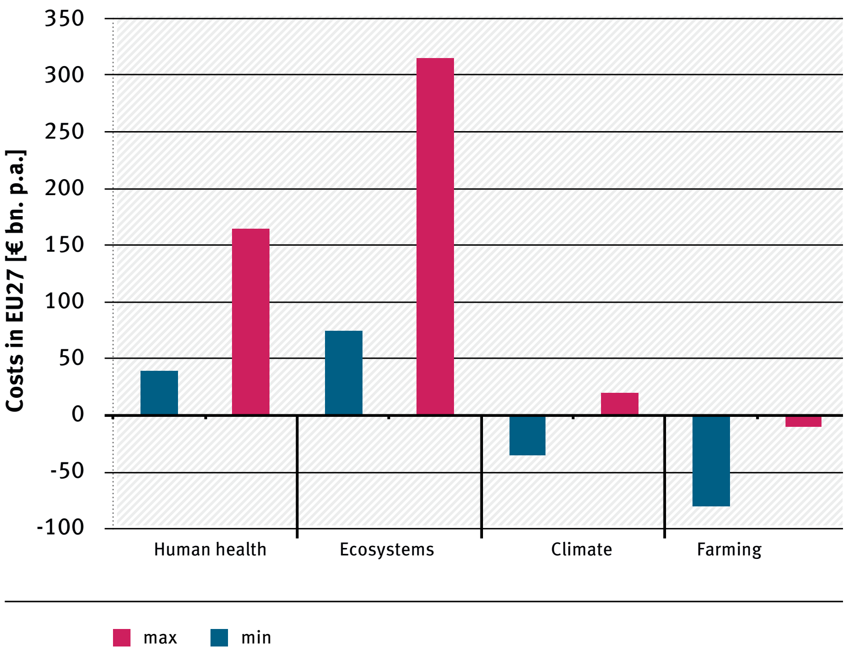
2.6 Economic effects

The use of reactive nitrogen compounds helps to increase crop yields. It is estimated that the benefit in the form of higher crop yields in the EU is between 20 and 80 billion euros per year (see Fig. 8). On the other hand, there are also societal costs, which arise due to harmful effect on human health and to damage to ecosystems. While it is not possible to quantify the damage precisely, van Grinsven et al. (2013) estimate that the intensified nitrogen cycle leads to societal costs of several tens or hundreds of billions of euros (see Fig. 8; van Grinsven et al., 2013). This order of magnitude has since been confirmed by other studies (Stokstad, 2014). Research findings indicate that the macroeconomic costs of the increased use of nitrogen considerably exceed the benefits (Sutton et al., 2011, van Grinsven et al., 2013).

Outlook: In future it would also make economic sense to reduce the use of reactive nitrogen compounds, and to consider the benefits of necessary utilisation more carefully. A sustainable nitrogen cycle not only offers environmental benefits, but is also economically advantageous, not least because the agricultural sector still offers considerable potential for effective and relatively inexpensive measures for the avoidance of emissions of reactive nitrogen (in particular ammonia and nitrates).

Figure 8

Maximum and minimum estimates of costs and benefits (here negative values) associated with the use of reactive nitrogen (values for 2008) in four sectors in the EU-27



van Grinsven et al., 2013; ES&T; 47, 3571–3579

3. Needs for action and policy strategies

Since the 1980s, the negative environmental impacts of the intensified nitrogen cycle have been a topic of discussion. The sustainable reduction of nitrogen pollution became an important objective in environmental policies. A key role was played by international marine conservation conferences and the Convention on Long-Range Transboundary Air Pollution (see Box 3). In 1987, the 2nd International North Sea Conservation Conference introduced one of the first quantitative nitrogen reduction targets – namely to halve the anthropogenous nitrogen depositions by 1995 in comparison with the 1985 levels. This target was only reached in Germany a few years ago. The draft environmental policy programme of the Federal Environment Ministry in 1998 gives prominence to the problems caused by nitrogen and proposes a reduction of the nitrogen surplus in agriculture to 50 kilograms of nitrogen per hectare per year (kg N ha^{-1} yr^{-1}) as a strategic target.

As a central indicator for the sustainability of farming, the nitrogen surplus (farm-gate balance; cf. Box 2) was included in the indicator set of the Sustainability Strategy (2002) and the National Strategy for Biological Diversity (2007). As an interim goal, the German Government specified that by 2010 the surplus for agricultural land should be limited to 80 kg N ha^{-1} yr^{-1}. Thereafter, the quantitative target was to be further reduced, which has not yet been done. This step would require a broad public discussion. UBA proposes as an ambitious but achievable target that the nitrogen surplus in the farm-gate balance should be reduced to 50 kg N ha^{-1} yr^{-1} by 2040 (cf. Annex 2).

Regionally, the nitrogen surpluses in Germany show considerable differences, with very high values in regions with high livestock numbers (Fig. 9).

However, nitrogen emissions are not restricted to the agricultural sector. Reactive nitrogen is also introduced into the environment by modes of transport, wastewater treatment plant and industrial plant. In 1993, a combined working group of the German government and the laender carried out the first quantification of Germany's nitrogen cycle and began the development of a nitrogen reduction strategy. The Nitrogen Reduction Programme eventually published in 1997 proposed measures for all relevant sectors (Alfred Töpfer Academy for Nature Conservation (NNA), 1997). In 2009, UBA produced an integrated strategy for the reduction of nitrogen emissions which was based on updated values for nitrogen flows and which included further measures (UBA, 2009b).

In the past, effective measures have been implemented to reduce losses of reactive nitrogen into the environment, in particular in the field of wastewater treatment and through the reduction of emissions of nitrogen oxides in the manufacturing and transport sectors. However, there have not been comparably effective measures in the agricultural sector.

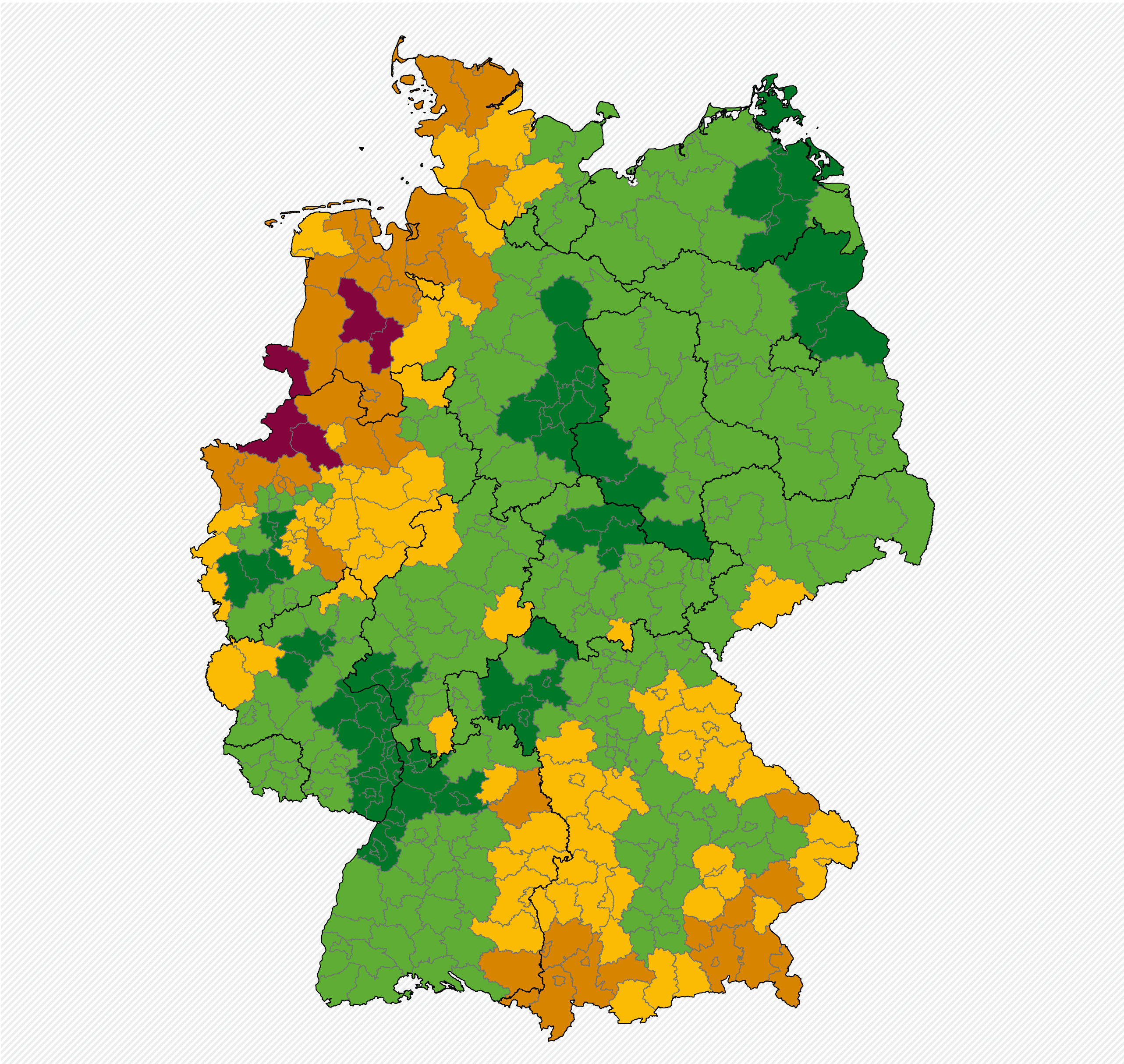
Despite some successes, important reduction targets have either not been met or it is already clear that it will not be possible to meet the targets set for future years unless additional measures are implemented. For example, the mean value for agricultural nitrogen surpluses for recent years has been about 97 kg N ha^{-1} yr^{-1} (see Box 2) – well above the 80 kg N ha^{-1} yr^{-1} which should have been achieved by 2010. Other examples of important policy targets and critical loads which will probably not be met are summarised in Chapter 2, such as achieving good groundwater quality by 2015.

The failure to meet targets is due in part to the fact that a comprehensive solution to the problems posed by nitrogen is hardly possible by implementing separate technical measures in individual areas. Rather, it is necessary to adopt an integrated approach to the various problems in all relevant policy areas (policy integration). In addition it is also important that we all change our behaviour (UBA, 2013a). A solution would be well worth while, because if it were possible to achieve an effective reduction in the amounts of reactive nitrogen released into the environment this would lead to positive effects regarding various other environmental problems (cf. Nitrogen cascade, Box 1). The issue of nitrogen should therefore be tackled with a coordinated and efficient combination of complementary instruments. The 7th Environmental Action Programme of the EU, which came into force in January 2014, and which has a binding character for EU institutions (Council, Commission and Parliament) specifies the main aspects of the EU environmental policy until 2020. One such objective is a sustainable und resource-efficient control of nutrient cycles (nitrogen and phosphorous). The closer

Figure 9

Distribution of the surpluses of the nitrogen field balance (in kg N ha^{-1} yr^{-1}) in the administrative districts and towns in Germany (mean for 2009 to 2011)

The mean value of the surpluses of the nitrogen balance for Germany fo 2009–2011 is 65 kg N ha^{-1} yr^{-1}; the corresponding mean value of the gross nutrient (farm-gate) nitrogen balance is 96 kg N ha^{-1} yr^{-1} (Box 2)



(Bach, 2010, Bach, 2014).

harmonisation at national and European levels could be supported by an explicit nitrogen strategy of the German government which included demanding quantitative targets (indicators) and place demands on all sectors. Initiatives in Germany at the laender level are also tackling the problems raised by nitrogen, for example the project started in 2012: "Analysis and evaluation of the nitrogen budget in Baden-Württemberg"[1].

[1] Cf.: http://www.lubw.baden-wuerttemberg.de/servlet/is/56176/

Box 2

The nitrogen surplus in the agricultural sector

The nitrogen surplus, calculated as gross nutrient balance (or farm-gate balance), is an indicator of the nitrogen losses from agriculture; calculated from the difference between the mass flow of nitrogen into agriculture (e.g. chemical fertiliser, animal feed imports, biological nitrogen fixation, and atmospheric deposition of oxidised nitrogen) and the mass flow of nitrogen in products out of agriculture (marketed animal and plant produces). The farm-gate balance is usually expressed in kg nitrogen per hectare farmland per year (kg N ha^{-1} yr^{-1}).

