MEASURES TO ADDRESS AIR POLLUTION FROM AGRICULTURAL SOURCES

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Editor: Markus Amann
International Institute for Applied Systems Analysis (IIASA)

International Institute for
Applied Systems Analysis
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Abstract

This report reviews the perspectives for reducing emissions from agricultural activities, focusing on (i) the open burning of agricultural residues, (ii) mineral fertilizer application, and (iii) manure management. Many Member States have implemented the ban of burning of agricultural residues following Community legislation, providing ample practical experience of successful implementation, including effective enforcement. Application of mineral fertilizer contributes approximately 20% of total ammonia emissions in the EU-28. Improving nitrogen use efficiency, inter alia through precision farming, and the use of urease inhibitors can reduce these emissions.

About 75% of all ammonia emissions in the EU-28 are caused by manure management from livestock farming, with 80% of manures originating from 4% of the farms. Well-documented experience exists in Member States with a host of measures, and several European countries have established programmes to promote integrated manure management approaches, which at the same time enhance the economic performance of agricultural firms.

The authors

This report has been produced by

        Markus Amann[1]
        Adriana Gomez-Sanabria[1]
        Zbigniew Klimont[1]
        Rob Maas [2]
        Wilfried Winiwarter[1]

Affiliations:

        [1] International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
        [2] National Institute for Public Health and the Environment (RIVM), Bilthoven, Netherlands

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Executive Summary

In view of the persistent urgency to reduce emissions of NH_3 and PM2.5 in Europe, this report reviews the perspectives for reducing such emissions from agricultural activities, focusing on (i) the open burning of agricultural residues, (ii) mineral fertilizer application, and (iii) manure management.

While **open burning of agricultural residues** is banned under EU regulation No 1306/2013, numerous Member States report substantial emissions from this category, and this share is expected to increase in the future without further policy interventions. The practical experience in the Member States that have implemented the ban show that net costs ban are considered negligible, as the advantages to soils are assumed to balance costs for training of farmers, inspection, machinery and man power for ploughing under.

Application of mineral fertilizer contributes approximately 20% to total NH_3 emissions in the EU-28. However, there are large differences across countries, inter alia, related to the use of urea fertilizers, which result in particularly high NH_3 emissions. There are practical means available to reduce emissions from mineral fertilizer application, including enhanced Nitrogen Use Efficiency, *inter alia,* through precision farming, and the use of urease inhibitors are on the market.

About 75% of all NH_3 emissions in the EU-28 are caused by **manure management** from livestock farming. Due to the skewed size structure of agricultural holdings, about 80% of manures leading to these emissions are caused by 4% of the farms. There are striking variations across Member States, reflecting the different structures of the agricultural systems in the EU.

There is clear evidence in in Member States that emissions can be reduced at all stages of the feeding-housing-storage-application chain, i.e., during , grazing, housing, manure storage, and application of manure. However, a balanced combination of medium-cost measures could effectively reduce overall NH_3 emissions from the total chain while potentially avoiding the most expensive measures. A number of European countries have established programmes to promote integrated management approaches, which at the same time enhance the economic performance of agricultural firms.

List of acronyms

BC	Black carbon
CLE	Current legislation
CO_2	Carbon dioxide
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Program of the Convention on Long-range Transboundary Air Pollution
EU	European Union
GAINS	Greenhouse gas - Air pollution Interactions and Synergies model
GDP	Gross domestic product
IED	Industrial Emissions Directive
IIASA	International Institute for Applied Systems Analysis
IIR	Informative Inventory Reports
kt	kilotons = 10^3 tons
MCP	Medium Sized Combustion Plants
NEC, NECD	National Emission Ceilings (Directive)
NFR	'Nomenclature For Reporting' of emission inventories to EMEP/EEA
NH_3	Ammonia
NMVOC	Non-methane volatile organic compounds
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
O_3	Ozone
OC	Organic carbon
PJ	Petajoule = 10^{15} joule
PM10	Fine particles with an aerodynamic diameter of less than 10 μm
PM2.5	Fine particles with an aerodynamic diameter of less than 2.5 μm
PRIMES	Energy Systems Model of the National Technical University of Athens
SO_2	Sulphur dioxide
TSAP	Thematic Strategy on Air Pollution
VOC	Volatile organic compounds

Contents

1 Context

In its Clean Air Programme for Europe (COM(2013)918 final), the European Commission has laid out a comprehensive approach to improve air quality in Europe. The main legislative instrument to achieve the 2030 objectives of the Clean Air Programme is Directive 2016/2284/EU on the reduction of national emissions of certain atmospheric pollutants, which entered into force on 31 December 2016 (the NEC Directive or NECD). Next to the reduction of ammonia (NH_3) emissions from agricultural sources, the Directive allocates highest priority on the control of primary PM2.5 emissions, especially from wood and coal combustion in the household sector.

A recent outlook on future emissions and air quality in the EU (Amann M., Anderl, et al. 2017), based on latest information of economic development and emission inventories, indicates that by 2030 exposure to fine particulate matter will remain a significant threat to human health, despite the sharp decline in energy-related air pollutant emissions throughout the European Union that will result from the implementation of the NEC Directive and other source-oriented legislation. Also, while there will be substantial progress towards meeting the WHO guideline value for exposure to PM2.5, it will not be fully achieved, especially in areas where solid fuel combustion in households will prevail.

In view of the persistent urgency to reduce emissions of NH_3 and PM2.5, this report reviews the perspectives for controlling agricultural emissions from manure handling, mineral fertilizer application, and agricultural waste burning.

Section 2 reviews the relevance of these emissions in the European Union and how this would change up to 2030. Section 3 addresses the burning of agricultural residues, Section 4 emissions from mineral fertilizer application, and Section 5 manure management. Section 6 summarizes key findings.

2 The importance of pollution from agricultural sources

2.1 Impacts of agricultural emissions

Agricultural activities emit a wide range of air pollutants that have serious negative impacts on human health, vegetation and ecosystems. Emissions include:

- ammonia (NH_3), mainly from livestock farming, manure management, and mineral fertilizer application,
- fine particulate matter (PM2.5), i.e., small particles with a diameter of less than 2.5 μm, *inter alia,* from the burning of agricultural residues, soil cultivation, from crushing of bedding material by movements of livestock, and agricultural machinery (diesel engines),
- nitrogen oxides (NO_x), from the fertilization of agricultural soils, agricultural machinery, space heating, and
- volatile organic compounds (VOC) from metabolic processes of vegetation, manures, burning of agricultural residues, and agricultural machinery.

In addition, agricultural activities release substances that act as greenhouse gases, i.e.,

- methane (CH_4) from ruminants (enteric fermentation), manure treatment, rice production, and burning of agricultural residues,
- nitrous oxides (N_2O) from microbial processes in agricultural soils and in manure,
- CO_2 from fuel combustion (agricultural machinery, space heating, etc.) and build-up/release of soil carbon due to land operations and land use change

These emissions have multiple impacts on human health, vegetation, and climate change. Further emissions attributable to the sector agriculture (from agricultural machinery and from buildings) are not discussed in this report.

Related to air pollution, exposure to fine particulate matter has been identified as a major threat to human health (Pope et al. 2002; WHO 2013). In 2005, 88% of the population of the European Union was exposed to PM2.5 concentrations that exceeded the WHO guideline value of 10 μg/m^3. It is estimated that as a consequence statistical life expectancy was shortened by nine months on average, and more than 400,000 cases of premature deaths annually can be associated with this exposure (Amann M., Anderl, et al. 2017).
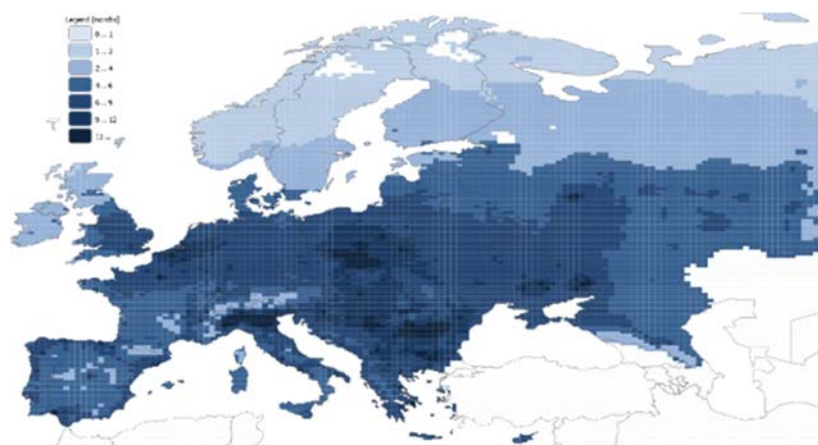

FIGURE 2-1: LOSS OF STATISTICAL LIFE EXPECTANCY FROM EXPOSURE TO PM2.5 IN 2005 [IN MONTHS]. SOURCE: AMANN ET AL., 2017

Fine particulate matter in ambient air consists of a several components, including primary emissions of particles that are directly emitted, and secondary particles that are formed in the atmosphere from gaseous precursor emissions.

Agriculture contributes to both pathways: direct emissions occur from processes that re-suspend pre-existing particles from surfaces (soil cultivation, material transfer, or animal movements) or as a result of combustion, when new particles are formed from incompletely oxidized molecular fragments of fuel constituents that condense while flue gases cool off. Sources include the open burning of agricultural residues, which produces especially small size PM (typical range < 1 μm). The other impact of agriculture is via NH_3 emissions, which react in the atmosphere with SO_2 and NOx, mostly originating from energy combustion and industrial processes to form secondary inorganic aerosols, and via VOC emissions, which form secondary organic aerosols.

A host of monitoring clearly shows that in Europe secondary particles typically constitute about 40-60% of total PM2.5 mass in ambient air. Modelling studies consistently demonstrate that the formation of secondary inorganic aerosols (i.e., ionic compounds like ammonia nitrate or sulphate) is often limited by the availability of ammonia, both in urban situations (e.g., Petetin et al., 2016 for Paris; Lackner et al., 2014 and Uhrner et al., 2014 for Graz, Austria), but also in many rural areas across Europe (Beauchamp et al., 2013; Theloke et al., 2013). As a consequence, (changes in) ammonia emissions have direct impact on PM2.5 concentrations in ambient air, whereas altering NO_x or SO_2 emissions will have much smaller effect.

