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Emissions from agriculture and their control potentials

TSAP Report #3

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Summary

This report reviews recent developments that are potentially relevant for the control of agricultural emissions of air pollutants such as ammonia and particulate matter in Europe.

The principles of current methods and techniques of ammonia emission controls in agriculture have a sound scientific basis that is well proven in practice. No fundamentally new insights and fundamentally new techniques have emerged over the last decade. The known techniques have been applied at a much larger scale in an increasing number of countries, leading to a wider acceptance and becoming part of the good practice, and costs have declined through learning effects, economy of scale, and consideration of synergistic effects. For example, in several countries specialized contractors have taken over some of the activities (e.g., low-emission manure application), which has substantially reduced costs.

More than 90% of all emissions to air of ammonia derive from the agriculture sector. A range of emission control options is now proven to be effective in practice in more and more countries. Many of these measures are cost-effective and have co-benefits for the farmers, especially when additional synergistic effects are considered. Modified animal feeding, covered slurry storages, low-emission manure and urea fertilizer application techniques are examples of such cost-effective means to cut ammonia emissions in many situations. In particular, modified animal feeding can decrease NH_3 emissions from all stages of the animal manure management chain, and, at the same time, decrease N_2O emissions and odour.

In practice, ammonia emission reduction efficiencies and costs of these measures are sensitive against the chosen reference system and depend on local factors, such as weather and soil conditions, differences in management practices and in the technical performances of abatement measures. In many countries, there is limited experience with low-emissions techniques, due to technical, economic and cultural barriers that prohibit their implementation. However, in several cases technological and institutional experience has been successfully transferred between countries, resulting in even higher cost efficiency than originally anticipated.

While cost estimates of low-emission techniques remain uncertain for specific farms due to the inherent variability of important factors across farms, costs tend to be higher on small farms than on large farms. Also, costs tend to be higher in countries with little experience than in countries with lots of experience, due to differences in knowledge and technology infrastructure.

With regard to emissions of particulate matter from agriculture, a ban of open burning of agricultural waste has been common practice in most EU countries.

Nevertheless, remote sensing data indicate variable implementation efficiency which indicates a further potential for emission reductions of particulate matter.

The report points out how many of these new developments have been incorporated into the GAINS integrated assessment model.

More information on the Internet

More information about the methodology of the GAINS (Greenhouse gas – Air pollution INteractions and Synergies) integrated assessment model and interactive access to input data and results is available on-line: http://gains.iiasa.ac.at/TSAP.

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List of acronyms

BREF	Best Available Technology (BAT) Reference document
CAP	Common Agricultural Policy
CLRTAP	Convention on Long Range Transboundary Air Pollution
CRF	Common reporting format
EC	European Commission
EDGAR	Emissions Database for Global Atmospheric Research
EU	European Union
EU-27	27 Member States of the European Union
EUROSTAT	Statistical Office of the European Union
FAO	United Nations Food and Agriculture Organization
GAEC	Good Agricultural and Environmental Condition standards
GAINS	Greenhouse gas – Air pollution INteractions and Synergies
GFED	Global Fire Emissions Database
IPPC	Integrated Pollution Prevention and Control
LECA	light expanded clay aggregates
LSU	Livestock Unit (standardized animal unit to compare different species)
N	Nitrogen
N_2O	Nitrous oxide
Natura2000	Network of protected areas in the EU
NH_3	Ammonia
NIR	National Inventory Reports
NUE	nitrogen use efficiency
NVZ	Nitrate Vulnerable Zone
PM10	Particulate matter, aerodynamic diameter less than 10 µm
PM2.5	Particulate matter, aerodynamic diameter less than 2.5 µm
TAN	Total ammoniacal nitrogen
TFRN	UNECE Task Force on Reactive Nitrogen
TSP	Total Suspended Material (particulate matter)
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nation Framework Convention on Climate Change

1 Introduction

1.1 Sources and impacts of ammonia emissions

Ammonia (NH_3) can be released into the atmosphere from basically all ammonium containing products. Livestock and especially animal manures are the most important sources of NH_3 emissions in EU-27, followed by the application of mineral nitrogen fertilizers. Hotspots of NH_3 emissions are found in regions with high animal densities, both in intensive production systems with housed animals such as in the Po Valley (Italy), in Denmark and the Netherlands, as well as in regions with a predominance of grazing animals such as in Ireland (Figure 1.1). Household waste, industrial production and fuel combustion are minor sources.

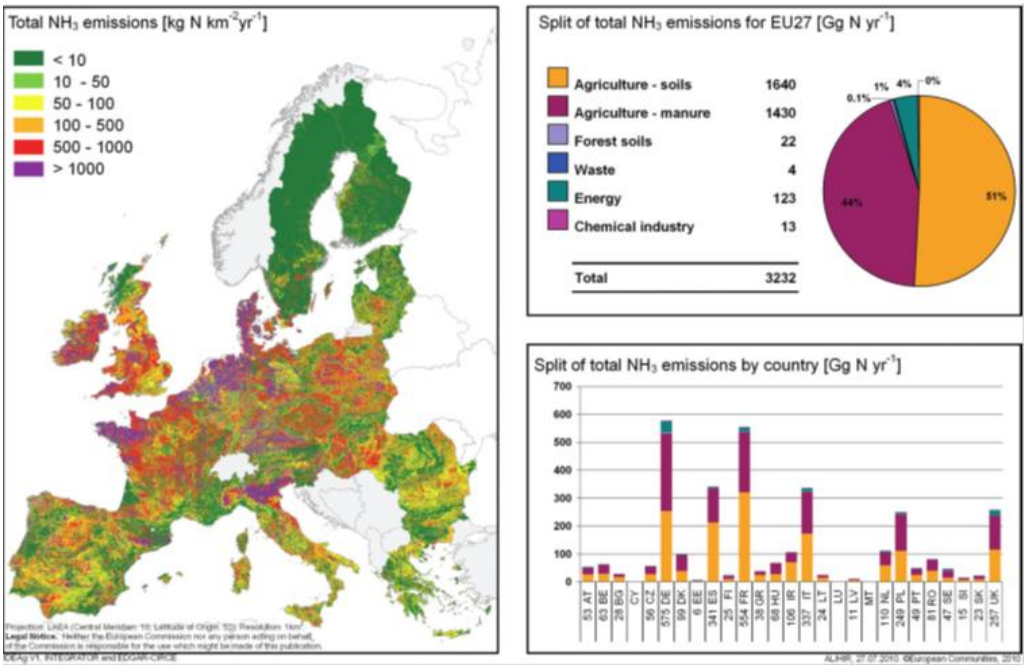

Figure 1.1: Total NH_3 emissions in the EU-27 around the year 2000 from terrestrial ecosystems, industry and waste management (Leip et al., 2011)

Ammonia can be released during various stages of the animal production and animal manure management chains (Figure 1.2). Emissions may occur from (i) animal feed (mainly silage productions), (ii) animal manure excreted in housing systems and in pastures, (iii) animal manure in storage systems, and (iv) from animal manure applied to crop land. In addition, ammonia emissions may occur from fertilizer application (especially from urea- and ammonium-based nitrogen fertilizers).

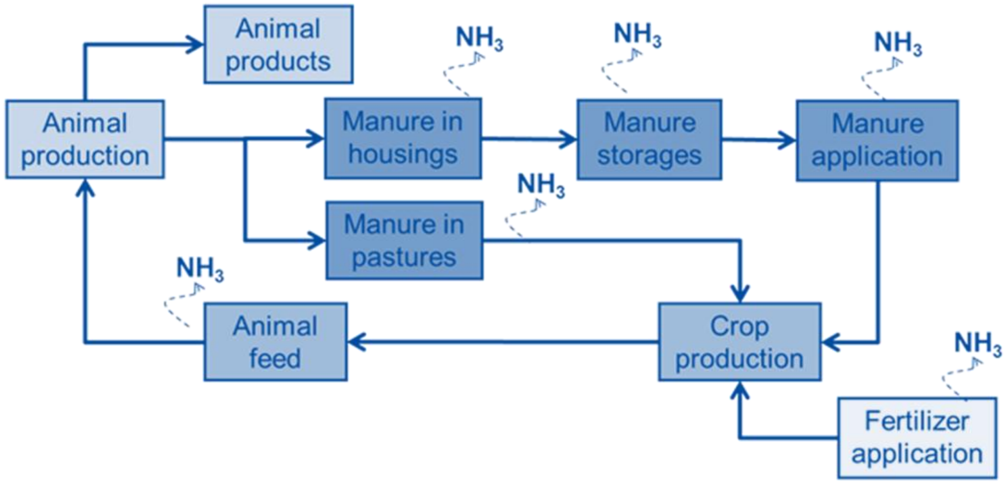

Figure 1.2: Key sources of ammonia emissions in the various steps of the livestock production and animal manure management chains

Ammonia emissions are of concern because deposition of NH_3 can cause acidification of soils (Van Breemen et al., 1983) and eutrophication of natural aquatic and terrestrial ecosystems. This results in loss of biodiversity (Bobbink et al., 1998). In addition, NH_3 is a precursor for secondary particulate matter (PM2.5 and PM10) in the atmosphere (Erisman and Schaap, 2003), which has adverse effects on human health (Moldanová et al., 2011). NH_3 is also an (indirect) source of nitrous oxide (N_2O), a potent greenhouse gas.

The Gothenburg Protocol of the UN Convention on Long-range Transboundary Air Pollution (UNECE, 1999) and the EU National Emission Ceilings directive (EC, 2001) have set limits to national total NH_3 emissions. Countries have to report their NH_3 emissions to the UNECE and the European Commission. Moreover, countries have to report their NH_3 emissions, as a basis for their N_2O emission inventory, to the UNFCCC.

1.2 Options to reduce NH_3 emissions

There exist various ways to control emissions of NH_3, depending on the sources of NH_3 emissions. Calculations with the GAINS model show that the specific measures suggested in the Draft Annex IX that has been prepared for the revision of the Gothenburg Protocol could reduce total NH_3 emission in the EU-27 by 10-20% depending on ambition level (Wagner et al., 2012). Extending controls to all measures implemented in GAINS leads to a maximum mitigation potential of about 30%.

This report summarizes the main practical and cost effective means for reducing NH_3 emissions in Europe. It reviews recent scientific, technological, economic and institutional developments that could modify earlier estimates of mitigation potentials and emission control costs. The report builds on the guidance document for preventing and abating ammonia emissions from agricultural sources that has been recently prepared for the revision of the Gothenburg Protocol (UNECE, 2012) of the Convention on Long-Range Trans-boundary Air Pollution. It also refers to the revised Reference Document on Best Available Techniques for the Intensive Rearing of Poultry and Pigs, adopted in 2003 within the framework of the Integrated Pollution Prevention and Control Directive (IPPC) of the European Commission Joint Research Centre (BREF).

