

Assessment Report on Ammonia – 2020

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This report is written at the request of the Executive Body of the Convention on Long-Range Transboundary Air Pollution as part of the 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 decision takers of ammonia impacts and costs and benefits of measures could have been a reason for this. This report aims to fill some of these gaps.

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.

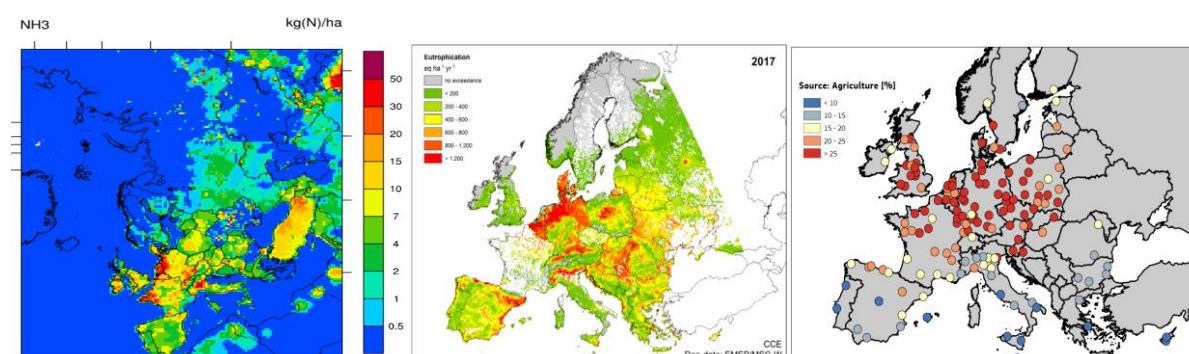


Figure 1: Ammonia emission density 2013 (EMEP-MSCW), exceedance of the critical load for nitrogen in 2017 (CCE) and contribution of ammonia to PM2.5-concentrations in 2015 (JRC)

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. To a lesser extent, also chemical fertilizers contribute to ammonia emissions. A small part (around 10%) of the annual ammonia emissions comes from industry, households and traffic. In Europe, ammonia is the dominant cause of nitrogen deposition on nature areas and the subsequent loss of plant species, butterflies and birds (figure 2). This is even the case in areas with high densities of traffic and emissions of nitrogen oxides. However, in the eastern part of North America, nitrogen oxides are dominating (Kanakidou et al, 2016).

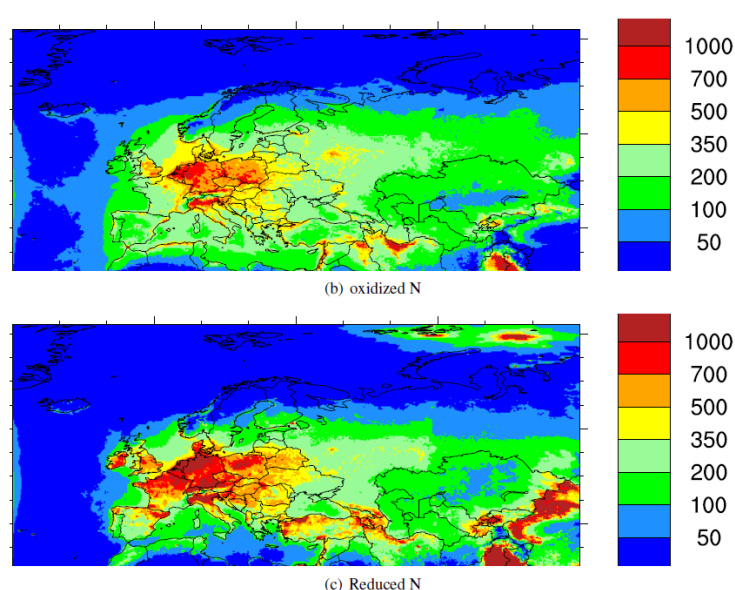


Figure 2: Deposition of Nitrogen oxides (top) and Ammonia (bottom) in 2017 in kg N per hectare (EMEP, 2019)

Recently, awareness has increased 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 areas of Europe with high population densities, more than half of the particulate matter concentrations is not emitted directly, but is formed in the air when ammonia reacts with nitrogen oxides or sulphur dioxide (the so-called secondary particles). Also, in North America and Asia the role of ammonia in the formation of particulate matter is getting more attention (Plautz, 2018), Purohit et al, 2019).