The surplus is a calculated value that cannot be measured directly, because it involves large losses to the environment. The most important loss path is denitrification (i.e. the conversion of reactive nitrogen into atmospheric nitrogen; cf. Box 4), followed in equal parts by the emission of reactive nitrogen into the atmosphere and the loss of nitrates into groundwater and surface waters. The smaller the surplus, the lower are the nitrogen losses to the environment and therefore the lower are the harmful impacts. A sustainable and productive farming sector will always lead to a nitrogen surplus, because it operates in an open system; the objective is to minimise this. The following policy goals were determined for the nitrogen surplus (gross-nutrient or farm-gate balance):

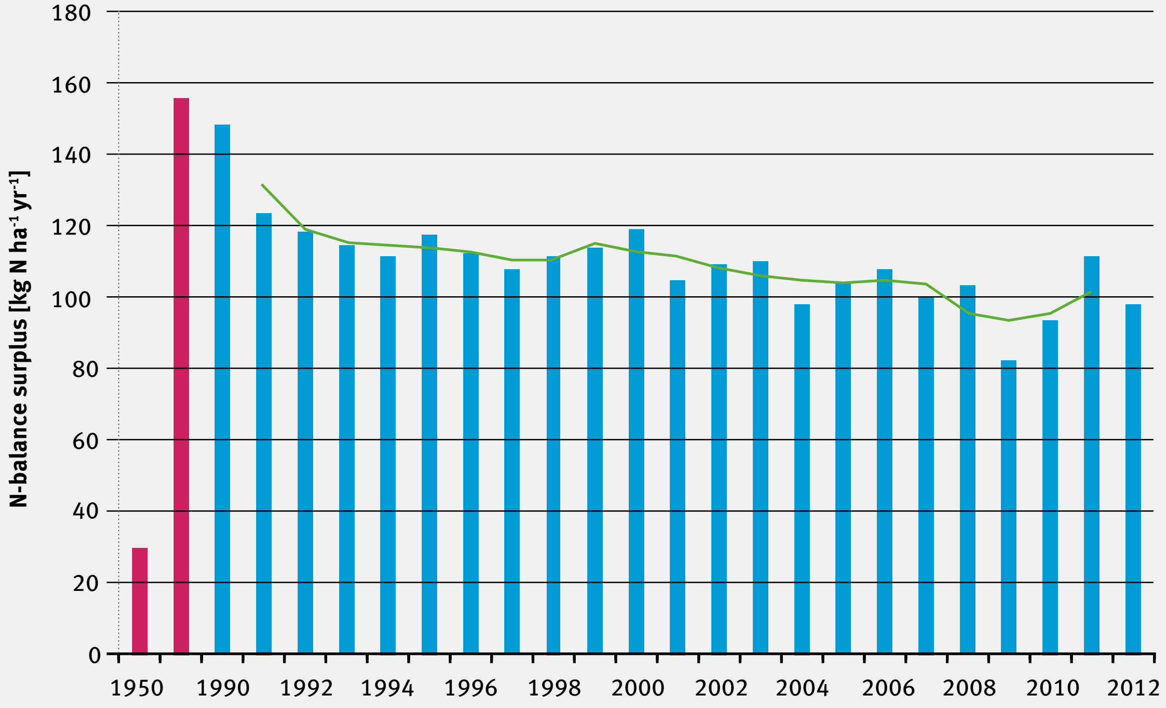
Sustainability strategy: Reduction to 80 kg N ha^{-1} agricultural land by 2010, further reduction by 2020.

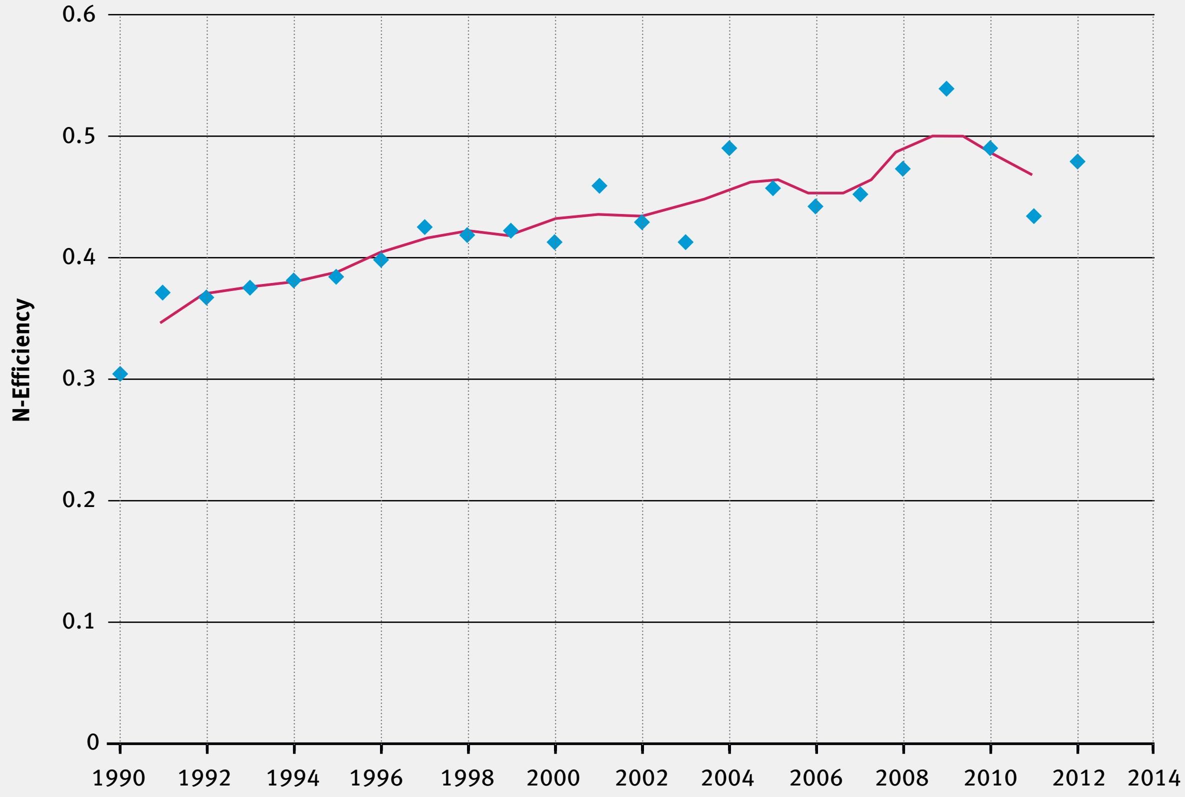
National Strategy for Biological Diversity: By 2010 the nitrogen surpluses in the gross nutrient balance should be reduced to 80 kg N ha^{-1} yr^{-1}, with a further reduction by 2015.

Figure B 2.1 (top) shows the progress of the moving three-year mean since 1990; the value for 2010 is 96 kg N ha^{-1} yr^{-1}, which is 16 kg N ha^{-1} yr^{-1} above the target value. The marked initial decrease is primarily due to reduction in livestock levels in the early 1990s following German unification; the relatively slight reduction over the past ten years can be explained by an increase in yields while the use of chemical fertiliser remained roughly constant. In a European comparison, the German value is in the upper third of the surpluses; the EU27 average is about 50 kg N ha^{-1} yr^{1} (Eurostat, 2011). The lower graph shows the nitrogen efficiency (or nitrogen productivity) over time. This expresses the ratio of nitrogen outputs in agricultural products over nitrogen inputs. The nitrogen efficiency of the German agricultural sector has increased steadily over the past 20 years from less than 40 per cent to about 50 per cent.

In contrast to the farm-gate balance, the field balance (as currently required in the Fertiliser Ordinance) does not take atmospheric losses into account. It therefore only represents a part of the farm-gate balance. Depending on the method used, the value for the field balance in Germany is usually 10 to 30 kg N ha^{-1} yr^{1} lower than the corresponding farm-gate balance (UBA, 2009a, Bach, 2010, Osterburg and Techen, 2012).

Figure B 2.1 (right): Top: Nitrogen surplus (farm-gate balance); the green line shows the moving three-year mean; the red bar show the indicator values for 1950 and 1980 (not directly comparable with later values due to a change in methodology); **Bottom:** Nitrogen efficiency. Data: http://www.bmelv-statistik.de/index.php?id=139 (as of: 04/2014), (UBA, 2011); own diagram


N-balance surplus [kg N ha⁻¹ yr⁻¹]
0
20
40
60
80
100
120
140
160
180
1950
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012


N-Efficiency
0
0.1
0.2
0.3
0.4
0.5
0.6
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014

Box 3

Environmental targets for reactive nitrogen compounds in international conventions and agreements

Baltic Marine Environment Protection Commission – Helsinki Commission, HELCOM

In order to restore the good ecological status of the Baltic marine environment by 2021, HELCOM agreed on the Baltic Sea Action Plan in 2007, which contains quantitative reduction targets for nutrient inputs. These targets were subjected to a scientific review and revised targets were agreed at the HELCOM Ministers meeting in October 2013. The goal of the Baltic Sea Action Plan is to limit the inputs of reactive nitrogen into the Baltic Sea by water and by air to some 800,000 t N yr^{-1} by 2021.

Based on best available scientific knowledge, at or below this value there would be no more significant eutrophication of the Baltic Sea. Under the Baltic Sea Action Plan, Germany is required to reduce its nitrogen loads from water and air by a total of 7,670 t N yr^{-1} by 2021 in comparison to the period 1997 to 2003 – corresponding to some 10 per cent of the current levels.

Further information: www.helcom.fi

Convention on Long-range Transboundary Air Pollution, CLRTAP

A fundamental objective of the Convention on Long-range Transboundary Air Pollution initiated in 1979 was to limit and, as far as possible, gradually reduce and prevent air pollution. In 2012, a revised Gothenburg Protocol included national emission reduction commitments to be achieved in 2020 and beyond (UBA, 2014b). Germany committed itself to reductions of national emissions of nitrogen oxides (NO_x) and ammonia (NH_3) of 39 % and 5 %, respectively, by 2020, relative to the levels in 2005. In the case of ammonia this only represents a minor reduction.

Further information: www.unece.org/env/lrtap/lrtap_h1.html

Convention on Biological Diversity, CBD

The Convention, agreed on in Rio de Janeiro in 1992, has as its main objectives the conservation of biodiversity and the sustainable use of its components, and fair and equitable sharing of benefits arising from genetic resources. In 2010, a strategic plan was formulated with twenty biodiversity targets (Aichi Targets) to be achieved by 2020. Target 8 is that, pollution, including from excess nutrients, should have been brought to levels that are not detrimental to ecosystem function and biodiversity by 2020.

Further information: www.cbd.int

4. Germany's nitrogen cycle

A budget of the emission sources and flows of reactive nitrogen compounds in the environment is the basis for the development, assessment and selection of measures and instruments in terms of their emission reduction potentials and possible side-effects in other environmental media. In order to ensure comparability of national budgets, methodology guidelines were developed under the Convention on Long-Range Transboundary Air Pollution (CLRTAP, 2013), on the basis of which the budget for Germany was drawn up and continues for the year 2009 (UBA, 2009a). Wherever it was possible the budget was updated and refers to the reference period 2005–2010. The key data sources are listed in Annex 1.

In December 2013, legislative proposals for the revision of the EU clean air policies were presented (Environment Directorate General of the European Commission [DG Environment], 2013). Amongst these the EU Commission recommends the generation of such a budget (described above) in order to make it possible to adopt targeted measures. Other European countries are also drawing up regular national nitrogen budgets (Heldstab et al., 2013, Heldstab et al., 2010).

4.1 Budgeting nitrogen flows in Germany (2005–2010)

The most important (anthropogenous) nitrogen flows in Germany are shown in Figure 10. About 4200 Gg of reactive nitrogen[2] find their way into the national nitrogen cycle in Germany every year, either because molecular nitrogen is converted into a reactive form or because reactive nitrogen is imported. The most important inputs into the national cycle are:

- The industrial production of ammonia from atmospheric nitrogen for chemical production, accounting for approx. 2700 Gg N yr^{-1} (Verband der Chemischen Industrie e. V. (VCI), 2012),
- The import of animal feed, approx. 370 Gg N yr^{-1} (Federal Minister of Food and Agriculture (BMEL), 2013),
- Emissions of reactive nitrogen from the power industry, manufacturing, households, and the transport sector, approx. 440 Gg N yr^{-1} (UBA, 2012),
- Biological N-fixation in agriculture (BMEL, 2013) and in terrestrial ecosystems (own estimate), totalling approx. 275 Gg N yr^{-1}
- The transboundary import of nitrogen in rivers, approx. 320 Gg N yr^{-1} (Fuchs et al., 2010, UBA, 2014a), and in the atmosphere, approx. 250 Gg N yr^{-1} (Fagerli, 2012).

Important flows within the budget are the 890 Gg N applied to agricultural areas every year as manure and the national sale of chemical fertiliser of 1640 Gg N yr^{-1} (BMEL, 2013), which corresponds to most of the industrially fixed nitrogen. 665 Gg N is available in agricultural products for food consumption or for the production of food products.