1.3 Other agricultural emissions

The agricultural sector is also responsible for the release of other compounds than ammonia. As end products of biogenic processes, the greenhouse gases methane and nitrous oxide are being released and also quantified in the GAINS model. At least for the spatial scales considered here these compounds are not relevant for air pollution, and are mainly considered in terms of their climate impact only (see e.g. Höglund-Isaksson et al., 2012).

An aspect that merits further attention, however, relates to agricultural emissions of particulate matter (PM), especially the fine fractions (PM10 and PM2.5). Here it is the field burning of agricultural waste (cropland burning) which is a sizable source in many countries (see Section 4).

1.4 Structure of the report

The remainder of this report is organized as follows: Section 2 reviews, for the main sources of agricultural NH_3 emissions, the basic principles that allow reducing emissions, and highlights recent scientific, technological and institutional developments that provide new insights into the potential and costs for reducing NH_3 emissions in Europe. Section 3 discusses implications on future ammonia emissions of Europe-wide policies and regulations that are aimed at other issues. Section 4 looks into PM emissions from agricultural waste burning and other agricultural sectors, while section 5 discusses how to use the new insights into the future mitigation potentials in GAINS for a cost-effectiveness analysis for the revision of the Thematic Strategy on Air Pollution. Conclusions are drawn in Section 6.

This report summarizes the findings from the first phase of the Service contract on 'Monitoring and Assessment of Sectorial Implementation Actions' (ENV.C.3/SER/2011/0009). A draft version provided a basis for consultations with experts from different stakeholders, whose feedbacks have been incorporated into this final version of the report. More details are provided in the Annex to this report.

2 Recent developments in NH_3 emission reduction measures

Ammonia emission abatement measures are available for all steps (stages) in the sequence of animal production and manure management, i.e. feeding, housing, manure storage, application of mineral/manure fertilizer, and grazing. The following categories of measures are distinguished in the Annex IX of the Gothenburg Protocol (UNECE, 1999):

- Nitrogen management — affects all stages
- Animal feeding strategies — affect all manure stages
- Animal housing systems — affect this and subsequent stages
- Manure storage systems — affect this and subsequent stages
- Manure application — affects one stage
- Fertilizer application — affects one stage

These (categories of) measures may affect each other in terms of effectiveness and efficiency. Nitrogen management, taking into account the whole nitrogen cycle, is seen as an integral measure, which may affect all sources of NH_3 emissions, and help to prevent pollution swapping. Improving nitrogen management at the farm level by, for example, use of low-emission application measures should result in adjustments (reduction) of mineral N fertilizers application (EC, 2001).

The basic principles for NH_3 emission control have been well-known for decades already. During the last 10 years no scientific breakthroughs have occurred and no fundamentally new low-emission techniques have been developed. However, the known measures have been implemented at an increasing number of farms and an increasing number of countries due to (i) the implementation of national legislations (e.g. the Netherlands, Denmark) and EU Directives (e.g. IPPC Directive), (ii) the improved cost-benefit ratio of various techniques due to learning and up-scaling, (iii) positive synergy effects for farmers, who increasingly appreciate the benefits of low-emission techniques, either as part of good agricultural practices, and/or anticipation of possible forthcoming regulations. Hence, voluntary measures as part of ‘good agricultural practices’ have also contributed to the increased implementation of low-emission techniques, although there is limited quantitative information about such voluntary measures.

In addition to the technical and management measures outlined in the Gothenburg Protocol, there are also possible structural measures that influence ammonia emissions, such as the spatial planning of (new) animal housing systems relative to NH_3-sensitive areas, changes in the Common Agricultural Policy (e.g. milk quota systems), and changes in markets that may influence NH_3 emissions and/or the impact of NH_3 emissions. Changes in markets and agricultural policies that lead to changes number of animals per animal category and hence in NH_3 emissions will be addressed through the baseline scenario. Effects of spatial planning that lead to a different spatial distribution of NH_3 sources within a country will not be addressed in this report, as long as they do not affect total emissions on a national and EU level.

This chapter summarizes the main measures that are available in practice to reduce NH_3 emissions from agricultural activities and reviews recent developments and new data that motivated a scientific update of the earlier estimates of mitigation potentials and costs. The methodology for cost calculations in the GAINS model (including the possibility to differentiate between investment costs that are subject to depreciation and may be assessed depending on their respective size, and operation costs including maintenance, energy and personnel) were described by Klimont and Winiwarter (2011).

2.1 Animal feeding strategies

Animal feeding strategies decrease ammonia emissions from manure in both housing and storage, and the subsequent application to land (Aarnink and Verstegen, 2007; Bakker et al, 2002; Bannink et al., 1999; Carré et al., 1995; Kebreab et al., 2001; Paul et al., 1998; Portejoie et al., 2004). Feeding strategies are implemented through

- (i) phase feeding,
- (ii) low-protein feeding, with or without supplementation of specific synthetic amino acids and ruminal bypass protein,
- (iii) increasing the non-starch polysaccharide content of the feed, and
- (iv) supplementing pH-lowering substances, such as benzoic acid.

Most important are phase feeding and low-protein animal feeding.

Phase feeding is an effective and economically attractive measure for reducing nitrogen emissions in an integrated way. Young animals and high-productive animals require more protein than older, less-productive animals. Hence, decreasing the protein content of the feed of older and less-productive animals decreases the nitrogen excretion by these animals and thereby also the ammonia emissions from the excrements. This can be measured, for example, in the levels of urea-nitrogen in milk, which can be used as diagnostic indicator for protein feeding (Nousiainen et al., 2004). Total ammonia emissions from all farm sources may decrease by 5-15% (average 10%) for a decrease of mean protein content by 10 g per kg in the diet.

It is however difficult to provide a unique number for the emission reduction efficiency of such measures, due to the lack of well-defined ‘reference’ (or baseline) feeding strategies, which differ greatly over countries. Furthermore, efficiencies depend on the specific composition of animal categories, resulting in differences in feed requirements and nitrogen excretion.

Low-protein animal feeding is thus one of the most cost-effective and strategic ways to reduce NH_3 emissions. Low-protein animal feeding also decreases N_2O emissions and increases the efficiency of N use in animal production. Moreover, there are no animal health and animal welfare implications as long as the requirements for all amino acids are met.

Low-protein animal feeding is most applicable to housed animals, and less for grassland-based systems with grazing animals. Grass is in an early physiological growth stage and with high degradable protein, and grassland with leguminous species (e.g., clover and lucerne) has relatively high protein content. While there are ways to lower the protein content in herbage (e.g., through balanced N fertilization, grazing/harvesting the grassland at later physiological growth stage, etc.), and the ration of grassland-based systems (through supplemental feeding with low-protein feeds), these options are not always feasible in practice.

2.2 Animal housing

Two developments have affected the cost-effectiveness of low-emission housing techniques and systems. First, due to trade liberalization, farms have generally become bigger over time, and as a consequence costs of NH_3 emissions abatement have declined. Yet, NH_3 abatement for animal housing is still relative expensive. Second, several animal housing systems have to be refurbished to meet the new EU animal welfare regulations after 2012 and also to meet requirements of retailers and supermarkets. These regulations require larger and more natural living area for animals, leading to a relative increase in NH_3 emissions and thereby also to a relative increase in the cost of low-emission techniques.

The available techniques to reduce NH_3 emissions from animal housing apply one or more of the following principles (Aarnink, 1997; Chambers et al., 2003; Gilhespy et al., 2009; Groenestein and Van Faassen, 1996; Groot Koerkamp, 1994; Melse and Ogink; 2005; Misselbrook and Powel, 2005; Monteny and Erisman, 1998; Ni et al., 1999; Sommer et al., 2004; Zhao et al., 2011):

- Decreasing the surface area fouled by manure;
- Rapid removal of urine; rapid separation of faeces and urine;
- Decreasing air velocity and temperature above the manure;
- Reducing pH and temperature of the manure;
- Drying manure (esp. poultry litter);
- Removing (scrubbing) ammonia from exhaust air; and
- Increased grazing time, i.e., decreasing housing time.

All principles are scientifically sound and practically proven. Different animal categories require different housing systems and environmental conditions, and therefore different techniques.

Costs of the measures to reduce ammonia emissions from housings are related to:

- depreciation of investments,
- rent on investments,
- increased use of energy,

- operation, and
- maintenance.

Costs per kg NH_3 abated vary, depending on different techniques/variants and farms sizes. There may be benefits related to improved animal health and performance, although such benefits may be difficult to quantify. In housing, a major share of overall costs (indicatively, two thirds, using data presented by Klimont and Winiwarter, 2011) refers to investment-related costs.

2.2.1 Cattle housing

The recently revised Guidance Document on preventing and abating NH3 emissions from agricultural sources (UNECE, 2012) lists six practical means for reducing NH_3 emissions during cattle housing (Table 2.1).

Table 2.1: Ammonia emissions abatement techniques of cattle housing systems

Housing type	*Emission reduction*	*Emissions (kg/cow place/year)*
Cubicle house (Reference system)	n.a.	12[a]
Tied system (Traditional reference system)	n.a.	12[a]
Grooved floor		2
Optimal barn climatization with roof insulation		5
Grazing 12h/24h, relative to ref 1	10%	10.8[b]
Grazing 18h/24h, relative to ref 1	30%	8.4[b]
Grazing 22h/24h, relative to ref 1	50%	6.0[b]
Chemical air scrubbers (forced ventilation systems)	70-95	1.2

a/ _ Emissions with full time housing of the animals; Based on a walking area of 4-4.5 m^2 per cow and permanent housing.
b/ These numbers hold for season-long grazing (assumed about 200 days). They show the relative reduction of annual emissions as compared to the reference system with no grazing. Grazing for part of the days requires that barn surfaces are kept clean.
n.a. Not applicable.

The figures presented in Table 2.1 for NH_3 emissions refer to reference systems for dairy cattle with modest milk production (~5000 kg per cow per year) and fed with feed with modest protein content. Tied systems with relatively low NH_3 emissions are not favoured for animal welfare and ergonomic reasons.

For the cubicle housing system, there are three well-developed NH_3 emissions abatement techniques, namely (i) grazing, (ii) grooved floors, and (iii) roof insulation and barn climate controls.

