TEXTE
80/2011

UN ECE-Convention on long-range transboundary air pollution - Task Force on Reactive Nitrogen

Systematic cost-benefit analysis of reduction measures for ammonia emissions in agriculture for national cost estimates

Umwelt Bundes Amt
Für Mensch und Umwelt

| TEXTE | 80/2011

FEDERAL MINISTRY OF THE ENVIRONMENT, NATURE
CONSERVATION AND NUCLEAR SAFETY – INTERNATIONAL
CO-OPERATION IN THE FIELD OF ENVIRONMENT

Project No. (FKZ) 312 01 287
Report No. (UBA-FB) 001527/E

UN ECE-Convention on long-range transboundary air pollution – Task Force on Reactive Nitrogen

Systematic cost-benefit analysis of reduction measures for ammonia emissions in agriculture for national cost estimates

by

Helmut Döhler (Project management)
Brigitte Eurich-Menden
Regina Rößler
Robert Vandré
Sebastian Wulf
Kuratorium für Technik und Bauwesen
in der Landwirtschaft (KTBL) e.V.

On behalf of the Federal Environment Agency (Germany)

UMWELTBUNDESAMT

This publication is only available online. It can be downloaded from
http://www.uba.de/uba-info-medien/4207.html
along with a German-language version.

ISSN 1862-4804

Study performed by:	Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) e.V. Bartningstraße 49 64289 Darmstadt
Study completed in:	June 2011
Publisher:	Federal Environment Agency (Umweltbundesamt) Wörlitzer Platz 1 06844 Dessau-Roßlau Germany Phone: +49-340-2103-0 Fax: +49-340-2103 2285 E-Mail: info@umweltbundesamt.de Internet: http://www.umweltbundesamt.de http://fuer-mensch-und-umwelt.de/
Edited by:	Section II 4.3-D Effects of Air Pollution on Terrestrial Ecosystems Gabriele Wechsung

Dessau-Roßlau, November 2011

Report Cover Sheet

1. Report No. UBA-FB 001527	2.	3.
4. Report Title Systematic Cost-Benefit Analysis of Mitigation Measures for Agricultural Ammonia Emissions, Supporting National Costing Analysis		
5. Author(s), Family Name(s), First Name(s) Döhler Helmut, Eurich-Menden Brigitte, Rößler Regina, Vandré Robert, Wulf Sebastian	8. Report Date 30.4.2011	
	9. Publication Date 11/2011	
6. Performing Organisation (Name, Address) Association for Technology and Structures in Agriculture (KTBL) Bartningstraße 49 D-64289 Darmstadt Germany	10. UFOPLAN-Ref. No. FKZ 312 01 287	
	11. No. of Pages 34	
7. Funding Agency (Name, Address) Umweltbundesamt (Federal Environmental Agency) Postfach 14 06, 06813 Dessau-Roßlau	12. No. of Reference 17	
	13. No. of Tables, Diagrams 20	
	14. No. of Figures 14	
15. Supplementary Notes		
16. Abstract		

In this project, the methods for the determination of the expenses for the reduction of agricultural ammonia emissions were updated, and the costs of selected, representative mitigation measures suitable for Germany´s agriculture were newly calculated. The reduction costs are determined based on the ratio of the extra costs for the reduction measure and the emission reduction in comparison with a reference system.

Protein-adapted feeding in pig fattening generally leads to lower expenses for feedstuff, which provides negative reduction costs (- € 3.5 to - € 13.5 per kg of NH_3 depending on the reference system). Pig fattening in naturally ventilated housing causes reduction costs of € 9.2 per kg of NH_3 as compared with forced-ventilated animal houses. However, this amount cannot always be exclusively attributed to ammonia emission reduction (allocation) because naturally ventilated houses are generally built for the improvement of animal welfare and animal health. Single and multiple-stage air purifica-

	tion techniques in forced-ventilated pig fattening houses are a technically efficient, though cost-intensive reduction measure (€ 4,6 - € 8,6 per kg of NH_3). Solid covers for pig slurry stores (concrete ceiling, tent) are characterized by high investment expenses and a long service life causes moderate reduction costs (€ 1.1 - € 2.5 per kg of NH_3). Floating covers (plastic sheet, granules) are almost cost-neutral given reduction costs of € 0.3 to € 0.9 per kg of NH_3 (pig slurry) if the fertilizer value of the conserved nitrogen is included in the calculation. Cattle slurry requires significantly higher extra costs for the covering of slurry stores because the natural floating cover itself reduces emissions (€ 1.3 to € 12 per kg of NH_3). If annual spreading performances are low (1,000 to 3,000 m³/a), only promptly incorporation of cattle and pig slurry is cost-effective. If spreading performances are high, the costs of emission reduction for the techniques trailing hose, trailing shoe, slot injector, and slurry cultivator only range between € 0.3 and € 0.5 per kg of NH_3. In this case these techniques are cost-neutral if the fertilizer value is considered. High or moderate mitigation costs (€ 3.6 - € 5.7 and € 0.5 - € 1.1 per kg of NH_3) were determined for incorporation and urease inhibition during urea fertilizer application. However, there is great insecurity with regard to actual emissions from urea. The calculations were carried out separately for individual operation steps in animal production (feeding, animal house, store, spreading). Emission reduction in one operation step influences the quantity of nitrogen in the following steps. This context including reduction effects and reduction costs is shown using a pig fattening technique as an example
17.	Keywords Ammonia, emissions, mitigation costs, livestock housing, animal manure, urea, pig slurry, cattle slurry, feeding, animal house, storage, distribution

18. Price	19.	20.

Table of contents

1 Introduction

By signing the Göteborg protocol in 1999 and by adopting the NEC directive 2001/81/EC of the European Parliament and the Council in 2001, Germany accepted the obligation to adhere to a national limit of 550 kt per year for the emissions of ammonia (NH_3) and not to exceed this limit as of the year 2010. According to the current prognosis, however, it is impossible to remain below this emission limit without additional measures for the reduction of ammonia emissions (OSTERBURG ET AL 2010). For the reduction of ammonia emissions, a wide range of measures in animal housing and the storage and distribution of animal manures is available. These measures must be evaluated very differently with regard to their suitability and effectiveness as well as the expenses caused by them. Based on the UN/ECE Guidance Document and appendix XI of the Göteborg protocol, an overview of the measures as well as their reduction potential and their suitability was compiled (chapter 2).

The obligations of the contracting states do not include the calculation of reduction costs. However, such calculations are essential for economic and industrial management aspects of national and international scenarios for political counselling. The most recent national calculations of expenses for the reduction of ammonia emissions were carried out by the KTBL in a project realized on behalf of the Federal Environmental Agency and the Federal Ministry of Food, Agriculture and Consumer Protection in 1999 - 2002. The methods were not founded on an agreement with international committees. In addition, they were based on estimates in many areas. Thus, the results have so far not been comparable with those of other contracting states. It is the goal of this project to update the methods for the determination of reduction costs based on international agreements (EC 2003, UN/ECE 2007) in order to increase transparency and internal consistency and to allow for a comparison at the international level. In addition to cost calculations, the methods also include the calculation of benefit effects (e.g. saved fertilizer, feedstuff, or work steps) (chapter 3).

The expenses for selected measures of ammonia emission reduction suitable for Germany in the activity areas feeding, animal housing, storage, and application were newly calculated with the aid of the developed methods. The current reduction costs are listed and a short technical description of the reduction measures is given in the following chapters.

The earlier ammonia emissions are reduced in the process chain, the higher losses at the following stages of the process chain may occur. The reduction of NH_3 losses in the animal house, for example, leads to an increased content of ammonium nitrogen (NH_4-N) in the store and a resulting higher risk of losses at this process stage. Without additional reduction measures in the store, e.g. by covering the slurry store with floating sheets, N quantities conserved in the animal house are therefore partially lost at a later stage. Conversely, an investment in an emission-reducing slurry application technique is particularly efficient if reduction measures have already been taken during slurry storage because in this case the slurry contains more NH_4-N. For this reason, it is important to consider the effectiveness and efficiency of reduction measures during the entire process chain. This was examined in chapter 10 for selected combinations of individual process stages.

2 Ammonia emission reduction measures in agriculture

This project considers process-technological and organizational measures for the reduction of ammonia emissions from livestock farming as well as the application of urea fertilizer.