The removal of reactive nitrogen from the cycle has not been sufficiently recorded. Some 900 Gg of dissolved nitrogen compounds are introduced annually into marine and coastal ecosystems via rivers (without taking retention in surface water bodies into account), either directly or through neighbouring countries (Fuchs et al., 2010). The atmosphere transports some 560 Gg reactive nitrogen every year into other countries (Fagerli, 2012). Denitrification also accounts for a significant removal of reactive nitrogen (cf. Box 4). From wastewater treatment, 340 Gg N yr^{-1} are released into the atmosphere as molecular N_2 (German Association for Water, Wastewater and Waste (DWA), 2011). Denitrification in surface waters, in agro-ecosystems, in natural and semi-natural ecosystems and in groundwater can only be approximately specified based on current data[3] Finally, a number of industrial products (e.g. building materials, paints) also contain reactive nitrogen. According to first estimates about 10 kg reactive nitrogen per person per year are used for the production of these products (Sutton et al., 2011, Gu et al., 2013)[4]. However, the material flows of the reactive nitrogen contained in these products (interna-

[2] Gg = gigagram, corresponding to 1000 tonnes

[3] There is a difference of approx. 750 Gg N yr^{-1} between the nitrogen surplus in the agricultural sector and semi-natural terrestrial ecosystems and the determined inputs into the atmosphere and surface waters. A large part of this is denitrified. However, this estimate represents only a first approximation because (i) data from various sources are being combined, and (ii) the possible accumulation of reactive nitrogen and the time-delay for the passage into the groundwater has not been taken into account.

[4] 4 In Germany, every year approx. 2700 Gg N is industrially fixed and 1640 Gg N of this is marketed as chemical fertiliser. The remaining 1000 Gg N yr^{-1} (or 12.5 kg N per person per annum) is used for further industrial processing.

tional trade, product storage, waste disposal, recycling) have so far hardly been documented, so that there are considerably gaps in the budget in this case.

Box 4

Denitrification

Nitrates are broken down in the environment (as part of the nitrogen cascade), generating molecular nitrogen and traces of nitrous oxide. This denitrification takes place in surface waters, in soils (unsaturated zone) and in aquifers (saturated zone), as well as in wastewater treatment plant. The nitrate reduction takes place under anaerobic conditions, mostly through the action of micro-organisms. Reduction agents may be:

- organic compounds (heterotrophic reduction) or
- inorganic compounds, in particular iron sulphides (autolithotrophic reduction).

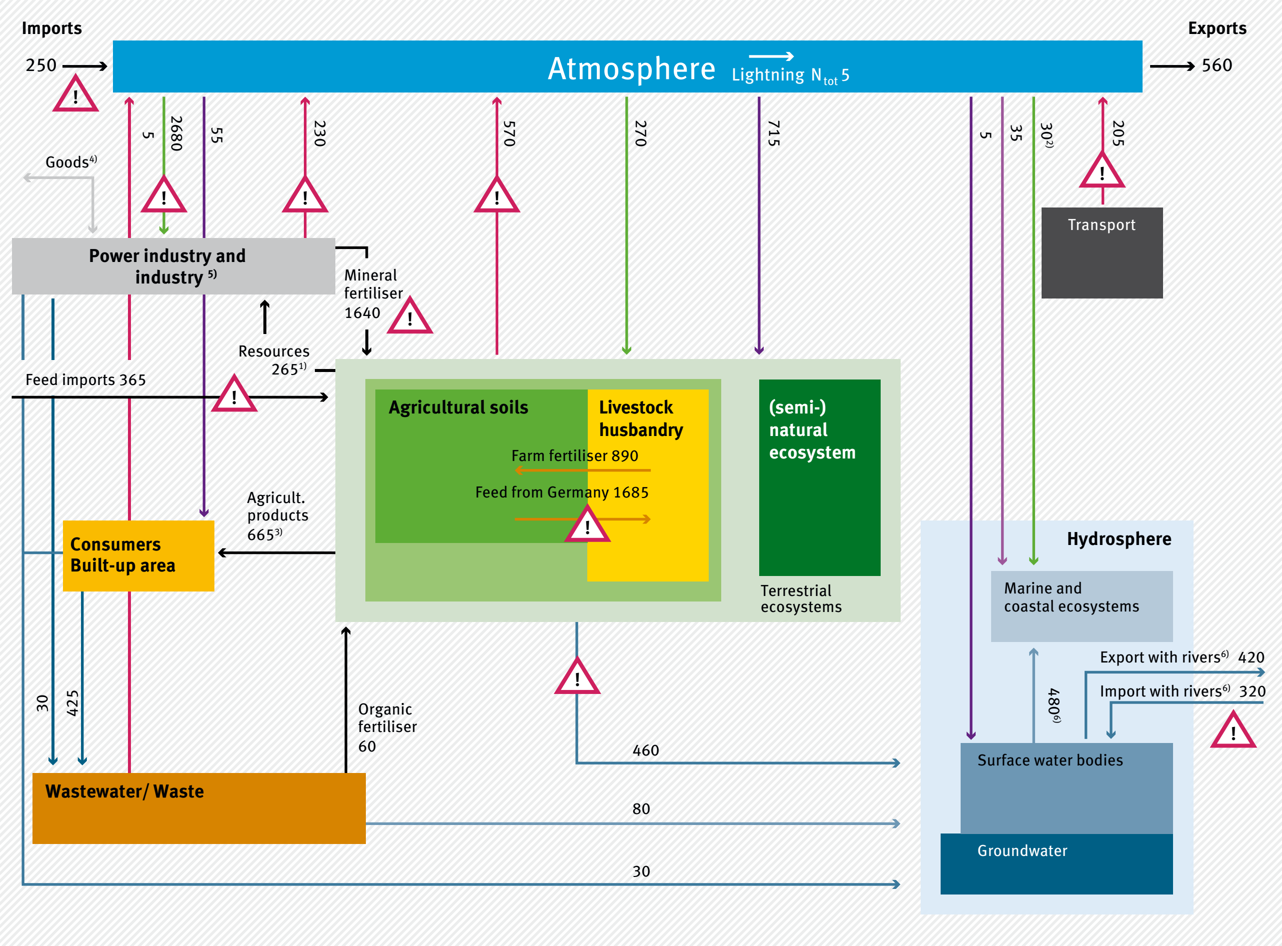
In soils and surface waters, only the reaction with organic compounds plays a role. Due to the conditions (presence of oxygen and a surplus of nitrates), the reduction process is rarely complete. There is a regular supply of more organic compounds due to the decomposition of biomass. The situation is different in aquifers. Here there are usually only low levels of organic carbon, which limits the scope for reduction considerably. And if nitrates are degraded by the oxidation of iron sulphides, then the reduction capacity will gradually be lost (because no new mineral can be formed or supplied from elsewhere). The result is that within a relatively short period there can be a permanent increase in the nitrate concentration (Bergmann et al., 2014, Hansen et al., 2011).

Denitrification makes a significant contribution to decreasing the burden of reactive nitrogen. But it must also be taken into account that the reduction of nitrates is also linked with undesirable consequences (e.g. the release of nitrous oxide or the depletion of non-regenerative reduction potential), and that the agricultural sector is losing valuable fertiliser.

A regional quantification of denitrification remains very difficult and this is currently one of the main uncertainties in drawing up nitrogen budgets (Groffman, 2012, Schlesinger, 2009, Bach, 2010).

Figure 10

The key flows of reactive nitrogen in Germany (in Gg N yr^{-1})



Atmospheric emissions | Nitrogen fixation | Deposition | Transport with/in water bodies | Other material flows

All values are rounded to 5 Gg N yr^{-1}. Where data are available, means are given for 2008-2010. Otherwise the value for 2010 was used or the last available value. The data for surface waters are for the period 2006-2011, and the data for atmospheric depositions for 2005-2007. For details cf. Annex 1.

The import of manure (mainly liquid manure and dry poultry manure) and the import of biomass as fermentation substrate (as well as possible exports) are not contained in the budget. Over the observation period this probably represents an omission of at least 20 Gg N yr^{-1}. Flows of plant fermentation residues within the agricultural sector are also not taken into account (ca. 100-150 Gg N yr^{-1}).

The triangles indicated indicate important opportunities for measures in Germany (cf. Chapter 5).

1) Includes industrial crops (sugar beet, tobacco, fibre plants, etc.) and a first estimate for the nitrogen flow due to harvested wood (70 Gg N yr^{-1}).
2) Only the Baltic Sea.
3) Includes all animal and plant products with the exception of animal feed and industrial crops. Losses from further processing, marketing and consumption are still included.
4) The nitrogen flow in industrial products cannot be quantified at present.
5) Includes small domestic heating units in households.
6) Allowance cannot be made for retention in bodies of surface water due to lack of data for the observation period. Older evaluations show that, depending on the distance flowed and other factors, retention (and in particular denitrification) can account for up to 50 per cent (Fuchs et al., 2010).

4.2
Comparing the German N-cycle with European and global levels

Quantifications of the nitrogen cycle are also available for the global and the European levels (Fowler et al., 2013, Sutton et al., 2011). A comparison of the estimates for the entry of reactive nitrogen into the cycle in Germany, with the European and global levels (Tab. 1) shows that natural processes make a much greater contribution to the nitrogen cycle at a global level, due to the large areas covered by oceans, than they do in Europe and Germany, where anthropogenous effects are more intensive.

Table 1

Rate of input of reactive nitrogen into the environment (in 1000 Gg N yr^{-1})

	Global	Europe	Germany
Biological N-fixing	58.0 (14.0 %)	0.3 (1.5 %)	0.1 (2.0 %)
Lightning	5.0 (1.0 %)		
N-fixing in oceans	140.0 (34.0 %)	0.5 (2.5 %)	
Sub-total	203.0 (49.0 %)	0.8 (4.0 %)	0.1 (2.0 %)
Haber-Bosch	120.0 (29 %)	16.6 (74 %)	2.7 (74 %)
Biological N-fixing in farming	60.0 (15 %)	1.0 (4 %)	0.2 (6 %)
Fodder imports		0.5 (2 %)	0.4 (10%)
Combustion processes	30.0 (7 %)	3.7 (16 %)	0.4 (10 %)
Sub-total	210.0 (51 %)	21.8 (96 %)	3.6 (98 %)
Total	413.0 (100 %)	22.6 (100 %)	3.7 (100 %)
Area-related [kg ha^{-1}]	8	53	103

Global: Fowler et al. (2013), Europe: Sutton et al. (2011), Germany: this study

4.3
Emissions of reactive nitrogen

In addition to the intensity of the nitrogen cycle (i.e. the total amount of nitrogen in the cycle), the emissions of reactive nitrogen are an important parameter in view of the direct relationship to the effects. Table 2 presents the mean annual emissions in Germany for the most important nitrogen compounds and the key emitting groups.

The figures show that agriculture has meanwhile become the most important sector for the release of reactive nitrogen into the environment. Due to the greater reductions achieved in other sectors, the relative share of remaining emissions caused by agriculture increased over the past 20 years, despite the fact that measures adopted to reduce agricultural emissions have shown some effects. In the 1990s, less than half the total emissions of reactive nitrogen compounds were from agriculture (Eichler and Schulz, 1998). This highlights how important it is to use existing reduction potential, particular in agriculture, and to adopt appropriate measures.