- NH_3 emission reductions from longer outdoor grazing time depend on the baseline value (emissions from housed animals), the time the animals are grazing, and the N fertilizer level of the pasture (Bussink, 1992 and 1994; Jarvis et al., 1989). The potential for increased grazing time is often limited by soil type, topography, farm size and structure (distances), climatic conditions, etc. It should be noted that grazing of animals may increase other forms of N emissions (e.g., nitrate-N leaching and N_2O emissions). Changing from a fully housed period to grazing for part of the day is less effective in reducing NH_3 emissions than switching to complete (24 hour) grazing, since buildings and stores remain dirty and continue to emit NH_3 with restricted grazing. Grazing management (strip grazing, rotational grazing, continuous grazing) is expected to have little additional effect on NH_3 losses. Though grazing systems are low-cost systems, there is a tendency of increased non-grazing or zero-grazing systems in several countries. Zero-grazing systems have the advantage of offering a more controlled diet to the cattle leading to higher productivity. Introduction of milk robots with three times milking per day is a driver for zero-grazing systems. However, costs of zero-grazing systems (and ammonia emission reductions) are higher than those of grazing systems.

- The ‘grooved floor’ system for dairy and beef cattle housing with ‘toothed’ scrapers running over a grooved floor is a reliable technique to abate NH_3 emissions. Grooves should be equipped with perforations to allow drainage of urine. This results in a clean, low-emission floor surface with good traction for cattle to prevent slipping. Ammonia emission reduction ranges from 25-46% relative to the reference system. This abatement technique can be applied only to new cubicle housing systems, or for major reconstructions of existing houses. It is a relatively cheap technique, although not much experience has been obtained in practice until now.
- Finally, optimal barn climate control with roof insulation and/or automatically controlled natural ventilation can achieve moderate emission reductions (20%) due to decreased temperature (especially in summer) and reduced ventilation rates. This is a relatively cheap technique, depending also on the roof isolation.

Another control option, acidification of slurries, has been discussed for several years but applied to some extent only in a few countries. This measure may decrease NH_3 emissions by up to 60% in pig housing systems and has recently been assessed as a Category 1 technique in the Guidance Document (UNECE, 2012), but could work equally well for cattle housing systems with slurry storage underneath slatted floors. However, various possible side-effects and concerns exist related to the use of acids on farms.

2.2.2 Pig housing

The recently revised Guidance Document on preventing and abating NH3 emissions from agricultural sources (UNECE, 2012) lists a variety of options to reduce NH_3 emissions in pig housing. Commonly applied measures are (i) frequent removal of the slurries, (ii) decreasing the surface area of slurry-fouled floor, (iii) cooling of the slurries, and (iv) air scrubbing.

Ammonia emission can be reduced by 25% by lowering the emitting surface area through frequent and complete (vacuum assisted) drainage of slurry from the floor of the pit. Where this is possible to do, this technique has no cost.

Partly slatted floors covering 50% of floor area generally emit 15-20% less NH_3, particularly if the slats are metal or plastic-coated, which is less sticky for manure than concrete. Lower emissions from the solid part of the floor can be achieved by inclined (or convex), smoothly finished surfaces, by appropriate siting of the feeding and watering facilities to minimize fouling of the solid areas, and by good climate control. Further reduction of the emitting area can be achieved by making both the partly slatted area and the pit underneath smaller.

Surface cooling of manure with fins using a closed heat exchange system can reduce emissions by 45-75% depending on animal category and surface of cooling fins. This technique is most economical if the collected heat can be exchanged to warm other facilities such as weaner houses.

Treatment of exhaust air by acid scrubbers (mainly sulphuric acid) or biotrickling filters has proven as practical and effective for large-scale operations in Denmark, Germany, France and the Netherlands. This is most economical in new houses, as for existing stables retrofit costs are higher due to costly modifications of existing ventilation systems. Acid scrubbers have demonstrated ammonia removal efficiencies of 70-90%, depending on their pH-set values. Scrubbers and biotrickling filters also reduce odour and particulate matter by 75% and 70%, respectively. Further information is needed on the suitability of these systems in South and Central Europe. Operating costs of acid scrubbers and trickling filters are particularly sensitive to extra energy use for water recirculation and to the need to overcome increased back pressure on the fans. Optimisation methods can minimize costs, especially for large operations. For example, a study conducted in 2007 showed that overall costs of NH_3 emission reductions from pig housing systems in the Netherlands averaged 0.016 euro per kg of pig carcass produced (Baltussen et al., 2010). At the time of the study, only large (IPPC) farms had technologies installed to reduce emissions by 40-60% (from combined housing and storage). It was estimated that costs will rise to 0.04 Euro per kg of pig carcass in 2013, when also small pig farms in the Netherlands will have to comply with emissions and welfare standards. Assuming that 200 kg of pig meat is produced per pig place per year, costs of NH_3 emission reduction and welfare measures are 7.2 Euro/pig-place or 3 Euros/kg NH_3 N saved.

NH_3 emissions from pig housing can also be reduced by acidifying the slurry to shift the chemical balance from NH_3 to NH_4+. The manure (especially the liquid fraction) is collected into a tank with acidified liquid (usually sulfuric acid, but organic acids can be used as well) maintaining a pH of less than 6. For piglet housing, emission reductions of about 60% have been observed. Acidification of slurries has been tested especially in the Netherlands, using nitric acid, and in Denmark, using sulfuric acid. Both techniques have been demonstrated in practice, although there are side-effects and concerns about emissions of other undesired substances and the danger of using acids.

2.2.3 Poultry housing

For laying hens and for broilers, NH_3 emissions abatement techniques apply to three different systems for layer hens, namely (i) cages, (ii) enriched cages, and (iii) non-caged layers (aviaries and "free range"). Traditional cages (batteries) are prohibited in EU-27 from 2012. Enriched cages can be seen as the replacement system, providing more space to the layers than in the traditional cages. Emissions can be reduced through (i) drying of the manure and decreasing the surface area of manured fouled area, and (ii) air scrubbing. A detailed description of the options is provided in the Annex.

- Ammonia emissions from battery deep-pit or channel systems can be lowered by reducing the moisture content of the manure through ventilation of the manure pit. Collection of manure on belts and the subsequent removal of manure to covered storage outside the building reduce NH_3 emissions, particularly if the manure has been dried on the belts through forced ventilation. Manure should be dried to 60–70% dry-matter to minimize formation of NH_3. Manure collected from belts into intensively ventilated drying tunnels, inside or outside the building, can reach 60 –80% dry matter content in less than 48 hours; however, in such cases exposure to air and subsequently emissions are increased. Weekly removal from the manure belts and transfer to covered storages reduces emissions by 50% compared with bi-weekly removal. In general, emissions from laying hen houses with manure belts will depend on (i) the length of time that the manure is present on the belts; (ii) drying systems; (iii) poultry breed; (iv) ventilation rates at the belt (low rate = high emissions), and (v) feed composition. Aviary systems with manure belts for frequent collection and removal of manure to closed storages reduce emissions by more than 70% compared to deep litter housing systems.
- Treatment of exhaust air by acid scrubbers or biotrickling filters has been successfully employed in several countries. Acid scrubbers remove 70-90% of NH_3 while biological scrubbers remove 70%. Both techniques also remove fine dust and odour. To deal with the high dust loads, multistage air scrubbers with pre-filtering of coarse particles have been developed. Problems with dust and

clocking of the filters have been identified as main obstacles for the large-scale implementation of air scrubbing techniques in poultry housing, together with the energy requirements for ventilation. Positive side effects of air scrubbing are improved climatic conditions in the housing systems and improved productivity.

- Finally, regular addition of aluminium sulphate (alum) to the litter in non-caged housing systems decreases ammonia emissions from buildings by up to 70%, and reduce also in–door concentrations of ammonia and particulate matter (PM2.5) thus improving production.

2.3 Manure handling

2.3.1 Manure storage

Measures to reduce NH_3 emissions from manure storage systems apply one or more of the following principles:

- Decreasing the surface area;
- Reducing the pH and temperature of the manure;
- Drying manure (especially poultry litter).

These basic principles are well-known for decades, and no fundamentally new techniques or scientific breakthroughs have occurred during the last decade (Chambers et al., 2003; Fangueiro et al., 2008; Groot Koerkamp, 1994; Misselbrook et al., 2005; Smith et al., 2007; Sommer et al., 2004). However, the Nitrates directive requires modified storage conditions and storage times, which has implications on NH_3 emissions and mitigation potentials. The directive demands leak-tight manure storages and sufficient storage capacity, related to longer prohibition periods for manure application. However, the Nitrates directive does not require covered manure storages. Leak-tight manure storages of sufficient capacity are relatively costly. The length of the closed period depends on the length of growing season, the vicinity of vulnerable water bodies, climatic conditions vulnerable to leaching, and manure types (solid < liquids). The length of the closed period ranges from three to nine months in EU-27.

The production of manure is a function of

- the number and type of animals present,
- the number of hours per day and year that the animals are indoors,
- the housing type (i.e., slurry or separated collection of urine and faeces),
- the addition of (flush, spilling, rain) water,
- the addition of bedding material (litter), and
- the excretion per animal.

The required storage capacity (in cubic and square meters) depends on

- the supply of manure,

- the demand for manure (for application to land or for transport to elsewhere), and
- the length of the closed period.

The best proven and most practicable method to reduce emissions from slurry stored in tanks or silos is to cover them with ‘tight’ lids, roofs or tent structures. While it is important that such covers are well sealed or tight to minimize air exchange, some venting must be provided to prevent the accumulation of flammable gases, especially methane. Floating cover sheets consist of plastic, canvas, geotextile or other suitable material. Floating covers are difficult to implement on tanks, especially on those with high sides, because of the substantial vertical movement needed during filling and emptying.

Minimizing stirring of stored cattle slurry and some pig slurries (depending on the diet of the pigs and the dry matter content of the slurry) and introducing new slurry below the surface will allow the build-up of a natural crust. Crusts can significantly reduce NH_3 emissions at little or no cost for the time that the crust is sufficiently thick and fully covers the slurry surface. The emission abatement efficiency will depend on the nature and duration of the crust. Abatement with natural crust is an option only for farms that do not have to frequently mix the manure for spreading, and do have slurries that produce crusts. LECA (light expanded clay aggregates) balls and hexa-covers can be applied to non-crusting pig manure or digestate from anaerobic digesters.

There are a few options for reducing NH_3 emissions from stored farmyard (solid) manure from cattle and pigs. Experiments in DK and UK have shown that covering farmyard manure piles with plastic sheets can substantially reduce NH_3 emissions without significant increase in methane or nitrous oxide emissions. However, there is little empirical evidence yet from practice.

