AMMONIA EMISSIONS FROM GERMAN ANIMAL HUSBANDRY

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ABSTRACT

Ammonia emissions from German agriculture were estimated for the years 1990, 1995 and 1999, their development until 2010, and potentially achievable reductions and the cost involved were forecast.

Emission factors for animal housing, manure storage and application were determined on the basis of own and published investigations, and agreed at national level. The different animal husbandry systems and manure treatment techniques common in Germany were considered. Data and information on the application extent of these systems and techniques were generated by conducting surveys in different regions typical of Germany. Using this information and the data on livestock numbers available from official livestock censuses ammonia emissions from German agriculture were calculated.

According to the calculations performed, ammonia emissions from animal husbandry amounted to 610 10^6 kg (Gg or thousand tons) in 1990 and fell to about 470 10^6 kg in 1999. This sharp decrease is ascribed to the strong decline in livestock numbers in the new Federal States between 1990 and 1992 after the German reunification.

Potentials of abatement techniques were calculated against the background of international agreements on emission reduction. Emission reduction shall begin with a nutrient-adapted feeding. Plowing under manure directly after application constitutes an effective and economical measure for all livestock categories. Other areas particularly suited to reducing ammonia emissions depend on livestock category. According to the different abatement scenarios performed, Germany can meet its commitment to reduce the total ammonia emissions to 550 10^6 kg by 2010 assuming further technological development.

KEYWORDS. Ammonia Emission, Emission Factor, Emission Forecasting

INTRODUCTION

In international notes Germany and other countries undertake to reduce harmful emissions. The reduction of ammonia emissions is regulated within the UN/ECE Multipollutant - Multieffect - Protocol (UN/ECE, 1999) and the EU Directive on National Emission Ceilings (EU, 2001). According to these agreements Germany has to reduce its ammonia emissions to 550 10^6 kg by 2010, this is a reduction rate of 28% of the emission in 1990.

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So far ammonia emissions have been calculated simply by multiplying the numbers of the animals of individual livestock categories by category-specific emission factors. It is estimated that 80 to 90% of German ammonia emissions come from agriculture. So the intended emission reduction can affect agriculture strongly. There is a need to calculate the emissions more exactly than in the past and to find ways of reduction. Therefore emission factors have to consider the influences of the different animal keeping, manure handling and application systems. Furthermore information on the application extent of these different systems is required.

The analyses of the past allows us to forecast future development to some extent. On the basis of the emission figures for the various ammonia emission sources and available abatement techniques, possible emission reduction scenarios and cost involved can be calculated.

METHOD

The whole work was done by a group of experts from several German research and advisory organisations. The details and complete results were published by the Federal Environmental Agency (UBA) in Germany (Döhler et al, 2002). On the basis of former own investigations, knowledge, experience and published results of other investigations ammonia emission factors for animal husbandry were generated. The factors shall describe the emission from the different production systems as exactly as possible. These emission factors are so detailed as data allowed, e.g. a certain factor for pig fattening in forced ventilated houses with fully or partly slatted floors or a certain factor for liquid manure storage without an additional cover. Such individual emission factors were generated for the spheres:

· animal housing,

· manure storage,

· manure field application,

· abatement techniques.

These individual emission factors have to be multiplied by the number of animals which are kept in the respective system or their manure is stored in a certain system or applied on field with a certain technique (Fig.1). Because such structural data are not available from official statistics, they were conducted by a survey of advisors and consultants in 11 different regions of Germany. These 11 different districts represent the inhomogeneity of German agriculture.

The multiplication of the individual emission factors by the structural data belonging to them result in the emission value for particular livestock categories and management systems. These values are added to the total ammonia emission. Future emissions were forecast with the help of some reflections and assumptions on the further development of livestock numbers and technical systems. Operational costs of emission reduction were calculated.

