Assessment Report on Ammonia – 2019

First draft August 2019

This report is written at the request of the Executive Body of the Convention on Long-Range Transboundary Air Pollution (item 1.1.3.2 of the 2018-2019 work plan of the Convention). The Task Force on Integrated Assessment Modelling was asked to coordinate the work and cooperate with experts from the Task Force on Measurement and Modelling and the Task Force on Reactive Nitrogen.

The report brings together available data and research findings from various studies. Its goal is a comprehensive and policy oriented overview. The focus of this report is on ammonia. Both ammonia and nitrogen oxide emissions contribute to eutrophication and acidification, as well as the formation of secondary particulate matter. In the past decades, policy efforts have been more focused on emission reduction of nitrogen oxides than on ammonia emission reduction. Gaps in knowledge of ammonia impacts and the costs and benefits of measures could have been a reason for this. This report aims to fill this gap.

1. Current status and trends

There are large regional differences in ammonia emissions in Europe and in the world. Areas with high emission densities correspond with areas with a high loss of biodiversity and a large share of secondary particulate matter in the exposure of population. Those secondary particles play a significant role in the transboundary fluxes of air pollution and in the current air quality in large parts of Europe and North America.

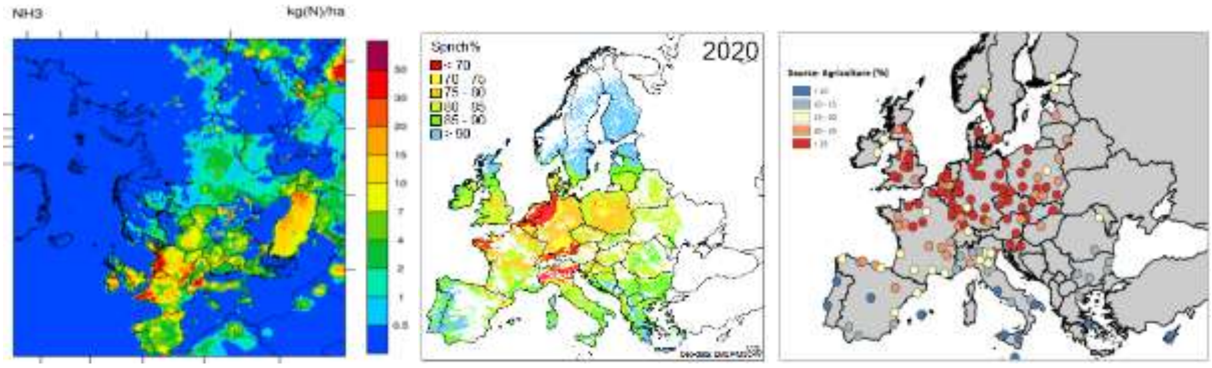


Figure 1: Ammonia emission density 2013 (EMEP-MSCW), estimated share of protected grassland species in 2020 (CCE) and contribution of ammonia to PM2.5-concentrations in 2015 (JRC)

In areas with high densities of livestock emissions per hectare are 3-5 times higher than on average in Europe. Ammonia emissions are mainly caused by manure excretion in stables and meadows, manure storage and manure application. Also chemical fertilizers contribute to ammonia emissions. A small part (around 10%) of the annual ammonia emissions comes from industry, households and traffic. Recently it became clear that ammonia emissions not only lead to a loss of biodiversity, but also contribute significantly to the formation of particulate matter and the associated health risks (e.g. Maas and Grennfelt, 2016). In some areas more than half of the particulate matter concentrations is not emitted directly, but is formed in the air when ammonia reacts with nitrogen oxides and sulphur dioxide (the so-called secondary particles).

Figure 2a shows the origin of the particulate matter concentrations in in 2009 in cities (measured as PM2.5 - particulate matter with a diameter of less than 2.5 micrometer). The light green and dark green bars show the secondary particles (ammonium nitrates and ammonium sulphates respectively) that are both influenced by ammonia emissions. See also the source apportionment in Brussels according to Sherpa-model of JRC (figure 2b). The pink line in the figure 2a indicates the air quality guideline level of 10 micrograms per cubic meter of the World Health Organisation (WHO, 2005). In Benelux-countries and surrounding parts of Germany and France more than 50% of the average PM2.5 concentration consists of secondary particles. According to EMEP modelling foreign sources contribute 70-80% to the secondary PM2.5 concentrations in Benelux countries.