Emissions reduction efficiencies are estimated relative to a reference system. Two reference systems should be distinguished, i.e., liquids/slurries and solid manures (dung). For both cases, storage without any covered surface and without treatment of the manure/slurry is assumed as a reference. Storage of solid manure requires a leak-tight underground.

Costs for measures to lower ammonia emissions from housings are related to

- depreciation of investments,
- rent on investments, and
- maintenance.

As a rule of thumb, costs for of covering the manure storage account for 25-40% of the costs of the manure system itself. Costs for storage of solid manure (1-5 Euro/ton/year) (are lower than costs for storage of slurries (5-7 Euro/m^3/year), depending on the size and the type of construction (Table 2.2).

Table 2.2: Emission control options for cattle and pig slurry storage

Abatement measure	*Emission reduction efficiency*	*Applicability*	*Costs (€/m³/yr)*	*Extra costs (€/kg NH_3 N reduced)*
Store with no cover or crust (Reference)	0			
'Tight' lid, roof or tent structure	80%	Concrete or steel tanks and silos. May not be suitable on existing stores.	2-4	1.0-2.5
Plastic sheeting (floating cover)	60%	Small earth-banked lagoons.	1.5-3.0	0.6-1.3
Allowing formation of natural crust by reducing mixing and manure input below the surface (floating cover)	40%	Only for slurries with higher content of fibrous material. Not suitable on farms where it is necessary to mix and disturb the crust in order to spread slurry frequently. Crust may not form on pig manure in cool climates.	0	0
Replacement of lagoon, etc. with covered tank or tall open tanks (depth > 3 m)	30-60%	Only new build, and subject to any planning restrictions concerning taller structures.	15	
Storage bag	100%	Available bag sizes may limit use on larger livestock farms.	2.5 (includes cost of storage)	
Floating LECA balls, 'Hexa-covers'	60%	Not suitable for crusting manures	3.0-4.0	2-5
Plastic sheeting (floating cover)	60%	Large earth-banked lagoons and concrete or steel tanks. Management and other factors may limit use of this technique.	1.5-3.0	0.5-1.3
"Low technology" floating covers (e.g. chopped straw, peat, bark, etc.)	40%	Concrete or steel tanks and silos. Probably not practicable on large earth-banked lagoons. Not suitable if materials likely to cause slurry management problems.	1.5–2.5	0.3-0.9

2.3.2 Manure application

The principles for reducing NH_3 emissions from manure application are well-known for decades, and also for this processing stage, no fundamentally new techniques and scientific breakthroughs have occurred in the last decade. However, a number of recent developments influence application potentials and costs for some measures. Most importantly, the known techniques are now applied at a much larger scale and in more countries, which led to considerably lower costs. The up-scaling has taken place mainly through contractors; many animal farmers in for example the Netherlands and Denmark have outsourced manure application to specialized contracting firms, who use large machines with high capacity in terms of m^3 manure and/or m^2 land applied per men hour. Also, farmers appreciate that grass is less smothered with slurry when using low-emission techniques, instead of the splashplate technique. On the other hand, tractor costs (and energy) costs are often higher with slurry injection than with surface (and band) application of slurries, and there is also some evidence that nitrous oxide (N_2O) emissions are higher with injection of slurries compared to surface (and band) spreading of slurries. These side-effects are also reasons that deep injection, which in theory is a most effective way for NH_3 emission reduction, has been replaced in part by shallow-injection.

Further, the timing of manure application has changed during the last decade as a result of the Nitrates directive. The directive imposes longer prohibition periods for manure application to decrease the risk of nitrate leaching. Ammonia emissions might however increase with longer prohibition periods because manure application is then more concentrated during the growing seasons with higher temperatures and less precipitation.

Low-emission manure application techniques involve machinery that (i) decreases the exposed surface area of slurries applied to surface soil, and/or (ii) buries slurry or solid manures through injection or incorporation into the soil. Costs of these techniques are in the range 0.1 to 5 Euro/kg NH_3-N saved, with lowest costs for immediate incorporation of slurries and solid manure. Costs are very sensitive to farm size, and whether specialist contractors are involved. The following options are available (for details see Bittman et al., 2007; Huijsmans et al., 2003; Misselbrook et al., 2004; Smith et al., 2000; Soegaard et al., 2002; Sommer et al., 199; 1997; Sommer and Olesen, 1991; Webb et al., 2010):

- Band-spreading slurry at the soil surface using trailing hose or trailing shoe methods;
- Slurry injection – open slots;
- Slurry injection– closed slots;
- Incorporation of surface-applied solid manure and slurry into soil;
- Dilution of slurry by at least 50% in low pressure water irrigation systems.

For determining emission reduction efficiencies and costs, the reference application technique is defined as untreated slurry or solid manure spread over the whole soil surface (‘broadcast’) without subsequent incorporation and without targeted timing to minimize ammonia loss. For slurry, the reference technique would consist of a tanker equipped with a discharge nozzle and splash-plate. For solid manures, the reference would be to leave the manure on the soil surface without incorporation.

Table 2.3: Ammonia emission reduction techniques for manure application, their emission reduction efficiencies and associated costs.

Manure type	*Application techniques*	*Emission reduction, %*	*Cost, € per kg NH_3-N saved*
Slurry	Injection	70-90	-0.5 to 1.5
	Shallow injection	60-80	-0.5 to 1.5
	Trailing shoe,	30-60	-0.5 to 1.5
	Trailing hose	30-35	-0.5 to 1.5
	Dilution	30	-0.5 to 1
	Management systems	30-50%	0 to 2
Solid manure	Direct incorporation	30-90	-0.5 to 2

Band-spreading at or above the soil surface is commonly referred to as 'trailing hose' (also known as 'drag hose' and 'drop hose')' and 'trailing shoe' (also known as 'drag shoe' and 'sleighfoot'). Trailing shoe and trailing hose systems are distinguishable from each other through the presence (trailing shoe) or absence (trailing hose) of a 'shoe' or 'foot' device at the outlet of each slurry distribution/application pipe which slides (or floats) on the surface of the ground with little or no penetration. Greater efficiency is generally reported for sliding shoes because they apply manure in narrower bands. This leads to more contact with the soil and less contact with live or dead vegetative material, which is pushed aside more effectively by the shoe than the hose, even if the hose is very close to the ground.

Injection – open slot is mainly applicable to grassland or minimum till cropland prior to planting. Different shaped knives or disc coulters are used to cut vertical slots in the soil up to 50 mm deep, into which slurry is placed. Spacing between slots is typically 200–400 mm and machine working width is typically ≤6 m. To be effective for reducing ammonia and increasing the availability of nitrogen to the crop (while minimizing crop injury), injection should be to a depth of approximately 50 mm and the space between injector tines should be less than 300 mm. Also, the application rate must be adjusted so that excessive amounts of slurry do not spill from the open slots onto the surface. The technique is not applicable on very stony soils, or on very shallow or compacted soils, where it is impossible to achieve uniform penetration to the required working depth. The method may not be applicable on very steep fields due to the risk of runoff down the injection furrows. Slurry injection systems require higher tractor power than broadcast or band-spreading equipment.

Injection – closed slot can be relatively shallow (50–100 mm depth) or deep (150–200 mm). The slurry is fully covered after injection by closing the slots with press wheels or rollers fitted behind the injection tines. Deeper injection is required when greater volumes of manure are injected to avoid manure oozing to the surface. Shallow closed-slot injection is more efficient than open-slot in decreasing NH_3 emissions, but, less widely applicable than open-slot injection. Some deep injectors comprise a series of tines fitted with lateral wings or 'goose feet' to aid soil penetration and lateral dispersion of slurry in the soil so that relatively large application rates can be achieved. Tine spacing is typically 250–500 mm and working width ≤4 m. Although NH_3 reduction efficiency is high, the applicability of the technique is restricted mainly to the pre-sowing season on arable land and widely spaced row crops (e.g., maize). Mechanical damage may decrease herbage yields on grassland or growing solid-seeded arable crops. Other limitations include soil depth, clay and stone content, slope, high tractor power requirement and increased risk of leaching, particularly on tile drained soils.

Incorporating surface applied manure or slurry by either ploughing or shallow cultivation is an effective means of decreasing NH_3 emissions. Highest reduction efficiencies (90% emission reduction) are achieved when the manure is completely buried within the soil, directly after application, while incorporation within 24 hours has an emission reduction of only 30% (Table 2.3). Ploughing results in higher emission reductions than other types of machinery for shallow cultivation. The applicability of this technique is confined to arable land. It is less applicable to arable crops grown using minimum cultivation techniques compared to crops grown using deeper cultivation methods. Incorporation is only possible before crops are sown. This is the main technique for reducing emissions from application of solid manures on arable soils.

Ammonia emissions from dilute slurries with low dry matter content are generally lower than for whole (undiluted) slurries because of faster infiltration into the soil. Slurry added to irrigation water applied to grassland or growing crops on arable land is also an effective application technique. Slurry is pumped from the stores, injected into the irrigation water pipeline and brought to a low pressure sprinkler or travelling irrigator, which sprays the mix onto land. Dilution rates may be up to 50:1 water: slurry.

Low-emission manure application increases the manure nitrogen use efficiency. Total ammoniacal nitrogen (TAN) that is not volatilised can be considered as potentially equivalent to chemical N fertilizer. Therefore, reduced ammonia losses can be considered to replace chemical fertilizer applications on a 1:1 ratio. Low-emission manure application techniques also reduce the odour associated with manure application. They also minimize the occurrence of herbage contamination and therefore increase the crop canopy height onto which slurry can be applied without threatening crop quality. This is particular relevant for grassland, where slurry contamination can reduce grazing palatability or silage quality and may transfer pathogens (e.g., Johne's disease) between farms if manure or equipment is shared. These methods also allow slurry application on growing arable crops (particularly cereals), which are generally not considered suitable to receive slurry applied using splashplate. The use of low-emission techniques can therefore increase the flexibility of slurry application management by allowing more land area to be treated on days when weather conditions are more suitable for low ammonia volatilisation and optimal slurry-N utilisation, and when soil moisture conditions are suitable to allow machinery traffic with minimal soil compaction.

2.3.3 Manure processing

Manure processing is increasingly seen as part of a systems approach solution to improve the use of nutrients in manure and to decrease emissions to the environment in regions with intensive livestock farming systems. In such areas, simple manure separation techniques may help to increase nutrient use efficiency, and they can be used for energy generation on the farm scale. Improvement of nitrogen use efficiency (NUE) of livestock farming systems involves also the optimization of the feed composition. The whole chain from feed to manure application should be considered. However, manure processing techniques itself may also cause emissions, inter alia, NH_3. Figure 2.1 provides an overview of the possible manure processing and treatment steps for pig slurry.