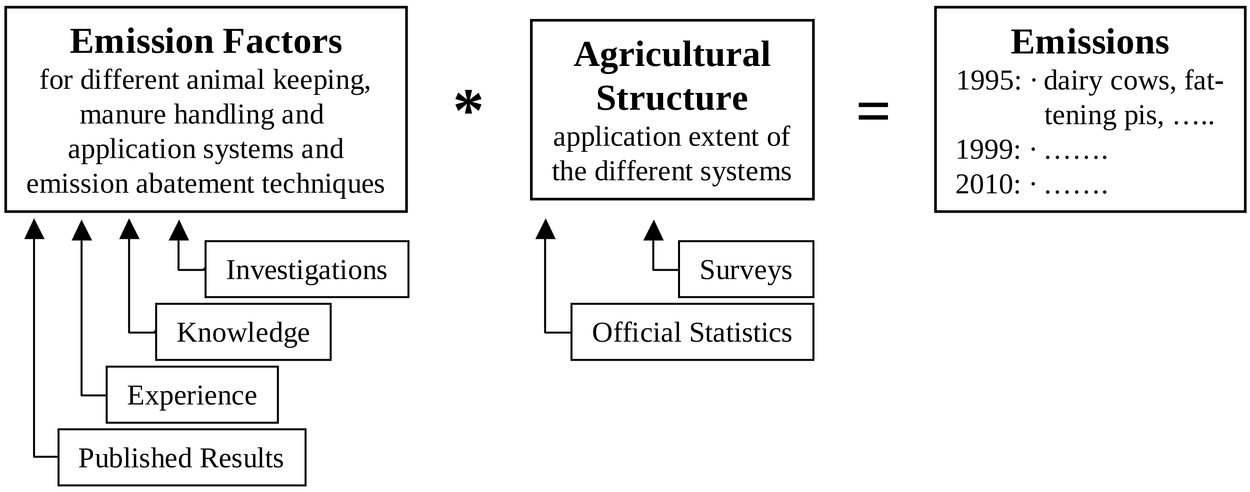

Figure 1. Emission Calculation Procedure.

RESULTS

Emission Factors

Ammonia emission factors could be found for the most relevant animal production systems common in Germany. Emission is influenced by a number of parameters such as animal breed and performance, production data, e.g. the length of a fattening period and the body mass of the animals, feed/nutrient composition and intake by the animals, technical equipment, and climate and weather conditions. Data are based on very different investigations using different methods, techniques and are not easy to compare. So the following emission factors are mean values or lower and upper values are given if sufficient data were available, and represent the state of knowledge.

Animal Housing

In cattle husbandry different ammonia emission factors could be found for dairy cattle on the one hand and beef cattle and calves on the other hand (Tab. 1). The main differences have to be noted between tied housing and loose housing systems, especially in dairy husbandry. While there are no differences between liquid and solid manure systems. Only the sloped floor emits slightly more ammonia than the other loose housing systems. The differences between tied housing and loose housing systems in beef cattle (125 to 600 kg body mass) and calves (up to 2 years old) husbandry are rather small. Ammonia emissions from these animal categories are noticeably lower than those from dairy cattle (600 kg body mass, 6000 kg milk yield per year) due to the lower substance turnover.

Table 1. Ammonia Emission Factors for Cattle Husbandry.

Keeping System	Ammonia Emission (kg NH_3-N place^{-1} year^{-1})		
	Mean Value	Lower Value	Upper Value
Dairy Cows			
Tied housing liquid manure	4	3	5
solid manure	4	3	5
Loose housing			
Cubicles liquid manure	12	9	15
solid manure	12	9	15
Deep litter	12	n.s.	n.s.
Sloped floor	13	n.s.	n.s.
Beef Cattle and Calves			
Tied housing liquid manure	2.0	n.s.	n.s.
solid manure	2.0	n.s.	n.s.
Loose housing fully slatted floor	2.5	n.s.	n.s.
sloped floor	3.0	n.s.	n.s.

n.s. – not specified

In pig fattening in forced ventilated houses (with additional heating in wintertime) liquid manure systems cause lower ammonia emissions than systems with solid manure (Tab.2). Differences between fully and partly slatted floors are not clear. Especially in systems with partly slatted floors ammonia emission depends considerably on the actual design and how it act together with ventilation. So if the non slatted area gets dirty, emissions can be higher than from fully slatted systems. In very well functioning partly slatted floor systems with clean non slatted areas emission can be slightly lower than in fully slatted systems. A rather new system in pig husbandry are the outdoor-climate houses with natural ventilation. According to first investigations on these systems they emit less ammonia than forced ventilated systems. Lower temperatures, especially in wintertime, seem to indicate that. Very high air exchange rates in such systems point against lower emissions. To what extent they are compensated by pen design (pig kennels/huts) further investigations have to show.

Table 2. Ammonia Emission Factors for Pig Fattening.