Table 2

Proportions of the main N-compounds and emitting groups in the mean annual emissions affecting air and surface waters in the current budget period

	Air			Water		
	NO_x	NH_3	N_2O	NO_3^-/NH_4^+	Total [Gg N yr-1]	%
Agriculture	33	435	88	424	980	63
Traffic	192	13	2		207	13
Industry/ Energy sector	166	15	27	10	218	14
Households/ Wastewater treatment plants/ Surface run-off*	21	1	6	135	163	10
Total [Gg N yr-1]	412	464	123	569	1568	100
%	26	30	8	36	100	

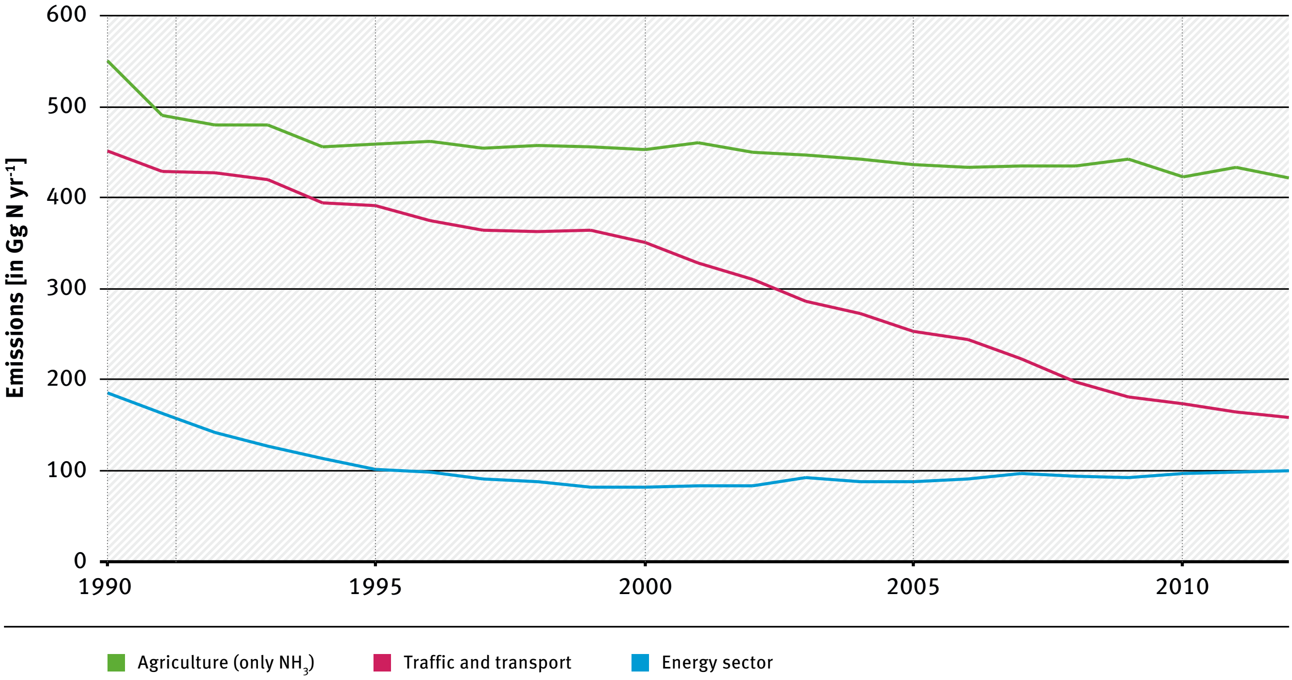
* Includes urban systems and the entire surface run-off, because currently no distinction can be made between agricultural and other areas. The atmospheric emissions include small domestic combustion units.

4.4 Changes over time of key emissions

Since 1990, the emissions of reactive nitrogen into the air have decreased considerably (Fig. 11). The greatest reduction, of more than 50 per cent, was achieved in the transport sector. In particular, the introduction of increasingly stringent emission controls for road vehicles (cf. Box 4) led to a significant reduction in exhaust

Figure 11

Changes over time of NO_x-emissions from transport and the energy sector and of NH_3-emissions from agriculture into the air



UBA, 2014d

emissions – despite an increase of 61 per cent in goods transport and 31 per cent in private transport between 1991 and 2013.

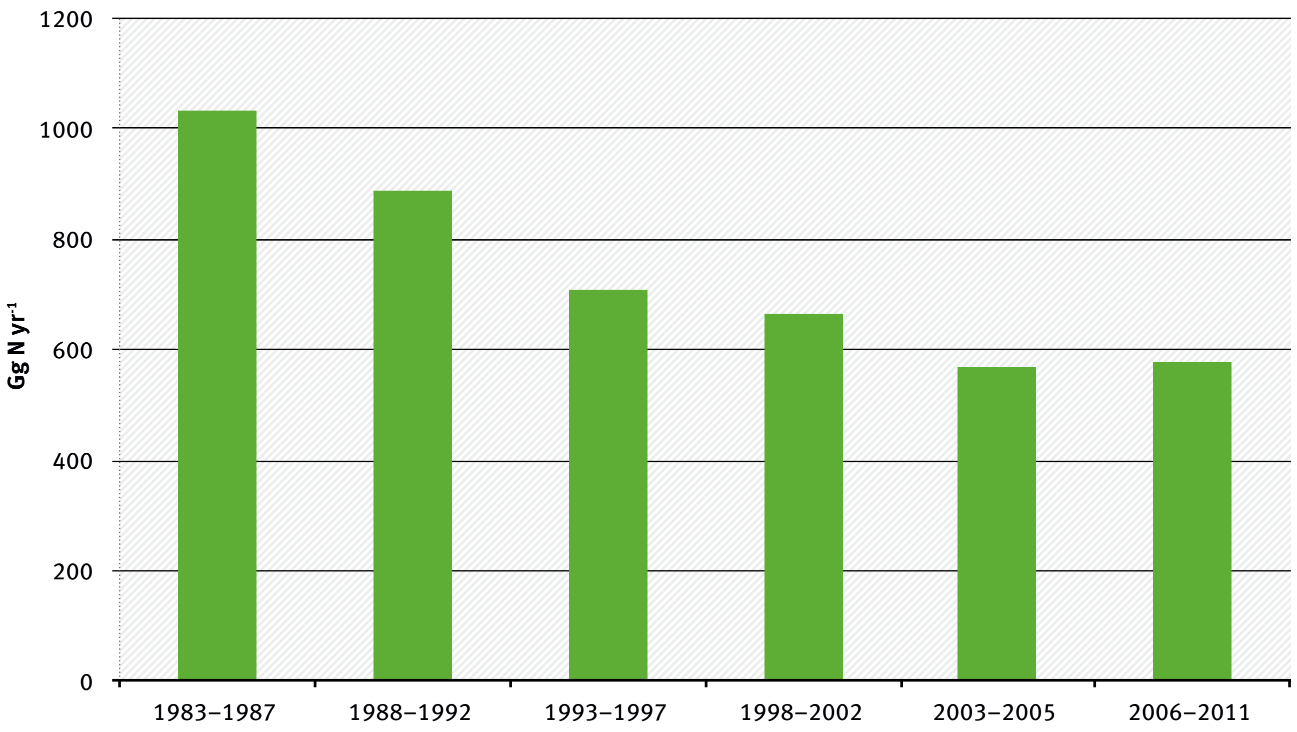
The emissions in the energy sector also showed a marked decline until the early 2000s, but there was then a levelling out or even a slight increase, attributable to the increased introduction of biogas-fired combined heat and power systems and of biomass-fired power stations, among other factors. Biogas experienced a boom, especially between 2007 and 2012. However, for each kilowatt-hour of power generated by a combustion engine in a biogas-cogeneration unit, more NOx-emissions are released than in a large power station, which is one of the main reasons for the rise in emissions from industrial energy generation.

The ammonia emissions from agriculture showed a sharp decline in the early 1990s, which is due primarily to the reductions in livestock numbers. Subsequently, the average decrease has been less than one per cent per year.

The inputs of nitrogen into surface water bodies have also been reduced considerably since the mid-1980s (UBA, 2009a). However, in recent observation periods the levels have flattened out (Fig. 12). In view of the greater reductions achieved in other sectors, the relative contribution of agriculture to nitrogen inputs into surface waters increased continually from 1983 to 2011 – from 54 per cent to 79 per cent (Fuchs et al., 2010, UBA, 2014a und g).

Figure 12

Changes over time of nitrogen inputs into bodies of surface water



Fuchs et al., 2010, UBA, 2014a

Box 5

Formation of reactive nitrogen by combustion

Burning fuel in small and large combustion plants, in gas turbines and engines, or the incineration of waste can generate reactive nitrogen (as nitrogen oxides, NO_x), and depending on the nature of the processes involved, three types are distinguished:

- Fuel NO_x: Nitrogen oxides generated as a result of the nitrogen contained in the fuel. If low-nitrogen fuels are used, then the observed level of NOx emissions depends on the extent to which the other two formation processes are effective.
- Thermal NO_x: With rising combustion temperatures, an increasing proportion of the molecular nitrogen (N_2) from the combustion air is converted to NO_x. Thermal NO_x dominates the emissions at high combustion temperatures, with local temperature peaks being particularly relevant. Since the energy efficiency of systems (energy consumed in useful work/total energy input) increases with the mean combustion temperature, there is a conflict of goals. This can be resolved by measures to avoid local temperature peaks in combination with effective end-of-pipe systems to reduce the emission of nitrogen oxides.
- Prompt NO_x: Fuel radicals formed by the combustion process cause molecular nitrogen (N_2) from the combustion air to be converted to NO_x. Prompt NOx is generally only of relatively minor importance.

The emissions of NO_x can therefore be reduced by the use of low-nitrogen fuels, by optimisation of the combustion processes, and by exhaust gas treatment (reduction of nitrogen oxides).

EU emission control standards for road vehicles:

Table B 5.1: Overview of NO_x-emission limit values in accordance with EU emission standards.

	Units	Private vehicles / LGV			HGV		
		Euro 4	Euro 5	Euro 6	Euro IV	Euro V	Euro VI
Petrol	g/km	0.08	0.06	0.06			
Diesel	g/km	0.25	0.18	0.08			
Diesel	g/kWh				3.5	2.0	0.4

However, in some cases the values determined in the idealised test procedures can be much lower than real driving emissions. This difference is to be reduced by new, adapted test cycles. As a further improvement, portable emissions measurement systems (PEMS) should be employed.

5. Measures and recommendations for action

The negative environmental impacts of reactive nitrogen depositions and the failure to meet environmental targets highlight the urgent need for further measures to reduce losses of reactive nitrogen to the environment.

The problem of reactive nitrogen calls for a consistent combination of a range of instruments and will involve changes to regulatory systems, together with the introduction of economic incentives, and the provision of improved information and advice at all levels of society. Some climate change mitigation measures can lead to positive synergy effects. For example, improved energy efficiency or changes to mobility systems may also help to improve the nitrogen situation. However, in other cases conflicts can arise, as described earlier with the increased use of biomass as a source of energy.

The national budget (Fig. 10) shows points in the cycles where additional measures should be adopted in Germany in order to achieve significant reductions in environmental impacts caused by reactive nitrogen:

- The largest reduction potential in absolute terms is in the agricultural sector and in the consumption of farm produce. The proposed reduction of the nitrogen surplus in the farm-gate balance from 95 kg N ha^{-1} yr^{1} at present to 50 kg N ha^{-1} yr^{1} in 2040 corresponds to a reduction of the total surplus by some 700 Gg N yr^{1}. A key contribution to increasing the nitrogen efficiency could be made by avoiding unproductive losses and reducing levels of animal protein-feed, e.g. if the general public adopted a more plant-based diet with and overall reduction in meat consumption (UBA, 2013a). The more efficient fertilisation with manure and a reduction in the demand for fodder would also make it possible to reduce the use of chemical fertilisers.

- Emissions from industry, the energy and transport sectors, and households could also be reduced by 2030 if appropriate measures are introduced.

- The levels of reactive nitrogen in industrial products are still inadequately documented (cf. Chapter 4). However, it is clear that more efficient use and increased reuse could lead to a reduction in the overall demand for industrial nitrogen (Gu et al., 2013).

- In addition, international cooperation is necessary to further reduce transboundary transport of reactive nitrogen compounds in rivers and in the atmosphere.

5.1 Agricultural policies

The budget in Chapter 4 show that about two-thirds of the losses of reactive nitrogen into the environment come from agriculture. The realignment of agricultural policies is therefore essential for the reduction of the nitrogen burden. The most cost-efficient measures in Germany and in many other European countries are meanwhile to be found in the agricultural sector (International Institute for Applied Systems Analysis (IIASA), 2014, UBA, 2009a).

In order to tackle the challenges raised by reactive nitrogen and achieve sustainable, competitive and productive agriculture, the existing regulatory provisions and subsidy policies need to be adapted and harmonised (Möckel et al., 2014). The Agriculture Commission at the Federal Environment Agency (KLU) has made significant proposals in this respect (KLU, 2013b). These include limits to livestock densities, maximum nitrogen surpluses, a minimum proportion of legumes in the crop sequence as a necessary requirement for entitlements to subsidy payments, and the introduction of grazing premiums. Despite some improvements and the paradigm shift that has been initiated, the agreed reforms of the EU Common Agricultural Policy on their own will hardly ease the nitrogen situation. In some regions, growing energy maize will add to the problems, in particular because of the reactive nitrogen contained in the vegetable part of fermentation residues and in many cases the increased potential for nitrate leaching after maize planting in autumn. Finally, ploughing up grassland leads to the loss of most of the assimilated nitrogen to the groundwater or to the atmosphere. It is therefore essential to avoid the ploughing up of pastures as far as possible. Policy changes are also needed in these sectors. The proposals of the Agriculture Commission at UBA should therefore be taken into account by the German Government and the laender when implementing the measures nationally and when formulating further reforms (KLU, 2013a and b).