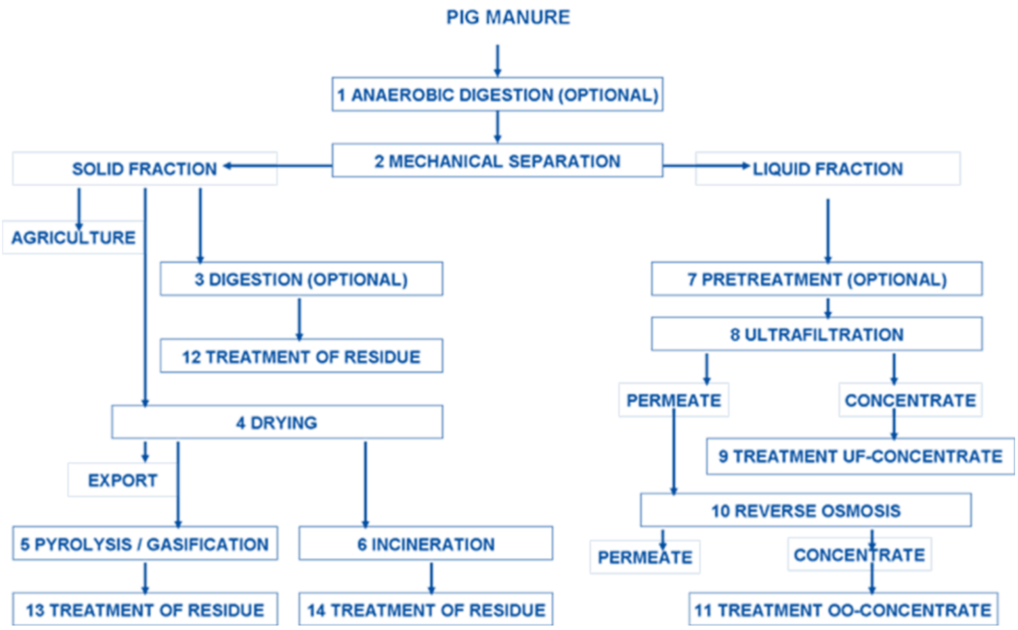

Figure 2.1: Possible processing steps in pig manure treatment

Various barriers to implement manure treatment have been identified, such as high investments and operating costs for high-tech manure processing techniques, legislation (e.g., permits to build manure treatment installations, conditions for export/import of processed products), acceptance by farmers and society, and possible risks associated with the operation. These barriers limit implementation of manure processing in practice. Manure processing techniques affect nitrogen emissions to water and air, phosphorus inputs to soil, and greenhouse gas emissions, both during the process itself and through the use of the end- and by-products.

An integrated system analysis is needed for an overall assessment of the environmental impacts of these techniques, addressing nitrogen, phosphorus and greenhouse gases emissions. Unfortunately, there is very little information available about NH_3 emissions associated with the various manure processing techniques. A recent scenario study suggested that manure processing has relatively little influence on total NH_3 emissions in a country and or region, almost independent of the manure processing technique (Lesschen et al., 2011).

2.4 Nitrogen management as means to reduce emissions

Nitrogen management is an integral approach to minimize nitrogen losses (e.g., Rotz et al., 2004). It is based on the premise that decreasing the nitrogen surplus and increasing nitrogen use efficiency (NUE) contributes to lower emissions of NH_3. On mixed livestock farms, between 10 to 40% of the nitrogen surplus is related to NH_3 emissions, while the remaining part will be lost through N leaching and denitrification (for the average conditions of dairy farming in the Netherlands). Nitrogen management also aims at preventing pollution swapping between different nitrogen compounds and environmental compartments. Nitrogen input-output balances at the farm level are prerequisites for optimizing the nitrogen management. NUE should be managed in concert with overall nutrient efficiencies and other factors such as pest control.

Farms of similar types may differ a lot in management. Farms with poor nutrient management often have high nitrogen surplus in their farm nitrogen balance and low NUE. Lowering the nitrogen surplus and increasing NUE is often economically beneficial due to decreased resource use and/or increased yields. On the other hand, efficiently managed farms generally have good economic and environmental performances, and may not easily decrease N surplus and increase NUE further.

It has to be understood that the relationship between N surplus and NUE is not linear. N surplus and NUE are defined as

$$N\ surplus = (N\ input) - (N\ output) \qquad [1]$$

$$NUE = (N\ output) / (N\ input) \qquad [2]$$

$$N\ surplus = (1\text{-}NUE) * (N\ input) \qquad [3]$$

where N surplus, N input and N output are expressed in kg per ha per year; NUE is expressed either as a dimensionless fraction or as percentage. Evidently, N surplus can be decreased by increasing N output and/or decreasing N input, and NUE can be increased by increasing N output and/or decreasing N input. Larger N output can be achieved by increasing the yield (produce) and/or the N content of the produce (including animal wastes) exported from the farm. Lower N input can be achieved by lowering the import of nitrogen via fertilizers, animal feed, manure and other possible sources into the farm. In general, N surplus will decrease if NUE increases; however, a change to more productive and N-responsive crop varieties and/or animal varieties may lead to increases of NUE, N surplus, N output and N input.

Choosing appropriate nitrogen management techniques depends on the farm type. A distinction should be made between (i) specialized arable and vegetable farms, (ii) mixed farms, with livestock and cropped land for producing animal feed, and (iii) specialized animal farms, with little or no land. They differ in the type of N inputs and outputs, the on-farm transformation processes, and the ease with which these inputs, outputs and processes can be modified.

Common mixed farming systems include dairy and beef production systems, pig production systems and poultry production systems, which grow a significant fraction of the feed on the land of the farming system. As livestock density increases, the need for importing additional feed increases, and thereby the amount of N imported increases. The most dominant mixed farming system in Europe is dairy farming, which covers roughly 20% of the surface area of agricultural land. Studies show that better management can lead to higher efficiency and improved financial results. Improving the utilization of nutrients from manure while decreasing the use of synthetic fertilizers is a cost-effective measure to decrease N surplus and increase NUE. Studies in The Netherlands show that lowering the N surplus by 1 kg N per ha decreases NH_3 emissions from grassland-based dairy farms by on average 0.25 kg per ha (Oenema et al., 2012). Hence, 25% of the N surplus on these dairy farms is lost via NH_3 volatilization, while the remaining 75% is lost through N leaching and denitrification. These farms had implemented already the measures discussed in paragraphs 2.1, 2.2 and 2.3. Probably more than 25% of the N surplus is lost via NH_3 volatilization on dairy farms that have not implemented NH_3 emission abatement techniques.

The integral approach may be seen as an extension to known abatement options that would allow to avoid losses and to better provide agricultural production (animals, plants) with the amounts of nitrogen needed. The principles are apparent already in the low protein feeding strategies, or in low ammonia emission application techniques for urea, including the replacement of urea by other less volatile fertilizers.

3 Agricultural policies and regulations with impacts on future NH3 emissions

Agricultural emissions of ammonia are determined by the level and types of agricultural activities, the prevailing agricultural practices that influence emissions, and by the application of dedicated emission control measures. A wide range of drivers influences these factors.

Agricultural activities, and especially the use of animal manure and fertilizers, are affected by five categories of EU policies and measures:

- The Agenda 2000 and the reform of the Common Agricultural Policy (CAP), including cross compliance, agri-environmental and rural development regulations;
- The EU Water Framework Directive, Nitrates Directive and Groundwater Directive;
- Air and climate change related EU directives (National Emission Ceilings Directive, the Directive on Ambient Air Quality, the Directive on Industrial Emissions, and policies related to the Kyoto protocol);
- Nature conservation legislation, including the EU Birds and Habitats directives; and
- Animal welfare regulations.

Relations between these policy instruments and the points of action are shown in Figure 3.1.

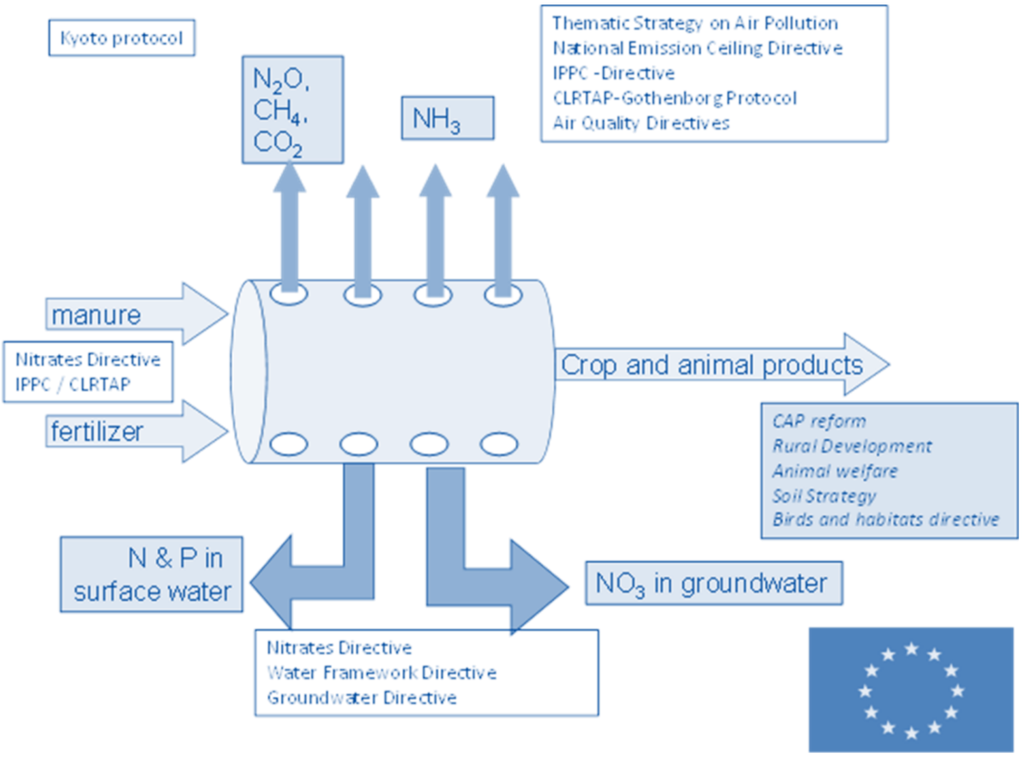

Figure 3.1: Overview of the EU policy instruments directly and indirectly acting on the use and losses of N in agriculture

A recent study (Velthof et al., 2011) revealed that significant reductions in N emissions in the EU-27 have emerged from the implementation of the Nitrates directive compared to a "Without Nitrates Directive" scenario (in 2008 3.4% reduction for NH_3, 6.3% for N_2O, and 16.4% for N leaching). A further decrease in N emissions in the near future is expected from measures in the Nitrates directive that call for larger areas designated as NVZs in the EU-27 and for stricter measures in the Action Programmes (e.g., fertilizer application standards).