Figure 3a shows the origin of the particulate matter concentrations in in 2009 in cities (measured as PM_{2.5} - 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 3b). The pink line in the figure 3a 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 PM_{2.5} concentration consists of secondary particles. According to EMEP modelling foreign sources contribute 70-80% to the secondary PM_{2.5} concentrations in Benelux countries.

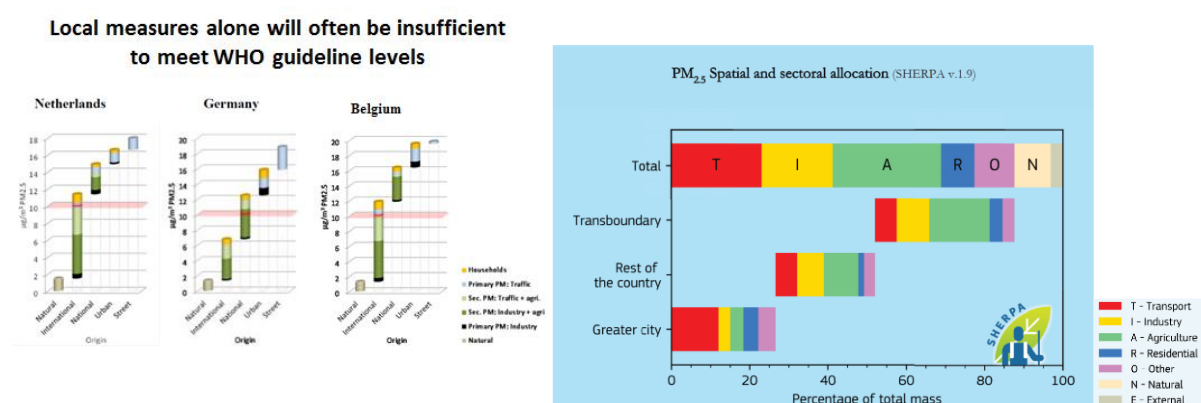


Figure 3: (a) Origin of urban PM-exposure in the Netherlands, Germany and Belgium according to the GAINS-model (IIASA, 2014b) and (b) in Brussels according to the Sherpa-model (JRC, 2015)

Currently, exceedances of the EU Air Quality Limit Value of particulate matter occur frequently in cities 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 in Europe and north America 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 (EMEP-Trend report 2016).

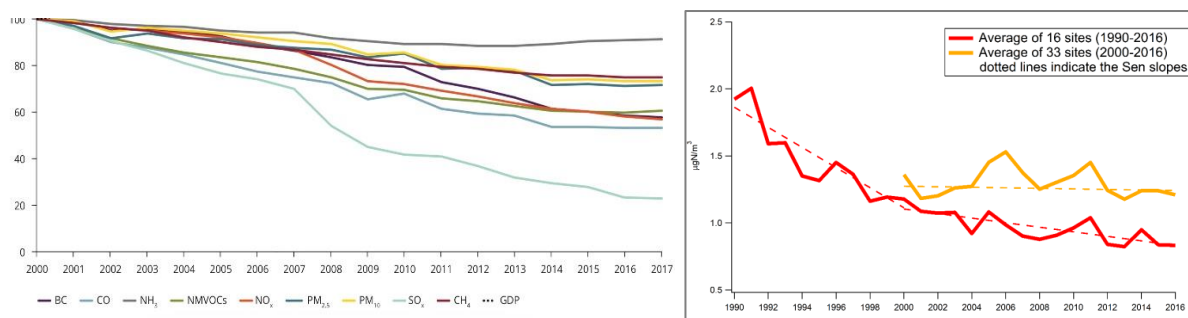


Figure 4: Trends in EU-28 emissions, 2000 = 100 (EEA, 2019) and European ammonium concentrations ($\mu\text{g}/\text{m}^3$) (CCC)

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 European Union and several countries have defined the WHO-guideline value for PM_{2.5} as their long term target (e.g see the Clean Air Programme for Europe - EC, 2013). However, from the source apportionment of PM_{2.5} concentrations (figure 3) it is clear that in many cities meeting the WHO Air Quality Guideline value for PM_{2.5} 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).

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 PM _{2.5}	
	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). The availability of ammonia in the air explains why PM-concentrations did not decline as much as expected. However, due to decreasing availability of nitrogen oxides and sulphur dioxide, the share of the ammonia emission that is converted into secondary aerosols is decreasing. Subsequently, a higher share of the ammonia emission is deposited on land (source: EMEP??).