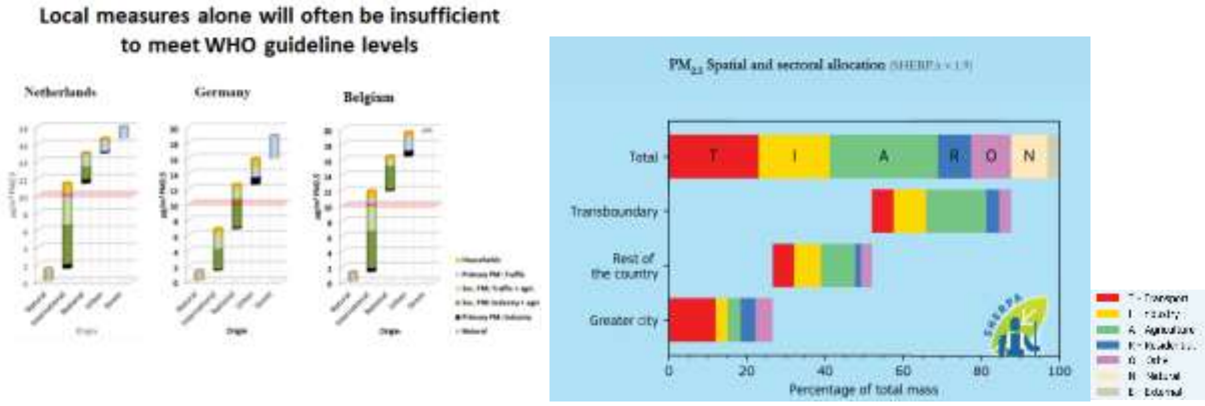


Figure 2: (a) Origin of urban PM-exposure in the Netherlands, Germany and Belgium according to the GAINS-model (IIASA, 2014b) and (b) in Brussels according to the Sherpa-model (JRC, 2015)

Currently, exceedances of the EU Air Quality Limit Value in cities area occur frequently during weeks with unfavourable weather conditions and high ammonia emissions, e.g. in early spring when manure that was stored during the winter is applied on agricultural land (LCSQA, 2015).

Since 2000 only modest reductions of ammonia emissions were achieved compared to the reductions of other pollutants like sulphur dioxide, nitrogen oxides and primary particulate matter. Observations of ammonium concentrations show no significant downward trend in Europe after 2000.

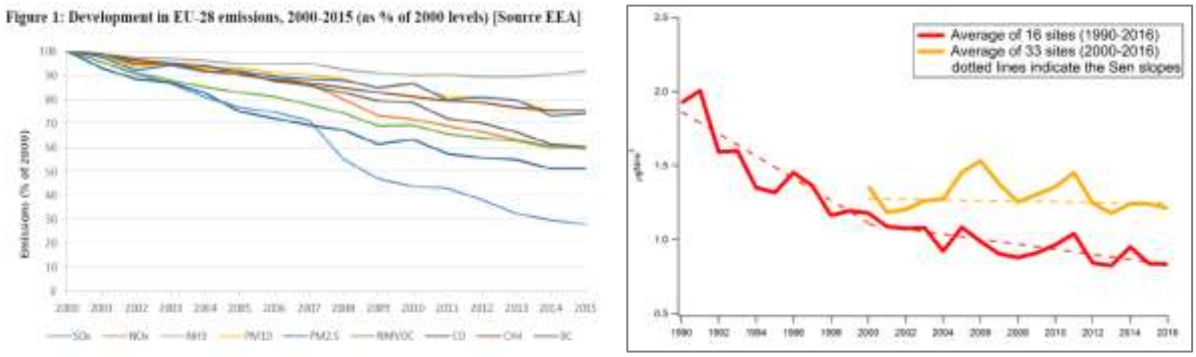


Figure 3: Trends in EU-28 emissions (EEA) and European ammonium concentrations (CCC)

Emission projections in Europe and North America also indicate that future ammonia emission reductions will be relatively small, compared to the emission reductions of sulphur dioxide, nitrogen oxides and primary particulate matter.

The Clean Air Programme for Europe (EC, 2013) has defined the WHO-guideline values as a long term target. From the origin of PM2.5 concentrations (figure 2) it is clear that in many cities meeting the WHO Air Quality Guideline value for PM2.5 will not be possible without substantial reductions in emissions of ammonia, nitrogen oxides and sulphur dioxide in the wider region. For nitrogen oxides and sulphur dioxides EU-wide emission reductions of around 60% (between 2005 and 2030) are obliged under the revised NECD, but for ammonia the reduction obligation is only 5% (before 2030) up to 15% (after 2030).