Thereby, although agricultural emissions originate mainly in rural areas, they make an important contribution to health-damaging PM2.5 concentrations even in cities, where most of the European population lives. This is clearly demonstrated in Figure 2-2, which presents the contributions from different emission sources to ambient PM2.5, for the urban traffic stations that provided for 2009 sufficient data to the AIRBASE database of the European Environment Agency (EEA). Secondary inorganic aerosols, typically limited by the availability of NH_3, constitute about half of total PM2.5 concentrations, even at urban traffic stations, throughout the EU. For comparison, their contributions alone are similar to the guideline value for PM2.5 concentrations of 10 μg/m^3 established by the World Health Organization (WHO).
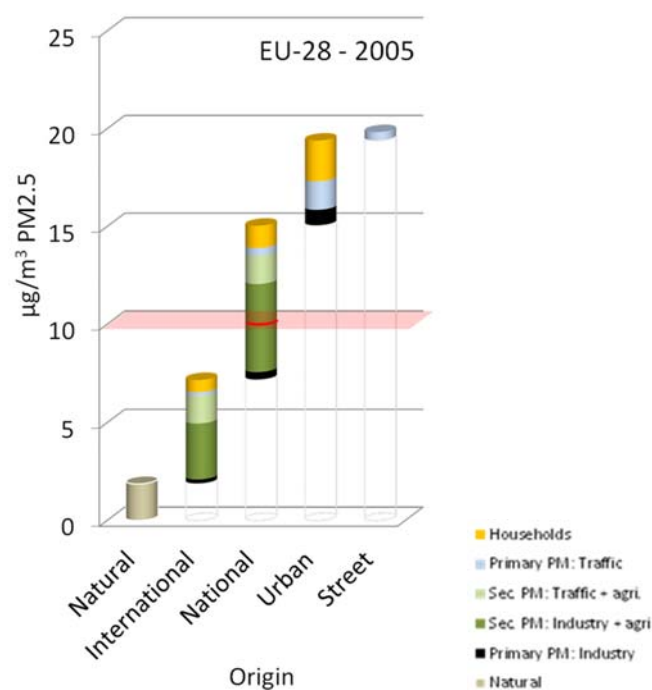
FIGURE 2-2: SOURCES OF PM2.5 AT URBAN TRAFFIC STATIONS IN 2005; AVERAGE OF ALL TRAFFIC STATIONS IN THE EU-28; SECONDARY INORGANIC AEROSOLS, TYPICALLY LIMITED BY THE AVAILABILITY OF NH_3 ARE INDICATED IN GREEN.

In addition, excessive deposition of nitrogen imposes a serious threat to the biodiversity of European ecosystems, adding to the increasing pressure from fragmentation and climate change. It is estimated that in 2005 about 78% (430,000 km^2) of the area protected under the Birds Directive and the Habitat Directive (i.e., Natura2000 areas) received nitrogen deposition in excess of the critical loads for eutrophication that represent sustainable thresholds for intake of polluting deposition. Both NO_x and NH_3 emissions contribute to nitrogen deposition, but as NO_x emissions have been reduced by about 50% in the last decades, now the major share of excess deposition can be traced back to NH_3 emissions.

Furthermore, deposition of reduced nitrogen from NH_3 emissions acts also as one precursor for the acidification of (forest) soils, together with deposition of sulphur and nitrogen from NO_x emissions. Due to the significant reductions of SO_2 and NO_x emissions in the last decades, the threat of acidification has greatly declined, so that in 2005 acid deposition exceeded the critical loads in about 12% of the forest area in the EU. The further emission reductions following recent legislation will diminish this risk further, although by 2030 the overwhelming majority of remaining excess deposition will be caused by emissions of NH_3.
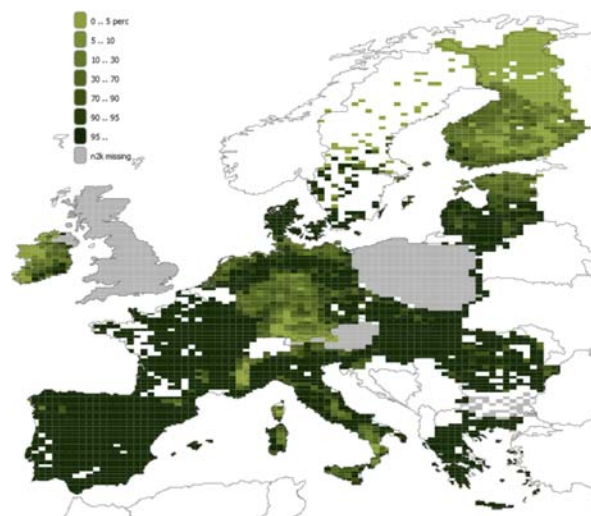
FIGURE 2-3: PERCENTAGE OF NATURA2000 AREAS WITH NITROGEN DEPOSITION ABOVE THEIR CRITICAL LOADS FOR EUTROPHICATION IN 2005. GREY AREAS INDICATE NO DATA

2.2 The contribution of the agricultural sector to total NH₃ and PM2.5 emissions

Given the diversity of activities, the relative contributions of the agricultural sector to total emissions differ across pollutants. Most importantly, agricultural activities (excluding energy combustion for heat and machinery) account for the largest share of NH_3 emissions in the European Union. Contributions to other pollutants are significantly smaller, although some cost-effective potential for reductions of these emissions warrants consideration of this sector in holistic approaches for air quality improvements. Based on the GAINS estimates (Amann, Anderl et al., 2017) that provided the basis for the assessment of the cost-effectiveness of emission reductions, agriculture contributes about 90% to total NH_3, 6% to direct (primary) emissions of PM2.5, (excluding the burning of solid fuel for space heating and drying), and less than 1% to SO_2, NO_x and VOC (excluding 'background' emissions from agricultural soils and vegetation) (Figure 2-4). The EEA (2017) reports slightly different numbers, with 94% for NH_3 and 4% for PM2.5, due to different definitions of source sectors.
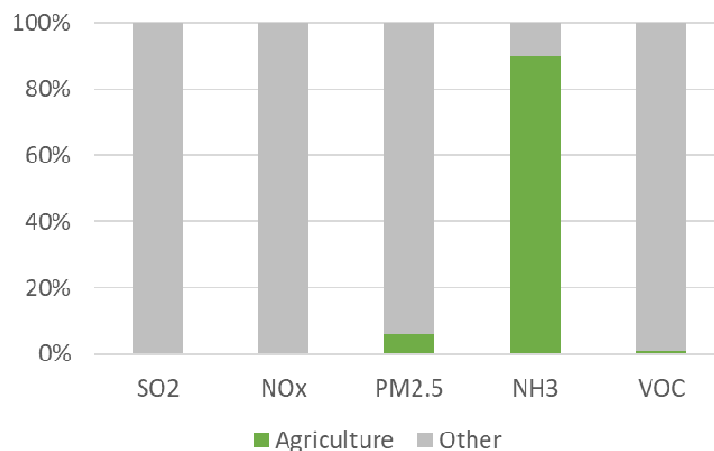

FIGURE 2-4: THE SHARE OF AGRICULTURAL SOURCES FOR THE MAIN AIR POLLUTANTS (EXCLUDING EMISSIONS FROM SOILS AND VEGETATION), EU-28, 2005 (SOURCE: GAINS)

2.3 Future trends

The PRIMES/CAPRI 2016 REFERENCE scenario (Capros et al. 2016), which provides the basis for the 2017 EU Outlook on emissions and air quality in the EU (Amann M., Anderl, et al. 2017), projects for 2030 no major changes in overall livestock numbers for the EU-28 compared to 2015 (Figure 2-5). This follows the decline after 2005; a slight decline in cattle numbers after 2015 is compensated by other animal categories. At the same time, continuation of trend towards larger farms has to be anticipated.
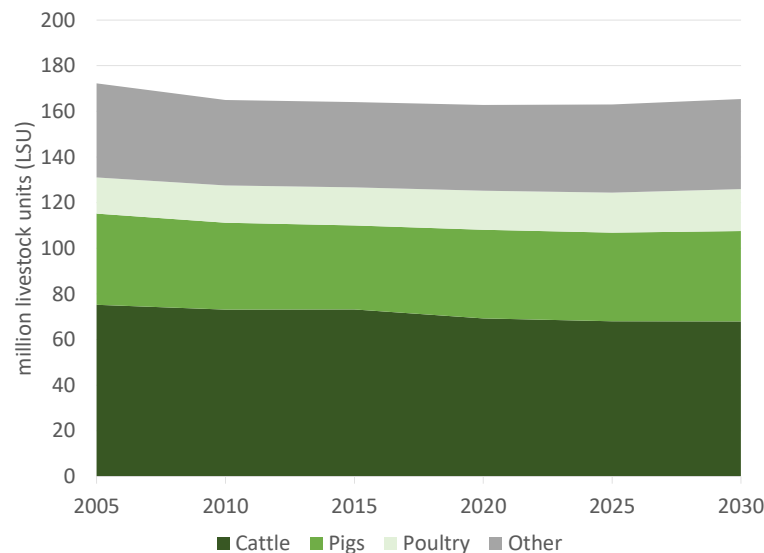

FIGURE 2-5: PROJECTION OF LIVESTOCK NUMBERS FOR THE EU-28 UP TO 2030; SOURCE: PRIMES/CAPRI 2016 REFERENCE SCENARIO

Strongly influenced by these structural changes in the agricultural sector, without additional control legislation total emissions of NH_3 in the EU-28 are projected to decline by 5% in 2030 relative to 2005.

In terms of emission controls, the European Union has established regulations for emissions at large farms under the Directive 2010/75/EU of the European Parliament and of the Council (Industrial Emissions Directive). For the intensive rearing of poultry or pigs, Decision (EU) 2017/302 of 15 February 2017 provided a recent update by establishing best available techniques (BAT) conclusions[1].

However, the Directive on National Emission Ceilings (2016/2284/EU) has established for 2030 an obligation to reduce, among other pollutants, emissions of NH_3 in all Member States, with an overall 19% reduction requirement for the EU-28 as a whole, in relation to 2005. This requires Member States to implement further measures to reduce their emissions of NH_3. Although Member States are free to choose the measures to bring down emissions to these levels, the illustrative analyses presented in the 2017 EU Outlook on emissions and air quality in the EU (Amann M., Anderl, et al. 2017) explores cost-effective ways to meet these reduction requirements in all Member States, given the baseline projections on agricultural activities as outlined in the PRIMES/CAPRI 2016 REFERENCE scenario.

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[1] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2017.043.01.0231.01.ENG&toc=OJ:L:2017:043:FULL

On an aggregated level for the EU-28, about 60% of the total NH₃ emission reductions would be achieved by improved manure management and 25% from optimized mineral fertilizer application (Figure 2-6). Obviously, the importance of different sectors varies across Member States, owing to structural differences, the level at which emissions are already controlled, and the stringency of the target, which is influenced, inter alia, by the environmental pressure in a region.