Based on the UN/ECE Guidance Document, appendix IX of the Göteborg protocol, and the BAT reference document (BREF) “Intensive Rearing of Poultry and Pigs“ (EC 2003), the most important measures in the area of livestock farming are listed and evaluated with regard to their effectiveness and suitability for practice in Table 1.

2.1 Feeding

The quantity of nitrogen excretion in faeces and urine is linearly dependent on the intake of nitrogen (crude protein) in feedstuff. Approximately 65% of the nitrogen taken in by pigs is not used for growth and excreted. Feeding according to the requirements of the animals allows an oversupply of the animals with crude protein to be reduced and thus nitrogen excretions and ammonia emissions to be decreased. Multiple-phase feeding enables crude protein supply during fattening to be adapted to the demand of the animals. The addition of lysine and possibly other essential amino acids allows the crude protein content in the feed to be reduced even more without having to accept performance losses (growth, carcass quality, meat quality) of the animals. Not only environmental reasons, but also costs and animal health speak in favour of multiple-phase feeding. The reduction of the crude protein content between initial and final fattening reduces feed expenses. The amount of the savings depends on the quantity of amino acids used and the market price of the feed components. The crude protein content is reduced by decreasing the share of expensive protein components (extracted soybean meal) in the final fattening feed, which accounts for approximately two thirds of the feed in the entire fattening period. The higher technical and organizational requirements of multiple-phase feeding must be considered negative.

2.2 Housing

Selection of techniques

The calculation of NH_3 reduction costs requires a sufficient data basis. For this reason, reduction measures in cattle and laying hen housing must be postponed for the time being. In those two areas, reliable results on the effects of different housing techniques on ammonia emissions are not available. The quantity of ammonia emission reduction which can be realized by building low-emission animal houses mainly depends on the existing housing systems. Cattle and poultry housing in Germany is showing a development from low-emission housing systems used in the past towards housing techniques which emit more ammonia. The loose housing is the most widely used housing system for dairy cattle, whereas tied housing as a low-emission housing technique is continuously losing in importance for reasons of animal protection and welfare. The conventional cage housing of poultry has been forbidden in Germany since the beginning of 2010, which has led to changes in the structure of housing for laying hens. In Germany, the use of enriched cages, for which European law provides no time limit, is only permitted for a limited period of time in existing housing systems. However, such cages are defined as a reference system for the evaluation of techniques in the “Guidance document for preventing and abating ammonia emissions” of the UN/ECE.

Pig fattening: Free ventilated house

Temperature-insulated or littered lying and resting areas are characteristic of free ventilated houses. Except for the deep litter house, free ventilated houses are classified in a lower emission category than forced-ventilated houses with fully slatted floors because the lower temperatures in the free ventilated house reduce the ammonia emission potential (reduction: ca. 35%). With regard to energy requirements, free ventilated houses must also be evaluated more favourably because ventilation and heating are not necessary. Higher labour requirements due to more difficult cleaning and disinfection as well as a greater need for repairs must be considered negative. Free ventilated houses can only be realized as a new building. The motivation for their construction is generally animal welfare.

Exhaust air purification

Exhaust air purification systems are an end-of-pipe technique for the reduction of ammonia emissions. They are defined as a category 1 measure in the UN/ECE Guidance Document. However, they are not yet a state-of-the-art technique for low-emission animal housing systems (EUROPEAN COMMISSION 2003).

The techniques offered include biofilters, trickle bed reactors (biowashers), chemical scrubbers, and combined two or three-stage techniques. For litterless pig housing, a biofilter system, three trickle bed reactors, as well as 2 two and three-stage techniques each have been certified according to the Cloppenburg guidelines and the DLG test frame. Another single-stage chemical scrubber with pre-spraying passed the DLG SignumTest in littered short-term poultry housing. Biofilters are used primarily for odour reduction. According to the test criteria of the DLG, they are not suitable as sole ammonia separators in animal housing. Therefore, trickle bed reactors and multiple-stage systems were used for cost calculations.

The reduction potential of trickle bed reactors amounts to 70%, while multiple-stage systems may reach 90% and more. The effectiveness of NH_3 removal depends on regular system maintenance, which increases fixed system costs. If acid is used for pH control, an additional store for acid-containing washing water is necessary. Directly before spreading, the washing water can be mixed with slurry. The spreading costs grow because the quantity of slurry to be spread increases.

In principle, exhaust air purification is only possible in animal houses with forced ventilation because the exhaust air from the animal houses must be collected and led through the cleaning system by fans. Housing techniques with free ventilation, such as open loose houses for cattle, cannot be equipped with an exhaust air filter. Therefore, the main application area is pig housing. Currently, virtually no practical experience from poultry housing is available. Here, primarily the high dust load causes problems because it makes the continuous operation of exhaust air purification systems more difficult. Exhaust-air cleaning systems can be realized in new buildings and as retrofit units. They require high investment expenses. In practice, exhaust air purification systems are therefore often built only when other measures (e.g. feeding and removal of manure) are insufficient in order to guarantee immission protection.

2.3 Storage of animal manures

Ammonia losses from slurry stores can be minimized by covering open stores. A distinction is made between natural and artificial covers.

Natural floating covers are the simplest and most inexpensive form of slurry store covering. These covers primarily form on cattle slurry, but they also develop on pig slurry rich in fibre and dry matter. The reduction potential ranges between 30 and 80% for cattle slurry and between 20 and 70% for pig slurry.

A higher reduction effect of up to 90% is realized by means of artificial **covers with chopped straw.** However, the straw cover must be at least 10 cm thick. The effectiveness of both cover variants (natural floating cover and chopped straw) is limited on farms with frequent slurry distribution because the natural floating layer or the straw layer are destroyed temporarily or permanently. Straw covers must be replaced after stirring.

If **granules** are used, material losses are lower than in the case of straw. They float again shortly after the slurry has been stirred. Therefore, only a small amount of the granules is spread with the slurry. However, it is necessary to replace the lost material. Emission losses are reduced by 80 to 90%.

Floating sheets also have a reduction potential of 80 to 90%. Their advantage lies in low maintenance requirements. Precipitation water must be led or pumped into the slurry lying underneath.

Floating bodies and **solid covers**, such as a concrete cover, a tent roof, or a plastic cover, have the highest reduction potential of up to 95%. However, floating bodies are only suitable for liquid pig slurry without a natural floating layer. When the slurry is stirred and sucked in, one must make sure that floating bodies are not sucked in with the slurry in order to avoid losses, clogging, and damage. Solid covers have the longest service life and low maintenance requirements. Another advantage over other kinds of coverage is that rainwater input is avoided. Due to the static load, however, a tent roof is not suitable for all slurry containers.

2.4 Land spreading of animal manures

Ammonia losses during the application of animal manures can be reduced by applying emission-reducing techniques and organizational measures. In addition to the conventional broadcast spreader, trailing hoses and trailing shoes as well as open slot injectors are state of the art. The goal of these techniques is a reduction of the emitting surface and a shortened dwell time of the slurry on the bottom.

The **band spreader** deposits the slurry on the soil in parallel bands by means of hoses. As compared with the broadcast spreader without direct incorporation, NH_3 losses can be reduced especially in growing crops and while spreading thin slurry. If the dry matter content is high, the effect is small because the slurry bands can dry up without penetrating into the soil.

The **trailing shoe** is a further development of the trailing hose spreader for application on grassland. The slurry is also spread using a system of hoses, which, however, are equipped with a “shoe-like” reinforcement at the end. This shoe part crop or grass leaves and stems and place slurry in bands on the soil surface. This reduces contamination of crops and grass by manure and allows the slurry to be incorporated into the upper soil layer (0-3 cm). Like the trailing hoses, this technique provides greater reduction potential for pig slurry than for cattle slurry because pig slurry is runnier.

Open slot injectors have even greater reduction potential for ammonia losses than band spreading booms and trailing shoes (assumption: 60% for cattle and pig slurry). This technique is suitable for application on grassland and in growing crop stands. Application by slot discs, through which the slurry is applied, avoids crop soiling. However, the turf is damaged. Newer slot techniques try to minimize this damage by means of smaller slot depth. The necessary draft power requires smaller working widths.