Text box on ammonia in North America

To be added

Trends in emissions and concentrations & policies

Table 1: Emission reduction requirements according to the revised NEC-directive for countries with high ammonia emissions per km² in percentages of the 2005 level

	NH_3		NO_x		SO_2		Primary PM2.5	
	2020-2030	2030-NECD	2020-2030	2030-NECD	2020-2030	2030-NECD	2020-2030	2030-NECD
Belgium	2	13	41	59	43	66	20	39
Denmark	24	24	56	68	35	59	33	55
France	5	13	50	69	55	77	27	57
Germany	4	29	39	65	21	58	26	43
Italy	5	16	40	65	35	71	10	40
Netherlands	13	21	45	61	28	53	37	45
United Kingdom	8	16	55	73	59	88	30	46
EU 28	6	19	42	63	59	79	22	49

Source: Directive (EU) 2016/2284 of the European Parliament and the Council, December 2016

The formation of secondary particles can be reduced via emission reduction of either nitrogen oxides and sulphur dioxide or of ammonia, or both. For the formation of a particle of ammonium nitrate in the air, one molecule of ammonium and one molecule of nitrate is needed (and two molecules ammonium and one sulphate). Despite emission reductions of nitrogen oxides and sulphur dioxides the concentrations of secondary particulate matter did not show a comparable decline between 2000-2014 (EMEP, 2016). Obviously, the availability of ammonia in the air explains that PM-concentrations don’t decline as much as expected.

Further emission reductions of ammonia would be required to prevent the exceedance of WHO-guideline values for particulate matter concentrations as well as avoiding the exceedance of critical loads of ecosystems. In areas with a high density of livestock emission reductions of 30-50% would be required to meet such long term targets.

Ammonia is not the only loss of nitrogen from agriculture to environment. Other losses are leaching nitrate to groundwater and water streams, emissions of nitrous oxide (N_2O, a potent greenhouse gas) and emissions of NO_x from agricultural land (see figure 4).

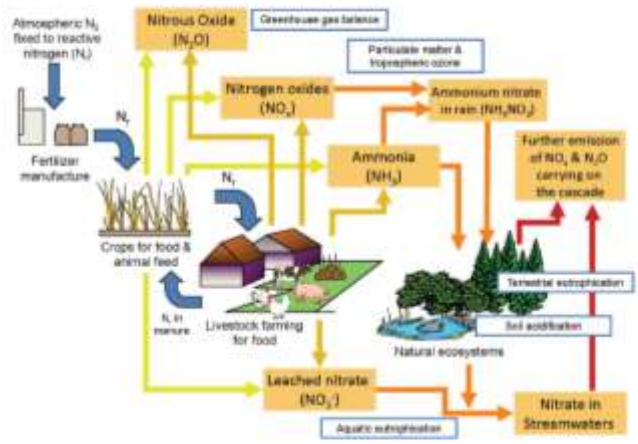


Figure 4: Agricultural nitrogen flows (Source: ENA)

An integrated policy strategy is needed to avoid that ammonia reduction would increase other nitrogen related problems and to optimize potential synergies. Potential synergies and trade-offs can also be found beyond the nitrogen cycle. Losses of other nutrients (e.g. phosphate), methane emissions and carbon sequestration are also linked to changes in the nitrogen cycle.

2. Sources and abatement measures

Manure from livestock farming is responsible for more than 70% of the emissions of ammonia in Europe. The use of mineral fertilizer in agriculture contributes 20% to the ammonia emissions. Traffic, industry and people make up the other 10%. In Europe around 50% of the emissions from livestock come from cattle, 30% from pigs and 20% from poultry (IIASA, 2017).

Housing (40%), storage (20%), application (35%) and grazing (5%) are the main stages in the manure-chain that cause ammonia emissions. These stages are not independent of each other. E.g., cleaner housing means more nitrogen is kept in the manure. Coverage of manure storage has the same effect. It means that potentially more ammonia could be emitted during application on land. Therefor low-emission manure application is the cornerstone of an effective ammonia abatement strategy, and – as was also shown in studies in e.g. Germany and France – the measure with the largest emission reduction potential. In Germany low-emission manure application would cover almost 60% of the total technical abatement potential (Wulf, et al, 2017). In France, ADEME estimated that direct incorporation and injection will form 60% of the total abatement potential in France (Etienne Mathias et al, 2013).