FIGURE 2-6: FURTHER REDUCTIONS OF NH₃ EMISSIONS TO REACH THE EMISSION REDUCTION REQUIREMENTS OF THE NECD IN 2030, BEYOND THE 2017 LEGISLATION BASELINE, BY SECTOR

The corresponding analysis for **PM2.5** emissions (Figure 2-7) clearly identifies, for a number of Member States, the implementation and enforcement of the ban on open burning of agricultural residuals as a cost-effective measure. Again, relative to the baseline emissions of 2030, this measure could deliver about 40% of the additional PM2.5 emission reductions that are enshrined in the NECD.
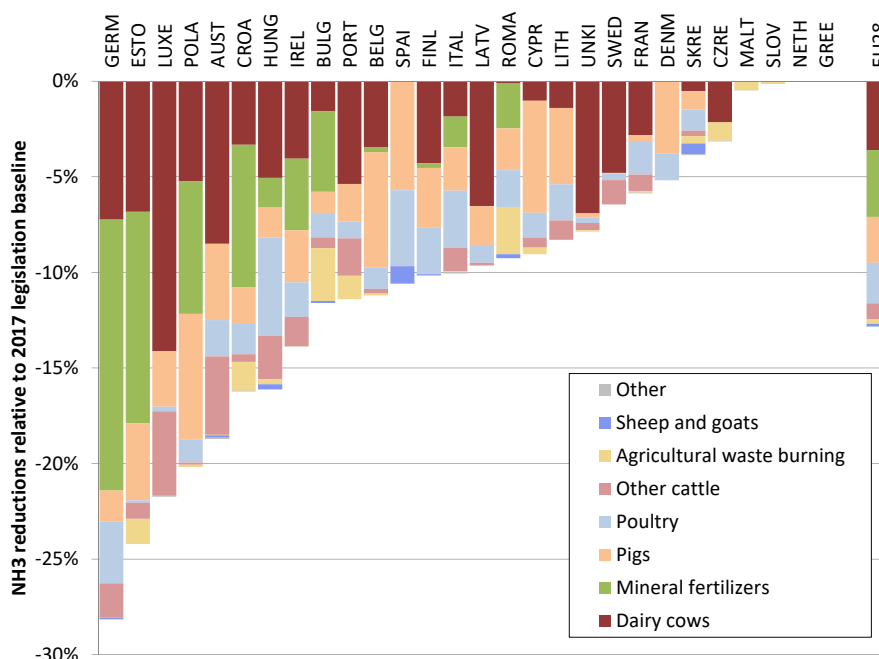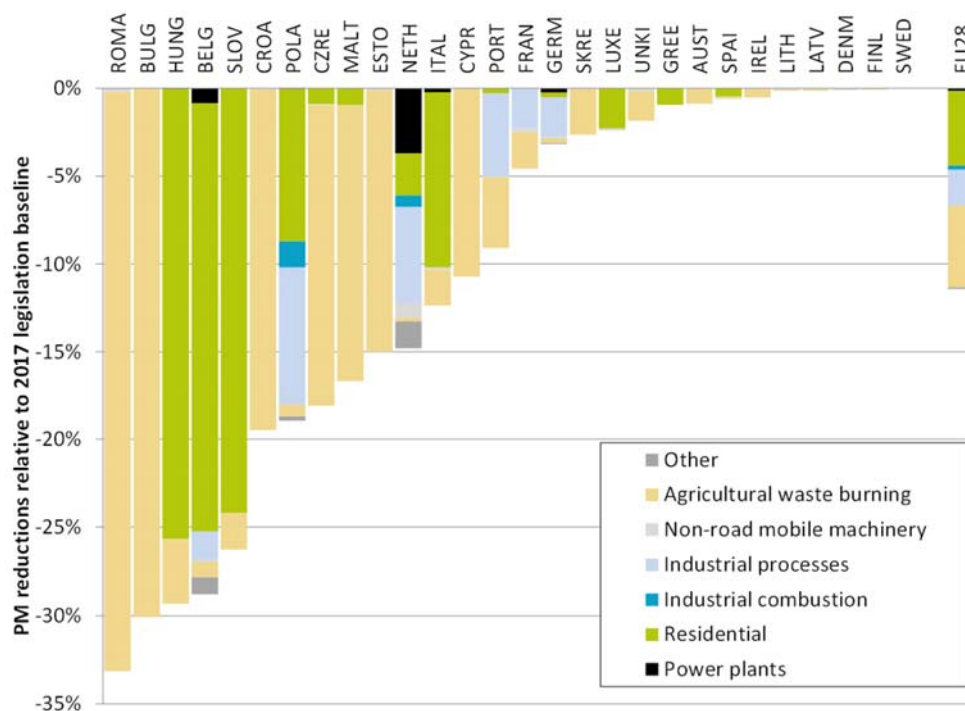
FIGURE 2-7: FURTHER REDUCTIONS OF PM2.5 EMISSIONS TO REACH THE EMISSION REDUCTION REQUIREMENTS OF THE NECD IN 2030, BEYOND THE 2017 LEGISLATION BASELINE, BY SECTOR

However, as the NECD is not expected to fully reach the WHO long-term health and ecosystems objectives, in the long run even further reductions would be necessary, in particular for NH_3, given the fact that emissions of other pollutants will be greatly reduced by 2030 (i.e., SO_2 by 79%, NO_x by 63%, PM2.5 by 50% and VOC by 40%, relative to 2005).

The above analysis clearly highlights three priority lines for a reduction of agricultural emissions:

- The enforcement of a ban on open burning of agricultural residuals,
- Actions on mineral fertilizer application, and
- Manure management measures.

3 Agricultural waste burning

The removal of excess plant material after harvest is an important step in agricultural production, allowing for weed and pest control while preparing the soil for new seeds. Burning agricultural material is a cost-efficient way of removal as it saves the more labour-intensive process of mechanical removal or ploughing under (EEA, 2016), although it may destroy carbon-rich material that otherwise could be used for soil melioration (Lal, 2004; Lal, 2007). The open burning of agricultural waste emits a wide range of substances, including air pollutants such as PM2.5, including BC and OC, NO_x, NH_3, VOC and CO, and greenhouse gases CH_4 and CO_2, not precluding the carbon neutrality assumption of CO_2 from biomass burning.

Burning of agricultural residuals needs to be clearly distinguished from wildfires. The latter, an unintended process, exhibits rather different spatial and temporal patterns, as wildfires tend not to appear on agricultural areas or concentrated in the time period after harvest.

Open burning of agricultural waste is banned under EU regulation No 1306/2013 on the financing, management and monitoring of the common agricultural policy. Specifically, Annex II defines the so-called Good Agricultural and Environmental Conditions (GAEC). As minimum requirements, GAECs need to be specified at the national or regional level, taking into account the specific characteristics of the areas concerned, including soil and climatic condition, existing farming systems, land use, crop rotation, farming practices and farm structures. With respect to open burning, GAEC 6 refers to 'Maintenance of soil organic matter level through appropriate practices including ban on burning arable stubble, except for plant health reasons'. Some countries define clear rules for when and how such exceptions can be granted, e.g., the UK.

3.1 Relevance of the emission source

The open burning of biomass has long been recognized as an important source of air pollution and greenhouse gases, especially at the local scale and during specific episodes, due to the visual impacts of fires and their plumes. However, there is less experience in the quantification of emissions, due to irregular frequencies of fires, uncertainties in the quantities of burned material and the complexities of establishing emission factors that are representative for local conditions.

The EMEP/EEA Emission Factors Guidebook (EEA, 2016) provides methods to estimate emission from this source. Tier 1 is based on simple aggregated area estimates for cropland residues and a default emission factor for each pollutant. The Tier 2 method estimates emissions for the major crop types. Tier 3 would employ country-specific methods involving process modelling and/or detailed measurements. Most of the Member States that report these emissions rely on the Tier 1 or 2 methods.

Alternatively, remote sensing methods (using sensors installed on satellites) have been employed to estimate the extent of open biomass burning, including agricultural fires, and their emissions (van der Werf et al. 2010). While uncertainties in resulting emission estimates are high, the occurrence of fires and their intensity (FRP - fire radiative power) is more robust and provides means for independent validation of country-reported data. Figure 3-1 shows an example of distribution and PM emission intensity of agricultural fires over Europe in 2008 based on the global fire emission database (GFED v3.1; (van der Werf et al. 2010).

Remote sensing data is available since 2003. Active fire data from the MODIS satellite mission has been used to assess the development of agricultural burning activity in Europe (here, fires include all open burning on agricultural land).
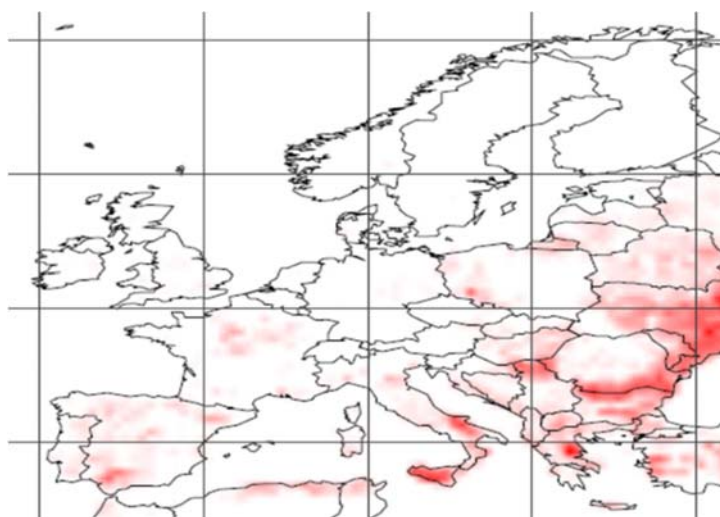
Figure 3-2 shows for all Member States the fire counts per million ha of arable land for the period 2003-2015[2]. The time series are ordered by the sum of fires/ha over the whole period in a country. Overall, at the level of the EU-28 a slight decline is observed. Several countries exhibit a significant decline after 2007-2009 (Denmark, France, United Kingdom, Estonia), while the number of fire incidents remained high in Bulgaria, Portugal, Greece, Croatia, Romania, and Italy. In other countries, fires were rarely observed, e.g., Austria, Belgium, Finland, Netherlands, Slovakia, Sweden, Germany, Ireland (Figure 3-3).

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[2] Data from FAO - http://www.fao.org/faostat/en/#data/RL

Figure 3-3: Time series of agricultural fire activity (number of fires and fire radiative power (FRP)) for selected countries and the EU-28 based on the MODIS data