The applicability of trailing hoses and trailing shoes as well as slot techniques is restricted by limited suitability for sloped fields and limited manoeuvrability.

The **slurry cultivator** has the highest reduction potential for NH_3 emissions. The great reduction effect is reached by means of direct slurry incorporation into the soil. The cultivator is only suitable for areas without vegetation. As compared with other techniques, which do not deposit the slurry in the soil, the direct cultivation of the soil requires a tractor with more engine power.

Incorporation can also be carried out after spreading using an intermittent technique and conventional soil cultivation equipment. The slurry is spread using a broadcast spreader and incorporated shortly after distribution. The thicker the slurry and the higher the temperatures are, the more important it is to incorporate the slurry is quickly as possible. If the slurry is incorporated within one hour, the reduction potential comes close to the reduction potential of the slurry cultivator. It decreases significantly if incorporation is carried out within 4 hours after distribution (70%/50% for pig/cattle slurry).

Another reduction technique during application of manure is the **thinning** of slurry. As compared with pig slurry, cattle slurry has a higher dry matter content, which reduces the flowability of the slurry. This prevents the slurry from running off quickly from plant parts and quickly penetrating into the soil. Homogenizing and thinning enables the flowability of cattle slurry to be increased and faster penetration into the soil to be guaranteed. The efficiency of distribution is reduced by thinning, which increases the expenses correspondingly.

Table 1: Ammonia reduction measures in livestock farming

Place of emission reduction	Reference system	Reduction measure	Animal species	Reduction potential (%)	Effectiveness/ applicability
Feeding	Single-phase feeding	Multiple-phase feeding (two, three, and multi-ple-phase feed-ing) with crude protein adapta-tion	Pig	10-30	Amino acid supplements are necessary in order to avoid performance losses. Tech-nical requirements for two and three-phase feeding are low. For multiple-phase feeding, technical and organizational re-quirements are higher, and large invest-ments are needed.
Housing	Forced-ventilated house, fully slatted floor	Free ventilated house	Pig	35	Only suitable for new buildings, higher la-bour requirements are compensated for by low energy expenses. Motivation: ge-nerally animal welfare.
	Without exhaust air purification	Exhaust air purification	Pig	70-90	Requirements: Central exhaust air con-duction, additional storage container nec-essary if acid is used, higher distribution requirements, effectiveness of NH_3 sepa-ration dependent on system type and maintenance
Storage	Open storage container	Natural floating layer	Pig Cattle	20-70 30-80	Reduced effectiveness on farms with fre-quent slurry distribution
		Chopped straw	Pig/cattle	70-90	Reduced effectiveness on farms with fre-quent slurry distribution
		Granules	Pig/ cattle	80-90	Material losses must be replaced.
		Floating sheets	Pig/ cattle	80-90	Low maintenance requirements
		Floating bodies	Pig	>90	Suitable only for pig slurry without a float-ing layer. Particular care is necessary when homogenizing the slurry and suck-ing it off.
		Solid cover (tent roof, concrete, plastic)	Pig/cattle	85-95	Low maintenance requirements, no rain-water input, longest service life. Not every tank is suitable for a tent roof (statics)
Spreading	Broadcast spreader without incorporation	Trailing hose	Pig/cattle	30/ 20	No damage to the turf on grassland. Only little effect on uncultivated soils and if the dry matter content is high. Rather unsuitable for sloped fields..
		Trailing shoe	Pig/cattle	50/ 40	For growing crop stands and grassland. Avoids soiling of the crop stand and dam-age to the turf. Rather unsuitable for sloped fields.
		Open slot injection (discs)	Pig/cattle	60	For growing crops and grassland. No soil-ing of the crop stand. Smaller working widths (6-9 m). Rather unsuitable for sloped fields. Potential damage to the turf.
		Cultivator	Pig/cattle	90	Not for grassland and growing crop stands
		Complete incorporation within 1 hour	Pig/cattle	90	Not for growing crop stands, greater la-bour organization requirements
		Complete incorporation within 4 hours	Pig/cattle	70/ 50	Not for growing crop stands, greater la-bour organization requirements.
		Slurry dilution 1:1	Rind	50	For better infiltration of slurry with high dry matter contents. Higher spreading ex-penses due to reduced efficiency. Higher risk of soil damage due to driving over.

Sources: DÖHLER ET AL. 2002; EURICH-MENDEN ET AL. 2011; IBK 2008

2.5 Urea as nitrogen fertilizer

Urea is the most important source of NH_3 emissions from the application of mineral fertilizers. The enzyme urease hydrolytically converts urea into ammonium in the soil. During this process, the pH-value in the soil increases, which promotes the formation and release of NH_3. Like in the case of animal manures, the incorporation of urea into the soil allows NH_3 losses to be avoided. In addition, the use of urease inhibitors, such as N-(n-butyl) thiophosphoric acid triamide (NBTPT, "Agrotain"), can delay urea conversion and thus facilitate infiltration into the soil before conversion.

3 Methods

3.1 Goals and requirements

The systematic cost analysis of techniques for the reduction of ammonia emissions serves to harmonize reduction measures at the national and the international level. In order to guarantee the validity of the determined reduction costs as basic data for this harmonization, a uniform calculation method must be applied which fulfills the following requirements (cf. DÖHLER ET AL. 2002 page 30 ff.):

- Practical relevance: The calculations must be based on important techniques applied in agricultural practice.
- Universality and flexibility: The methods must be able to be applied to different approaches and techniques depending on the region, the farm type, and farm size. It must be possible to extend the considered system limits, if necessary, so that all techniques relevant for the NH_3 emissions and their costs are taken into consideration.
- Transparency: standard prices; the process components and calculation steps considered must be explicit.
- Comparability: Marginal assumptions, units, reference values, and algorithms must be standardized as far as the other requirements permit.

3.2 Scope, approach, and system boundaries

In farm livestock farming, the following techniques are considered when ammonia reduction costs are determined: Feeding, housing, storage and application of animal manures.

Specific reduction techniques belong to each method (chapter 2). The reduction costs are determined as expenses for the technique per unit of NH_3 emission reduction (€ per kg of NH_3). The expenses for the technique and ammonia emission reduction are determined as the difference in relation to the corresponding values of the technique without the application of the reduction technique (reference system). The expenses for the technique and ammonia reduction are indicated per animal (feeding), per animal place (housing), or per volume or weight of animal manures (storage) depending on the technique (cf. EC 2003, p. 330, Table 7.7).

The influence of upstream techniques on the reduction costs of the considered technique can be integrated using the marginal assumptions, such as the NH_4-N quantity per animal place in the calculation of the reduction costs of techniques applied in housing. The calculation models are structured such that process chains can be modelled. This means that the quantity of NH_4-N loads and possibly the slurry volumes which result from a combination of techniques or measures are available as an input value for the following technique.

3.3 Costs

For the determination of the reduction costs, all additional costs incurred by a farm due to a reduction technique are added up as expenses for the technique. Since the costs of the technique result from the difference of the process costs with and without the application of the technique, all deviating cost points must also be shown for the reference system. If process steps serve other process goals in addition to ammonia reduction, the relevant share of the costs must be attributed to the individual goals (allocation).

The additional expenses can be offset by cost savings resulting from the technique. Such cost reductions are listed separately if they are caused directly by the technique. However, they are only offset against the additional expenses if they are the result of ammonia reduction.

Table **2** lists the kinds of costs that may be considered (cf. UN/ECE 2007, p.4, table 1; EC 2003, p. 331, table 7.8).

Table 2: Cost categories in the calculation of the costs of techniques on an annual basis (€/a).