Low emission manure application could increase the availability of nitrogen for crop growth if applied at the right time and could also reduce the need for mineral fertilizer, which would give an additional 10% ammonia reduction. If low emission manure application would replace the use of mineral fertilizer in agriculture, it would reduce the total costs of ammonia emission reduction, prevent a shift to water and groundwater pollution and reduce the emission of nitrous oxide (a potent greenhouse gas that is linked to the use of mineral fertilizers).

Manure could become a valuable nutrient resource, instead of a waste flow. However avoiding conflicts with the groundwater pollution and obtaining the most effective use of manure requires registration of the amount of manure that is used. Also transport of manure from livestock farms to arable land will have to be organised. Ideally supply and demand of nutrients in a region is balanced. E.g., in the Netherlands in 2016 52% of the nitrogen that was imported via fodder and mineral fertilizers was exported in the form of agricultural products. The rest (48%) was lost to the air, water and soil. This looks bad, but considering that in 1990 only 30% of the imported nitrogen was exported again, one could also notice a considerable improvement in the efficiency of nitrogen use.

An integrated nitrogen approach could especially be financially attractive for modern large scale farmers. According to IIASA, 80% of the manure in Europe is produced by 4% of the farms. For small scale farms in areas in eastern and southern Europe with a low density of livestock, current nitrogen losses are less of a problem.

According to IIASA, technically more ammonia emission reduction is feasible than agreed under the NEC-directive, e.g. up to 50% reduction in Germany (IIASA, 2014a, IIASA, 2017). The optimal strategy where additional marginal costs would equal marginal benefits would allow for ammonia reductions of up to almost 40% in Germany and 30% in France (table 2).

For most countries, the average costs of ammonia emission abatement would be € 0.5-1.5 per kg ammonia. Such measures include cleaner housing for pigs and poultry, covered manure storage and low-emission manure application. Most of the additional reductions in countries that have already applied low-cost abatement techniques, such as Belgium, Denmark and the Netherlands, would cost in the range of € 2.5-4 per kg ammonia (Wagner et al, 2011). Measures would include further housing adaptation and deep injection of manure. The use of gas scrubbers for purifying the air from stables would form the high end of the cost-curve, with costs up to € 15 per per kg ammonia.

Table 2: NH_3 emission projections and abatement potential (source: IIASA)

	NH_3 emission level 2005 in mln kg	reduction percentages			
		2020-2030	2030 - NECD	2030 - cost-optimal	2030 - technically feasible
Belgium	74	2	13	16	19
Denmark	73	24	24	37	47
France	675	5	13	29	37
Germany	593	4	29	39	50
Italy	422	5	16	26	29
Netherlands	146	13	21	25	25
United Kingdom	308	8	16	21	22
EU28	3982	6	19	27	35

IIASA, 2014a

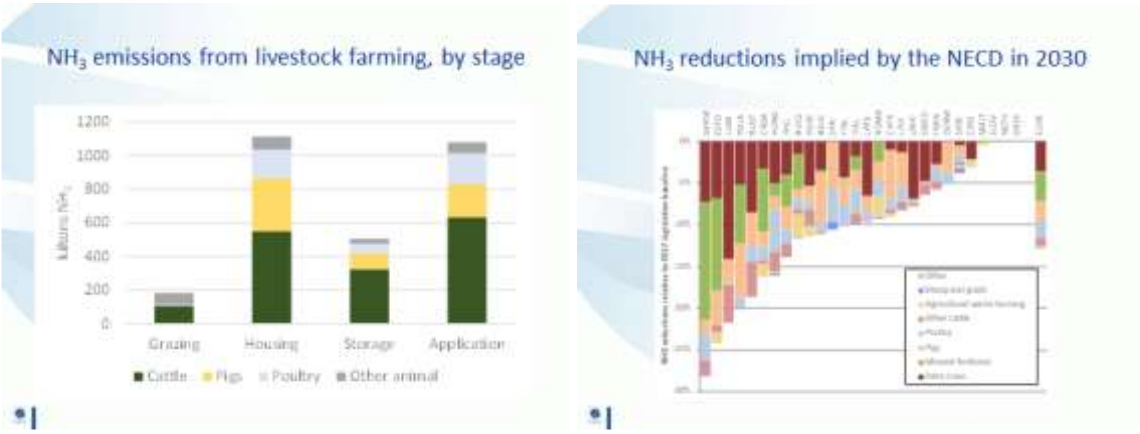


Figure 3: Main sources of ammonia emissions and ammonia reductions up to 2030 implied by the EU-National Emissions Ceilings directive (IIASA, 2017)