The example of Denmark shows that the introduction of binding measures coupled with detailed surveys and effective implementation makes it possible to achieve considerable improvements in the nitrogen situation. Without impairing the competitive situation of farmers, it has been possible to reduce ammonia emissions in Denmark by 40 per cent since 1990. The nitrogen surplus also went down by some 40 per cent over the same period. Meanwhile, the improvements are also being reflected in lower levels of nitrate leaching and nitrogen depositions.

In the following, some important fields of action are outlined where steps can be taken to tackle the challenges. The important objective is to increase nitrogen efficiency.

Amendment to the Fertiliser Ordinance

The Fertiliser Ordinance is a central control instrument for dealing with nitrogen in the agricultural sector, and therefore for reducing nitrogen surpluses. Currently, a new version of this Ordinance is being prepared. The Federal Minister of Food and Agriculture has set up an evaluation group, organised by the Thünen Institute, with representatives of the Federal State ministries of agriculture, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, and UBA (Osterburg and Techen, 2012). The key proposals cover the following aspects:

- Improved fertilisation planning and nutrient balances, in order to allow the optimisation of the nutrient cycle (including a plausibility check for the N-removal in basic fodder);
- An obligation to receive advice after repeatedly exceeding maximum nutrient levels;
- Limitation of the period in which manure can be spread;
- Requirements for immediately working manure into untilled land and the use of suitable application equipment, i.e. the ground-level, low-emission application of liquid manure;
- The inclusion of all organic fertilisers (including fermentation residues) in the upper application limit of 170 kg N ha^{-1};
- Determining standard storage capacity so that liquid manure can be held for a minimum storage period of nine months.

In view of the fact the groundwater nitrate levels in Germany are still frequently above critical levels, giving rise to the prospect of EU infringement proceedings, al the recommendation should be considered in the discussion.

In a joint statement, the scientific advisory boards for agricultural policies (WBA) and for fertilisation matters (WBD) together with the Council of Experts for Environmental Matters (SRU) recommended a revision of the Fertiliser Ordinance along the lines of the basic principles already developed; they also made further additional proposals (WBA, WBD & SRU, 2013). For example, in the Fertiliser Act (Article 3, para. 2), the requirement for good agricultural practice should explicitly include the avoidance of threats to natural ecosystems (WBA, WBD & SRU, 2013).

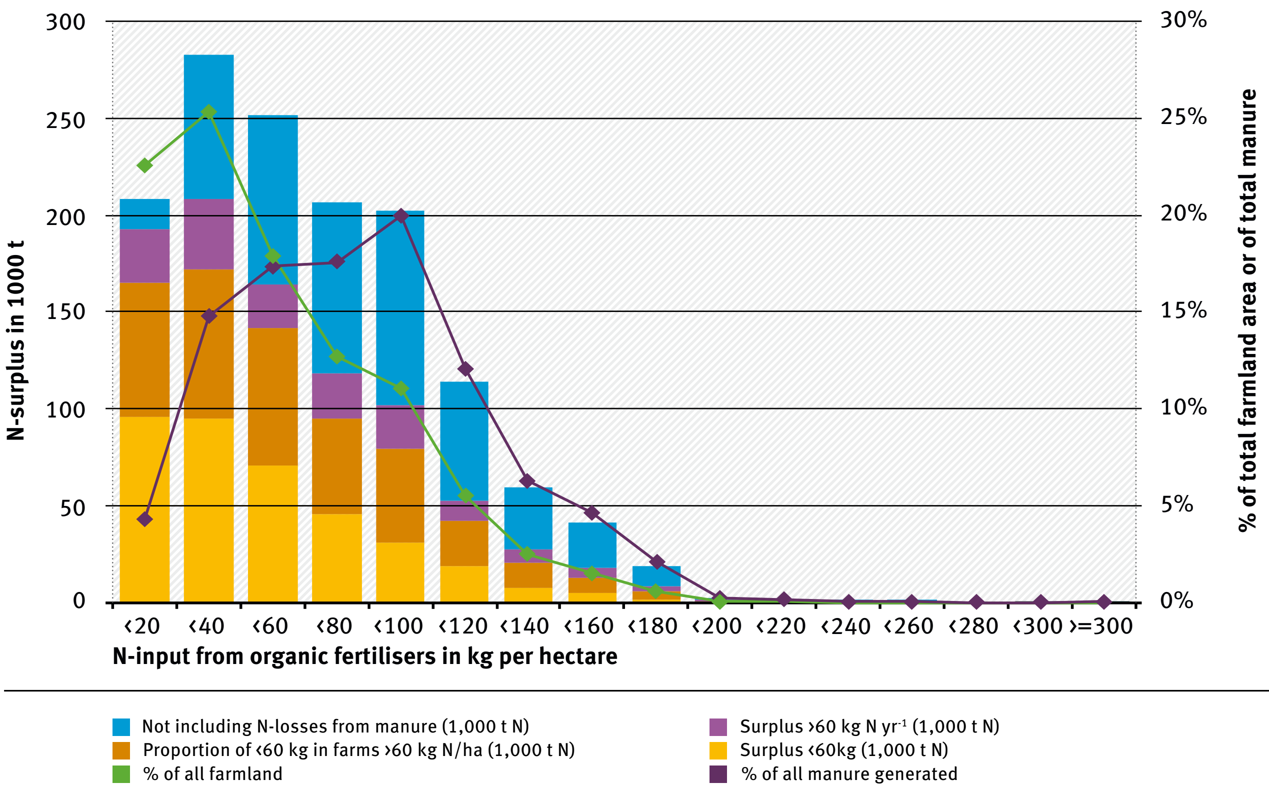
By implementing these recommendations it would be possible to reduce the overall surplus in the agricultural sector by 20 per cent or some 300 Gg N yr^{1} (Fig. 13). This would make it possible to achieve the national target of limiting the nitrogen surplus to 80 kg N ha^{-1} yr^{1} (cf. Box 2). In order to further reduce impacts on ecosystems, the Fertiliser Ordinance should be amended to include regulations for the following requirements:

- Reducing maximum limit levels
  Limits for fertiliser should be based to a greater extent on the actual nutrient needs of the crop, and a reduction of the upper limit for the application of nitrogen in manure in order to ensure its efficient utilisation (Gutser et al., 2010).

Figure 13

Estimated N-surpluses against N-inputs in organic fertiliser per ha farmland (per community; this correlates broadly with livestock density)

Yellow – Farms with a N-surplus below the levels proposed in the revised Fertiliser Ordinance (DüV); Brown and Red: Farms with a N-surplus above the limit values (the Red part must be reduced); Blue: losses to the atmosphere that are not considered in the Fertiliser Ordinance. The nitrogen surpluses in all types of farm need to be reduced (Osterburg and Techen, 2012)



- **Minimising losses to the atmosphere**
  In order to avoid losses to the atmosphere, manure should be worked into untilled soil within one hour of application and the regulations should require urea-based fertiliser to be applied using low-emission methods[5]. In addition, new, low-emission application technologies should be further developed on the basis of practical experience (e.g. slit injection, strip tillage) and made obligatory for specific applications after a suitable transitional period.

- **Applying fertilisers on sloping land**
  According to the Fertiliser Ordinance, the farmer must take care when applying fertilisers containing appreciable levels of nitrogen that there is no run-off into surface waters. In order to improve biotope conservation, this provision should in future also include run-off onto adjacent areas of land. In order to allow more effective prevention of run-off from steeply sloping land, the distance to waterside banks should be increased and the provision extended to include less steeply sloping land.

- **Applying manure near watercourses**
  The relevant provision in the Fertiliser Ordinance should be extended so that the application of fertilisers containing nitrogen or phosphate and growing media is completely banned within a distance of five metres from the bank edge of bodies of surface water (at least those of 1st or 2nd Order).

[5] This could include a ban on high- emission applications (e.g. on grassland), and obligations to use certain application techniques (e.g. injection) or a specified (European) formulation (e.g. in combination with temporarily effective urease inhibitors).

- **Reducing the permissible surpluses of the field and farm-gate balance**
  The permissible nutrient balance at field level surpluses of the nutrient comparison in accordance with the Fertiliser Ordinance should in future be reduced in order to minimise losses to the environment and to achieve the proposed German targets for a nitrogen surplus in the farm-gate balance (Box 2) of 50 kg N ha^{-1} yr^{1}. The balancing methods of the Fertiliser Ordinance should be extended to include a farm-gate balance, so that atmospheric losses and animal feed flows can also be considered and potential improvements become more obvious. Furthermore, it is important to carry out regular re-evaluations of the calculation factors specified for the nitrogenous excretions per animal or for atmospheric losses, and to carry out up-dates where necessary (UBA, 2009a).

- **Improved compliance with the Fertiliser Ordinance**
  In future, failing to comply with the limit levels for the application of fertilisers, or exceeding the permissible surpluses in the nutrient comparison, or not meeting the specifications intended to avoid run-off to surface water should lead to an obligation to receive advice, with penalties imposed for repeated serious transgressions.

In order to ensure that manure is applied in accordance with needs and that the legal provisions can be implemented efficiently data from various sources should be compared at regular intervals. Sources include, in particular, the nutrient balance drawn up in accordance with the Fertiliser Ordinance, details of the amounts of manure transported between farms, the numbers of livestock held, and the details given when applying for plant certification concerning the use of the manure. The records on the marketing of manure and fermentation residues kept in accordance with the Ordinance on the Marketing and Transport of Farm Manure (WDüngV) can already be regular obtained by the laender (federal states) under current reporting regulations. A possibility should be created for such inquiries to be made about the nutrient balances determined in accordance with the Fertiliser Ordinance, or the regular submission of such data should be made obligatory. Such reporting obligations should also be introduced for other important data, such as the use of bio-waste or the results of surveys of the supply situation of soils (Agriculture Chamber Lower Saxony (LWKNI), 2013).

The Commission for Agriculture at UBA (KLU) has also issued a statement about the revision of the Fertiliser Ordinance (KLU, 2014). Among other things, the Commission recommends a further reduction of permissible N-surpluses, the introduction of the gross nutrient balance at the farm level, which is less vulnerable to manipulation, an extension of the periods during which manure may not be applied, together with a corresponding expansion of storage capacities. For the further reduction of environmental impacts due to nitrogen (among others) from farming, the Commission also recommends national standards for plants dealing with manure, liquid manure, and silage leachate. Corresponding provisions ought to be included in the new Ordinance on Plants Dealing with Water-Polluting Substances (AwSV).

Using additional agricultural support

Agricultural support is a key instrument for promoting nitrogen- efficient production systems such as ecological farming[6] (Schulz et al., 2009, Flessa et al., 2012, Bach, 2013), and for acknowledging environmental contributions which go beyond the legal requirements, e.g. encouraging forms of low-emission application which are not yet obligatory. Adequate levels of support must be ensured in future for the conversion to farming in accordance with ecological principles. Support for low-emission application techniques should continue to be provided (and as far as possible extended) by the federal states by means of the second pillar of the agricultural support system. Much more use could be made of the Agro-investment Promotion Programme (AFP; cf. Plan for the Joint Task on Agricultural Structures and Coastal Protection in Germany) as an instrument to reduce nitrogen-losses in the environment, e.g. by promoting environmentally-friendly indoor livestock facilities.

Inter-regional balance for nutrients

Currently, some regions with high concentrations of livestock produce more manure than is needed locally (LWKNI, 2013). By exporting the nutrients to areas where there is a shortage of farm manure, it would be possible to reduce local environmental impacts and would at the same time increase the nitrogen efficiency by reducing the use of chemical fertiliser. A key precondition for this is that manure must be made easier to transport (e.g. by solid-liquid separation) and at the same time manure must gain or regain acceptability in the recipient regions. This nutrient balance can be achieved by amendments to the Fertiliser Ordinance and by the promotion of appropriate

[6] For example, farms operating in accordance with ecological principles generally have a much higher nitrogen efficiency und lower nitrogen surpluses than conventional farms. See: http://www.umweltbundesamt.de/publikationen/foerderung-des-oekolandbaus-als-strategischer

Adequate levels of support must be ensured in future for the conversion to farming in accordance with ecological principles.

technologies. An important factor for monitoring and for the provision of advice to policy-makers is a quantitative registration of the amounts of manure which are subsequently applied (LWKNI, 2013, Möckel et al., 2014).

Reducing the demand for animal feed

As a result of the high livestock levels and the increased use of concentrated fodder rather than grassland growth, including for ruminants, currently half of arable land is needed for growing animal feed. In addition, the German agricultural sector depends on animal feed imports accounting for some 400 Gg nitrogen per year (cf. Chapter 4)[7].The animal feed imports have led to increased competition for land and to negative environmental impacts in the exporting countries (Häusling, 2011, KLU, 2013a, UBA, 2013a), while contributing to the nitrogen surplus in Germany, again with negative effects.