Type of costs	**Examples; annotations**
A) Fixed costs	
Investments: time-dependent depreciation	e.g. batch mixers for feed mixing, freely ventilated animal house, exhaust air purification system, tent roof for slurry store, slurry cultivator; linear depreciation of the bound capital; capital costs (linear depreciation plus interests) can be calculated alternatively as a regular annuity
Interest costs	linear and constant
Insurance	percentage corresponding to the investment
Maintenance, building maintenance and repair	percentage corresponding to the investment
B) Variable costs	
Investments, depreciation depending on performance	applied in the case of machines whose value decreases primarily due to wear given high annual performance (e.g. the slurry distributor of a private contractor) or in cases where the use of the machine for reduction measures only accounts for a small share of annual performance (e.g. tractor)
Repairs	only for machines and plants; building repairs are included in the fixed costs; generally, the percentage corresponding to the investment is considered.
Labour costs	changes due to increased / reduced manpower requirements (e.g. an additional driver for intermittent slurry distribution)
Resources	e.g. fuel and lubricants for machines, fattening feedstuff
C) Others	
Indirect follow-up costs	e.g. increased spreading volume due to reduced evaporation from slurry stores with floating covers
Indirect cost savings	e.g. NH_3 emission reduction increases the N-content of organic manure and thus reduces mineral fertilizer expenses

3.4 Ammonia emission reduction

The reduction of ammonia emissions is determined as the difference of the emission of the technique without any reduction measures (reference system) and the technique with reduced emission. For the emission of the reference system, emission factors from national emission reports are used (Haenel et al. 2010) or derived from the literature.

Whenever possible, relative instead of absolute emission factors are used which are related to the NH_4-N content and/or the emitting surface (Table **3**). The use of relative emission factors allows changes in the reference values (e.g. N-flow, surface) to be modelled by the calculations.

The reduction of the emissions by means of one technique is indicated as a percentage or as a separate emission factor related to the reference emission.

Table 3: NH_3 emission factors for reference techniques

Emission factor	Unit	Range of application	Source, annotations
3	kg NH_3-N/(TP•a)	Pig fattening, forced-ventilated house with fully slatted floor	DÖHLER ET AL. 2002; EURICH-MENDEN ET AL. 2011
16	g NH_3-N/(m^2•a)	Pig slurry in an open store without a natural floating cover	corresponds to 15 % of the NH_4-N (Emission inventory, HAENEL ET AL. 2010) for a 1000 m³ round container.
3,3	g NH_3-N/(m^2•a)	Cattle slurry in an open store with a natural floating cover	corresponds to 15 % of the NH_4-N (Emission inventory, HAENEL ET AL. 2010) for a 1000 m³ round container, including a. 70 % reduction due to the natural floating cover and stirring twice a year
25	% of NH_4-N	Pig slurry, broadcast application	Spring, 15 °C (DÖHLER ET AL. 2002)
50	% of NH_4-N	Cattle slurry, broadcast application	Spring, 15 °C (DÖHLER ET AL. 2002)
11.5	% of ureaf-N	Urea fertilizing, arable land	HAENEL ET AL. 2010

4 Mitigation costs: Feeding

The most effective ammonia emission mitigation technique in fattening pig housing is reduced nitrogen intake via feedstuff because it allows both total nitrogen excretion and ammonia emissions to be decreased significantly. The crude protein content in the feedstuff, the quantity of nitrogen excretion and ammonia emissions show a linear correlation. A reduction of the nitrogen intake by one percent reduces nitrogen excretion by fattening pigs by 10% while ammonia emissions decrease by 10 to 13% (AARNINK et al. 2003; CANH et al 1998). In phase feeding, different feed rations with demand-oriented crude protein content and amino acid composition (Protein-adapted phase feeding) allow nitrogen intake to be reduced. Since protein-reduced feedstuff does not contain the required quantity of limiting amino acids in the feed protein, these amino acids must be provided as a supplement, which is generally added to the mineral feedstuff.

The feeding techniques can differ significantly in practice. The developed calculation methods are applied to selected techniques here, which are not claimed to represent the conditions in Germany. This requires more calculations based on varied assumptions as well as a verification of assumptions and results by means of practical data.

According to the UN/ECE Guidance Document, the reference system for feeding is often not clearly documented, and variations between countries are significant. Depending on the crude protein content of the reference, however, a reduction of the crude protein content by 2 to 3% is possible according to the Guidance Document. In order to prevent insufficient supply with essential amino acids and consequent performance losses (growth, meat quality and structure) at the beginning of the fattening period, however, the addition of more amino acids is necessary. Therefore, two references are used as a comparison for the calculation of the reduction costs:

- **Reference 1:** Single-phase feeding with conventional feedstuff (crude protein content 19%)
- **Reference 2**: Single-phase feeding with protein-adapted feedstuff (crude protein content 17.5%, significant addition of amino acids)

Single-phase fattening is more and more losing in importance in Germany, whereas two or three-phase fattening is meanwhile state of the art in new buildings and is continuously gaining in acceptance (R. WINTERSPERGER, AELF Coburg; M. WEGENAST, Beratungsdienst Schweinehaltung und Schweinezucht e.V., Sigmaringen/ Boxberg, oral communications 2011). A total of three techniques were considered in the calculation of the reduction expenses for ammonia emissions:

- **Two-phase** feeding with an adaptation (reduction) of the crude protein content from 17.5% (beginning of the fattening period) to 15% (end of the fattening period) beginning at a live weight of 70 kg; addition of significant quantities of amino acids
- **Three-phase** feeding with an adaptation (reduction) of the crude protein content from 17.5 % (beginning of the fattening period; live weight: 30-50 kg) to 16% (middle of the fattening period; live weight: 50-90 kg) and 15% (end of the fattening period; live weight: 90 kg until the end of the fattening period). During all phases, significant quantities of amino acids were added.
- **Multiple-phase** feeding with addition of significant quantities of amino acids (adaptation/reduction of the crude protein content from 17.5% to 14% in 10 kg steps).

The assumptions made in two-phase feeding correspond to the feeding recommendations in Bavaria and are roughly identical with the crude protein contents in the RAM feedstuff used in Lower Saxony.

The assumed feed mixtures contain different percentages of wheat and barley. In addition, the assumptions were based on extracted HP soya bean meal as a protein carrier and 1% of soya oil as a dust binder. Amino acids were added via the mineral feed. The calculations for conventional single-phase fattening were based on mineral feedstuff containing 6% lysine and 1.5% methionine. For all other feeding variants, mineral feedstuff containing 10% lysine, 1.5% methionine, and 2% threonine were assumed. Mineral feedstuff without added amino acids is no longer sold commercially in Germany.

The calculations were carried out in an exemplary manner for different animal house sizes (517, 960, and 1,920 animal places) according to the KTBL standard BAUKOST version 2.7 (2010). The assumptions were based on forced-ventilated animal houses with fully slatted floors. Indicated emissions from this kind of housing are 0.3 kg NH_3-N per kg N, which corresponds to 30% (Haenel et al. 2010). The development of growth as well as energy and crude protein demand were determined in an exemplary manner for animals at a medium performance level (daily weight gain 800 g) according to algorithms of the Society for Nutrition (GFE, 2006). A nitrogen flow model was developed which was used to calculate the nitrogen input, the retention of nitrogen, total nitrogen excretion, and nitrogen excretion in urea and faeces based on the crude protein input, crude protein retention, and crude protein excretion.

Fattening was assumed to begin at a live weight of 30 kg. Given a daily weight gain of 800 g, the end of the fattening period is reached at a live weight of 118 kg after an average fattening time of 112 days. The assumptions were based on 2.5 fattening periods per year.

4.1 Technical description of the techniques

As an example of the wide variety of potential feeding techniques, a selection of techniques is presented here to which the calculation model was applied.

Feeding systems for dry feed consist of the feed silo, the mixing station (only for multiple-phase feeding), the feed pipe, the automatic feed dispenser, and the feeding computer. The feedstuff is either poured into the feed reception funnel directly underneath the feed silo, or it is transported to the reception funnel by feeding augers. The system is controlled manually or by a timer. Chain conveyors move the feed mixture via the feed pipe to the inlet valves in the animal house and the automatic feed dispensers (tube feeders).

(Single-) phase feeding (references)

In single-phase feeding, only one kind of feedstuff is used during the entire fattening period. When the system is started, the driving station begins to pull the conveyor chain in the feed pipe. At the same time, a spiral conveys the feedstuff from the silo and the reception funnel into the feed pipe and transports it into the animal house (Figure **1**). The feedstuff is metered out at the automatic feed dispenser. As soon as the last feed dispenser has been filled, the conveyor chain is stopped by an automatic switch, and the feed residues remain in the feed pipe until the next feeding session. This technique provides advantages under the aspect of labour management. However, it is not optimal with regard to feed expenses and the covering of animals' demand.