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 up to 30-50% would be required to meet such long term targets.

Ammonia emissions are not the only way nitrogen nutrients from agriculture are lost 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 nitrogen oxides from agricultural land (see figure 5).

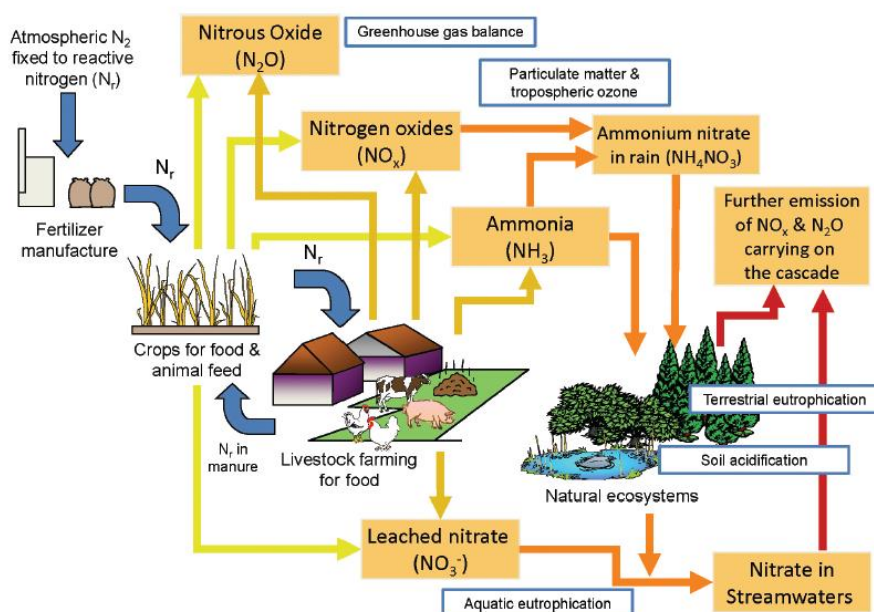


Figure 5: Agricultural nitrogen flows (Source: ENA)

An integrated policy strategy is needed to avoid that ammonia reduction measures would increase other nitrogen related problems, and to optimize potential synergies. E.g. ammonia emissions could decrease with deep injection of manure on grassland, but this could increase leaching of nitrates to groundwater or lead to higher emissions of nitrous oxide. 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. To illustrate this: low nitrogen cattle feed could decrease ammonia emissions, but could enhance methane emissions, and vice versa.

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. Therefore, 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 (Mathias et al, 2013).

The UNECE Task Force on Reactive Nitrogen has prepared a guidance document on Integrated Sustainable Nitrogen Management, which puts ammonia emission reduction in the broader context of more efficient use of nitrogen in agriculture (TFRN, 2020).

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. Less use of mineral fertilizer would lead to further ammonia reduction, especially if this involves a reduction in the use of urea-fertilizers. If low emission manure application would replace the use of mineral fertilizer in agriculture, it would also reduce the total costs of the ammonia emission reduction strategy.

Reduction in the total amount of nitrogen that is brought on land, would prevent a shift to water and groundwater pollution and reduce the emission of nitrous oxide.

The challenge is to convince farmers that manure is 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 feed 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. The costs of low-emission manure application vary between € 0.2-4 per kg ammonia, depending on the type of manure and the technology chosen (Reis et al, 2015)

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: NH₃ 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