3.1.1 Share of emissions in total

3.1.1.1 Current situation

Member States are obliged to report emissions from the open burning of agricultural residuals in their emission inventory submissi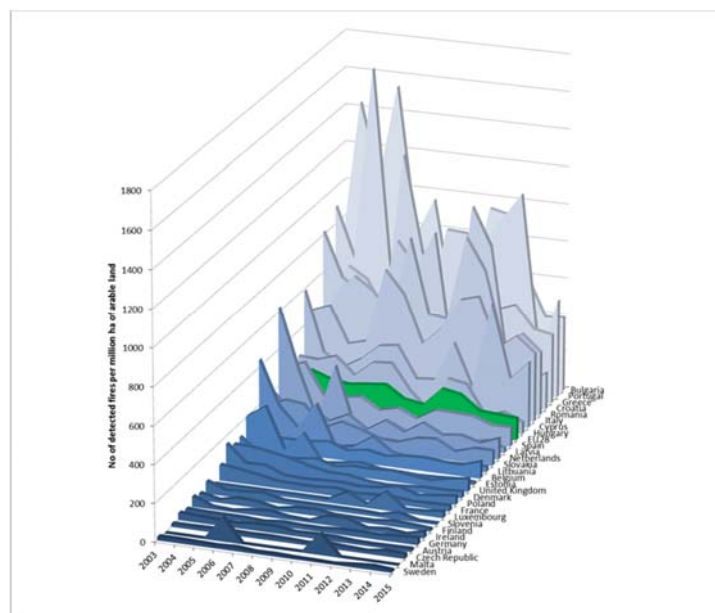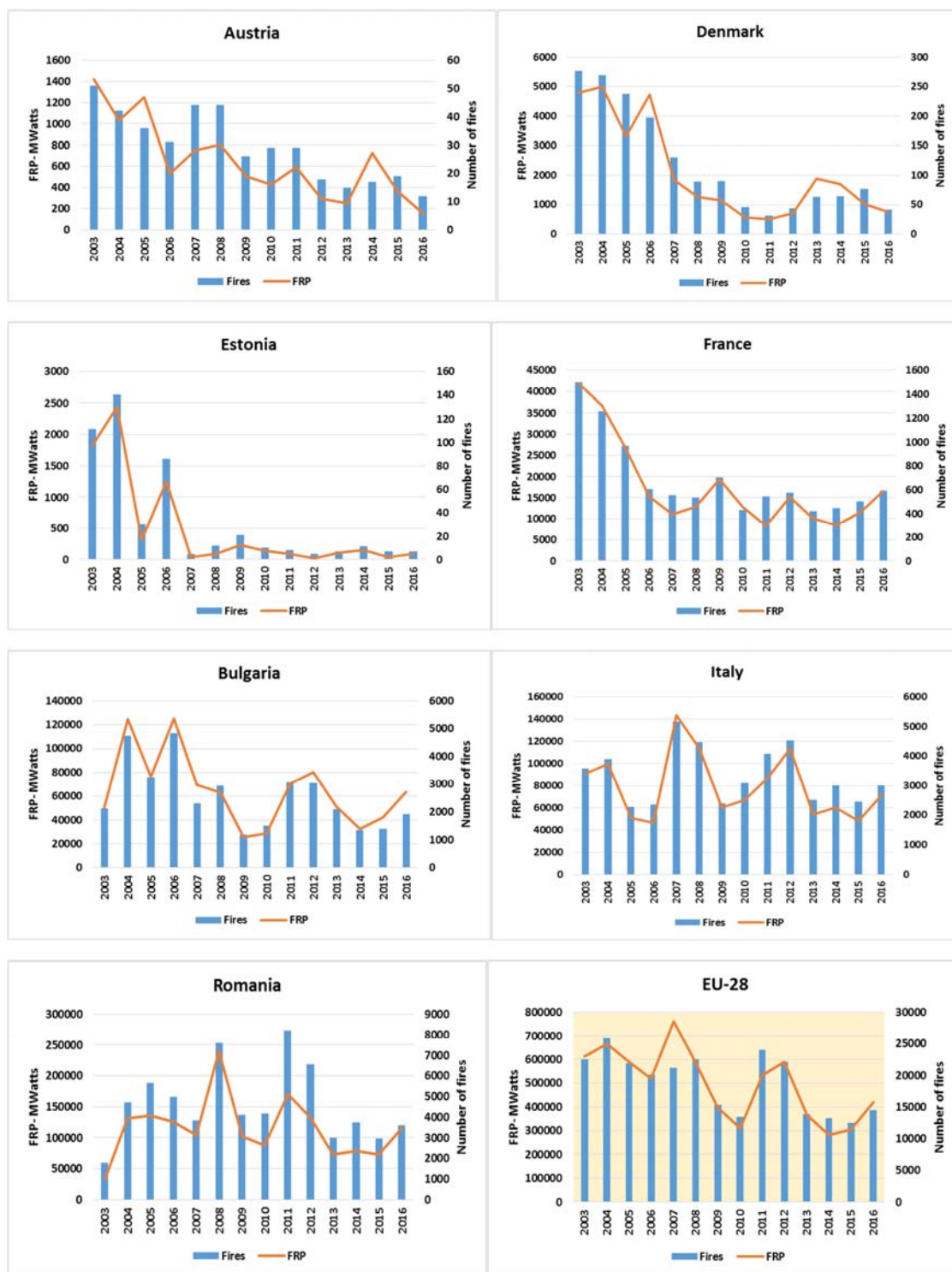ons to EMEP/EEA. According to these national reports, currently this activity accounts for about 0.7% of total PM2.5 emissions within the EU (Figure 3-4), detailed country data are provided in the Annex). However, there are large differences between the figures reported by Member States in the relevant categories, ranging from Portugal with 3.2% and France 2.6% to no emissions reported by many other countries. To some extent, this difference can be explained by the fact that burning of agricultural residues is banned in the EU and effectively enforced in a number of Member States reducing the number of fires to minimum, so that indeed burning might not occur. However, it is also conceivable that some inventory agencies do not include emissions from illegal activities in their reports (Amann et al., 2014). This is confirmed by the analysis of the remote sensing data (see earlier discussion).

By combining satellite data with emission factors from literature (consistent with the EEA emission inventory guidebook), alternative estimates have been derived by IIASA. These suggest that in 2015 burning of agricultural waste accounted for 3.3% of total PM2.5 emissions in the EU-28, with particularly large contributions in Mediterranean countries (up to 20% of total PM2.5 emissions in Malta and Greece) and some Eastern European countries (Figure 3-4).
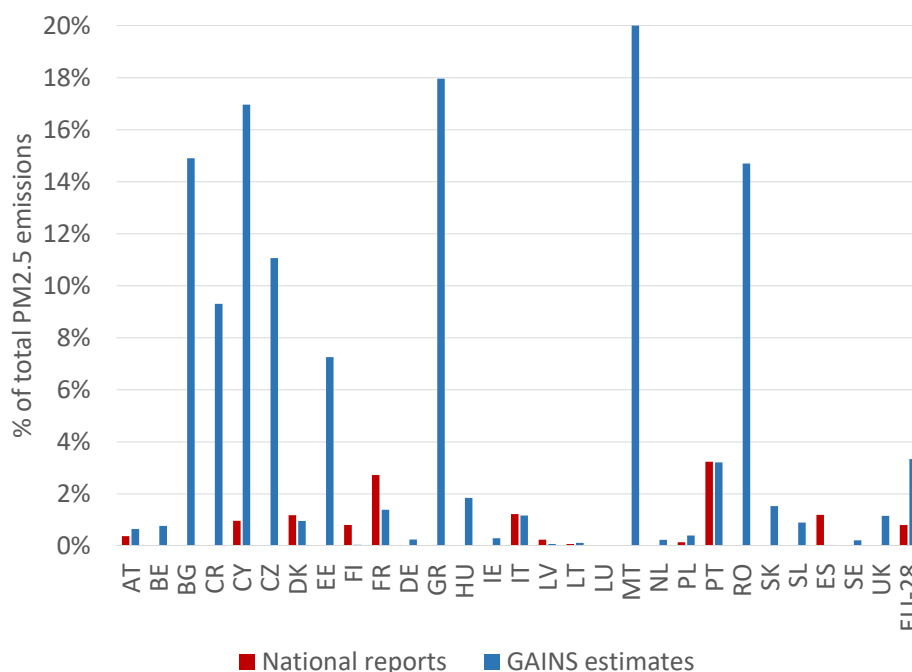
FIGURE 3-4: CONTRIBUTIONS OF THE OPEN BURNING OF AGRICULTURAL WASTE TO TOTAL PM2.5 EMISSIONS IN 2015; FIGURES REPORTED BY MEMBER STATES IN THEIR OFFICIAL INVENTORIES COMPARED TO GAINS ESTIMATES.

For the future, the 2017 Outlook on emissions and air quality (Amann M., Anderl, et al. 2017) does not assume for the baseline case changes in current national practices up to 2030. Thus, without further policy interventions, emissions from agricultural waste burning would remain at current levels. Given

the forthcoming declines in the emissions from other sources, this will increase the relative share of agricultural waste burning in total emissions of PM2.5.

3.2 Options for reducing emissions

3.2.1 Banning open burning of agricultural residues

EU-wide legislation that bans burning of agricultural waste has been defined in the framework of the so-called cross compliance of the CAP (Council Regulation (EC) No 1306/2013)[3]. In practice, quitting the practice of waste burning requires new forms of managing the remaining organic substrate. The easiest option is to remove it mechanically by ploughing under. It has been argued that crop residues remaining in soil are beneficial for soil quality as they bring in nutrients (N, P) that otherwise might get lost, and they replenish soil carbon. The incentive to do so may however differ strongly by country, depending on soil type and quality, climate factors, crop type (permanent crops vs. annual crops), and even availability of equipment (Stan et al. 2014). Also, bans may require monitoring mechanisms to be provided.

Net costs of a ban are considered negligible, as the advantages to soils are assumed to balance costs for training of farmers (to provide alternatives, also for pest control, and to explain the advantages of these alternatives), inspection, and machinery and man power for ploughing under.

As many Member States have implemented the ban of burning of agricultural residues following Community legislation (Figure 3-3), there is ample practical experience, including effective enforcement.

For instance, bans are in place in France, with derogations for agronomic or sanitary reasons, which has led to a reported decline in emissions of 25% between the years 2000 and 2005. Effective enforcement is critical. In France, the ban has been included in the farmers' obligation to maintain 'Good Agricultural and Environmental Conditions', for which violations result in reductions of direct payment to farms under the Common Agricultural Policy (Desjeux et al., 2007). However, an official inter-ministerial letter (République Française, 2011), referring to the stakeholder process of the Grenelle Environment Forum, insists on an improved enforcement of the existing ban, which could reduce PM2.5 emissions from this source by another 30%. Also, vine shoots (and sugarcane in French overseas areas) should be considered.

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[3] http://data.europa.eu/eli/reg/2013/1306/oj

4 Mineral fertilizer use

Mineral fertilizer contains the plant nutrient Nitrogen (N) in different chemical forms. Ionic forms of nitrogen that are soluble in water (ammonia, nitrate) or compounds are available to plants, as they can be easily converted. Typical fertilizers are (i) ammonium- or nitrate based salts, and (ii) urea, a safe compound rich in Nitrogen (46%), which can be easily produced and transported as a solid granulate. Outside Europe, when the necessary infrastructure like pressurized tanks exist, also anhydrous ammonia is used.

Especially urea is quickly converted into ammonia in the farming environment by way of the ubiquitous bacterial enzyme urease, a process that releases considerable ammonia into the air. Typically, between 5% and 40% of the nitrogen is lost as ammonia, compared to 0.5% to 5% for ammonium nitrate fertilizers (Misselbrook et al., 2014; EEA, 2016). Emissions are influenced by application type (common method is surface broadcast application), soil type (high pH soils trigger ammonia release), and soil humidity or rainfall after application that reduce the release (Buijsman et al., 1987).

The choice of fertilizer type is influenced by crops and soil quality, but mostly by prevailing agricultural practices and infrastructure available in specific countries. Southern and Eastern European countries, as well as Germany and UK, have higher shares of urea in their fertilizer mix.

4.1 Relevance of the emission source

According to the latest national emission inventories (http://www.ceip.at/), application of mineral fertilizer contributed approximately 20% to total NH_3 emissions in the EU-28. The independent estimate conducted for the GAINS model result in similar numbers (Figure 4-1).

However, there are large differences across countries, both in the national reports and in the GAINS estimates. Mineral fertilizer use is a substantial source of NH_3 emissions in France, Croatia, the Czech Republic, Germany and Lithuania, where it contributes close to or more than 25% to total emissions. GAINS estimates suggest this also for Bulgaria, although the national inventory does not report such figures[4]. In contrast, fertilizer application accounts for less than 10% in Austria, Denmark, Finland, Cyprus and Malta.

It is interesting to note that urea, while only providing 18% of the fertilizer nitrogen, causes 50% of NH_3 from mineral fertilizer application. It is estimated that more than 70% of EU emissions are caused by urea application in Germany, Croatia, Italy, Poland, Slovenia, Ireland and Estonia (see Figure 4-1).

For the future, the 2017 Outlook on Emissions and Air Quality anticipates, based on the projections of agricultural activities of the PRIMES/CAPRI 2016 REFERENCE scenario, only a slight decline of NH_3 emissions from mineral fertilizer use, unless action to change current practices is taken.