Enforcement

Lessons from the Netherlands and Flanders learn that enforcement of regulation is essential for an effective implementation of ammonia abatement measures. E.g. the installation of air scrubbers itself proved to be insufficient, additional measures had to be taken to guarantee its use.

Registration of manure transport also remains to be a challenge to prevent groundwater pollution or illegal export and dumping.

Transboundary co-operation is needed to avoid illegal transport and dumping of manure. This would increase the effectiveness of ammonia emission reduction measures and could avoid increased concentrations of nitrate in groundwater.

Urea fertilizer

Low emission manure application can have a large contribution to reducing ammonia emissions, especially when combined with less mineral fertilizer use. One of the types of mineral fertilizer that contributes relatively much to ammonia emission is urea fertilizer. This type of fertilizer is relatively cheap and widely used in Germany, where the share of fertilizer use in the total ammonia emissions is around 25%. Substitution of this type of fertilizer is a cost-effective measure (0,1-2,8 €/kg NH3) (Wulf S, et al., 2017).

Additional ammonia emission reduction measures will not only lead to other emission projections for 2030 but also to different estimates for public health damage and damage to ecosystems. Table 3 shows loss in average life expectancy due to exposure to the total PM2.5 concentration. In the countries concerned approximately half of the PM2.5 concentrations is influenced by ammonia emissions. Please note that the variation of the loss in life expectancy among the population is large. Most people will only suffer from minor health effects, while for sensitive people the loss in life expectancy can be several years.

Table 3: Loss in life expectancy due to PM2.5-exposure for various emission projections

(in months; source IIASA)

	2005	2030 - Current legislation	2030 - cost-optimal	2030 - technically feasible
Belgium	10.2	5.9	5.0	4.5
Denmark	6.4	3.5	3.0	2.7
France	8.8	4.4	3.8	3.2
Germany	7.9	4.8	4.0	3.6
Italy	10.2	6.1	4.8	4.3
Netherlands	8.8	5.0	4.3	4.0
United Kingdom	5.8	3.7	2.9	2.6
EU-28	8.5	5.0	4.1	3.6

IIASA, 2014a

Table 4 shows the improvement in the protection of ecosystems due to a reduction in nitrogen deposition for various ambition scenarios. In some countries, notably Denmark and the Netherlands, the expected improvement would remain small, even with all technically available measures taken. This is due to the high density of livestock around nature areas in these countries, resulting in further loss in biodiversity. The risk is that charismatic plant species will be overgrown by grass, shrubs and nettle, what will also affect the variety of butterflies and birds. More structural changes would be needed to halt the loss in biodiversity in areas with a high livestock density.

Table 4: Reduction in ecosystem area with excess nitrogen deposition between 2005 and 2030

	2030 - Current legislation	2030 - Cost-optimal	2030 – technically feasible
Belgium	92%	100%	100%
Denmark	2%	3%	7%
France	25%	43%	55%
Germany	25%	46%	55%
Italy	44%	60%	66%
Netherlands	5%	13%	16%
United Kingdom	56%	80%	86%
EU-28	24%	35%	42%

IIASA, 2014a

One example of such a structural change is to close the agricultural nitrogen cycle. At the national scale a circular agricultural economy with a minimum of losses of nutrients to the environment will require more than only a change in agricultural production techniques. In addition “demand side” changes will be part of comprehensive approach. This includes reduction of food waste, reduction of overconsumption of calories and a shift towards more sustainable diets, i.e. diets that contribute less to losses of nitrogen. Reducing meat consumption forms a crucial element in such a sustainable diet. Halving the meat consumption would reduce ammonia emissions by 43% (Westhoek, 2014). That would also significantly reduce emissions of greenhouse gasses and require less land.

Another example of a structural change is the production of artificial meat or using insects or pulses as sources for proteins in the human diet.

Moreover, several studies have indicated the health benefits of less overconsumption and eating less meat (e.g. van Dooren, et al, 2014, Hallström et al, 2015). We should realize that currently more premature deaths in the world are related to obesity rather than to hunger.