A reduction in the overall need for animal feed, e.g. as a result of people adopting a more plant-based diet with reduced meat consumption, would be an important step towards lowering the nitrogen surpluses and would have various other positive effects, including for the climate (UBA, 2013a). Efforts should also be made to achieve a specific reduction in animal feed imports; contributions could be made by non-intensive livestock farming, and by feeding ruminants with grassland growth, as well as the increased cultivation of protein crops in Germany (Flessa et al., 2012).

Introducing economic control instruments

Economic incentives (and disincentives) can be an efficient way of promoting the reduction of nitrogen surpluses and encouraging consumer responsibility. However, the measures must be provided within a coherent overall strategy, because considerable administrative efforts will probably be involved. Elements could include a levy on nitrogen surpluses (Möckel, 2006), the adaptation of value-added tax rates on meat products, and the specification of maximum nitrogen loads in an area by means of tradable certificates (UBA, 2009a und 2013a, Lünenbürger et al., 2013).

Requirements for the long-term conversion of barns and indoor facilities covering a large proportion of livestock should be specified at the earliest opportunity. An effective approach, in particular for pig and poultry farms, is offered by the regulations limiting ambient pollution emissions. Under the German legislation on ambient pollution, some 80 per cent of poultry stocks (or 15 per cent of operations) are currently required to obtain official approval, but only some 20 per cent of pig stocks (or three per cent of operations). An important innovation is the obligation to install filters in large, air-conditioned indoor facilities on pig farms, which was agreed on in early 2013 between the German government and the laender, and which should now be included as quickly as possible in the Technical Instructions on Air Quality Control (TA Luft). For poultry farming, evaluations should be carried out at regular intervals to establish when developments in technology will allow the introduction of comparable requirements. The regulations should be formulated in such a way that methods which offer clear benefits for the well-being of the animals are not excluded, even if they limit the extent to which exhaust-air treatment is possible. While an important consideration, exhaust-air treatment is by no means the only approach as far as livestock farming is concerned. Scope is also offered for improvement in feeding systems, the storage of liquid manure in covered tanks, increased pasture grazing, a reduction in barn temperatures, the use of heat-exchangers in interim storage containers for liquid manure, functional floor coverings, or manure belt drying in poultry farming.

Investment support and regulatory requirements can make a key contribution towards low-emissions livestock housing. Comparable international models are for example the “green label” certification for livestock sheds in the Netherlands, and building requirements for livestock housing in Denmark. For smaller-scale operations it would be conceivable that certification would require reductions of emissions in comparison with a reference value, while leaving it to the operators to choose how to achieve this target (Jacobsen, 2012).

5.2 Clean Air policies

Amendment to EU Clean Air Policy

The EU Clean Air Policy regulates the protection of human health and ecosystems by specifying limits for levels of air pollution, with undertakings for the reduction of emissions. The aim is to avoid harmful peak concentrations and to reduce general background levels of pollution.

[7] One reason for the dependence on imports of protein crops can be traced back to the Kennedy Round of the international trade negotiations for the GATT agreements in the 1960s. In contrast to other agricultural products, and as a quid pro quo for concessions on the exports of grain crops, the duty-free import of protein crops was agreed for the EEC. This meant that protein crop production was relatively less profitable in Germany, and in consequence little effort went into crop breeding, etc. (Häusling, 2011).

The national emission reduction obligations act as an important stimulus for measures that are not covered by plant-related EU regulations, in particular relating to diffuse sources. The Gothenburg Protocol of the CLRTAP Convention agreed in 2012 includes further emission reduction commitments to be achieved by 2020 (cf. Box 3). Guidelines have been developed to support the implementation which summarise the effective measures to reduce ammonia emissions in the agricultural sector (Bittman et al., 2014).

At the end of 2013, the EU Commission presented proposals for the revision of the EU Directive on national emission ceilings (NEC Directive – 2001/81/EC) with emission reduction commitments to be achieved by 2030. Among other things, this has the goal of reducing by 2030, the areas in which critical loads were exceeded by 35 per cent (in comparison to 2005). The proposed reduction commitments are derived on the basis of the cost efficiency of the measures. These proposals should therefore be implemented as far as possible.

In the medium term, the introduction of a concentration limit value for ammonia to protect ecosystems, comparable to those for NO_2 or particulate matter with regard to human health, could contribute towards reducing the impact of reactive nitrogen in the affected areas (Grennfelt et al., 2013).

Air quality planning should pay more attention to the nitrogen problem

In procedures to grant planning permission and to certify installation, it is meanwhile necessary to take into consideration the effects of reactive nitrogen on ecosystems – in particular with regard to protected fauna and flora habitats (Kohls et al., 2014). Much of the background pollution of areas often comes from diffuse sources that are not subject to certification. The introduction of national and regional air quality planning to protect ecosystems (analogous to the approach adopted in the EU Water Framework Directive) would make it possible to reduce the pollution of ecosystems and to place more emphasis on the 'polluter pays' principle[8].

5.3 Surface waters

Water conservation regulations set binding environmental quality targets, but allow the relevant administrative bodies scope to choose which measures to adopt. With regard to the agricultural sector, agricultural environment programmes have proved successful. However, experience has shown that such voluntary measures are not always sufficient to achieve the targets. In addition, it should also be possible in certain areas to introduce binding requirements. An explicit provision could be included in the Fertiliser Ordinance that agricultural land use shall not lead to nitrate concentrations in excess of the targets of the Nitrate Directive (nitrate content < 50 mg l^{-1}), and that more demanding measures should be implemented in individual cases. In particular, more attention should be given in future to areas where leaching and run off represents a particular threat.

By specifying maximum concentrations of 2.8 mg l^{-1} (North Sea) or 2.6 mg l^{-1} (Baltic Sea) nitrogen for the limnetic–marine zone in the Surface Waters Ordinance it would be possible to take marine conservation better into consideration when planning the management of inland waterways and bodies of water.

5.4 Energy sector and small combustion installations

Emissions from the energy sector have ceased to decline in recent years, and in some areas – in particular where biogas is used as fuel in combustion engines – there has actually been an increase in NO_x-emissions (cf. Chapter 4). Much hope is placed in measures relating to biomass combustion, biogas engines and also to the large-scale combustion plants fired by fossil fuels such as coal, lignite or natural gas, which continue to play a dominant role.

In Germany, numerous regulations already exist that are expected to lead to a further reduction in emissions from the energy sector in the coming years. For example, the Ordinance on Small and Medium-Sized Combustion Installations (1 BImSchV) is expected to lead to improvements for small heating installations (UBA, 2013b) and, to a lesser extent, the implementation of the emission limit values specified in the EU Industrial Emissions Directive (IED) for large-scale combustion and waste incin-

[8] Since 2012, the Netherlands has been developing an Integrated Approach to Nitrogen (PAS) for dealing with nitrogen deposition to achieve Natura2000 site objectives. Approval is only granted, e.g. for new agricultural installations or roads, if an overall reduction in depositions is guaranteed. The AERIUS Model system was introduced as a planning tool, and a specialist convention was installed for the relevant critical loads.

eration plants will also reduce the NO_x-emissions from the energy sector. However, more could be achieved, and the technical requirements for medium-sized and large-scale combustion could be extended beyond the current limit values of the TA Luft and IED Directive (Jörss et al., 2014).

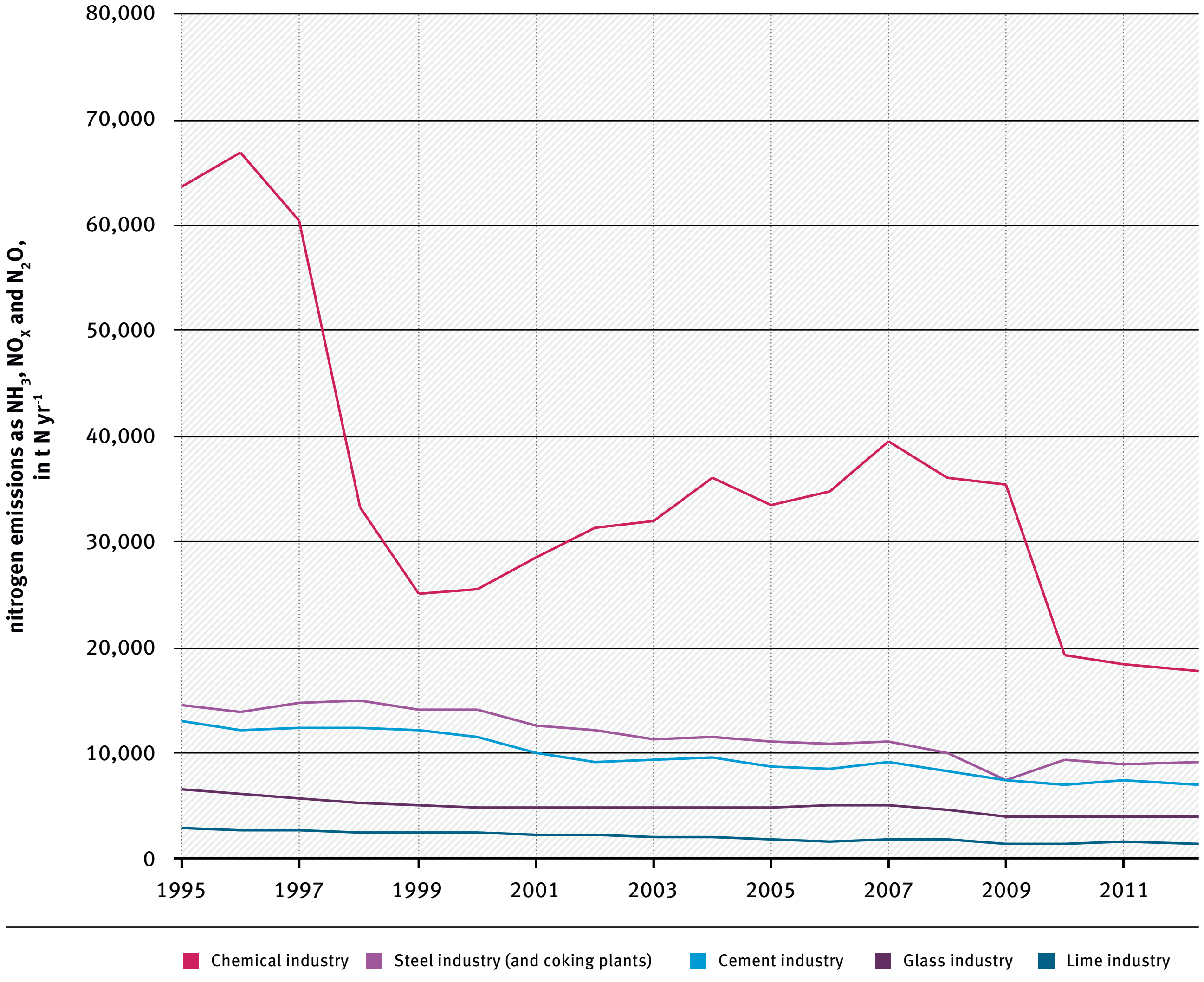
5.5 Industry

Figure 14 shows the development of the emissions of reactive nitrogen (in the form of NH_3, N_2O and NO_x) from the most relevant industrial sectors – namely the chemical, steel, cement, glass, and lime industries. In the period from 1995 to 2012 there was a marked decline in nitrogen emissions in all these sectors.

The main change has been the reduction in the emissions from chemical industry, which in the mid-1990s still accounted for some two-thirds of total industrial emissions. Over the period considered up to 2012, the emissions were reduced by more than 70 per cent, above all because of additional measures to reduce N_2O-emissions from the production of adipic acid and nitric acid. From 1999 to 2007, however, increased production levels in these two sub-sectors led to an increase in emissions of reactive nitrogen.

Figure 14

Development of the emissions of reactive nitrogen from the most relevant industrial sectors over the period 1995–2012



The cement industry roughly halved its nitrogen emissions over the period shown in Fig. 14, above all due to the widespread introduction of SNCR technology for NO_x-reduction. It is planned to achieve further reductions by 2020 by means of selective catalytic reduction technology, which has been prepared for application in demonstration plants sponsored under the environmental innovation programme of the Federal Environment Ministry (BMUB).

Nitrogen emissions from the steel industry declined by nearly 40 per cent – above all due to the increased use of secondary steel but also due to the increased implementation of primary measures for NO_x-reduction. The remaining nitrogen emissions now come mainly from sintering plants and the rolling mill warming ovens. In order to achieve further reductions, it will be necessary to consider the application of secondary reduction technologies.