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[4] GAINS estimates are based on default emission factors (EEA, 2016) and consumption of mineral fertilizer consistent with the Bulgarian national reports to the UNFCCC (CRF tables)
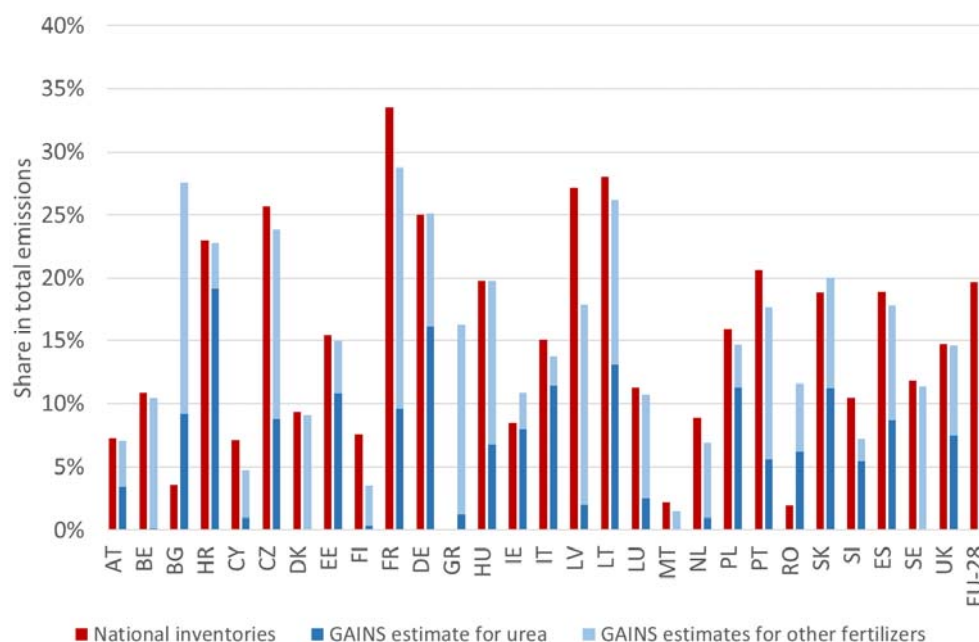
FIGURE 4-1: CONTRIBUTIONS OF MINERAL FERTILIZER APPLICATION TO TOTAL NH$_3$ EMISSIONS IN 2015

4.2 Options for emission reductions

Any reduction of emissions from mineral fertilizer application must avoid situations that favour the release of this compound, i.e., broadcasting under dry and warm conditions, and at high soil pH or low cation exchange capacity (Buijsman et al., 1987). Guidance documents (Misselbrook et al., 2014) on ammonia abatement include practical means, such as incorporating fertilizer into the soil (either through closed-slot injection or by cultivation) through irrigation immediately after application, slow-release coating, and urease inhibitors[5].

4.2.1 Increasing Nitrogen Use Efficiency

Following the definition of OECD (2008), Nitrogen Use Efficiency (NUE) is the ratio between nitrogen contained in a useful product divided by total N input. With ammonia emissions primarily depending on the amount of fertilizer applied, any reduction in nitrogen application also reduces emissions.

As a consequence of factors like concern for drinking water (nitrates directive) and nature protection (Natura 2000), European regulations are now limiting the maximum amount of fertilizer application and influence recommendations provided by extension services. In the EU-28, a long-term trend of declining fertilizer application is observed (more than 20% between their maximum in 1988 and 2014 according to FAOSTAT statistics on 'Nitrogen fertilizers'). While this change clearly reflects progress in reducing environmental impacts, it is rarely considered in relation to NH$_3$ emissions.

In the EU, nitrogen use efficiency (NUE) increased from 51% to 59% between 1990/92 and 2002/04 due to a variety of factors (OECD, 2008). However, despite these improvements, still on average more than 40% of the fertilizer applied to the environment is lost, which also represents a financial loss.

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[5] Approved urease inhibitors have been listed by the European Union (Commission Regulation (EC) No.1107/2008)

Therefore, methods to improve NUE have been a priority in agronomic research (Hierel et al., 2007). In essence, all of these methods aim at better targeting mineral fertilizer according to plants' needs, such that it is available at the time and place where plants can assimilate it. Also, proper accounting of manure (see next section) and regarding it as a nutrient resource can serve to minimize fertilizer application and hence ammonia emissions.

A practical approach to increase nitrogen use efficiency is precision farming. Precision farming relies on the optimised management of inputs onto a field considering the actual crop needs. This is in contrast with the traditional practices where fertilizers, water (irrigation), and pesticides are uniformly applied evenly across the field, ignoring any variability. Precision farming involves data-based technologies, including satellite positioning systems like GPS, remote sensing and the Internet, to manage crops and reduce the use of fertilizers (and increase nutrient use efficiency), pesticides and water.

The European Commission supports precision farming, as it could play a substantial role in meeting the increasing demand for food while ensuring sustainable use of natural resources and the environment (JRC/EU, 2014). Potential measures include site specific nitrogen management using sensors and VRA, automatic guidance system to reduce overlap, and controlled traffic farming minimizing soil compaction by using defined lanes for heavy machinery (Tavella et al., 2010).

For example, variable rate application (VRA) can improve N efficiency by 10-15% without impact on crop yield, with economic savings from reduced nitrogen fertilizer need; however, benefits of precision farming will strongly depend on local conditions (crop type, area, geographic regions) and on the efficiency of the reference/starting conditions.

Automatic guidance systems are already accepted technology, and their use keeps increasing. Costs are lower than those of other precision farming techniques, and benefits are well understood as they directly lead to lower input of seeds, fertilizers, chemicals, fuels, and labour, and might as well as increase yield.

The Dutch government is supporting precision farming in a number of ways. It allocated recently 1.4 million € for purchasing and processing satellite data to improve sustainability and efficiency of farming. This goes along government subsidies of 2 million € for the Dutch National Testing Ground for Precision Farming (NPPL) project[6].

There are, however, a few critical aspects and limitations with respect to precision farming. Profitability of precision farming depends on farm size as some of the equipment requires rather high investments. Fertilizer savings alone have been considered insufficient to trigger implementation of this technology (Auernhammer, 2001). On the other hand, some systems, for example global navigation satellite systems (GNSS), were quickly adopted by farmers of all sizes in the Netherlands, and currently about 65% of farmers use it, compared to 15% in 2007. Other important limitations include insufficient standards for data exchange between systems, lack of independent advisory/consultancy services, underdeveloped guidance and quantifications of environmental benefits, and incomplete knowledge of the causalities and determinants of yield.

4.2.2 Urease inhibitors

Urea fertilizers release much more nitrogen to the atmosphere in form of ammonia than other fertilizers – typically around 15%, which warrants attention for this source. Some European countries

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[6] https://joinup.ec.europa.eu/document/dutch-government-publishing-open-satellite-data-improve-agricultural-production-dutch

traditionally use a high share of urea, and due to low costs and partly also security considerations the share of urea in the overall fertilizer mix tends to increase (Rösemann et al., 2017).

Urea per se is taken up by plants only after conversion to ammonia via the enzyme urease. Ammonia dissolves in water and enters plant root systems in the form of an ammonium ion. Urease as an extracellular enzyme is ubiquitous, and allows the conversion process to proceed within a few hours, creating locally enhanced ammonium concentrations and consequently considerable emissions.

However, fertilizer companies have developed urea fertilizers coated with certain chemicals that are able to suppress the activity of urease. These urease inhibitors significantly slow down the formation and release of ammonia, so that no excess concentration leading to its emissions into the gas phase will occur, while formation will still suffice to supply the plants (Pasda et al., 2016). Urease inhibitors, slow-release coating, or the substitution of urea by ammonia nitrate, allow for emission reductions in the range of 30 – 90%. (Misselbrook et al., 2014).

Ready-mixed fertilizers with urease inhibitors are on the market, which reduce nitrogen losses and subsequently NH_3 emissions by up to 95%[7] compared to the reference application method (surface broadcast). For farmers, the handling is identical to that of standard urea fertilizer. Additional costs charged by producers are compensated by savings from lower fertilizer need and potential yield increases. Leading producers own patents to this product.

4.2.3 Other methods for fertilizers

A number of other approaches have been demonstrated to reduce ammonia emissions from application of nitrogen fertilizers (Misselbrook et al., 2014). Incorporation into the soil (either by closet-slot injection or cultivation) can effectively reduce nitrogen losses, and its efficiency will depend primarily on the depth of injection and soil texture. This approach can be also combined with other reduction options such as urea with slow-release coating or applying urea during seeding operations. Both would lead to saving time and money for the farmer. Another option is immediate irrigation after the fertilizer application. While this option offers high mitigation potential (up to 70% emission reduction), it is limited to areas where there is a need for water irrigation as otherwise risk of nitrate leaching increases.

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[7] https://agriculture.basf.com/en/Crop-Protection/Limus.html

5 Manure management

5.1 Relevance of the emission source

A large portion of the human influence of the global nitrogen cycle serves to supply domestic animals. As an important constituent of protein, nitrogen is needed to stimulate animal growth and product derived from animals, e.g., meat, milk, eggs and fibres. Animal feed is rich in nitrogen compounds (normally plant protein), which are excreted in faeces as part of the normal metabolism and converted into urea in the urine of animals. Urea easily transforms into NH_3 in the presence of the enzyme urease, and also organic nitrogen compounds can mineralize to yield ammonium ions, both emitted to the atmosphere. These conversion processes are well understood and have been quantified based on a large body of experimental data.

5.1.1 Share of emissions in total

Based on a wealth of scientific literature providing quantitative information on NH_3 emissions from animal husbandry during the different stages of manure treatment, i.e., housing, storage of manure, field application of manure, grazing (e.g., Buijsman et al. (1987), Monteney and Hartung (2007), appropriate emission factors have been developed and adopted in emission inventory guidelines (EEA, 2016).
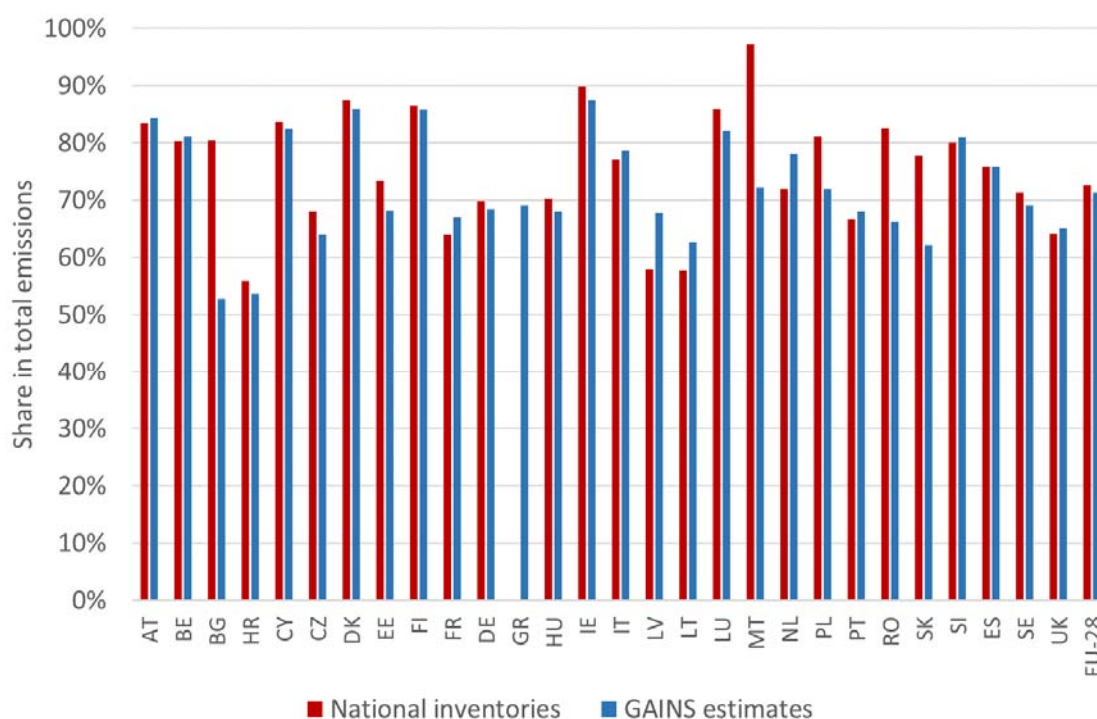
FIGURE 5-1: CONTRIBUTIONS OF LIVESTOCK FARMING INCLUDING MANURE MANAGEMENT TO TOTAL NH_3 EMISSIONS IN 2015

Based on this data, about 75% of all NH_3 emissions in the EU-28 are caused by livestock including manure management. This dominating share occurs in all Member States, and in particular in countries which apply higher Tier methodologies for estimating agricultural emissions (Figure 5-1), in which cases there is rather good agreement with the independent GAINS estimates. Differences across countries

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exist, but are less striking than for the other sources, and to some extent explained by different calculation methodologies.