Keeping System	Ammonia Emission (kg NH_3-N place^{-1} year^{-1})		
	Mean Value	Lower Value	Upper Value
Forced Ventilated House			
Liquid manure fully slatted floor	3	2	4
partly slatted floor	3	2	5
Solid manure deep litter (also with additives), cubicles	4	3	6
Outdoor-climate House			
Liquid manure kennels	2	n.s.	n.s.
Solid manure kennels	2	n.s.	n.s.
deep litter (also with additives), cubicles	4	n.s.	n.s.

n.s. – not specified

In poultry husbandry emissions vary very widely also within the individual keeping systems. But as the ammonia emission factors given in table 3 confirm, also in poultry husbandry a higher body mass and a higher substance turnover cause a higher emission. For emission reduction it is advantageous to convey the manure out of the animal house into the storage facility very quickly and also to dry the manure very quickly.

Table 3. Ammonia Emission Factors for Poultry.

Keeping System	Ammonia Emission (kg NH_3-N place^{-1} year^{-1})		
	Mean Value	Lower Value	Upper Value
Laying Hens			
Cages with manure pit	0.25	0.1	0.32
with manure conveyer belt	0.12	n.s.	n.s.
with manure conveyer and dryer	0.032	0.01	0.085
Aviary with manure drying	0.075	0.02	0.2
Ground floor / open keeping	0.26	n.s.	n.s.
Fattening Poultry			
Broiler with litter	0.04	n.s.	0.06
with manure ventilation/drying	n.s.	0.004	0.04
Ducks	0.12	0.08	1.0
Turkeys	0.6	0.4	0.7

n.s. – not specified

Manure Storage

Emissions during manure storage depend on a number of parameters. These are animal category and breed, feed/nutrient intake and excretion, temperature, wind conditions, nature and size of the manure surface and storage duration. A main influencing parameter is the total nitrogen content of the manure (N_{total}), so it is very common to indicate ammonia emission in relation to N_{total}. Liquid swine manure emits nearly double the amount of ammonia that liquid cattle manure emits (Tab. 4) mainly because of two reasons: 1. Liquid swine manure has a higher ratio of ammonium to total nitrogen content. 2. Liquid swine manure has a lower dry matter content and sediments more readily, so the surface is more watery, whereas liquid cattle manure sets up a natural floating layer on the surface in most cases. Investigations on solid manure are very rare. From the few results it appears that the ammonia emissions from solid manure are at least as high as those from lagoons. Till now it is not proved whether solid cattle manure emits less ammonia than solid swine manure. In practise feces pits are covered in any case, so emissions from there are nearly zero.

Table 4. Ammonia Emission Factors for uncovered Manure Storage.

Storage Facility	Ammonia Emission				Remarks
	(% of Manure N_{total} at Storage Begin)		(kg NH_3-N place^{-1} year^{-1})		
	Cattle	Swine	Cattle	Swine	
Liquid Manure container	8	15	8	1.5	
Lagoon	15	25	15	2.5	estimated
Solid Manure	25	25	25	2.2	
Feces	10	20	0.4	0.1	on farms feces pits are always covered

Covering is a very effective and economical measure of ammonia emission reduction for liquid manure which forms no or only an insufficient natural surface layer/crust (Tab. 5). Several technical solutions are available and in use. Odor emission is reduced as well, but in some cases higher emissions of methane or nitrous oxide can occur.

Table 5. Reduction of Ammonia Emission during Manure Storage in Relation to uncovered Liquid Manure.

Covered Liquid Manure Container	Ammonia Emission Reduction related to Liquid Manure uncovered with no Surface Layer or Crust in %	
	Liquid Cattle Manure	Liquid Swine Manure
Natural Surface Layer/Crust	30 – 80[1]	20 – 70[1]
Artificial Surface Layer		
Straw	70 – 90[2]	70 – 90
Granules, Surface Foil	80 – 90[2]	80 – 90
Solid Cover (concrete, plastic or tent)	85 – 95	85 – 95

[1] in dependence on the condition of the surface layer/crust
[2] in most cases there is a natural surface layer/crust, if not an artificial cover can be used

Manure Application on Field

Emissions after manure application depend on the parameters mentioned before, especially on weather conditions and ammonium (NH_4^+) content. So it is very common to express ammonia emission in relation to the ammonium content of the manure at the time of field application. But because of the different ammonium content of the various manures the absolute emission values are important. The absolute numbers given in Table 6 are calculated on the basis of tabular values. Special application techniques for liquid manure can reduce emissions. But emissions are influenced much more by the time between manure application and plowing under (Tab. 7).