In the glass industry, nitrogen emissions were reduced by some 40 per cent, both by primary measures and in new plants also by secondary measures. However, primary measures for NO_x-reduction (e.g. oxy-fuel furnaces, optimised near-stoichiometric combustion) are in conflict with the requirement to limit CO-emissions.

5.6 Transport

There will be considerable reductions in nitrogen emissions from road traffic in future, as an increasing proportion of vehicles comply with the Euro 6 standard for cars and EURO VI standard for light- and heavy-duty vehicles. Further potential is offered by sustainable integrated mobility. Additional measures can also be adopted in other transport sectors (diesel locomotives, waterway shipping, and air travel).

Road traffic

A key measure has been the introduction of the exhaust emission standard Euro 6, required for new cars from September 2015, and Euro VI, which has been required for heavy-duty vehicles since 2013. However, in future it will be necessary to ensure that compliance with the limit values on test beds also leads to corresponding reduction of the real driving emissions. For new vehicles complying with the Euro 6 standard, these real emissions are currently on average seven-times higher than the relevant limit value (International Council on Clean Transportation (ICCT), 2014). A reduction of the real emissions could be achieved by the use of portable emissions measurement systems (PEMS) in the classification procedure.

In addition, various non-technical measures could be implemented very quickly which would together offer promising potential for reducing reactive nitrogen emissions. Examples are the imposition of speed limits, or an increase in the tax on diesel fuel up to the level for petrol.

A positive effect on the levels of N-emissions would result from the increased use of environmental mobility systems (i.e. non-motorised transport and public transport) in preference to motor cars. This would require an improvement in the conditions for public transport, cyclists and pedestrians as well as government-backed information campaigns. A further reduction in nitrogen emissions could also be achieved by the promotion of low-consumption driving styles, the use of low-friction oil and tyres, and by retrofitting heavy duty vehicles (< Euro V) with SCR technology.

Rail transport and inland-waterway shipping

The previous limit values for emissions from diesel locomotives ended with the introduction of Level IIIB in 2012 and for inland-waterway ships with the introduction of Level IIIA in 2009 (Non-Road Machinery Directive, 2004/26/EC). Updating of the limit values for NO_x and particulates for diesel locomotives and inland waterway shipping would also be desirable in terms of the reduction of nitrogen emissions. In both cases, engines could not be adapted to meet these progressive limit values; it would be necessary to install end-of-pipe particle filters or SCR technology. The long working lives of locomotives and ships means that measures for emission reduction would probably only have a gradual effect, but this makes it important to implement them as soon as possible. The European Commission proposed such regulations in October 2014.

Air transport

In the case of air transport, further reductions in nitrogen emissions could be achieved by environmental levies. The imposition of a kerosene tax for domestic flights has been possible under EU law for some years: die EC Energy Taxation Directive 2003/96/EC gives EU Member States the opportunity to impose a tax on commercial inland flights. The introduction of a tax on aircraft fuel in Germany would require an amendment to the Mineral Oil Taxation Act.

5.7 Municipal water management

The technical standards for wastewater management in Germany are very high. More than 95 per cent of waste water undergoes nitrification/denitrification, which considerably reduces the inflow of reactive nitrogen into surface waters. However, in particular denitrification (cf. Box 4) can also involve emissions of small amounts of reactive nitrogen compounds (above all nitrous oxide). The continuous optimisation of the waste water treatment methods will in future further reduce the emissions of reactive nitrogen compounds. A further reduction would also be possible if the public were to reduce their consumption of protein (cf. Chapter 5.8).

In future, it might also be possible that, instead of denitrification (i.e. conversion to molecular nitrogen), the reactive nitrogen in the waste water could be separated out and reused as fertiliser, thus reducing the demand for chemical fertiliser (Swiss Federal Office for the Environment (FOEN), 2014, Sutton et al., 2011). In Germany, a few waste water treatment plants have already been equipped with the necessary stripping units[9]. The energy balance of this method still needs to be improved, but in future it could offer a useful and practical way to reuse reactive nitrogen.

5.8 The influence of consumers

The emissions of reactive nitrogen into the environment are also influenced by consumer behaviour. For example, a comparison of the "nitrogen footprints" (Fig. 15) of fruit, vegetables, and meat show that their production releases very different amounts of reactive nitrogen (Leip et al., 2013). For example, the consumption of less animal protein (Westhoek et al., 2014) reduces the emissions of reactive nitrogen as well as the associated environmental impacts. The consumption of more food from organic farming can also have beneficial effects for the nitrogen cycle, because the nitrogen surplus per product unit is frequently lower in comparison with conventional production.

Acting responsibly in terms of sustainable consumption can therefore lead to considerable benefits and also sends out important environmental policy signals (SRU, 2012, Bilharz et al., 2011, UBA, 2013a). According to a representative survey carried out on behalf of the Federation of German Consumer Organisations, the majority of consumers see a need or an urgent need for a reduction in harm to environment due to the nitrogen emissions from the farming sector. But at the same time the survey also suggests that the general public are for the most part not fully aware of the problems involved, or find them too complex.

The nitrogen footprint offers a readily understandable way of communicating how much reactive nitrogen is released every year by a person's lifestyle. A method for calculating this was developed in 2012 by an international group of research workers (Leach et al., 2012). Meanwhile a nitrogen footprint calculator has also been produced for Germany (http://www.umweltbundesamt.de/themen/luft/wirkungen-von-luftschadstoffen/wirkungen-auf-oekosysteme/ stickstoff-fussabdruck). This shows that some 24 kg of nitrogen per capita is released every year, with about 80 per cent of this coming from the food sector. The nitrogen footprint takes all emissions into account that are related to a consumed product, wherever they arise. Emissions in Germany generated by the production of goods for export are not taken into consideration. This factor, in combination with uncertainties relating to the data collection, explains why the average of 24 kg nitrogen per person per year is higher than the average value for the emissions in the national budget (ca. 19 kg nitrogen per person per year).

The nitrogen-footprint calculator can be used to illustrate how changes in behaviour can affect the release of reactive nitrogen. Comparisons with the carbon footprint (Xue and Landis, 2010) show that – despite some difference in detail[10] – the general messages (Box 6) about possible changes in behaviour are similar. However, compared with the carbon footprint it is more difficult to de-

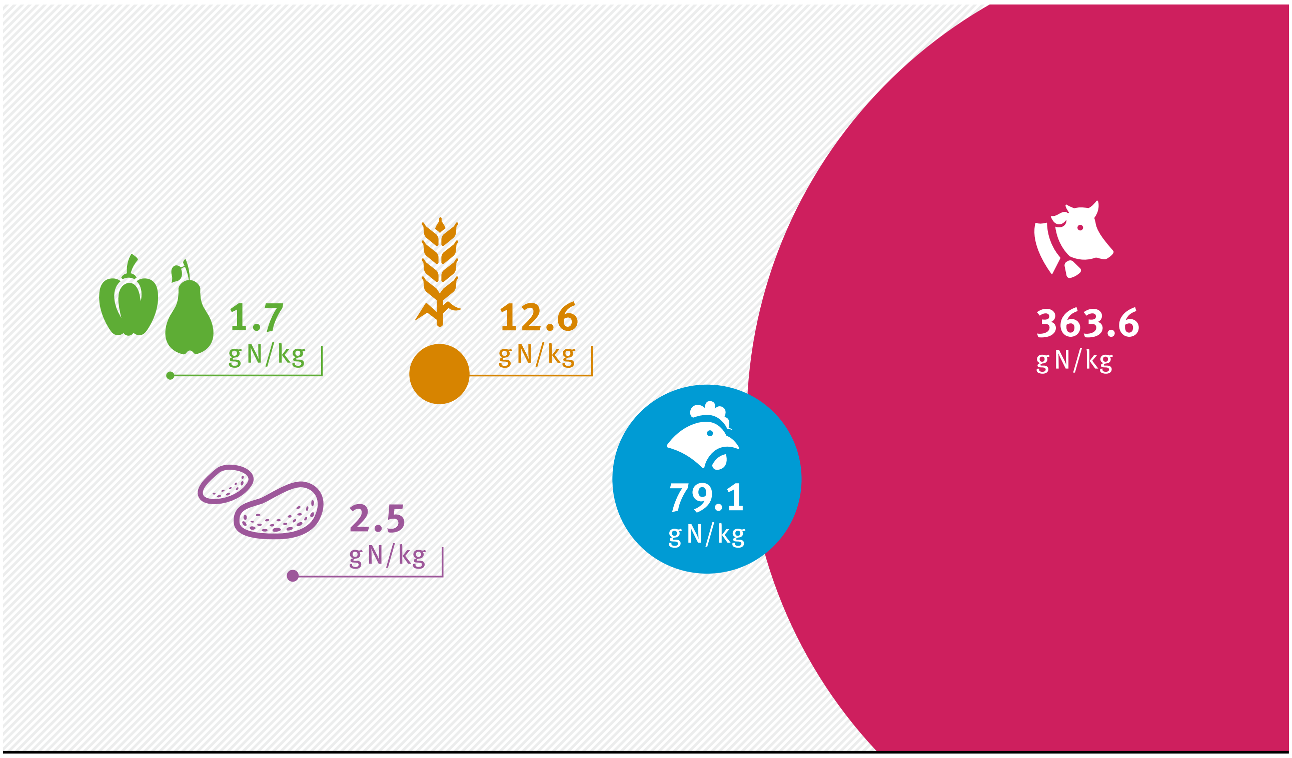
[9] An example is the planned nitrogen retrieval in the treatment plant of the Braunschweig Waste Water Association. The development of the method is supported by the Environmental Innovation Programme. Further information: http://www.bmub.bund.de/presse/pressemitteilungen/pm/artikel/naehrstoffrueckgewinnung-aus-klaerschlamm/

rive a target value, because consumption of some nitrogen is essential for a healthy diet.

In order to be able to draw more reliable quantitative conclusions, the calculation methods and data basis must be further improved and standardised as far as possible. The discussion about target values must also be continued. In order to raise awareness about the links between consumption and the nitrogen problem, the German government should also initiate suitable measures in kindergartens, schools, etc., and promote public awareness campaigns (UBA, 2013a).

Figure 15

Nitrogen footprint of types of food* in the EU



* only agricultural production

after Leip et al., 2013

Box 6

Key measures to reduce your personal nitrogen footprint

Reducing consumption of animal protein (Westhoek et al., 2014, Meier and Christen, 2013). Meat consumption in Germany is currently well above the levels recommended by the German Nutrition Society (DGE) for a healthy diet, whereas the consumption of fruit and vegetables is much lower than the recommended levels. A change in diet offers clear advantages for the environment and personal health.

- Avoiding food waste
- Using environmentally-friendly means of transport such as a bicycle, public transport or the railways
- Reduced energy consumption at home

[10] Compared with the average carbon footprint, nutrition plays a much greater role in the average nitrogen footprint. While (red) meat products have very high footprints in both cases, differences are observed above all for milk products and for foodstuffs which are energy-intensive to produce or which are transported over long distances. (Xue & Landis, 2010).

6. The global dimension

Reactive nitrogen represents a global challenge (Galloway et al., 2008, Sutton et al., 2011, Rockström et al., 2009), although the problem can take on very different forms in various regions of the world (Mueller et al., 2012). Globally, many areas used for agricultural purposes have a deficiency of nitrogen, which in some cases considerably reduces yields (International Assessment of Agricultural Knowledge, 2009, UBA, 2014e). Without further measures, the emissions of some reactive nitrogen compounds would increase massively by 2050 (Fig. 16; United Nations Environment Programme (UNEP), 2012, Sutton and Bleeker, 2013). This would presumably have dire effects for humans and the environment. Bodirsky et al. (2014) show that global nitrogen losses to the environment would more than double by 2050 if no further measures were adopted. If ambitious measures were implemented worldwide (such as improved N-efficiency, avoidance of food waste, etc.) then despite population growth and while feeding the world, it would still be possible to reduce nitrogen losses to between 36 and 76 per cent of the value in 2010.