The CAP reform may affect ammonia and greenhouse gas emissions directly by cross-compliance measures, and by several other measures such as changes in land use, set-aside, strategies to increase biodiversity and changes in number of dairy cattle as a consequence of the abolishment of milk quota. The overall effect of the 'greening measures' in the 1st pillar of the CAP (direct support) on NH_3 emissions is probably small, because the greening measures are not directly tailored to reduce NH_3 emissions. Instead, measures may lead to changes in emissions of NH_3 between regions. Support for covered and leak-tight slurry storages and for low-emission application techniques under the 2nd pillar of the CAP (the rural development programme) could however contribute to significant emission reductions and hence to achieving the national emission ceilings for NH_3 in the NEC Directive and the UNECE Gothenburg Protocol.

Other developments with potential impacts on gaseous N emissions include:

- Anaerobic digestion of manure for biogas production;
- Manure processing, including separation of solid and liquid fractions, ultra-filtration, reverse osmosis, drying, incineration;
- Biofuel production, and related changes in feed concentrates;
- Bio refinery of feedstuff, separation of protein, cellulose, phosphorus;
- Changes in feed composition ('space feed') and additives;
- Coupling feed production to animal production in Northwest Europe;
- Coupling feed production to animal production at global scale;
- Increasing global meat consumption;
- Animal welfare regulations;
- Changes in milk quota system and pig and poultry manure production quota;
- Changes in the prohibition period of manure applications;
- Changes in nature conservation (Natura 2000 areas),
- Changes in emissions sources, spatial planning and shelterbelts.

4 Agricultural PM emissions

Emissions of particulate matter (PM) in the agricultural sector originate from two distinctively different sources. One is the suspension of already existing small particles via motion, i.e. animals or agricultural vehicles lifting particles into the atmosphere, where they may remain for a considerable time, depending on the size. Such airborne material tends to be dominated by larger size PM fractions. The other source is the combustion of agricultural waste or cropland burning. As PM may be formed from the gas phase during this process, agricultural waste burning also releases very fine particles (PM2.5 and smaller) to the air.

Details of emissions, emission abatement and costs have been described by Klimont et al. (2002). There have been a number of updates introduced in the GAINS model since that report was published. The latest GAINS model also considers the results of recent measurements of PM emissions from livestock and field operations (e.g., ploughing, harvesting, tilling). While measurements in animal houses largely confirmed the previously used emission factors, the assessment of release of PM during field operations led to a revision of numbers (primarily drawing on studies made in the US and the UK, see Klimont et al., 2002). Most measurements indicated much higher PM2.5 emissions than previously assumed. Table 4.1 summarizes the current and projected contribution of PM and NMVOC emissions from agriculture in EU-27 based on the GAINS model. In the current baseline, this source is estimated to represent today nearly 20% of total EU-27 PM10, about 13% of PM2.5, and 2.5% of NMVOC emissions. In the future, the contribution of agriculture is expected to grow as the current legislation baseline does not foresee any additional legislation in this area. Field burning of agriculture residue and waste appears an important source for all species and especially for particulate matter.

Table 4.1: Contribution of agricultural sources to total emissions of PM10, PM2.5, and NMVOC in the EU-27; %

	PM10			*PM2.5*			*NMVOC*		
	2010	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Agricultural waste burning	7.6	8.4	9.0	9.6	11.1	12.5	2.5	3.1	3.3
Ploughing, tilling, harvesting	4.7	5.2	5.7	1.5	1.7	2.0	-	-	-
Livestock	7.6	8.9	9.9	2.2	2.7	3.1	n.a.	n.a.	n.a.
Total Agriculture	19.9	22.5	24.6	13.3	15.5	17.6	2.5	3.1	3.3

Emission levels of PM from agriculture burning were in the past estimated based on national inventory submissions that indicated significant reductions (or even complete elimination) of such emissions over time. Presumably, such development followed the ban of burning of straw and stubbles in most Member States[1] (MS) under compulsory Good Agricultural and Environmental Condition (GAEC) standards of the CAP. Beyond that, some MS also ban agricultural burning under national legislation, e.g., Denmark since 1991 and England since 1993. However, remote sensing data derived from the Global Fire Emission Database (GFED) database (http://www.globalfiredata.org), does not fully confirm these claims. Figure 4.1 shows the areas (grid cells of 0.5x0.5 degree) where agricultural fires were identified using remote sensing data for Europe in 2008; agricultural fires occurred in virtually all EU countries. It appears that while some MS enforce the ban fairly well, in several countries a large number of agricultural fires was identified, especially when considering the consensus in the remote sensing community (e.g., Heil et al. 2010; Fu et al. 2012) that GFED database significantly underestimate emissions from open biomass burning, including agricultural fires. The frequency and intensity of these fires varies from country to country and year to year; an example of relative shares in the global total from this source is shown in Figure 4.2. Currently, GAINS relies on the GFED retrievals showing the location of fires, while quantitative estimates are based on national estimates and global databases, e.g., Emissions Database for Global Atmospheric Research (EDGAR) and UN Food and Agriculture Organization (FAO).

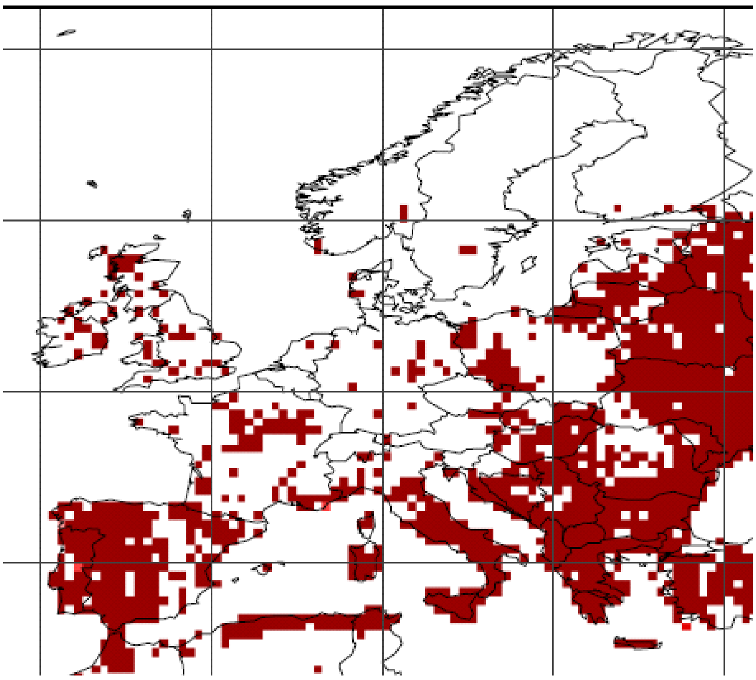

Figure 4.1: Grid cells (0.5x0.5 degree) for which agricultural fires were identified in 2008; as interpreted in the GFED v3.1 database (http://www.globalfiredata.org)

[1] Only Cyprus, France, Ireland, and Slovenia do not impose a ban under cross compliance GAEC standards.

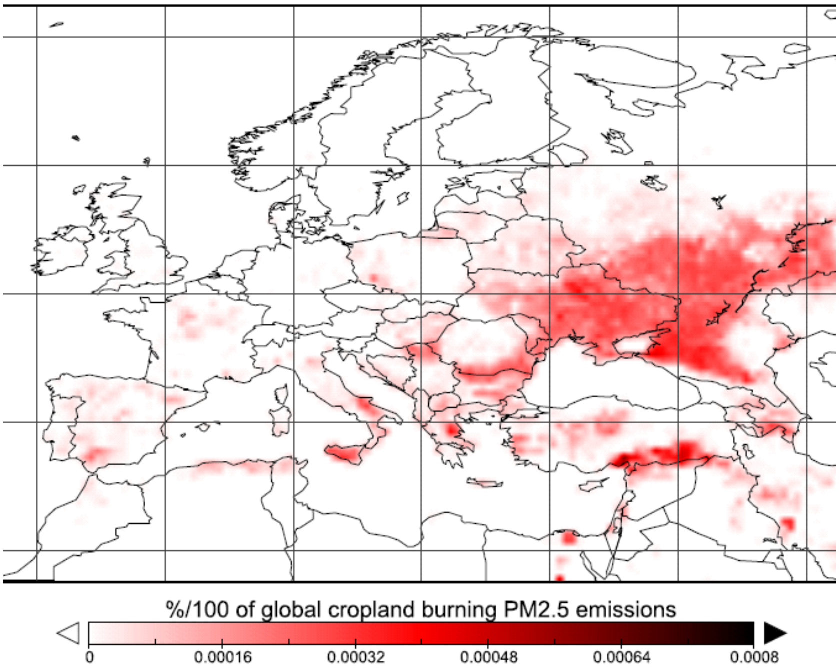

Figure 4.2: Share of European PM2.5 emissions from agricultural burning in the global total from this source in 2008; originates from GFED v3.1 database.

Table 4.2: PM abatement measures in agriculture

	Removal efficiency [%]			*Unit cost*
	TSP	**PM10**	**PM2.5**	**[Euro/kg TSP]**
Agriculture: Ploughing, tilling, harvesting - Low-till farming, alternative cereal harvesting	27.8	12.78	5	6.03
Cattle: feed modification	38.0	29.44	10	12.07
Cattle: hay silage	53.5	33.33	10	12.07
Dairy cows: feed modification	38.0	29.44	10	12.07
Dairy cows: hay silage	53.5	33.33	10	12.07
Other animals: good practice options	27.8	12.78	5	12.07
Pigs: feed modification	38.5	30.56	10	12.07
Poultry: feed modification	38.0	29.44	10	12.07
Free range poultry	27.8	12.78	5	24.13
Ban on open burning of agricultural waste	100	100	100	0.08

Table 4.2 displays for the abatement measures the assumed removal efficiencies, which are different for the respective size fractions, TSP, PM10 and PM2.5, and unit costs. Currently GAINS assumes that implementation and enforcement of a ban of agricultural burning completely eliminates emissions (100% reduction efficiency), that this emerges as an attractive option to reduce emissions from this source. However, as has been shown above, up to now real-life implementation or enforcement appears to be less effective. Thus, it will be important to identify the obstacles that prohibit full implementation, and how positive experience in some

countries could be transferred to other Member States. The GAINS model can incorporate such information through applicability parameters.