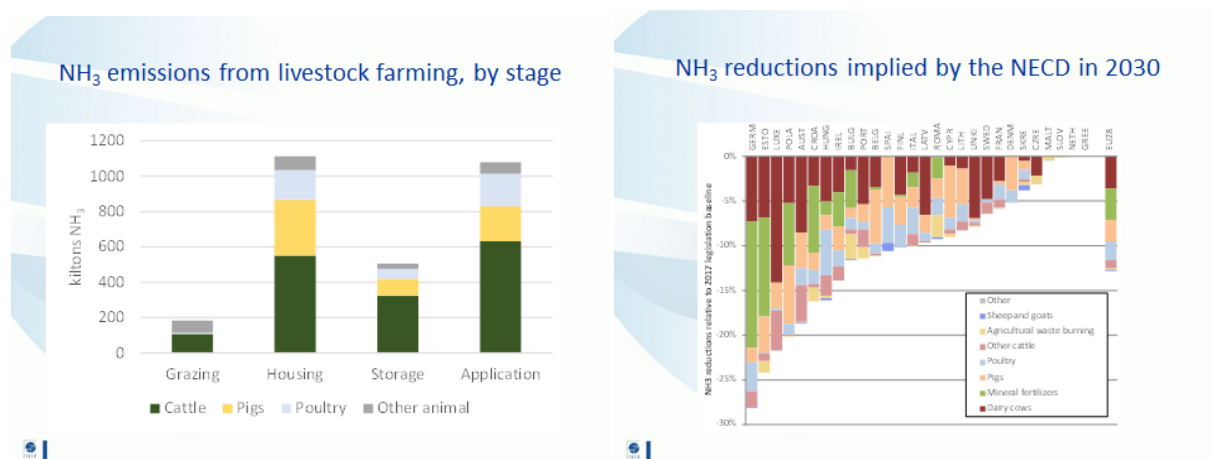


Figure 6: Main sources of ammonia emissions and ammonia reductions up to 2030 implied by the EU-National Emissions Ceilings directive (IIASA, 2017)

Ammonia in North America

In North America ammonia emissions have not decreased compared to the 1990 level. Beef and dairy cows are responsible for around two-thirds of the ammonia emissions from agriculture and fertilizer use around one quarter (Shepperd and Bitman, 2010). Cattle densities are highest in the mid-west of the United States and in Alberta (Canada). There are no specific policies to reduce ammonia emissions. However, for financial reasons, farmers have increased the nitrogen use efficiency over the years.

Deposition of reactive nitrogen is the highest in the eastern part of Canada and the United States. The main sources of nitrogen deposition in these regions are nitrogen oxides, a.o. from traffic and industry.

Concentrations of ammonium nitrates and ammonium sulphates are high in .. and are declining (?) due to reduction of precursor emissions (sulphur and nitrogen oxides) ??

Ammonia in Eastern Europe and Central Asia

Cattle densities in eastern Europe, central Asia and the Caucasus are lower than in western Europe. Compared to Russia and central Asia, cattle densities in Belarus and the Caucasus are relatively high.

During the early 1990s the number of cattle, pigs and goats decreased sharply. In Russia the available nitrogen in manure (organic fertilizer) was reduced by more than 85% between 1990 and 2000. Currently, around 80% of nitrogen input to agricultural land comes from mineral fertilizers (Lukin S. M. et al, 2014). Between 1990 and 2010, agricultural ammonia emissions from husbandry in the European part of Russia were reduced by 60% (Morozova et al, 2014).

The same developments can be observed in Kazakhstan: after a sharp decline in cattle numbers between 1993 and 1998, the numbers show a slow annual increase (Eserkepova et al., 2014)

Estimates for Belarus showed that with technically feasible measures (e.g. covered manure storage, immediate incorporation of manure) ammonia emissions from husbandry could be reduced by around 20%. But the costs (of around 100 million euros per year) seem still to be prohibitive. Implementation in pilot projects could be a step forwards. (Kakareka et al, 2014).

The nitrogen debate in the Netherlands

From 2016 ngo's challenged the existing nitrogen policy in the Netherlands in legal courts. In May 2019 the supreme court of the Netherlands blocked new permits for all activities that cause additional nitrogen deposition. In November 2018 the European Court of Justice had judged that permitting in the Netherlands was not in line with the Habitat Directive of the EU and would lead to further increase of nitrogen deposition, although all permits included European emission limit values, the obligations under the National Emissions Ceilings Directive were met, as well as the obligations under the Nitrate Directive. The construction of new animal housing, roads, houses and other buildings had to stop at once. This caused massive protests of both farmers and construction workers. Highways blockades caused traffic chaos across the country for several days. Farmers put the conclusion that ammonia was a dominant cause of biodiversity loss into doubt. Committees were formed to develop a way out and to scrutinize the data and models. The lesson was that the Habitat Directive should be taken more serious. And that what happened in the Netherlands could also happen in courts in other EU-countries.

From now on, all new activities will have to compensate their nitrogen contribution by 130% by financing additional nitrogen reduction measures. The main problem in the Netherlands is the high density of livestock and traffic and the scattered pattern of small nature areas. The scope for additional technical measures is very limited. That means that most probably the solution will have to be found in reduction of activity levels. The first easy measures were taken were the reduction of the speed limits on highways, additional funding for nature conservation and financial incentives to voluntary close pig stables. But the reduction of the cattle stock is still debated heavily. Some farmers promote new high tech solutions (e.g. cows with a higher milk productivity, additives to cattle feed and 'innovative' housing systems). Other farmers choose low tech solutions: more cows in the meadow would mean less ammonia, less methane, healthier cows, but with a lower productivity. However they would also require less cattle feed, less fertilizers and less antibiotics.