Table 6. Ammonia Emission Factors for Manure Application on the field.

Application Technique*	Ammonia Emission (% of Manure NH_4^+-N applied on Field)	Ammonia Emission (kg NH_3-N place^{-1} year^{-1})
Liquid Cattle Manure		
Splash plate	50	23
Trailing hose	46	21
Trailing shoe	35	16
Solid Cattle Manure	90	15
Cattle Feces Splash plate	20	0.5
Liquid Swine Manure		
Splash plate	25	1.3
Trailing hose	18	0.9
Trailing shoe	10	0.5
Solid Swine Manure	90	1.4
Swine Feces Splash plate	20	0.1
Dry Chicken Manure	90	#

* air temperature 15°C, application on uncovered soil, plowing under after 2 days (solid manure after 1 day)
\# it depends on chicken category/breed

Table 7. Reduction of Ammonia Emission after Manure Application on Field by Plowing under.

Application Technique*	Ammonia Emission (% of Manure NH_4^+-N applied on Field) Plowing under after 1 hour	4 hours	24 hours
Liquid Cattle Manure			
Splash plate	10	26	46
Trailing hose	4	15	39
Liquid Swine Manure			
Splash plate	4	9	21
Trailing hose	2	6	14
Solid Cattle and Swine Manure	10	45	90
Feces Splash plate	2	7	18

* air temperature 15°C, application on uncovered soil

Emission Factors of complete Production Chains

To compare different keeping systems the complete production chain is to be taken into consideration. In dairy cattle husbandry the differences are caused mainly by the housing system – loose or tied housing, although emissions from manure storage and application are quite different between systems with liquid or solid manure – but their sum is nearly the same (Fig. 2). Whereas in pig fattening, systems with solid manure cause higher ammonia emissions than systems with liquid manure because of the high emission during manure storage (Fig. 3).

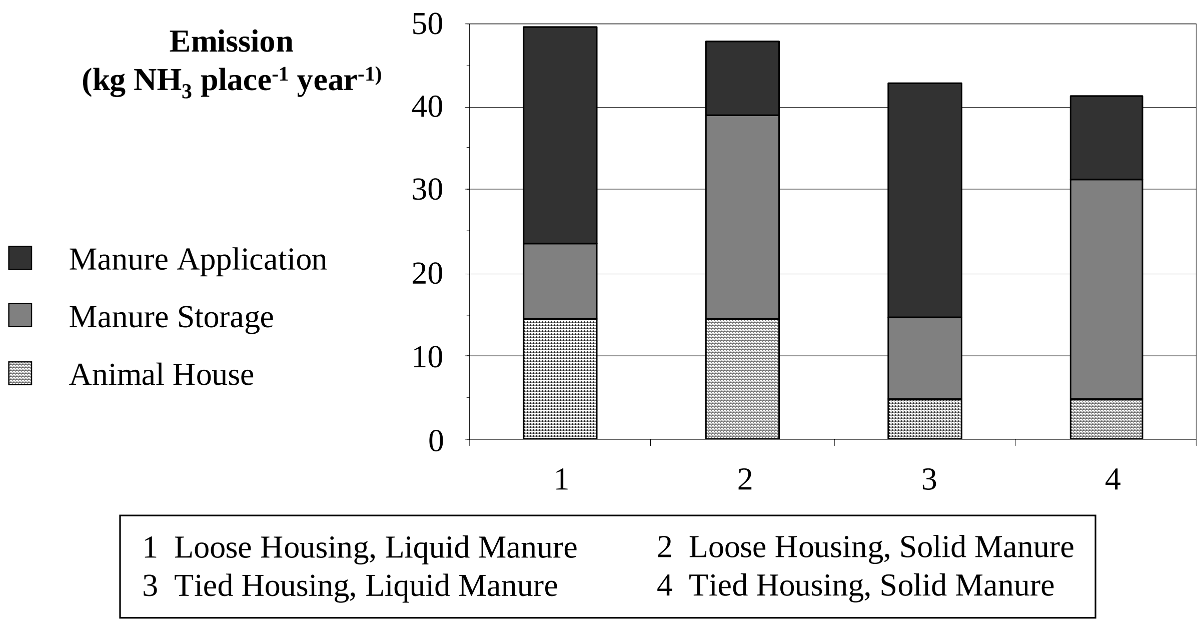

Figure 2. Cumulative Ammonia Emissions of Production Chains in Dairy Cattle Husbandry.