There are large differences across Member States in the shares of emissions caused by different farm sizes. According to EUROSTAT data (Figure 5-2), a large portion of all animals is kept on large farms. For the EU-28, only 4% of all farms (with and without animals) house more than 50 livestock units (LSU), although this share varies widely across Member States. For instance, the largest farms with more than 500 LSU represent 7% of all farms in Denmark, while less than 0.1% in 11 other Member States, most of them in Central and Eastern Europe.
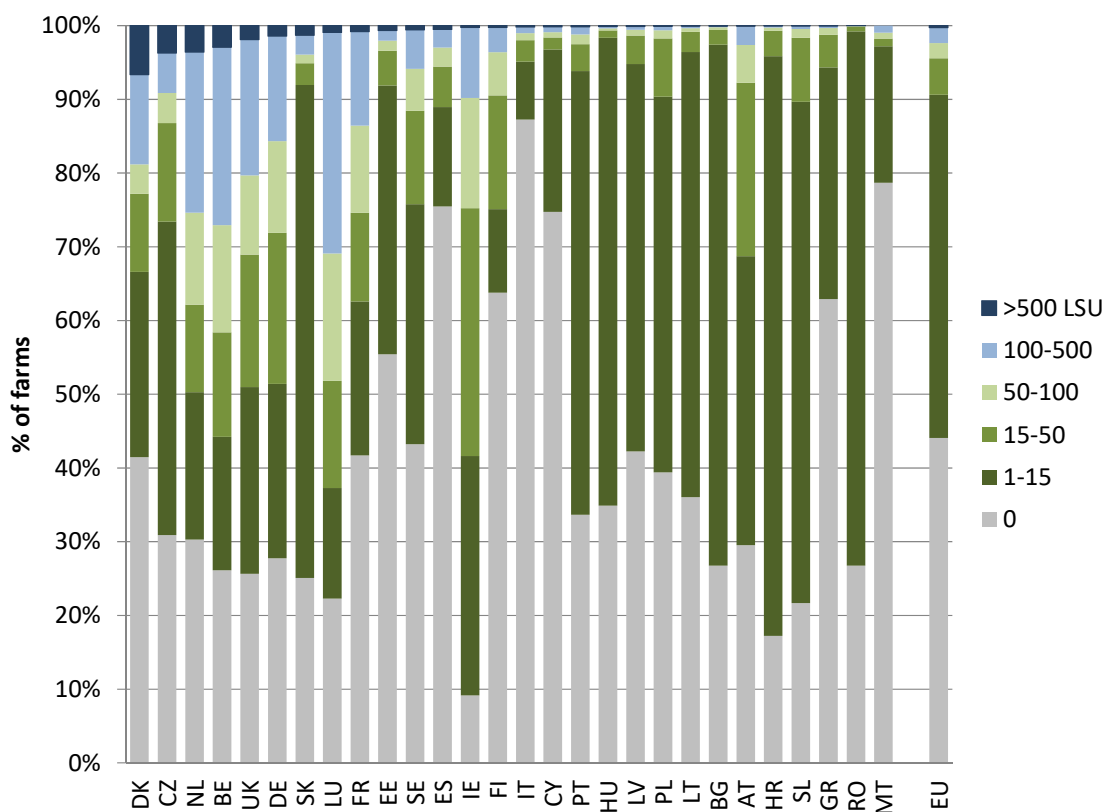
FIGURE 5-2: DISTRIBUTION OF FARM SIZES BY LSU IN 2005. ZERO LSU REFERS TO ARABLE FARMS WITHOUT ANIMALS.

This has direct impact on emissions: the largest farms (more than 500 LSU), representing about 0.3% of all farms, produce manure that releases about 22% of NH_3. 78% of all emissions were caused by manure from about 4% of all farms, i.e., farms with more than 50 LSUs (Figure 5-3). Again, there are striking variations across Member States, reflecting the different structures of the agricultural systems in the EU.
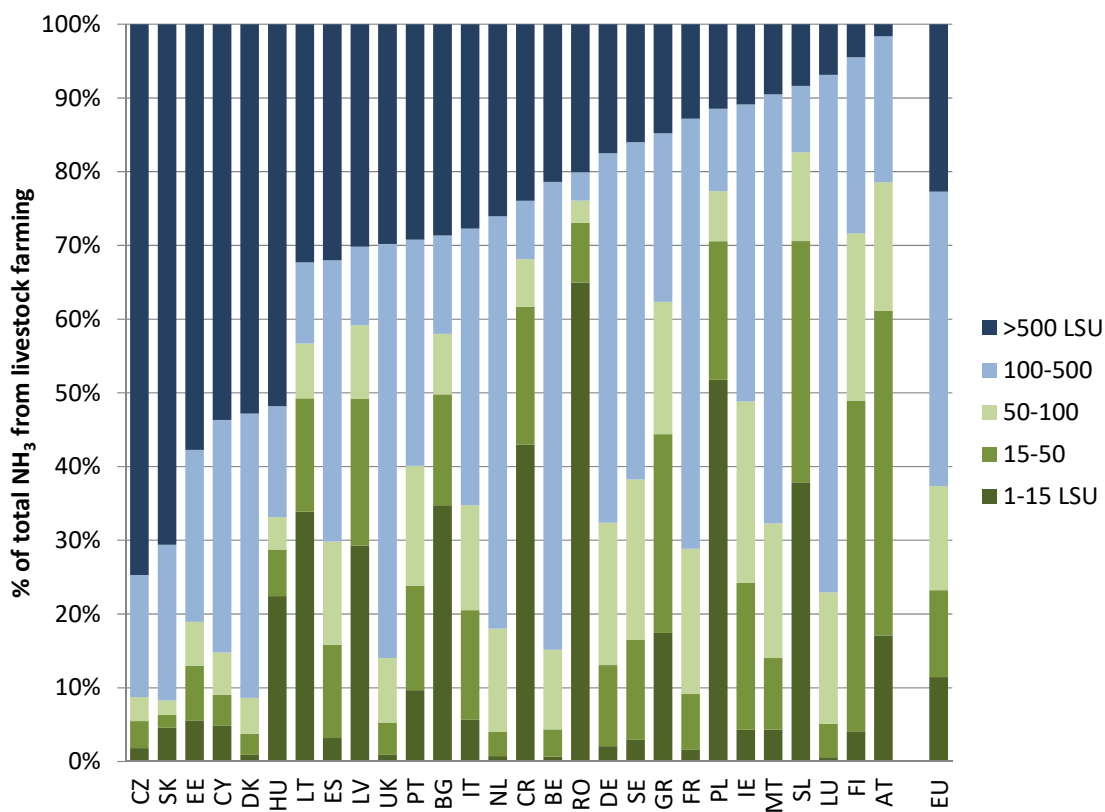
FIGURE 5-3: CONTRIBUTIONS FROM DIFFERENT FARM SIZES TO TOTAL NH₃ EMISSIONS FROM LIVESTOCK FARMING (2005)

Emissions from livestock farming occur during different stages in the manure management chain. In the EU-28, over 6% of NH₃ emissions from livestock farming occur during the grazing of animals, about 39% and 37% from animal housing and manure application, respectively, and almost 18% from manure storage (Figure 5-4).

FIGURE 5-4: NH$_3$ EMISSIONS FROM LIVESTOCK FARMING EMERGING DURING THE DIFFERENT STAGES IN THE MANURE MANAGEMENT CHAIN

5.2 Options for emission reductions

There are a number of practical options to reduce emissions from manure management, many of them applied at large scale in some, but not all, Member States. These include measures that reduce emissions during the individual stages of manure management, i.e., during grazing, fr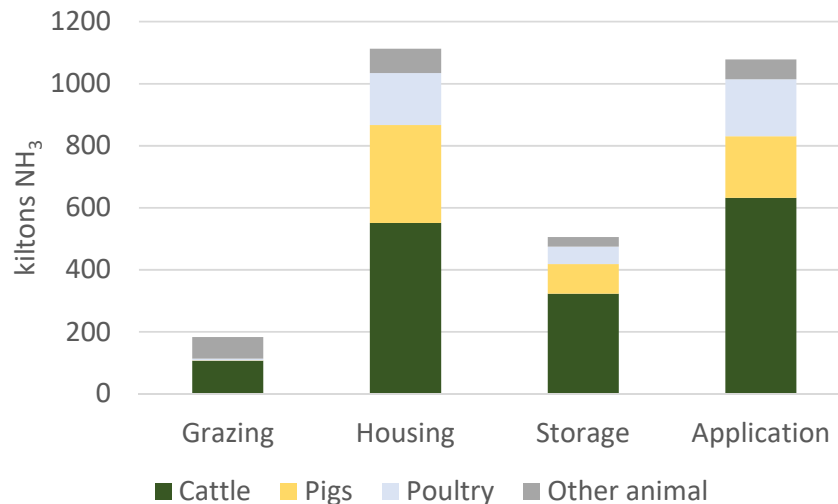om animal housing, manure storage and manure application, as well as integrated manure management plans that optimize overall emissions from the entire chain. However, it is important to realize that reducing animal housing emissions and covered storage will increase the nitrogen content of manure and will increase unabated ammonia emissions from manure application. In an integrated nitrogen management approach, low emission application techniques are important as well as replacing chemical fertilizers by 'organic' fertilizer and reducing the nitrogen content of feed.

Information on the effectiveness of emission control measures and their costs is well-documented (Bittman et al., 2014; Oenema et al., 2014; Groenestein et al., 2014; Amon et al., 2014; Webb et al., 2014; Reis et al., 2015).

5.2.1 Measures addressing individual stages

5.2.1.1 Extended grazing

Extending the grazing period could significantly reduce NH$_3$ emissions of cattle, because of lower direct emissions of animals on pasture compared to animals kept indoor. Shorter housing periods will not only reduce emissions from housing, but also from the subsequent storage and application of manure since less manure has to be managed. Emissions from housed dairy cattle and other cattle and the from subsequent manure management chain are typically more than an order of magnitude larger than from grazing. Provided availability of proper land, emissions are lowest from 24-hour grazing system. Otherwise, surface areas soiled with manure in the animal houses will continue to emit, e.g., during daytime when cattle houses are left empty for grazing (Groenestein et al., 2014). Subsequent emissions from manure storage and application will be lower in all cases.