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 per kg ammonia) (Wulf, 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 PM_{2.5} concentration. In the countries concerned approximately half of the PM_{2.5} 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 PM_{2.5}-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 red 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.

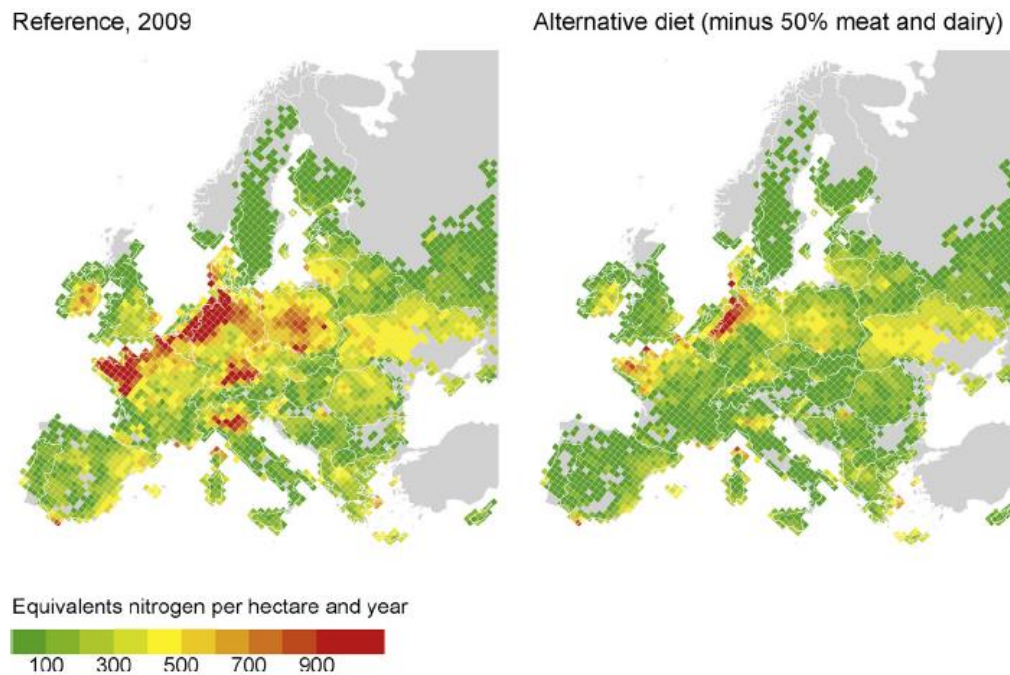


Figure 7: Annual exceedance of the critical load for N deposition in N ha1 for natural ecosystems, under the reference scenario and the 50% less meat and dairy alternative diet (from: Westhoek et al 2014)

3. Costs of policy inaction

Current agricultural practices lead to a loss of valuable nutrients. If farmers would take action to work towards a “circular” agricultural system, less nitrogen would be lost at the farm level and farmers would need to buy less mineral fertilizer. Currently 1.5 billion euro per year is spend in the EU to buy fertilizers. Moreover, for the society as a whole a circular agricultural economy could reduce the damage to public health and ecosystem services. And it would also reduce the agricultural contribution to climate change (via land use changes and emissions of greenhouse gasses).

Current damage in the EU to ecosystems and human health due to ammonia emissions were monetized by CE-Delft (de Bruyn et al, 2018). 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 (de Bruyn et al, 2018). Damage to public health from secondary particulate matter is dominant in 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). This is around 20% of the value agricultural production in the EU (that equals 285 billion euro per year). Note that the agricultural sector in Europe also receives a subsidy of around 15% of the total agricultural production value.

By definition, 60 billion euro is the (gross) societal costs of taking no additional policy actions. With an emission reduction of 30-50% the damage could be avoided. For agriculture, abatement costs can be estimated at 0.7-5.7 billion euro per year, depending on the policy ambition level (IIASA, TSAP-report #11, 2014). To reach a 30-50% reduction, in some regions additional non-technical measures would be required.

The damage cost estimate of €17.50 per kg ammonia 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.

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

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 ammonia.

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 ammonia for most countries, up to € 15 per kg ammonia in some 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 (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. 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.

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Annex 1: Priority research questions

To be discussed