The consequence of implementing these measures in the EU is presented in Table 4.3 (only emissions from agriculture in 2020 are shown). We compare the current legislation scenario with the maximum technical feasible reduction scenario that implies that all available measures are applied to the possible extent. Agricultural emissions in EU27 contribute about a quarter to total TSP and PM10, and 15% to PM2.5 emissions in the current legislation scenario. Applying all measures in agriculture would provide an abatement potential of 5-10% of total emissions, cutting agricultural emissions of PM from 25% to below 15% for TSP and PM10, and from 15% to below 5% for PM2.5.

Table 4.3: PM emissions from agriculture for 2020, by EU member country, kt

country	Baseline [kt PM]			MTFR [kt PM]		
	TSP	*PM10*	*PM2.5*	*TSP*	*PM10*	*PM2.5*
AUST	13.35	5.89	1.3	8.66	4.54	1.12
BELG	16.57	7.77	2.2	10.21	5.07	1.24
BULG	14.78	7.54	3	8.68	4.54	1.12
CYPR	0.81	0.39	0.12	0.45	0.23	0.06
CZRE	26.55	16.7	10.61	9.56	4.91	1.24
DENM	25.71	13.23	5.18	13.75	7.01	1.68
ESTO	4.01	2.21	1.07	2.05	1.09	0.27
FINL	8.55	4.23	1.48	5.28	2.75	0.68
FRAN	125.79	69.87	35.02	61.31	31.27	7.83
GERM	101.08	53.24	22.92	53.24	27.02	6.63
GREE	19.68	12.11	7.44	7.66	3.93	0.98
HUNG	21.49	10.47	3.61	13.27	6.75	1.66
IREL	7.95	3.78	1.12	4.91	2.53	0.65
ITAL	63.68	31.25	10.84	37.58	19.09	4.88
LATV	6.66	3.57	1.62	3.59	1.9	0.47
LITH	12.03	6.89	3.66	5.68	3	0.73
LUXE	0.26	0.11	0.02	0.18	0.08	0.02
MALT	0.21	0.11	0.05	0.1	0.05	0.01
NETH	9.35	5.41	3.15	4.45	2.03	0.46
POLA	70.77	32.19	7.58	46.4	23.99	6.02
PORT	18.74	11.2	6.51	7.68	3.91	0.99
ROMA	61.16	37.7	23.17	23.72	12.27	3.06
SKRE	13.09	6.08	1.66	8.17	4.19	1.12
SLOV	2.23	1.24	0.62	1.06	0.53	0.13
SPAI	121.07	67.72	33.95	56.93	29.17	7.26
SWED	12.83	6.65	2.76	7.16	3.72	0.93
UNKI	54.44	28.91	12.96	28.25	14.37	3.74

5 Modelling ammonia emission controls

5.1 Emission control options in GAINS

As the ammonia module of the GAINS model has been developed some time ago (Klimont & Brink, 2004), not all of the recent developments that affect the potential and costs of NH_3 emission reductions that are discussed in the preceding sections are currently incorporated in the GAINS calculations. The current version of GAINS considers the following NH_3 mitigation measures:

- Low nitrogen feed (animal feeding strategies);
- Housing adaptations by improved design and construction of the floor and manure management;
- Covered manure storage (distinguishing low and high efficiency options);
- Biofiltration (air purification), i.e., by treatment of ventilated air;
- Low ammonia application of manure (distinguishing high and low efficiency techniques);
- Improvement of urea fertilizer application or its substitution, e.g., with ammonium nitrate;
- Incineration of poultry manure.

The 2011 update of GAINS incorporated the findings of the UNECE Task Force on Reactive Nitrogen (TFRN) with regard to costs of measures (Klimont & Winiwarter, 2011). With these updates, it is considered that the approach currently used in GAINS for estimating emissions and mitigation potentials for NH_3 is appropriate, although some adjustments in input data may be useful to further take into account the most recent developments, which are described in the Annex.

In particular, there is a systematic issue with the definition of reference systems, against which the effects of emission control measures can be compared. For some emission sources, there are rather well-defined references (for example, the uncovered manure storage, the broadcasting of slurries and manures on the soil surface, broadcasting urea fertilizers on the soil surface). However, for other stages in the manure handling process, well-defined reference systems are more difficult to define, especially for animal feeding. For animal housing, there are various reference systems (loose-housing, tied stalls, cages, enriched cages, etc.), but there may be still a significant variation in practice, which adds uncertainty to the reference emissions. However, as long as farm-level modelling seems infeasible, there is no easy way to reduce such uncertainties in the short run.

Table 5.1 presents the ranges of costs for emission control measures applied to pig production (cattle production being in the same range), poultry production and fertilizer application. As country specific parameters are used, costs are different in different countries – the table presents 25-percentile and 75-percentile in order to indicate the range while exclude extreme values. Details, especially regarding the consequences of combining individual measures, have been documented i.a. by Klimont and Winiwarter (2011). The costs assessed clearly demonstrate that for ammonia abatement, the most cost-efficient options are low nitrogen feeding (providing the proper amount of protein to animals) and low emission technology of manure application. Especially "high efficiency" options, such as deep injection of liquid manure or immediate incorporation, provide additional nitrogen to soil, which may help save considerably on costs of mineral fertilizers if appropriately accounted for when estimating the total fertilizer requirements of a plot.

Table 5.1: Costs of ammonia emission abatement options, ranges for EU-27

Emission sector	***Cost range [€/kg N removed]***	
Pigs (liquid slurry)	*25-percentile*	*75-percentile*
Low protein feed	0.44	0.56
Low emission housing	21.05	25.82
Covered storage (floating cover)	0.41	1.03
Covered storage (fixed cover)	0.93	2.03
Low ammonia application technique (e.g. trailing hose)	1.23	1.68
Low ammonia application technique (deep injection)	0.23	0.46
Pigs (farmyard manure)		
Low protein feed	0.44	0.61
Low ammonia application technique (manure incorporation next day)	3.30	4.68
Low ammonia application technique (immediate manure incorporation)	0.83	1.17
Poultry		
Low protein feed	0.45	0.63
Low emission housing	3.23	4.59
Covered storage (fixed cover)	3.66	4.79
Low ammonia application technique (manure incorporation next day)	1.13	1.59
Low ammonia application technique (immediate manure incorporation)	0.28	0.40
Fertilizers		
Techniques to reduce ammonia emission from urea application, or substitution	1.47	1.70

5.2 Past achievements of countries

Ammonia abatement receives different priority in different individual EU member states. Some countries have made significant progress, while other countries have made little effort. We illustrate previous abatement efforts by comparing emission reduction scenarios for current legislation against those expected from the maximum technically feasible reductions. For countries that have made considerable progress, we expect differences to be small, while countries that have limited reductions on their emissions will have more possibilities to implement further measures in the future. This comparison is presented in Table 5.2. Similar to PM emissions, we focus on the agricultural emissions of NH_3, which typically account for 90% of total emissions.

Table 5.2: Agricultural NH_3 emissions by country for the year 2020; emissions from current legislation scenario and the maximum technically feasible reduction, as well as the scope for additional measures beyond current legislation

	Current legislation [kt NH_3]	*Maximum technical feasible [kt NH_3]*	Further *reduction potential*
Austria	*62*	*41*	34.1%
Belgium	70	56	20.4%
Bulgaria	36	29	18.3%
Cyprus	5	3	30.7%
Czech Rep.	70	53	23.7%
Denmark	55	40	25.9%
Estonia	12	8	35.9%
Finland	29	22	25.2%
France	606	385	36.4%
Germany	593	292	50.9%
Greece	53	42	19.9%
Hungary	75	53	29.8%
Ireland	118	102	13.3%
Italy	348	263	24.6%
Latvia	15	12	19.6%
Lithuania	40	31	22.1%
Luxembourg	4	3	29.1%
Malta	2	2	20.8%
Netherlands	117	106	9.0%
Poland	311	207	33.4%
Portugal	57	37	34.7%
Romania	130	109	16.3%
Slovakia	40	30	26.3%
Slovenia	19	15	20.0%
Spain	322	189	41.3%
Sweden	42	32	25.2%
UK	273	226	17.2%

This comparison identifies the Netherlands, a country known to have in place strict regulations on NH_3 abatement, as the region with the most limited potential for further action. However, for other countries local conditions (such as farm sizes and agricultural practices) emerge as important factors in addition to the ambition level for emission control policies. In particular, the applicability of measures depends strongly on farm structures, especially bearing in mind that not all measures can be implemented by small farms. This leads to relatively limited reduction potentials in countries like Romania and Bulgaria, where the share of small farms is considerable. Equally, in Ireland, the practice of outdoor animal husbandry may hamper efforts for further abatement, as technical abatement options for grazing animals are rather limited. In the case of Denmark, the lack of documentation (in the TFRN context) of their respective abatement techniques (such as slurry acidification) possibly leads to an underestimation of their efficiency, and thus an overestimation of the potential for further cuts.

6 Conclusions

Agricultural emissions of ammonia amount to about 90% of total ammonia emissions. If available technical mitigation measures would be fully applied in the EU, future emissions could be reduced by up to 30%. However, the mitigation potential for individual Member States depends strongly on local conditions (e.g., farm sizes, agricultural practices) as well as on the stringency and enforcement of already implemented measures and policies. The potential for further measures will typically be smaller in countries that have already made considerable efforts. In addition to technical measures, emissions could also be reduced through policies that affect animal numbers (e.g., as a consequence of changes in human diets – see e.g. Stehfest et al., 2009), or lead to structural changes in farm sizes, so that more efficient measures that are only applicable to larger farms could be applied. In this sense, some aspects of the proposed 2nd pillar of the CAP are expected to lead to lower NH_3 emissions. These non-technical measures are however not considered in any depth in this report.

As agricultural emissions of NH_3 are not strongly affected by "low carbon" scenarios, and impacts of climate policies have therefore not been evaluated in this report. However, there are important impacts on greenhouse gases (i.e., CH_4 and N_2O), which are already addressed in the GAINS model. Likewise, actions focused on other air pollutants (e.g., SO_2 or NO_x) only have modest implications for agricultural emissions of NH_3 and their abatement potential. Yet, there are potential spill-over effects from air pollution policies directed at ground-level ozone and acidification, in particular if they are designed to prioritise NO_x reductions over NH_3 mitigation. However, these trade-offs are addressed separately (Amann et al., 2011).