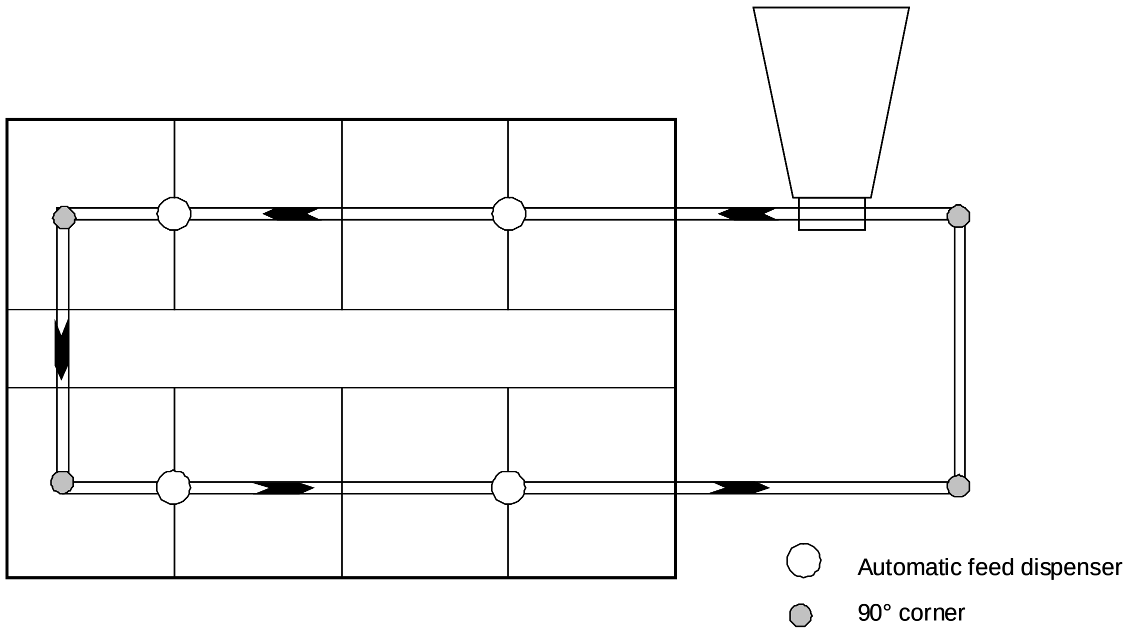


Figure 1: Schematic view of a single-phase feeding system

Multiple-phase feeding

Multiple-phase feeding allows for feeding fattening pigs in different weight phases according to their nutritional requirements. The fattening period is divided into different phases during which feed mixtures adapted to the current requirements of the animals are used. Different feed mixtures require additional feed silos for storage.

In multiple-phase feeding, two system variants are distinguished. In systems with a simpler design, a motor-driven feeding hopper conveys several feed mixtures one after the other into one single circuit. Electrically controlled transfer valves admit the feed to the feed pipe, which supplies the individual compartment with feedstuff. When the last automatic feed dispenser has been filled, the feed residues from the feed pipe are transported back into the feed silo before the next feed mixture is fed into the circuit. Thus, the fattening pigs are supplied with optimized feedstuff department-wise. Phase feeding via two or three separate circuits, which avoids the spreading of residues (e.g. antibiotics), is slightly more sophisticated. Since this kind of phase feeding is applied far more often in Germany than phase feeding via the same feed circuit (SCHULTE-SUTRUM 2010), this variant was used for the calculations (Figure **2**).

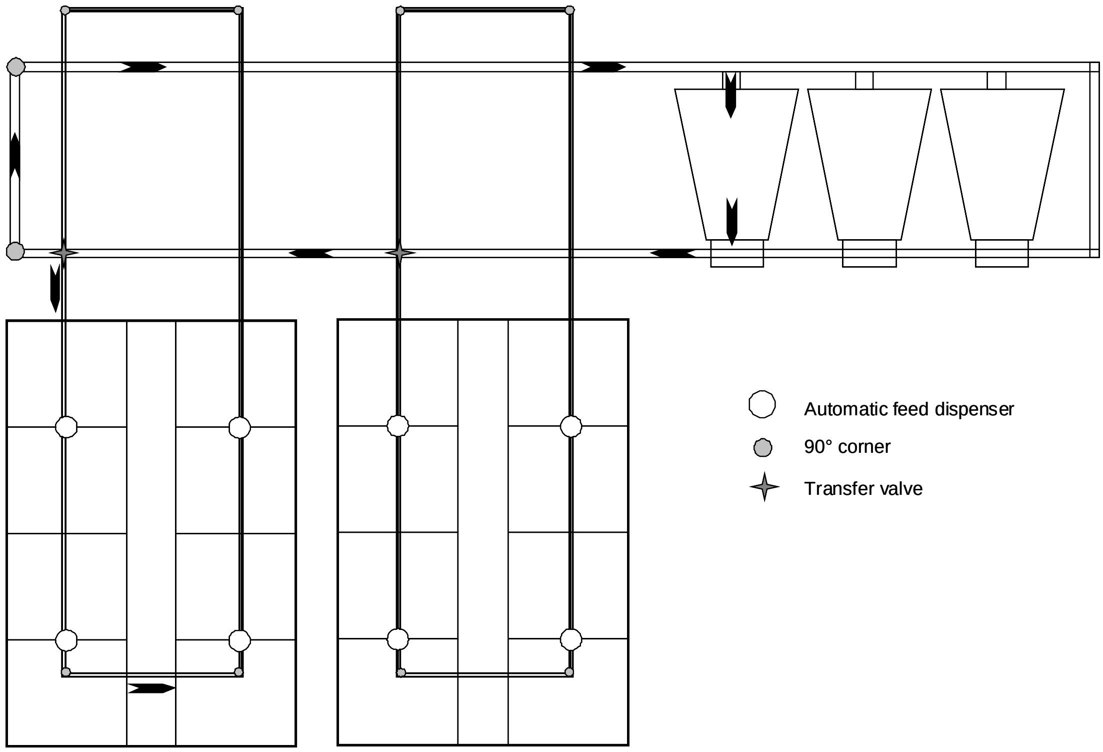


Figure 2: Schematic overview of a two-phase feeding system

A feeding technique which in principle enables many different feed mixtures to be combined and to be dispensed at one single automatic feeder is termed multiple-phase feeding. When this multiple-phase feeding method is applied, the individual components or premixed feedstuff stored in the silos are transported to a mixing container by feeding augers in preprogrammed quantity ratios and mixed for one automatic feed dispenser. Each silo must have one feeding auger. The mixing process is computer-controlled. After the mixing process, a spiral conveys the feedstuff from the feeding hopper to the feed pipe, from where a conveying chain transports it to the automatic feed dispensers. The metering of the feed mixture in the automatic feed dispensers is also controlled by computers with the aid of automatic valves. The filling height of the automatic feed dispensers can be determined using a sensor. While the feed mixture is still being transported to the automatic feed dispenser, the next mixing process in the mixing container is started. After the last automatic feed dispenser has been filled, the feeding system is shut down automatically by an automatic switch (Figure **3**).