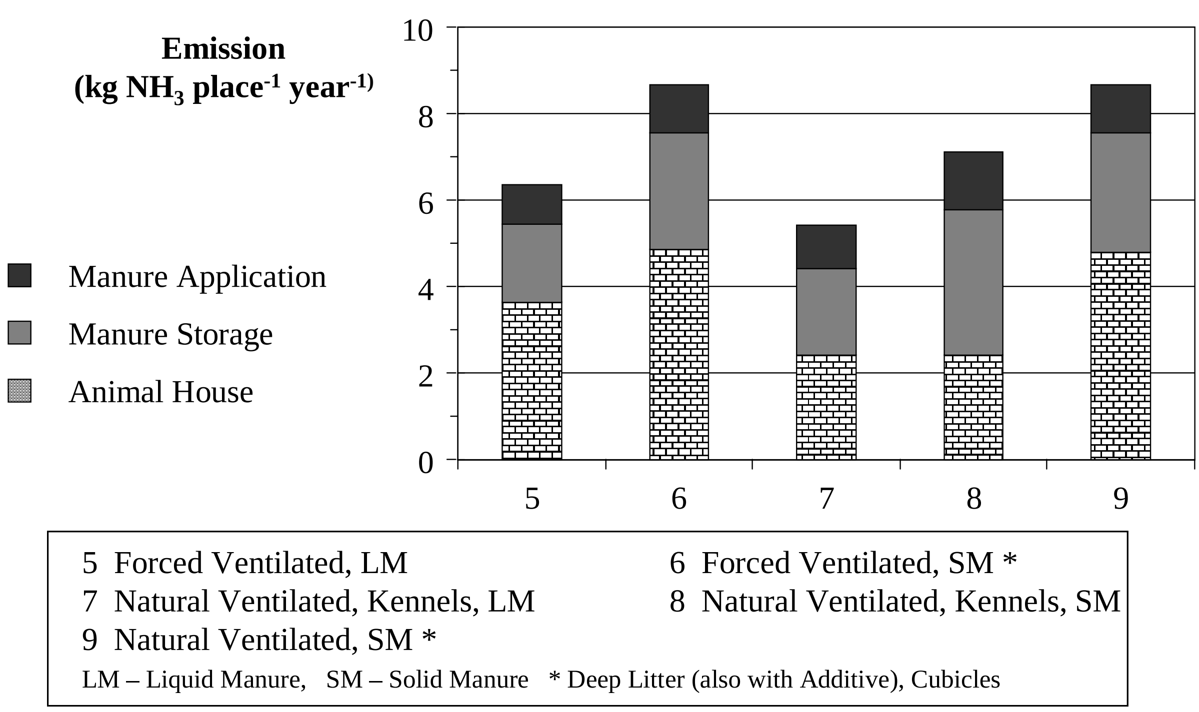

Figure 3. Cumulative Ammonia Emissions of Production Chains in Pig Fattening.

About 85% of the German dairy cattle are kept in systems with liquid manure, and this percentage will grow furthermore. Also there is and will be the tendency from tied to loose housing systems. It goes along with a decrease of stock with less than 40 cattle and an increase of larger stock, especially with more than 100 cattle. Potentials of ammonia emission reduction in cattle husbandry are above all in the sphere of manure application on field by using better manure application techniques and/or plowing under as soon as possible.

More than 90% of fattening pigs are kept in forced ventilated systems with liquid manure. This percentage will still grow slightly. It is possible that some additional litter will be stipulated for systems with liquid manure in the future. Potentials of ammonia emission reduction in pig fattening are covering liquid manure during storage and using better manure application techniques and/or plowing under as soon as possible. A nutrient adapted feeding should stand at the beginning of emission reduction.

Ammonia Emission

Ammonia Emissions from German animal husbandry were calculated at 613 10^6 kg (Gg or thousand tons) for 1990, the base year of the relevant international agreements (Fig. 4). In the years 1991 and 1992 emissions from animal husbandry decreased very sharply, according to the strong decline in livestock numbers in the new Federal States after the German reunification. Further decrease of livestock numbers and the use of modern techniques till 1999 have reduced ammonia emission only slightly.