The main environmental problems relating to nitrogen can therefore only be solved by international cooperation. Measures at national level will not be enough. European and global activities include:

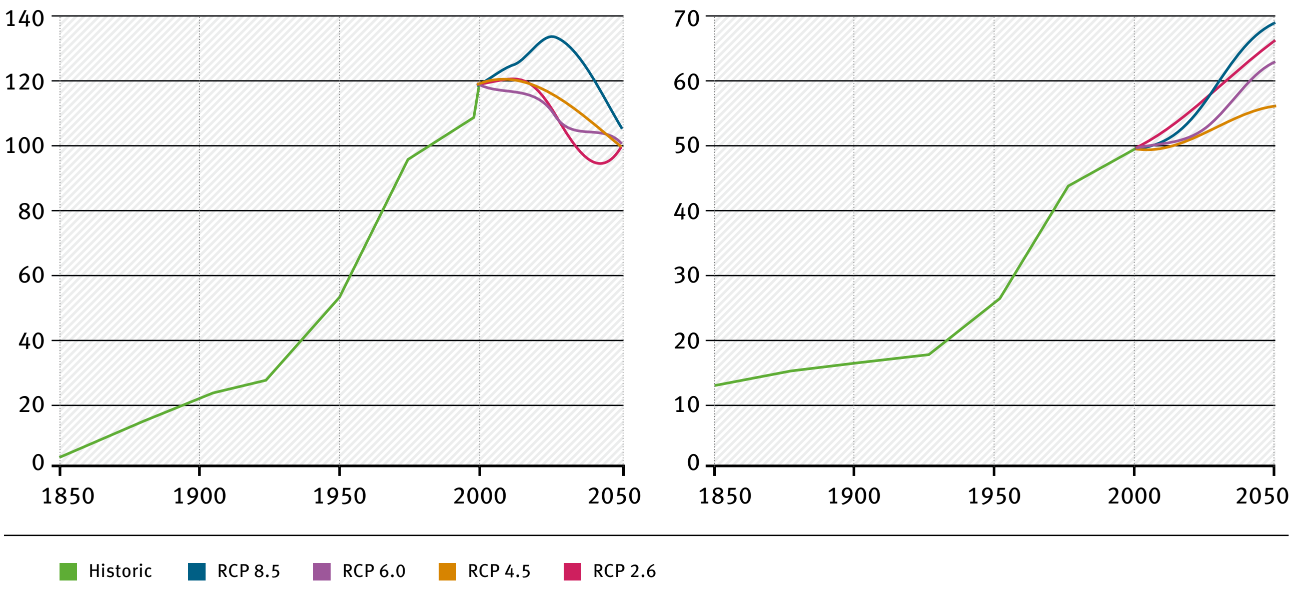
The "International Nitrogen Initiative" (INI), which has as its objective:

- To document, combine, expand and evaluate the knowledge about sources, and impacts on the environment and human health,
- To promote communication between polluters, scientists, and policy-makers
- To develop balanced strategies to increase nitrogen-efficiency and to avoid negative effects.

Figure 16

Global trends in emissions of nitrogen oxides (left, expressed as NO_2) and ammonia (right), 1850–2050 in million tonnes per year

Historic emissions and various IPCC scenarios



UNEP, 2012

The Global Partnership on Nutrient Management (GPNM), which brings together various actors from the fields of politics, business and civil society. The Secretariat of GPNM is provided by the United Nations Environment Programme (UNEP). GPNM proposes as a global target a 20 per cent increase in the nitrogen efficiency (in food production) by 2020 relative to 2008. At the same time, food security should be established in countries (in particular in Africa and parts of South America) which today face overuse of soil nutrients (Sutton et al., 2013).

The Task Force on Reactive Nitrogen (TFRN) under the Convention on Long Range Trans-boundary Air Pollution (cf. Box 3) has the remit to advise on policies for the optimised use of nitrogen and the reduction of nitrogen emissions and associated environmental impacts.

At the global level there is also a need for scientifically-based support for policy-makers which evaluates and presents the risks and possible counter-measures in terms of excessive burdens and inadequate supplies of reactive nitrogen ("too much and too little"). This task will in future be carried out by the International Nitrogen Management System (INMS), which is being initiated with funds of the Global Environment Facility (GEF).

7. Conclusions and outlook

The intensified nitrogen cycle is closely linked with many aspects of environmental policy (cf. Chapter 2). Measures and instruments to achieve existing environmental quality targets should therefore address the following aspects:

- Limitation of the production and import of reactive nitrogen,
- More efficient use of N_r
- Reduced emissions and losses by changes to consumer behaviour.

The greatest potential for reductions by technical measures is currently found in the agricultural sector. A cost-benefit analysis also shows that these measures have lower costs per kg reduction in emissions of reactive nitrogen. However, in addition to cost-effectiveness it is also most important to take synergy effects into account and to avoid shifting nitrogen emissions from one area of the environment into another ("pollution swapping"). Successful measures to avoid nitrogen losses to the environment contribute to the protection of biodiversity, of surface waters, and the climate.

Annex

Annex 1:
Amounts of nitrogen and reference periods for the nitrogen flows in Chapter 4

Type of flow in N-cycle	N-amount ($Gg\ yr^{-1}$)	Ref. period	Source of data
Industry, Energy			
Industrial N-Fixing	2677	2010	(VCI, 2012)
Emissions N_2O	28	2008 – 2010	(UBA, 2012) Source groups 1, 2 und 3 without transport
Emissions NH_3	16	2008 – 2010	(UBA, 2012) Source groups 1, 2 und 3 without transport
Emissions NO_x	187	2008 – 2010	(UBA, 2012) Source groups 1, 2 und 3 without transport
Industrial direct inputs (surface waters)	10	2006 – 2011	(Fuchs et al., 2010, UBA, 2014a)
Transport			
Emissions of N_2O	2	2008 – 2010	(UBA, 2012)
Emissions of NH_3	13	2008 – 2010	(UBA, 2012)
Emissions of NO_x	192	2008 – 2010	(UBA, 2012)
Built-up areas			
Urban systems (in surface waters)	19	2006 – 2011	(Fuchs et al., 2010, UBA, 2014a)
Agriculture			
Marketed chemical fertiliser	1642	2008 – 2010	(Bach, 2010), Data: www.bmelv-statistik.de/ index.php?id=139 (as of 2013)
Use of manure	891	2008 – 2010	(Bach, 2010), Daten: ww.bmelv-statistik.de/ index.php?id=139 (as of 2013)
Biological N-fixing	214	2008 – 2010	(Bach, 2010), Daten: www.bmelv-statistik.de/ index.php?id=139 (as of 2013)
Net agricultural production (total – domestic feed – industrial crops)	664	2008 – 2010	(Bach, 2010), Daten: www.bmelv-statistik.de/ index.php?id=139 (as of 2013)
Domestic animal feed	1683	2008 – 2010	(Bach, 2010), Daten: www.bmelv-statistik.de/ index.php?id=139 (as of 2013)
Industrial crops	194	2008 – 2010	(Bach, 2010), Daten: www.bmelv-statistik.de/ index.php?id=139 (as of 2013)
Organic fertiliser	58	2008 – 2010	(Bach, 2010), Daten: www.bmelv-statistik.de/ index.php?id=139 (as of 2013)
Emissions N_2O	88	2008 – 2010	(UBA, 2012)
Emissions NH_3	435	2008 – 2010	(UBA, 2012)
Emissions NO_x	33	2008 – 2010	(UBA, 2012)
Inputs into surface waters (erosion, drainage, seepage into groundwater)	424	2006 – 2011	(Fuchs et al., 2010, UBA, 2014a)
Natural/semi-natural rural ecosystems			
Biological N-fixing	57		(Cleveland et al., 1999)

Type of flow in N-cycle	N-amount ($Gg\ yr^{-1}$)	Ref. period	Source of data
Inputs into surface waters (natural erosion, total surface run-off [distinction between agricultural and other areas not possible at present])	33	2006 – 2011	(Fuchs et al., 2010, UBA, 2014a)
N_2O emissions	7		(De Vries et al., 2011)
NH_3 emissions	3		(De Vries et al., 2011)
NO_x emissions	7	2000	(Wochele et al., 2009)
N-withdrawal Harvested wood (70 million m^3; density: 500 kg m^{-3}; %-wt-N: 0.2)	70		
Waste water/waste			
Industrial waste water	31	2008	(Austermann-Haun and Carozzi, 2011)
Municipal waste water	423	2010	(DWA, 2011)
Wastewater treatment plant	82	2006 – 2011	(Fuchs et al., 2010, UBA, 2014a)
Emissions N_2O	5	2008 – 2010	(UBA, 2012)
Denitrification	340	2010	(DWA, 2011)
Atmosphere			
Lightning	3	2007	(Schumann and Huntrieser, 2007)
Total import	248	2010	(Fagerli, 2012)
Import N_{red}	117	2010	(Fagerli, 2012)
Import NO_x	131	2010	(Fagerli, 2012)
Total export	560	2010	(Fagerli, 2012)
Import N_{red}	261	2010	(Fagerli, 2012)
Import NO_x	299	2010	(Fagerli, 2012)
Total deposition terrestrial ecosystems	716	2005–2007	(Builtjes et al., 2011)
Farmland	451	2005–2007	
Natural, semi-natural ecosystems	266	2005–2007	
Total deposition Limnic ecosystems	6	2005–2007	
Total deposition coastal waters	36	2010	(Bartnicki et al., 2012)
Total deposition – built-up areas	54	2005–2007	(Builtjes et al., 2011)
Hydrosphere			
Import via rivers	322	2006 – 2011	(Fuchs et al., 2010, UBA, 2014a)
Export via rivers	422	2006 – 2011	(Fuchs et al., 2010, UBA, 2014a)
Export into sea (direct)	478	2006 – 2011	(Fuchs et al., 2010, UBA, 2014a)
Deposition Coastal waters	36	2010	(Bartnicki et al., 2012)
N-fixing (only Baltic Sea)	31	2010	(Rahm et al., 2000)

Annex 2:
New target values for the nitrogen surplus

It is not possible at present to derive a definite national target value for the nitrogen surplus which would not lead to any significant negative environmental impacts (cf. Chapter 2). Among other things, this is due to the variety of effects involved (which cannot be reliably included in a single model), the effects of spatial distribution (of the surplus and of sensitive receptors) and the fact that the surplus can be released either along airborne or water-borne pathways (with different effects in each case). However, since it is necessary in any case to significantly reduce the surpluses, the levels that can be achieved by good agricultural practice today and in future are important when it comes to setting target values. The following recommendations were evaluated:

Recommendations of the Agriculture Commission at UBA

In the course of the discussion of reforms to EU-CAP, the Agriculture Commission at UBA has recommended introducing a surplus of 50 kg N ha^{-1} yr^{-1} in the farm-gate balance as an obligatory greening component (KLU, 2011). This would represent an environmental contribution which could and should be made by all farms that receive direct payments.

Recommendations of the Association of German Agricultural Analytic and Research Institutes

The Association of German Agricultural Analytic and Research Institutes (VDLUFA) recommends maximum surpluses that it regards as currently feasible, depending on the amount of organic fertiliser-N (VDLUFA, 2012). The following values in the farm-gate balance were deemed to be realistic:

Type of farm	Organic fertilisation (kg N ha^{-1} yr^{-1})	Permissible N-surplus with N-Depo: 20 kg N ha^{-1} yr^{-1} (kg N ha^{-1} yr^{-1})	Permissible N-surplus with N-Depo: 10 kg N ha^{-1} yr^{-1} (kg N ha^{-1} yr^{-1})
I	$<$ 50	60	50
II	50 – 100	90	80
III	$>$ 100	120	110

The values proposed by the Association of German Agricultural Analytic and Research Institutes include an atmospheric N-deposition of 20 kg N ha^{-1} yr^{-1}; since efforts are being made to improve air quality by 2040 and reduce depositions, the table also includes a column in which the N-deposition has been reduced to 10 kg N ha^{-1} yr^{-1}. According to the figures given by Osterburg and Techen (2012), 57 per cent of farmland is operated with org. N < 50 kg N ha^{-1} yr^{-1} [calculated from the values for Class 40-60]; 33 per cent with org. N 50 to < 100 kg N ha^{-1} $yr^{-1}$and 10 per cent with org. N > 100 kg N ha^{-1} yr^{-1}), given an estimated area-weighted mean of 66 kg N ha^{-1} yr^{-1}.

Benchmark for farms operating on ecological principles:

The surpluses of organic farms, which are generally much lower than those for conventional farms, can also be used to derive a guideline value. Studies by Hülsbergen and Siebert (2010), and Bach (2013) calculate surpluses for organic farms that are well below 50 kg N ha^{-1} yr^{-1}.

Scenario calculations:

Scenario calculations carried out in the project “Greenhouse gas neutral Germany 2050” by the Thünen Institute (Osterburg et al., 2013) show that with increased N-exploitation and assuming developments in demand patterns which lead to lower livestock levels, the agricultural sector in Germany can achieve a farm gate balance of some 50 kg N ha^{-1} yr^{-1}.

Overall, these recommendations suggest that a surplus value of 50 kg N ha^{-1} yr^{-1} is an ambitious but realistic goal. This would result in a considerable reduction in negative impacts.

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