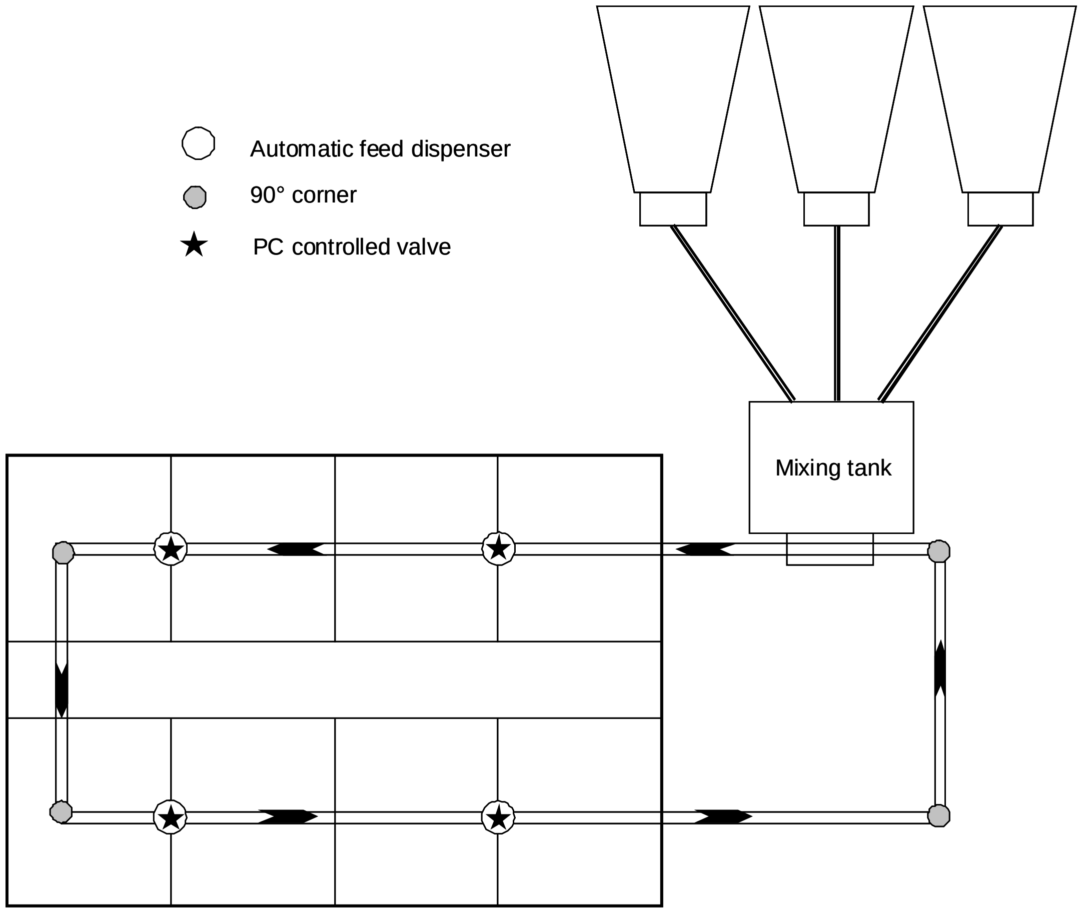


Figure 3: Schematic view of a multiple-phase feeding system

4.2 Nitrogen excretion and emission factors

In addition to the average growth performance of the fattening pigs, the quantity of nitrogen excreted depends on the quantity of crude protein intake and the digestibility of the crude protein. The calculations are based on uniform growth performance values. Differences in the quantity of nitrogen excreted thus result solely from a changed quantity of crude protein intake and the digestibility of the crude protein. The digestibility of the crude protein varies between 82 and 86% depending on feed composition. In principle, it is higher for feedstuff which contains a large percentage of extracted soya bean meal.

The calculated nitrogen excretions during conventional single-phase fattening amounts to 12.8 kg N per animal place and year ([AP•a], Table 4). This corresponds to ca. 5.1 kg N per animal and per fattening period. Relative N-excretions per animal (65%) roughly correspond to the value according to EUROPEAN COMMISSION (2003). A reduction of the crude protein content in the feedstuff by 1.5% over the entire fattening period results in a 12% reduction of nitrogen excretion. A division of the fattening period into two phases provides the most significant reduction of nitrogen excretion, whereas three-phase fattening has virtually no effect on excretion and losses as compared with two-phase fattening. The explanation for this result is that the assumed crude protein content during initial and final fattening was equally high in two and three-phase feeding. Thus, excretion during two-phase fattening only reach 9.6 kg N/ (AP*a) and 9.5 kg N/ (AP*a) during three-phase fattening. Multiple-phase feeding has the greatest reduction effect among the considered feeding variants. A reduction of the crude protein content to 14% and finer grading between the individual phases decreases N-excretion by 30% as compared with reference 1 and 20% as compared with reference 2 to a value of 9 kg N/ (AP*a). Ammonia losses are reduced by 35 and 26% respectively (Table **4**). Relative emission reduction during phase feeding is higher than the relative reduction of nitrogen excretion. This is caused by a reduction of the percentage of urine nitrogen in total nitrogen excretion, which amounts to 79% during conventional single-phase feeding, 73% during two and three-phase feeding, and 72% during multiple-phase feeding.

Table 4: Calculated N-excretion and NH_3 emission factors for different feeding variants

			Conventional	Protein-adapted, large quantities of added amino acids			
		Unit	**Single-phase fattening**	**Single-phase fattening**	**2-phase fattening**	**3-phase fattening**	**Multiple-phase**
Nitrogen excretion		kg N/ (TP•a)	12.8	11.2	9.6	9.5	9.0
Reduction of N-excretion	Ref. 1	%	-	12	25	26	30
	Ref. 2				14	15	20
Emission factor		kg NH_3/ (TP•a)	3.69	3.24	2.55	2.53	2.39
Emission reduction	Ref. 1	%	-	12	31	31	35
	Ref. 2				21	22	26

4.3 Feeding and emission mitigation costs

The calculated annual costs of the feeding variants range between € 109.22 (multiple-phase feeding, 1,920 animal places) and € 122.35 (conventional single-phase feeding, 517 animal places) (Table **5**). Total annual costs decrease with growing animal places numbers. This must be attributed to economies of scale in fixed costs due to growing animal place numbers, which is most clearly visible in multiple-phase feeding. The greatest savings in variable costs are also realized in multiple-phase feeding. The feed costs fall sharply because expensive extracted soya bean meal is saved especially in the middle and at the end of the fattening period when the largest quantity of feedstuff is consumed. In addition, the water demand of the animals is decreasing due to the reduction of the crude protein content. In the variable costs, only feed expenses and the costs of drinking water were considered.

Table 5: Costs of the feeding variants in €/ (AP•a)

		Conventional	Protein-adapted, large quantities of added amino acids			
	Animal places	**Single-phase fattening**	**Single-phase fattening**	**2-phase feeding**	**3-phase feeding**	**Multiple-phase feeding**
Annual costs	517	122.35	120.79	111.64	113.07	112.05
	960	121.62	120.06	110.63	111.80	109.91
	1,920	121.41	119.85	110.49	111.62	109.22
Variable costs	517 960 1,920	118.05	116.49	105.73	105.29	102.46
Fixed costs	517	4.30	4.30	5.91	7.77	9.59
	960	3.57	3.57	4.91	6.51	7.46
	1,920	3.35	3.35	4.77	6.33	6.76

Since savings in the variable costs are more significant than the higher fixed costs of the measures in the examples calculated here, all feeding variants show negative reduction costs as compared with the references (Table 6). Whether this is the rule in practice or not cannot be determined based on the current knowledge. This determination requires the verification of assumptions and results by means of practical studies.

Protein-adapted single-phase feeding already leads to considerable savings. The most interesting variant in particular for smaller farms is two-phase feeding with a reduction of the crude protein content by 15% (initial fattening) and 40% (final fattening). This allows significant savings in nitrogen excretion and ammonia losses to be realized. At the same time, the technical and organizational requirements as well as the expenses for the technique depending on the concept of implementation remain within reasonable limits for the farm. The cost savings due to the techniques along with the reduction of NH_3 emissions achieved at the same time result in negative reduction costs. The reduction expenses for this feeding variant amount to -€ 9.42 to -€ 9.66 per kg NH_3 (as compared with conventional single-phase feeding) and -€ 13.15 to -€ 13.55 per kg NH_3 (as compared with Protein-adapted single-phase feeding). The higher negative reduction costs as compared with Protein-adapted feeding as a reference result from the considerably lower reduction of emissions as compared with this reference and are a mere calculation effect. They are no criterion of preferability.

For larger fattening houses with large animal capacities, multiple-phase feeding is suitable due to economies of scale as well as a higher level of automatization and better feeding precision. For an animal house with 1,920 animal places, the reduction expenses for multiple-phase feeding reach -€ 9.41 per kg NH_3 (as compared with reference 1) and -€ 12.46 per kg NH_3 (as compared with reference 2).