To forecast ammonia emissions for the year 2010, different scenarios were performed. If there would be only changes in livestock numbers and no further technological development, ammonia emission from animal husbandry will amount to 461 10^6 kg in 2010. But it can be reduced to 429 10^6 kg if the use of emission reduction techniques is promoted. It can be seen as a realistic minimum of emission reduction. If further abatement techniques are made as mandatory condition, 411 10^6 kg seems to be possible as a realistic maximum of emission reduction.

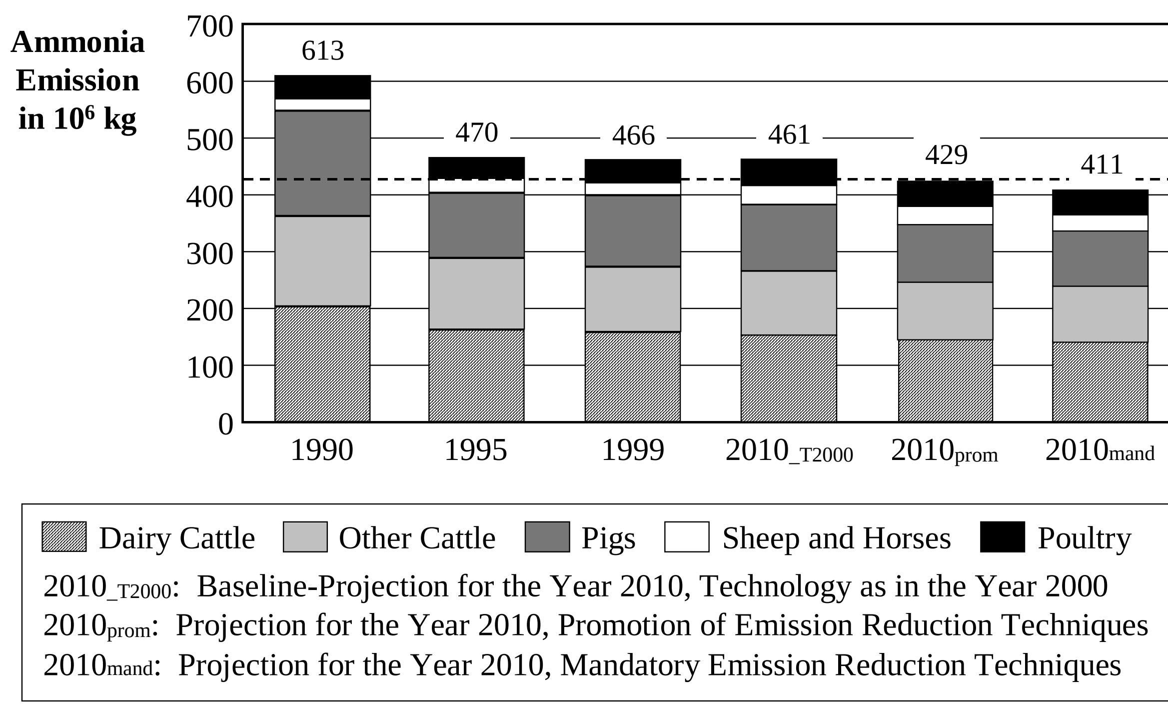

Figure 4. Calculated Ammonia Emission from Animal Husbandry from 1990 till 2010.

CONCLUSION

Ammonia emission factors were determined for the different management systems in the spheres animal house, manure storage, field application and abatement techniques. They represent the current state of knowledge and were agreed upon at the national level. Further research should focus on low-emission technologies in keeping systems, solid manure storage and manure application on land covered by vegetation.

Data from official livestock censuses were supplemented by conducting surveys in different regions typical of Germany. Such an extended data base is a prerequisite for detailed emission calculations.

The ammonia emissions from German animal husbandry estimated for 2010 range between 411 and 461 10^6 kg depending on the extent of use of low-emission techniques. This relatively small range emphasizes the necessity of further research and development of effective emission reduction techniques. To calculate total ammonia emissions, about 100 10^6 kg resulting from mineral fertilising and approximately 20 10^6 kg from other sources have to be added. Germany can meet its commitment to reduce ammonia emissions to 550 10^6 kg in 2010 if low-emission techniques will find a wider use. It requires additional efforts.

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