5.2.1.2 Optimized animal feeding

Farm animals receive protein in their feed, part of which finds its way into useful products (meat, milk, eggs) while the remainder is excreted and remains in the manure. Reducing nitrogen in the manure by optimizing feed to the livestock's need improves nitrogen use efficiency, and at the same time decreases emissions during all subsequent stages of the manure management chain. Adequate protein contents of feed have been listed by Oenema et al. (2014). Optimized feed or phase feeding (adjusting protein levels to the growth stage of animals, typically pigs) are possible techniques. Costs of adjusted feed including amino acid supplementation that may become necessary, depending on circumstances and feed price levels, range from potential net gains to small net costs (Oenema et al., 2014).

5.2.1.3 Treatment of exhaust (ventilation) air

For systems that require forced ventilation (typically pig and poultry houses, but rarely cattle), exhaust air can be treated via a filtration device (Figure 5-5 provides a general concept). Air scrubbers are designed to reduce PM10 emissions (and associated endotoxins), ammonia, and odour. They employ different devices for different compounds, like fabric filters for dust, bio-filters for odour, and chemical filters for ammonia (often using sulphuric acid as collecting substrate). The most advanced chemical air scrubber system reduces NH_3 emissions from pig houses by 95% compared to an unabated situation (Vonk et al., 2016). For poultry houses, removal efficiencies of chemical air scrubbers of 90% are documented.
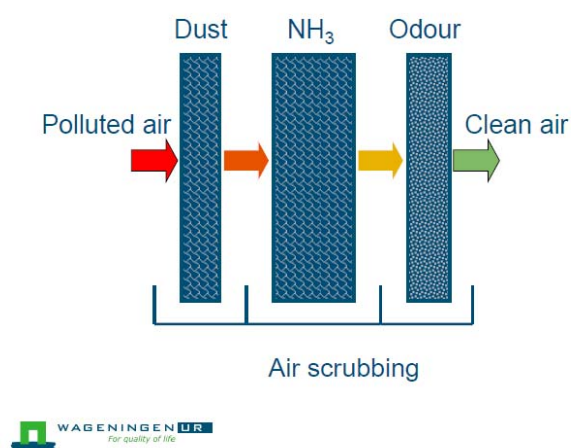
FIGURE 5-5: AIR SCRUBBING (SOURCE: C.M. GROENESTEIN WUR)

There is considerable experience in the Netherlands with air scrubbers in animal houses. Clean animal housing alone proved to be insufficient for protecting Natura2000 areas and to meet the obligations under the Bird- and Habitat Directive, i.e., to take 'appropriate measures to maintain and restore habitats to a favourable conservation status'. Since 2015, air scrubbers are required for permits of new animal houses or for the extension of existing houses in the vicinity of Natura2000 zones. For existing farms and farms in other areas, maximum emission standards should be met at the company level. Farmers can choose to replace traditional houses (built before 2007) with low emission houses.

Although ex-ante cost estimates suggested costs of air scrubbers (per kg ammonia reduced) to be more than five times higher than costs of manure injection (see below), the measure was accepted in the Netherlands in order to allow for further agricultural development (de Haan et al, 2009). However, initially, air scrubbers were not always operated in practice due to high operating and maintenance

costs. Advanced ICT technology made it possible for inspectors to confirm the actual operation of scrubbers, and thereby to enhance the enforcement of the regulation.

As an economic side-effect of the high costs of air scrubbers, holding pigs and poultry in small sized farms (less than 1000 pigs or less than 10.000 chicken) became less profitable, which contributes to accelerating the further increase in farm sizes including the development of mega-sized farms.

It is estimated that by 2030 this measures would reduce NH_3 emissions in the Netherlands by about 10 kiloton NH_3, i.e., about 20% of the current emissions from animal housing (Jimmink et al, 2017; Sterkenburg and van Alphen, 2017). Despite the recent nature of the legislation, by 2015 almost 40% of the pig farms in the Netherlands had installed an air scrubber, although this is not yet reflected in the official emission inventory.

5.2.1.4   Storage of manure

Emissions from manure storage make up to 18% of total emissions from manure management in 2015, according to GAINS. Klimont and Winiwarter (2011) describe covering manure stores among the more cost-effective ways to reduce ammonia emissions. Measures basically reduce exposure of manure to the atmosphere by a cover layer. In more efficient and more costly systems this can be a hard lid, less efficient but much cheaper are floating covers like plastic films, zeolite, light expanded clay aggregates (LECA®) balls, straw or woodchips, or just crust formation of the top manure layer. Covering manure is also a recommended technique according to guidance given by the UNECE Task Force on Reactive Nitrogen (Amon et al., 2014).

Covered manure storage is used in national strategies as an element of integrated ammonia management, or as one of several options specifically mentioned for emission reduction. The use of covers is explicitly mentioned in the NEC Directive (EU 2016/2284), singling out those systems which deliver emission reductions of 60% for new stores built after 2021, and 40% reductions for existing stores, following the above-mentioned UNECE guidance. In national approaches, covered storage finds explicit mention wherever emission assessment of individual farms is supported with models (e.g., Switzerland, www.agrammon.ch)

5.2.1.5   Manure injection

There are several ways to reduce ammonia emissions from manure application, all of them lowering the exposure of manure to the atmosphere. Manure can be applied very close to the surface (by means of trailing hose or trailing shoes), but more effective is the direct incorporation of either slurry or solid manure. Methods that directly insert manure into the soil can reduce emissions even further.

Highest efficiencies are achieved by deep injection, i.e., the application of slurry by placement in deep, vertical slots, typically about 150 mm deep, cut into the soil by specially designed tines. While in principle this could reduce emissions by up to 95%, proper application practices are important, and typically efficiencies of 80-85% are documented (Jimmink et al, 2017). Poor application could reduce the efficiency to less than 50% (de Haan et al, 2009) (Figure 5-6). Deep injection is applied in the Netherlands on two thirds of arable land.

Sod injection, i.e., the application of liquid manure by placement in bands with a slit cut into the soil beneath the bands using trailing shoes, reduces NH_3 emissions by 30-60%. This is comparable with the effectiveness of direct ploughing.

Ploughing in a second track could remove 0-30%, depending on the number of hours between the tracks. However, in the Netherlands, ploughing in a second track is forbidden since 2008.
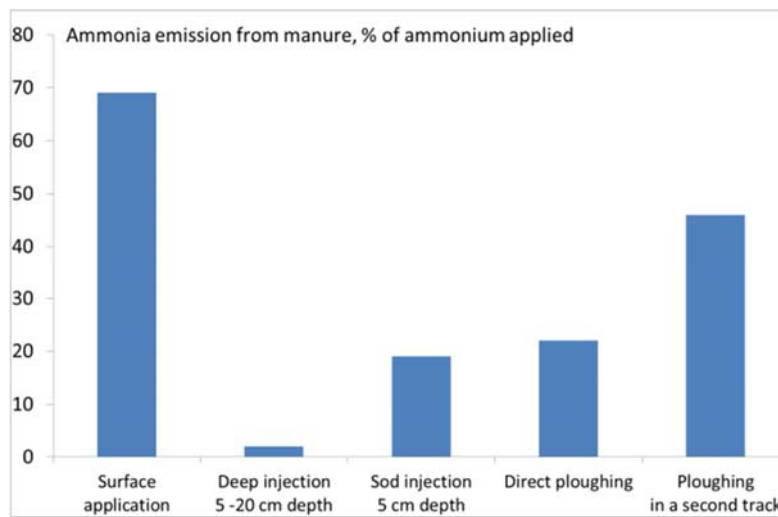
In the Netherlands, there is currently a debate to allow for certain farm types the surface spreading of manure with added water. This could reduce ammonia emissions by up to 50%, although the efficiency is strongly dependent on proper practices, which are difficult to enforce (de Haan et al, 2009). The UNECE (Webb et al., 2014) recommends dilution with water only in connection with irrigation.

The introduction of low emissions manure injection has created a new economic sector in the Netherlands. Instead of buying their own manure injection equipment, farmers now outsource this task to specialized companies. This contributed to a shift in employment from family-run farms to larger contractor firms. Also, the relatively high costs for small-scale farmers contributed to a further increase in farm sizes of the remaining farms. However, social impacts were limited as this development coincided with a growing lack of family successors that is experienced by many farmers.

In the Netherlands, low-emission manure spreading has reduced ammonia emissions from application by about 80% since 1990, so that this measure delivered the largest contribution towards meeting the national emission ceiling for 2010 (128 kt). Adverse impacts, such as damage to the soil structure and harmful effects on soil organisms and the meadow bird population are limited, temporary or could not be clearly demonstrated (de Haan et al, 2009).

Outside of the Netherlands, experience with manure injection is limited. Denmark reports that since the late 1990 the practice of slurry injection or mechanical incorporation into the soil has increased (Nielsen et al., 2015). This is done in combination with slurry acidification (see section below) to which more efforts are directed. Other countries refer to the less advanced application techniques (see specific sections on Germany and Switzerland below).

5.2.1.6 Slurry acidification

Lowering the pH of manure will have two effects that both reduce ammonia emissions. At higher acidity, (i) bacterial urease formation is inhibited, which reduces the conversion rate to NH_3, and (ii) any ammonia formed is protonated to NH_4^+, which strongly decreases volatility (*Jensen*, 2002). In the

scientific literature, acidification has been proposed using organic acids like lactic acid, which could be the result of an anaerobic fermentation process. Considerable amounts of sugar (e.g., glucose) are needed for adequate acid formation, such that the addition of inorganic acids proved to be more viable. Here it is sulfuric acid which finds practical application. Manures can be acidified directly in the pits of animal houses, during storage or during application.

Acidification of slurries, particularly with sulfuric acid, has been implemented successfully in Denmark, where application on 125 farms has been reported (Webb et al., 2014). Due to the large body of evidence collected from different experimental settings in Denmark, this abatement option is recommended in the Guidance from the UNECE Task Force on Reactive Nitrogen (Groenestein et al., 2014), despite reservations due to the hazards involved in handling strong acids at the farm.

While adding acids at the beginning of manure management chain, i.e., in the pits of animal houses, would maintain a neutral or low pH and low emissions throughout the process, most practical applications add sulfuric acid only at the final step, i.e., before application of manure. This minimizes practical impacts to established procedures while affecting at least this emission-intensive stage. Danish studies claim that, under national soil conditions, adding sulfur is to be considered beneficial.

Today, slurry acidification forms a key element of a very active abatement policy in Denmark. About 10% of cattle manure (and 4% of total manure) is treated, and emissions are considered to decrease by 50 - 60% where applied (Nielsen et al., 2015; Webb et al., 2014). The successful implementation suggests that costs do not emerge as a practical obstacle, even while no detailed cost estimations have been included in the guidance of the Task Force on Reactive Nitrogen (Webb et al., 2014).

Also, emission reductions for the application stage have been accounted for in the Danish national emission inventory. Reported emissions of NH_3 from agricultural sources declined by 44% between 1985 and 2013 (Nielsen et al., 2015), although other measures, including improved phase feeding, have contributed to this decline as well.

Using Danish emission factors, Geels et al. (2016) explored the potential impacts of adopting slurry acidification throughout Europe. Extrapolating emission changes to atmospheric concentrations and health impacts using atmospheric dispersion and impact models, the authors estimated that premature deaths due to air pollution could be reduced by six percent in Europe. However, this analysis did not factor in different local soil and climate conditions that could limit the application potential.