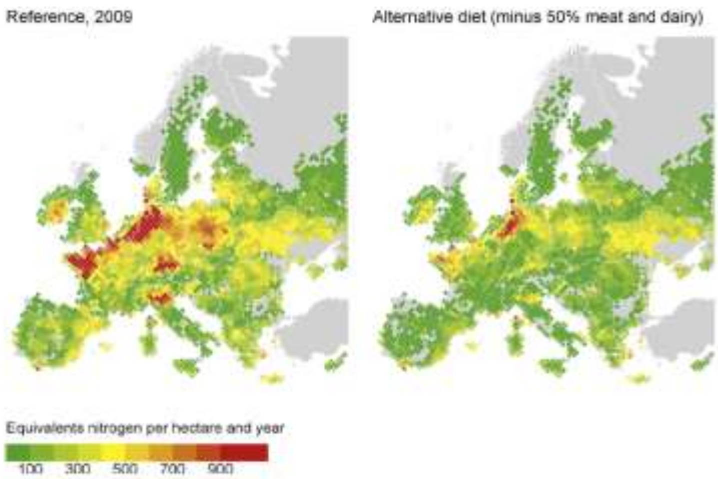


Figure 5: Annual exceedance of the critical load for N deposition in N ha1 for natural ecosystems, under the reference scenario and the 50% less meat and dairy alternative diet (from: Westhoek et al 2014)

3. Costs of policy inaction

Current agricultural practices lead to a loss of valuable nutrients, damage to public health and ecosystem services, and to climate change (via land use changes and emissions of greenhouse gasses).

Due to the losses of nitrogen, farmers need to buy more mineral fertilizer than would be case with a “circular” agricultural system. For the EU as a whole, the potential saving of reducing the loss of nitrogen to air can be valued at 1.5 billion euro per year (this figure does not yet include the savings from reducing the nitrogen losses to groundwater and surface water).

Losses of nitrogen to the air also lead to damage to ecosystems and human health. These external costs are not included in the food prices. According to CE-Delft the damage due to ammonia emissions can be valued at €17.50 per kg ammonia (plus or minus €7.50). This includes the contribution of ammonia to acidification, eutrophication and formation of particulate matter and related loss of live years. (Sander de Bruyn et al, 2018). Damage to public health from secondary particulate matter makes up the largest part of the total damage estimate. Damage to nature includes the costs of restoring nature areas (e.g. via liming or removal of grasses and bushes). The damage due to the total European agricultural ammonia emissions in 2030 could be valued at almost **60 billion euro** per year**,** plus or minus 25 billion, around 20% of the value agricultural production in the EU (285 billion euro per year).

By definition, 60 billion euro is the (gross) societal costs of taking no additional policy actions. For the net costs of inaction, we have to subtract the costs of additional abatement measures. For agriculture abatement costs can be estimated at 0.7-5.7 billion euro, depending on the policy ambition level (IIASA, TSAP-report #11, 2014). Note that the agricultural sector receives a subsidy of more than 40 billion euro per year (15% of the total agricultural production).

Including the damage costs in the prices of food, would lead to an increase of especially meat and dairy products. According to CE-Delft (The true price of meat, 2018) prices of beef and pork would have to be 40-50% more expensive respectively, to cover environmental damage. Damage due to nitrogen losses make up 60-70% of the total environmental damage from meat production. Raising prices of meat and dairy products would reduce the buying power of low income groups. However these effects would be negligible, if combined with a dietary change. Also prices of vegetables could go down when manure is used instead of mineral fertilizers.

The damage cost estimate of €17.50 per kg is higher than the abatement cost estimates. According to the German study (Wulf et al, 2017), the average costs of ammonia abatement would be € 0-4 per kg. The high end estimate of the most expensive reduction measure (air scrubbers on stables) would, according to this study, cost up to € 15 per kg.

4. Conclusions and recommendations

Ammonia emissions, concentrations and deposition in Europe show a moderate decline over the last 15 years compared to sulphur dioxide and nitrogen oxides. The damage of ammonia emissions to public health and ecosystems can be valued at € 10-25 per kg NH_3.
Substantial reductions of ammonia emissions, even beyond the current obligations in the revised NEC-directive, are still possible. Abatement costs of ammonia are significantly lower than the damage per kg, and vary from € 0-4 per kg NH_3 for most countries up to € 4-15 per kg NH_3 is areas with a high density of livestock.