Table 6: Emission reduction costs of the feeding variants in €/ kg NH_3

		Protein-adapted, large quantities of added aminoacids			
	Animal places	Single-phase fattening	2-phase fattening	3-phase fattening	Multiple-phase fattening
Emission reduction costs as compared with reference 1	517		-9.42	-8.05	-7.96
	960	-3.53	-9.66	-8.51	-9.04
	1,920		-9.60	-8.48	-9.41
Emission reduction costs as compared with reference 2	517	-	-13.15	-10.85	-10.25
	960	-	-13.55	-11.60	-11.89
	1,920	-	-13.45	-11.56	-12.46

5 Mitigation costs: Housing

Free ventilated houses for pigs have established themselves in practice. Growing requirements with regard to animal-friendly housing due to animal protection legislation could strengthen the position of the free ventilated house even more in the future. The emission effect of free ventilated houses is considered smaller as compared with closed, forced-ventilated houses. The indicated emission factors for fattening pigs in temperature-insulated houses with fully slatted floors amount to an annual 3 kg N per animal place (AP), which corresponds to 3.6 kg NH_3/(AP*a). The factor for free ventilated houses is 2 kg N/(AP*a), which corresponds to 2.4 kg NH_3/(AP*a) (Döhler et al. 2002, Eurich-Menden et al. 2011). The amount of the actual NH_3 emissions from animal houses is fraught with greater insecurities. The order of magnitude of the emissions and the smaller losses from free ventilated houses, however, are well described in the literature (Haeussermann 2006).

The emission reduction expenses for a free ventilated house as compared with a forced-ventilated house were calculated using a fattening pig house with 960 animal places as an example.

5.1 Technical description of the techniques

Forced-ventilated house (reference)

A closed, temperature-insulated, and forced-ventilated animal house with fully slatted pens serves as reference. A liquid manure technique is applied. The animals are kept in large groups of 40 animals.

Free ventilated house

The building is open with a temperature-insulated ceiling according to the principle of the so-called Nürtingen system. It is characterized by separate functional areas with a level concrete lying area in a temperature-insulated resting kennel and a perforated loose area. Liquid manure technique is applied. The animals are kept in large groups of 60 animals per pen.

5.2 Costs of housing and emission reduction

Pig fattening in the free ventilated house requires greater investments and therefore causes higher fixed expenses. The main motivation for the construction of a free ventilated house is generally animal-friendly housing and the securing of a good health status. In this case, emission reduction is a side effect. Therefore, it is useful to allocate the expenses to these target values. The considered animal house offers 0.92 m² of space per animal, compared with 0.75 m² in the closed reference system. In this case, a smaller percentage of the additional expenses (here: 20%) is allocated to emission reduction. This leads to reduction costs of € 1.84 per kg NH_3. In addition, more labour is needed, e.g. for the cleaning of the lying kennels. The variable expenses caused by these factors, however, are compensated for by energy cost savings in the unheated free ventilated house so that the variable costs of the two techniques do not differ significantly. This results in total NH_3 -reduction costs of € 9.18 per kg of NH_3 (Table 7).

Table 7: Process and emission reduction costs

	Unit	Reference: Closed animal house	Free ventilated house
Animal places	AP	960	960
Fixed costs	€/(TP•a)	29	40
Variable costs	€/(TP•a)	23	23
Costs of the technique	€/(TP•a)	-	11
N-bonus*	€/(TP•a)	-	0.57
Emission factor	kg NH_3-N/(TP•a)	3	2
Emission reduction costs	€/kg NH_3	-	9.18
Emission reduction costs with allocation**	€/kg NH_3	-	1.84

* Later losses during slurry application are considered. The bonus is not included in the reduction costs.
** Allocation: For emission reduction, 20% of the additional expenses were considered.

5.3 Sensitivity of the calculation

In addition to the above-described allocation of the costs, the reduction expenses listed in 5.2 are influenced by the inclusion of the nitrogen value and the consideration of NH_3 losses in the following techniques.

- The consideration of the value of conserved nitrogen reduces the expenses by 5%.
- The assumption of NH_3 losses of 15% during subsequent storage and 25% during application leads to a loss of 36% of the NH_3 saved in housing. This leads to increased reduction costs of 56%.

6 Mitigation costs: Exhaust air purification

In principle, exhaust air purification is only possible in animal houses with forced ventilation because the exhaust air from the animal houses must be collected and led through the cleaning system by fans. Due to the high costs, this technique is not state of the art in low-emission intensive livestock farming (so-called "best available technique" - BAT). In regions with intensive livestock farming, where the immission load is already significant, exhaust air purification systems are often the only option for the extension of production and the further development of existing farm locations.

In the present calculations of the reduction costs, the following exhaust air purification techniques are considered:

- No exhaust air purification (reference)
- Tricklebed reactor (biowasher)
- Multiple-stage exhaust air purification (2 and 3-stage systems)

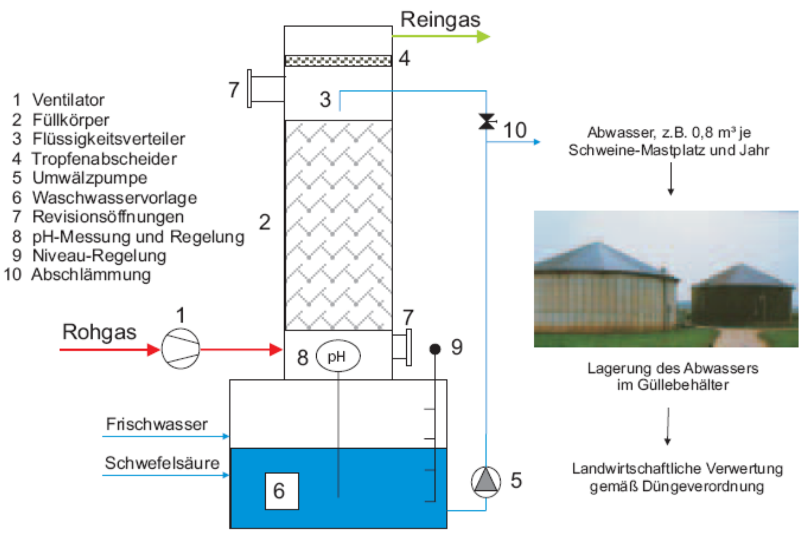
6.1 Technical description of the techniques

Ventilation without exhaust air purification (reference)

An animal house with central exhaust air conduction without any further exhaust air treatment is assumed as a reference technique. If the installation of an exhaust air purification system is planned in animal houses with decentralized ventilation (separate exhaust air system in every compartment), the reduction expenses due to the necessary additional conversion measures are higher.

Tricklebed reactors (biowashers)

In tricklebed reactors (biowashers), the exhaust air is conducted through a package of plastic filling bodies, which are continuously sprayed with water in an inverse current (Figure **4**). During the passage through the moistened filling bodies, ammonia dissolves in the water, and the microorganisms on the filling bodies degrade the odorants and the dust solved in the water. Tricklebed reactors allow at least 70% of the solved gaseous ammonia to be eliminated.



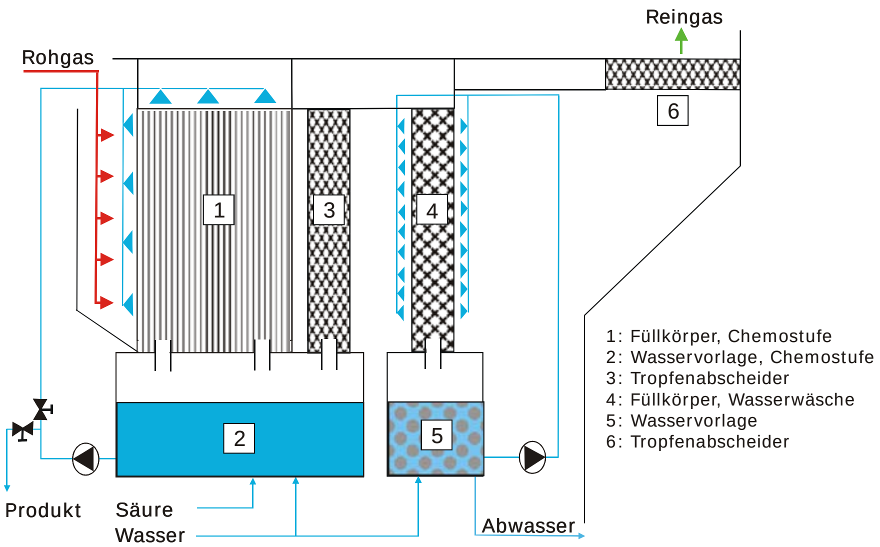
Rohgas – crude gas
Reingas – clean gas
Ventilator – fan
Füllkörper – filling body
Flüssigkeitsverteiler – liquid distributor
Tropfenabscheider – drop separator
Umwälzpumpe – circulation pump
Waschwasservorlage – washing water supply
Revisionsöffnungen – revision openings
pH-Messung… - pH measurement and control
Niveauregelung – level control+
Abschlämmung – de-sludging
Frischwasser – freshwater
Schwefelsäure – sulphuric acid
Lagerung des Abwassers im Güllebehälter – Storage of wastewater in the slurry tank
Landwirtschaftliche Verwertung gemäß Düngeverordnung - Agricultural utilization according to the Fertilizer Decree
Abwasser… Wastewater, e.g. 0.8 m³ per pig fattening place and per year