5.2.2 Integrated manure management plans

A balanced combination of medium-cost measures could effectively reduce overall NH_3 emissions from the total feeding-housing-storage-application chain while potentially avoiding the most expensive measures. Such an approach would aim to reduce nitrogen input, and prevent compensation of ammonia reductions at early stages (e.g., through low-emission houses) by higher emissions during subsequent storage and application phases. In particular, low protein feed for dairy cows, pigs and poultry and extended grazing periods for cattle could play important roles. Also, such integrated manure management strategies that minimize emissions from storage and application could potentially avoid costly technical measures, e.g., to control emissions from housing. For liquid manure systems, such strategies could consider tight manure storage and efficient (low emission) application of manure with deep injection where this is applicable. For solid manure systems, stricter requirements to rapidly incorporate solid manure into soils (within a few hours after application on land) could be considered. Obviously, all these measures are subject to the specific technical and physical limitations for their application (e.g., steep slopes for manure application techniques, minimum farm sizes, the maximum

potentials for new housing on larger farms where simultaneously low emission (closed) storage tanks are constructed and manures are efficiently incorporated into the soil).

The following sections provide brief summaries of national strategies that aim at an integrated approach for managing emissions from livestock farming.

5.2.2.1 Germany - The National Nitrogen Reduction Strategy

While still under development, cornerstones of a German Nitrogen abatement strategy have been officially adopted in the first Nitrogen-Report of the German Federal Government[8]. This report responds to the German international obligations under the Nitrate and NECD Directives to reduce nitrogen loads to groundwater and to the atmosphere, respectively. With non-compliance to the Nitrate Directive becoming a case at European courts[9], a new fertilizer application ordinance was issued per May 26, 2017. The additional international requirements (under the new NEC Directive Germany is obliged to reduce ammonia emissions in 2030 by 29% compared to 2005) may have played less of a role here.

Together with an updated fertilizer law, which governs implementation and enforcement, the ordinance is seen as a cornerstone to balance ecological needs and agronomical requirements[10]. Most critically, the ordinance limits the nitrogen surplus in agriculture due to fertilizer application to 60 kg/ha, aiming for 50 kg/ha in 2020. Also the timing of fertilizer application will be regulated, especially limiting fall application. Incorporation of manure in soil on unworked cropland must be conducted within four hours, or at least trailing shoes must be used for applying liquid manure on sown cropland or grassland. Also, urea fertilizer needs to be incorporated unless treated with urease inhibitors.

The expected impacts of these new regulations on emissions have not yet been quantified. However, measures refer to those developed by the German Advisory Council on the Environment (SRU)[11], which estimates up to $150 - 200$ kt NH_3 reductions. As only a part of the measures listed by SRU refers to fertilizer application, the ordinance might achieve reductions of about 60 kt NH_3. For comparison, total German NH_3 emissions from manure management were reported at 486 kt for 2015.

5.2.2.2 Netherlands – The 'Integrated Approach to Nitrogen' (PAS) programme

The Dutch PAS '*Programma Aanpak Stikstof*' (Integrated Approach to Nitrogen) programme aims to reduce environmental loads of nitrogen in Natura 2000 areas in order to facilitate better protection of the environment while opening room for further economic development. After a public consultation period in early 2015, an updated report has been published[12]. The programme allows enterprises (farms) to increase their activities provided that new emission abatement measures have been effectively implemented. In an integrated concept, emissions of very different sources (agriculture, industry, transport, energy) and their environmental impacts on substrates are considered.

A modelling tool (AERIUS 2016b)[13] assists enterprises in filing their permits, and results from these model calculations are binding. The tool allows to determine expected impacts of measures on

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[8] Stickstoffeintrag in die Biosphäre - Erster Stickstoff-Bericht der Bundesregierung. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, BMUB, Berlin, 31.5.2017

[9] http://www.umweltbundesamt.de/indikator-nitrat-im-grundwasser

[10] http://www.bmel.de/DE/Landwirtschaft/Pflanzenbau/Ackerbau/_Texte/Duengepaket_Novelle.html

[11] Nitrogen: Strategies for Resolving an Urgent Environmental Problem, Special Report, 2015

[12] *Programma Aanpak Stikstof 2015-2021 zoals gewijzigd na partiële herziening op 17 maart 2017;* Ministry of Economy and Ministry of Infrastructure and the Environment, 17 maart 2017, Publicatie-nr. 100306, Den Haag

[13] https://www.aerius.nl/en

deposition to sensitive habitats and Natura2000 areas, and hence to assess the further space for development (as additional emissions).

Specific actions mentioned in the program, and their expected emission reductions are:

- Introducing and tightening of ammonia emissions limits (in kg per animal place and year) for newly built animal houses, extension or complete reconstruction of the floor – expected reductions amount to 5 kt NH_3 between 2014 and 2030

- Further restricting ammonia emissions from manure application, allowing only for best available technology or similar methods, with trailing shoe to be phased out. Expected emission reductions are 0.5 kt NH_3 in the first phase, 2 kt NH_3 in total.

- Voluntary measures for low protein feeding of cattle and increased grazing, in line with the underlying agreements of the PAS. This is expected to reduce 3 kt NH_3 emissions annually.

In total, once fully implemented, the measures outlined in Annex 4 of the PAS report allow for emission reductions of 10 kt NH_3 per year (out of 95 kt NH_3 emissions officially reported for manure management in 2015); half of this volume is achievable by 2020.

5.2.2.3 Switzerland – The federal concept for air pollution control measures

The 'Concept for air pollution control measures of the Federal Government' of the Swiss Federal Council (September 11, 2009) aims at a reduction of NH_3 emissions by 40% compared to 2005 in order to achieve critical loads for nitrogen deposition, although without specifying a target year.

Recognizing that the majority of NH_3 emissions (95%) derives from agriculture, Switzerland provides financial incentives to investments that allow to reduce emissions. Supported measures include low-emission housing, storage and application of manure, as well as extended grazing as an option to reduce the use of urea fertilizers. Furthermore, integrated abatement over the manure management chain from feeding to application is encouraged. Organized as project bundles and financed jointly by the federal government and the cantons, about a third of the eligible farmers have profited from these supports (https://www.agrarbericht.ch/de/umwelt/stickstoff/ammoniakemissionen).

The Swiss Ordinance on Air Pollution Control[14] requests preventive measures to be taken by authorities. Additional measures are required in case of unsatisfactory air quality. Exceedance is to be assessed from the critical loads approach as there is no concentration threshold. The Swiss Environment Agency (BAFU) provides detailed guidance to harmonize the implementation of regulations on agricultural buildings[15] and for application of plant nutrients[16]. It also provides farmers access to the emission calculation software AGRAMMON[17], which facilitates the calculation of emissions for individual agricultural entities and an assessment of the effectiveness of different emission reduction measures.

Furthermore, the Federal Office for Agriculture supports consulting companies to advise and inform farmers on different topics, such as agricultural innovations, best practices and new legal requirements. A dedicated website (http://www.ammoniak.ch) was put into service, informing on ammonia abatement measures.

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[14] https://www.bafu.admin.ch/bafu/de/home/themen/luft/fachinformationen/massnahmen-zur-luftreinhaltung/luftreinhaltung-in-der-landwirtschaft.html
[15] BAFU und BLW 2011: Baulicher Umweltschutz in der Landwirtschaft, report UV-1101-D
[16] BAFU und BLW 2012: Nährstoffe und Verwendung von Düngern in der Landwirtschaft, report UV-1225-D
[17] http://www.agrammon.ch/

6 Summary

In its Clean Air Programme for Europe (COM(2013)918 final), the European Commission has laid out a comprehensive approach to improve air quality in Europe. The main legislative instrument to achieve the 2030 objectives of the Clean Air Programme is Directive 2016/2284/EU on the reduction of national emissions of certain atmospheric pollutants, which entered into force on 31 December 2016 (the NEC Directive or NECD). This Directive establishes for 2030 emission reductions requirements for the Member States, which imply, *inter alia, f*urther control of emissions from agricultural activities. Especially, there is a clear need to reduce ammonia (NH_3) emissions, which predominantly emerge from livestock farming and fertilizer application, in order to decrease the formation of secondary particles, which constitute an important share of PM2.5 in ambient air. Such reductions would also alleviate the pressure on biodiversity from excessive nitrogen deposition, especially in the Natura2000 nature protection areas. In addition, the enforcement of a ban on the burning of agricultural residues offers a cost-effective means for reducing primary emissions of PM2.5 in several Member States.

In view of the persistent urgency to reduce emissions of NH_3, and PM2.5, this report reviews the perspectives for reducing such emissions from agricultural activities, focusing on (i) the open burning of agricultural residues, (ii) mineral fertilizer application, and (iii) manure management.

While **open burning of agricultural waste** is banned under EU regulation No 1306/2013, numerous Member States report substantial emissions from this category. Remote sensing data indicate under-reporting by some countries, and independent estimates suggest that in 2015 about 3.3% of total PM2.5 emissions originated from this source. Without further policy interventions, the relative share of emissions from agricultural waste burning will increase in the future, given the emission reductions at other sources.

Many Member States have implemented the ban of burning of agricultural residues following Community legislation, providing ample practical experience of successful implementation, including effective enforcement. Net costs of a ban are considered negligible, as the advantages to soils are assumed to balance costs for training of farmers, inspection, machinery and man power for ploughing under.

Application of mineral fertilizer contributes approximately 20% to total NH_3 emissions in the EU-28. However, there are large differences across countries, inter alia, related to the use of urea fertilizers, which result in particularly high NH_3 emissions. Although urea provides only 18% of fertilizer nitrogen in the EU-28, it causes 50% of NH_3 emissions from all mineral fertilizer application. Without further policy interventions, no major changes are anticipated for the future.

There are practical means available to reduce emissions from mineral fertilizer application. First, enhancing Nitrogen Use Efficiency, inter alia through precision farming, will result in lower NH_3 emissions, next to a wide range of other benefits.

In cases where urea cannot be substituted by other forms of mineral fertilizers, ready-mixed urea fertilizers with urease inhibitors are on the market, which slow down the formation and release of ammonia, reducing nitrogen losses and subsequently NH_3 emissions by up to 95%.

About 75% of all NH_3 emissions in the EU-28 are caused by **manure management** from livestock farming. Due to the skewed size structure of agricultural holdings, about 80% of emissions in the EU are caused by 4% of the farms. There are striking variations across Member States, reflecting the different structures of the agricultural systems in the EU.

Emissions from livestock farming occur during different stages in the manure management chain. In the EU-28, about 6% of NH_3 emissions from livestock farming occur during the grazing period, almost 39% from animal housing, 18% from manure storage, and about 37% from manure application. Well-documented experience exists in Member States with measures that control emissions at different stages, e.g., through extended grazing periods, low emission housing including also scrubbing of ventilation air, covered storage of manure, and low-emissions application techniques of manure.

Reducing animal housing emissions and covered storage will increase the nitrogen content of manure and will increase unabated ammonia emissions from manure application. In an integrated nitrogen management approach, low emission application techniques are important as well as replacing chemical fertilizers by 'organic' fertilizer and reducing the nitrogen content of feed. Thus, a balanced combination of medium-cost measures could effectively reduce overall NH_3 emissions from the total feeding-housing-storage-application chain while potentially avoiding the most expensive measures. A number of European countries have established programmes to promote integrated management approaches, which at the same time enhance the economic performance of agricultural firms.

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