Cost-effective measures to further reduce ammonia emissions differ among various parts of Europe and North America. The limitation of the use of urea fertilizer, or even better, a further substitution of mineral fertilizers by manure is a relatively low cost strategy that can be applied everywhere. It would however require registration of manure transports in order to avoid conflicts with the Nitrate Directive.

Low emission manure application (injection on grassland and direct incorporation on arable land) is the most effective measure, but it requires investments in machines, that will pay back if the measure would be combined with less mineral fertilizer use (de Haan, 2009). Low emission manure application is currently the most effective abatement option e.g. for Germany and France to reduce ammonia emissions.

Areas with high livestock densities namely Belgium, Denmark and the Netherlands, have already taken these low-cost measures, in order to protect ecosystems. Further extension of the use of air scrubbers for stables would - although expensive – be a technical option in areas with a high density of livestock to increase the protection of public health and of nature-areas.

Further emission reduction of ammonia would require structural changes, including increasing the nitrogen use efficiency and ultimately closing the nitrogen cycle. Such an approach would require substitution of mineral fertilizers by the use of manure (“organic” fertilizer) and production of other sources of protein than meat. Also demand side changes would be needed, such as a reduction of food waste, overconsumption and dietary changes.

Linkages with water protection (e.g. nitrate leaching) and climate policies require attention in order to avoid negative side effects from ammonia abatement measures and to profit from potential synergies. E.g. for cattle, changes in feed might become an option to reduce ammonia emissions, but such a strategy would have to be combined with the aim to also reduce methane emissions. Less use of mineral fertilizers would have benefits for both air quality and climate. For the production of mineral fertilizer large amounts of natural gas are needed, and the use of mineral fertilizers contribute to emissions of nitrous oxide.

Because of the transboundary role of ammonia in the formation of secondary particulate matter and nitrogen deposition on ecosystems, it is important to continue the exchange of information on abatement policies. Clarity in the timing of envisaged ammonia abatement measures would help neighbouring countries to underpin their national air quality plans with quantitative estimates.

References

de Bruyn, Sander, et al, Environmental Prices Handbook EU28 version - Methods and numbers for valuation of environmental impacts, CE-Delft, 2018

CE-Delft, The true price of meat, 2018

Van Dooren, C, et al, 2014, Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns, Food Policy 44 p36–46, http://dx.doi.org/10.1016/j.foodpol.2013.11.002

EC, European Commission, 2013, Proposal for a directive of the European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants and amending Directive 2003/35/EC (COM(2013) 920 final)

EEA, 2017, Air Quality in Europe – 2017 report

EEA, 2018, Report on particulate matter and agriculture

EMEP, 2015, Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components, Status report 1/2015 – table C.11, C.13

EMEP, 2016, Air Pollution trends in the EMEP-region, EMEP/CCC-report 2016/1 (p39)

Hallström E., et al., 2015, Environmental impact of dietary change: a systematic review, Journal of Cleaner Production 91 (2015) p1-11, http://dx.doi.org/10.1016/j.jclepro.2014.12.008

Hettelingh, JP, et al, 2015, Effects-based integrated assessment modelling for the support of European air pollution abatement policies. In: W. de Vries, J-P. Hettelingh & M. Posch (Eds), Critical Loads and Dynamic Risk Assessments: Nitrogen, Acidity and Metals in Terrestrial and Aquatic Ecosystems.Springer, pp. 613-635

IIASA, 2014a. The Final Policy Scenarios of the EU Clean Air Policy Package, TSAP Report 11, Version 1.1a, International Institute for Applied Systems Analysis, February 2014

IIASA, 2014b, Urban PM2.5 levels under the EU Clean Air Policy Package, TSAP Report 12, International Institute for Applied Systems Analysis, October 2014

IIASA, 2017, Progress towards the achievement of the EU's air quality and emissions objectives, International Institute for Applied Systems Analysis, October 27 2017

JRC, 2017, Urban PM2.5 Atlas of air quality in European cities, European Commission, 2017

LCSQA, 2015, Observation et analyse en temps quasi-reel des episodes de pollution particulaire de Mars 2015. Laboratoire Central de Surveillance de la Qualité de l'Air

Maas R. and P. Grennfelt, (eds), 2016, Towards Cleaner Air, Scientific Assessment Report 2016, UNECE, http://www.unece.org/index.php?id=42861