The abatement options for NH_3 that are recommended by the UNECE Task Force on Reactive Nitrogen are already integrated in the GAINS model, and only minor adjustments are needed to fully reflect the latest scientific knowledge. Additional technical measures are being explored in practice, and may in principle become available in the future. Some of them have been discussed for a considerable time on a theoretical level, but little additional evidence on experience from practical implementation has been made available. As long as the more practical and feasible measures such as low protein feeding and low ammonia emission spreading of manure are not fully applied in many countries, a further focus on the more demanding approaches might not be needed. That said, a more integral approach, like managing nitrogen fluxes as a whole at country, regional or farm level, may offer an effective step forward to curb ammonia emissions in the longer term.

With regard to particulate matter (PM 10 and PM 2.5), emissions from agriculture currently contribute about 20% to total PM10 emissions in the EU and about 15% to PM2.5. There is significant potential for cost-effective reduction of these emissions, especially through efficient implementation and enforcement of an EU-wide ban or restriction on all agricultural waste burning which contributes about 2/3 and 1/3 of PM2.5 and PM10 from agriculture, respectively.

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ANNEX

A.1 Preparing new developments for GAINS

The new developments in emission reduction options and costs that are discussed in Section 2 can be reflected with the current structure of the GAINS model by adjusting some data for emission reduction efficiencies, applicabilities and costs.

Table A.1 summarizes proposed changes in abatement options and corresponding values for removal efficiencies for the emission control options to be considered in GAINS. The abatement option 'low nitrogen feeding, low efficiency' in that table reflects a modest decrease in the protein content of the animal feed (~1% absolute decrease), in line with the medium ambition strategy of the Guidance Document on preventing and abating NH_3 emissions from agricultural sources. In contrast, the abatement option 'low nitrogen feeding, high efficiency' reflects a significant reduction in the protein content (~2% absolute decrease), which is in line with the high ambition strategy. Similarly, 'low emission application' of solid manure may be done at 'low efficiency' (incorporation of manures within four hrs following application) or at high efficiency (directly application).

The abatement option 'grazing' (for various periods) has been considered as an abatement strategy, as NH_3 emissions are less from animal excrements dropped in pasture than dropped in housing systems. Depending on the reference, emissions from pastures (grazing) increase when the number of grazing days increase, proportional to the increase in droppings in pastures.

Table A.2 provides a proposal for the applicability and mean costs for the abatement options. Note that cost figures indicated for the various options are rough estimates and depend in practice on farm size and economic (market) conditions. It is recommended that country-specific estimates are collected every five years, also because costs tend to change (decrease) over time.

Table A.1: Proposal for adjusted emission removal efficiency numbers for the GAINS model.

Abatement option	Application	Removal efficiency, %			
		Animal housing	Storage	Application	Grazing
Low nitrogen feeding: low efficiency	Dairy cows	10	10	10	10
	Other cattle	10	10	10	10
	Pigs	10	10	10	n.a.
	Laying hens	10	10	10	n.a.
	Other poultry	5	5	5	n.a.
Low nitrogen feeding: high efficiency	Dairy cows	20	20	20	20
	Other cattle	20	20	20	20
	Pigs	20	20	20	n.a.
	Laying hens	20	20	20	n.a.
	Other poultry	10	10	10	n.a.
Grazing >22hrs/day, 180 days/y	Cattle	50	50	50	0*)
Grazing >18hrs/day, 180 days/y	Cattle	30	30	30	25*)
Grazing >12hrs/day, 180 days/y	Cattle	10	10	10	50*)
Grazing <12hrs/day, 180 days/y	Cattle	0	0	0	75*)
Animal house adaptation: low	Dairy cows	25	n.a.	n.a.	n.a.
	Other cattle	25	n.a.	n.a.	n.a.
	Pigs	40	n.a.	n.a.	n.a.
	Laying hens	40	n.a.	n.a.	n.a.
	Other poultry	40	n.a.	n.a.	n.a.
Animal house adaptation: high	Dairy cows	80	n.a.	n.a.	n.a.
(Air scrubbers, biofiltration)	Other cattle	80	n.a.	n.a.	n.a.
(Air scrubbers, biofiltration)	Pigs	80	n.a.	n.a.	n.a.
(Air scrubbers, biofiltration)	Laying hens	80	n.a.	n.a.	n.a.
(Air scrubbers, biofiltration)	Other poultry	80	n.a.	n.a.	n.a.
Covered Storages: low	Liquid manure	n.a.	40	n.a.	n.a.
Covered Storages high	Liquid manure	n.a.	80	n.a.	n.a.
Covered Storages: low	Solid manure	n.a.	40	n.a.	n.a.
Covered Storages high	Solid manure	n.a.	80	n.a.	n.a.
Low-emission application					
Low efficiency	Liquid manure	n.a.	30	n.a.	n.a.
Medium efficiency	Liquid manure	n.a.	60	n.a.	n.a.
High efficiency	Liquid manure	n.a.	80	n.a.	n.a.
Low efficiency	Solid manure	n.a.	40	n.a.	n.a.
High efficiency	Solid manure	n.a.	80	n.a.	n.a.
Urea application: low	Urea fertilizer	n.a.	n.a.	40	n.a.
Urea application: medium	Urea fertilizer	n.a.	n.a.	70	n.a.
Urea substitution: high	Urea fertilizer	n.a.	n.a.	90	n.a.
Manure incineration	Solid manure	n.a.	n.a.	60	n.a.
Manure processing	Solid manure	n.a.	n.a.	30	n.a.

*) emissions from grazed grassland increase, depending on the reference situation. The percentages reflect the changes in emissions relative to the emissions occurring with day and night grazing for 180 days per year (used as reference).

Table A.2: Proposal for adjusted data on applicability and costs of abatement options in GAINS

Abatement option	Application area	Applicability	Costs, € per kg NH_3-N abated
Low nitrogen feeding			
low efficiency	Dairy cows	> 50 LSU/farm; > 2 LSU/ha	0.5
	Other cattle	> 50 LSU/farm; > 2 LSU/ha	0.5
	Pigs	> 50 LSU/farm	0.5
	Laying hens	> 50 LSU/farm	0.5
	Other poultry	> 50 LSU/farm	0.5
high efficiency	Dairy cows	> 50 LSU/farm; > 4 LSU/ha	2.0
	Other cattle	> 50 LSU/farm; > 4 LSU/ha	2.0
	Pigs	> 50 LSU/farm	2.0
	Laying hens	> 50 LSU/farm	2.0
	Other poultry	> 50 LSU/farm	2.0
Grazing			
>22hrs/day, 180 days/yr	Cattle	< 2 LSU/ha	0
>18hrs/day, 180 days/yr	Cattle	< 2 LSU/ha	0
>12hrs/day, 180 days/yr	Cattle	< 2 LSU/ha	0
<12hrs/day, 180 days/yr	Cattle	< 2 LSU/ha	0
Animal house adaptation			
low efficiency	Dairy cows	New buildings	4.0
	Other cattle	New buildings	4.0
	Pigs	New buildings	4.0
	Laying hens	New buildings	4.0
	Other poultry	New buildings	4.0
high efficiency	Dairy cows	High-tech new buildings	8.0
- (Air scrubbers, biofiltration)	Other cattle	High-tech new buildings	8.0
- (Air scrubbers, biofiltration)	Pigs	High-tech new buildings	8.0
- (Air scrubbers, biofiltration)	Laying hens	High-tech new buildings	8.0
- (Air scrubbers, biofiltration)	Other poultry	High-tech new buildings	8.0
Covered storages			
low efficiency	Liquid manure	everywhere	1.0
high efficiency	Liquid manure	everywhere	2.0
low efficiency	Solid manure	everywhere	1.0
high efficiency	Solid manure	everywhere	2.0
Low-emission application			
low efficiency	Liquid manure	everywhere	1.5
medium efficiency	Liquid manure	No-stony land	1.5
high efficiency	Liquid manure	No-stony land	2.0
low efficiency	Solid manure	arable land	1.0
high efficiency	Solid manure	arable land	2.0
Urea application			
low efficiency	Urea fertilizer		1.0
medium efficiency	Urea fertilizer		1.5
high efficiency	Urea fertilizer		2.0
Manure incineration	Solid manure		8.0
Manure processing	Solid manure		10.0

*)emissions from grazed grassland increase

Data sources

In order to implement emission projections and estimates of associated mitigation potentials for individual countries, an in-depth review of available data sources that could potentially provide more detailed data for the GAINS calculations has been carried out. It was found that:

- There is not much information about ammonia abatement in the Nitrates Directive reports. Some Members States provide data about nitrogen excretion, which may be useful to improve the calculation of N excretion of livestock categories in GAINS. However, information is very scattered and differs between Member States. Thus, it is recommended not to use these data to modify GAINS. However, these data could be used to check uncertain figures.

- EUROSTAT provides data on fertilizer consumption and use, gross nitrogen balances, manure storage, and greenhouse gas emissions. These data can be used in the future to validate GAINS estimates or to update country-specific inputs of GAINS. It may be expected that the quality of these data will improve in the future, since EUROSTAT puts high efforts on collecting data for the agri-environmental indicators.

- The NIR (National Inventory Reports) 2011 reports to the UNFCCC and the CRF (common reporting format) tables can be used to validate/improve figures in GAINS on (i) manure management systems and (ii) nitrogen excretion. The following categories of manure management systems are available: anaerobic lagoons, liquid systems, daily spread, solid storage and dry lot, pasture range and paddock, and others. GAINS distinguishes three categories: solid, liquid, and grazing. It is recommended that GAINS uses the information systems provided in the CRF reports for a country specific approach, as these data are updated yearly (Note: most countries use a country-specific approach).

- The UNECE-CLRTAP databases partly overlap with the UNFCCC reports. Some reports contain detailed information about ammonia emission factors, housing type, manure storage type and implementation of ammonia abatement techniques. The following Member States use country specific methodologies for their ammonia emission inventory: Austria, Denmark, Germany, Finland, Ireland, Sweden, the Netherlands, Switzerland, and United Kingdom.

- There is scope for regionalization of NH_3 estimates in GAINS, but there are many uncertainties in the calculations on a sub-national level. Therefore, the quantification of NH_3 emissions on a country level will not be improved by summing up calculations on a sub-national level. Regionalization of the GAINS calculations should only be done if data are needed for fine-scale calculations (e.g., for calculation for N deposition), but not for obtaining more accurate estimates of country total emissions.