Mathias, Etienne, Edith Martin, 2013, Analyse du potentiel de 10 actions de réduction des émissions d'ammoniac des élevages Français aux horizons 2020 et 2030, ADEME, Décembre 2013

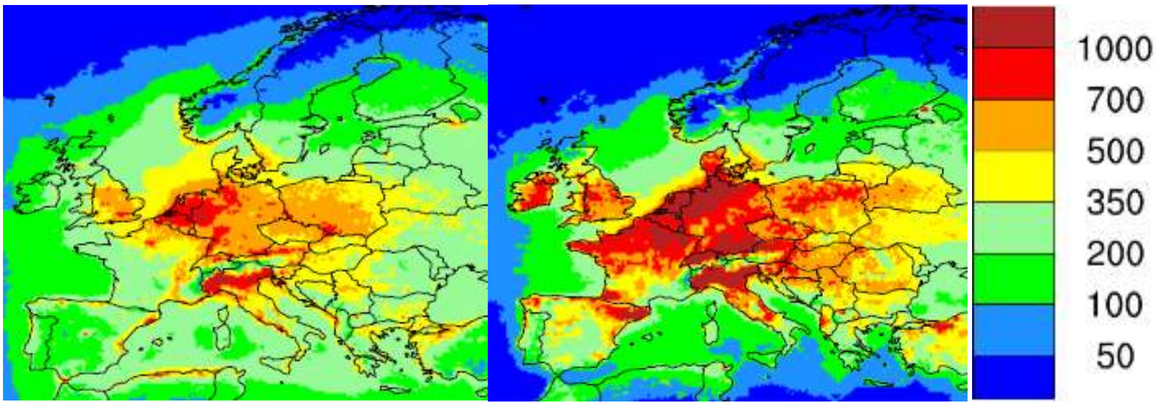
Wagner, Fabian. et al, 2011, Ammonia reductions and costs implied by three ambition levels, CIAM-report 5/2011

Westhoek, H., et al., 2014, Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. Global Environ. Change, http://dx.doi.org/10.1016/j.gloenvcha.2014.02.004

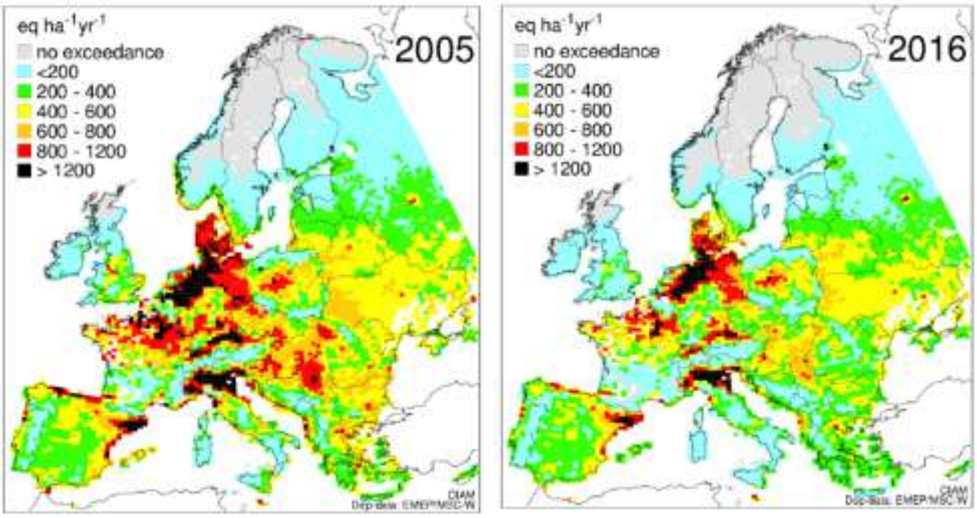
WHO, 2005, WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005

Wulf, Sebastian, Claus Rösemann, Brigitte Eurich-Menden, Ewald Grimm)Thünen, 2017, Ammoniakemissionen in der Landwirtschaft Minderungsziele und –potenziale Aktuelle rechtliche Rahmenbedingungen für die Tierhaltung, Thünen, Hannover 30.05.2017

Annex 1: recent maps of nitrogen deposition



Deposition of oxidised (l) and reduced (r) nitrogen in 2016 (EMEP)



Exceedances of Nitrogen Critical loads in 2005 and 2016

Annex 2: Priority research questions

To be discussed