Figure 4: Principle of a tricklebed reactor (KTBL publication 451, 2007)

Multiple-stage exhaust air purification systems

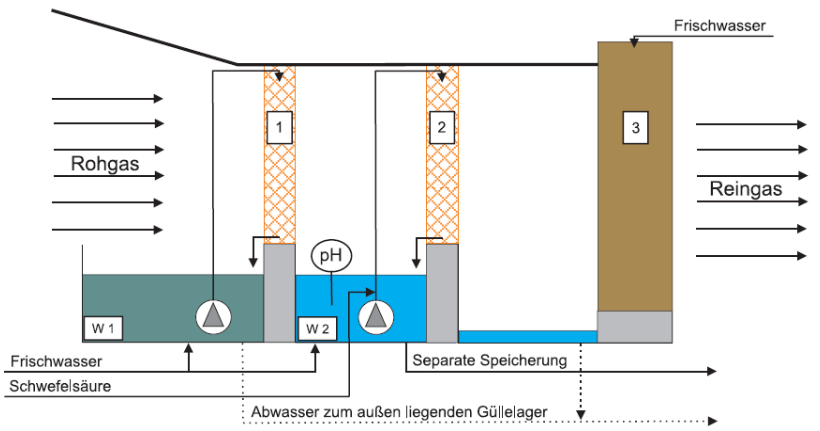
Up to 90% of the emissions can be retained by means of combined (2 or 3-stage) techniques. Two-stage exhaust air purification systems consist of chemical scrubbing and a downstream water stage (Figure **5**).

Like in the tricklebed reactor, ammonia and dust are solved in water on moistened filling bodies in the chemical washer. The pH-value of the water is set at <5 using sulphuric acid. Afterwards, the exhaust air reaches the water stage, where the odour is reduced. In three-stage exhaust air purification systems, the arrangement of the chemical and water scrubber is inverted. These systems feature a biofilter as a third stage (Figure **6**). First, the exhaust air flows through the water washer, where dust is separated. After-wards, ammonia is separated in the chemical scrubber. At the end, residual odours are degraded in the biofilter.



Füllkörper, Chemostufe – filling body, chemical stage

Figure 5: Principle of a two-stage exhaust air purification system (KTBL-publication 451, 2007)



Separate Speicherung – separate storage

Abwasser zum außen liegenden Güllelager – Wastewater to the outside slurry store

Figure 6: Principle of a three-stage exhaust air purification system (KTBL-publication 451, 2007)

6.2 Costs of exhaust air purification and emission reduction

Depending on the technique of exhaust air cleaning, the fixed costs account for approximately 50% of the annual costs (43-52%) given a 10-year depreciation period. Another quarter is caused by the increased energy requirements (25-32%). In comparison, the expenses for additional worktime requirements are secondary (2-9%).

The annual costs as well as the reduction expenses for the techniques are shown for three animal house sizes (Table **8**). The differences in annual and reduction expenses between the techniques are less pronounced than the economies of scale provided by a growing number of animal places. Given reduction costs of € 4.58 per kg NH_3 for 2,000 animal places, the three-stage exhaust air purification system is the most cost-effective variant.

The nitrogen bound in the washing water or the washing acid is spread together with the slurry. Here, part of the conserved NH_3-nitrogen is lost. This was considered in the indicated N-value, but not in the reduction costs.

Table 8: Annual costs and reduction expenses of exhaust air cleaning

	Unit	Animal places	Single-stage	Multiple-stage	
			Tricklebed reactor	Chemical washer + Water washers	Water washer + Chemical washer + Biofilter
Annual costs incl. bonus	€/(AP•a)	500	22	28	23
		1,000	18	24	18
		2,000	16	21	15
Reduction-potential	%		70	90	90
Reduction costs	€/kg NH_3	500	8,62	8.63	7.08
		1,000	7.18	7.32	5.47
		2,000	6.34	6.30	4.58

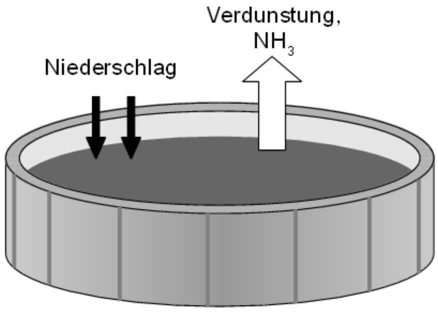
6.3 Sensitivity of the calculation

The consideration of the nitrogen value and the NH_3 losses in the following techniques would have the following consequences:

- The value of the nitrogen solved in the acid amounts to € 1.20/ (AP*a) (single-stage) and € 1.82/ (AP*a) (multiple-stage) The inclusion of the N-value in the calculation compensates for 5 to 12% of the costs listed in 6.2
- The assumption of NH_3 losses of 15% during subsequent storage and 25% during application leads to a loss of 36% of the nitrogen solved in the washing water if the water is spread together with the slurry. The reduction costs grow by 56% (cf. 5.3).

7 Mitigation costs: Slurry storage

Emission-reducing covers for round containers and earth stores are considered in the calculations. The reference system is an open, uncovered store.



Niederschlag – precipitation; Verdunstung - evaporation

For the annual NH_3 losses of the open reference stores, the emission factor of 15% of NH_4-N used in the National Emission Report (NIR) was assumed (HAENEL et al. 2010). In order to be able to model the influence of the surface on emission, this factor was converted into area-related NH_3 source intensities based on the assumption of a 1,000 m² round store with a surface of 250 m². For pig slurry, this results in a reference emission of 16 g/(m^2•d). For cattle slurry, the additional mitigating effect of a natural floating cover was considered. Here, the 70% reduction indicated in the NIR was used again with a reduced value for the time without a floating cover after the homogenization and distribution of the slurry. Consequently, the reference emission of cattle slurry with a natural floating cover is 3.3 g/(m^2•d).

Great insecurities remain with regard to the actual NH_3 losses during slurry storage. The few available measurements under practical conditions show a wide range of variation of the emission rates. However, both the order of magnitude of the values assumed here and the differences between cattle and pig slurry due to the different natural floating covers correspond to literature data (AMON & FRÖHLICH 2006; MÜLLER et al. 2006).

The emission reduction expenses for storage capacities of 500, 1,000, 3,000, and 5,000 m² (round containers) as well as 7,500 m² (earth store) along with the practice-relevant covers listed in Table **9** were calculated.

Table 9: Slurry covers

Variant	***Round container***	***Earth store***
Reference: open store	x	x
Concrete cover	x	
Tent roof	x	
Straw cover	x	x
Light bulk materials	x	x
Floating bodies	x	
Floating film	x	x

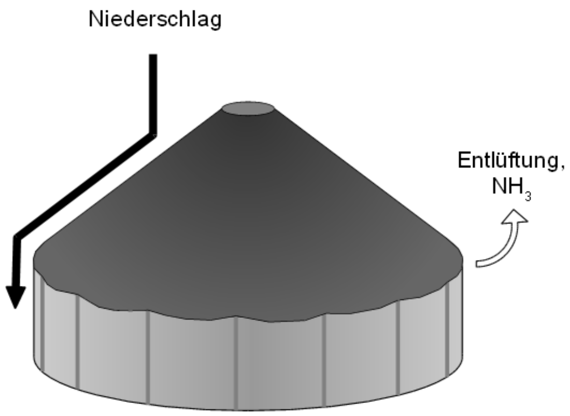
7.1 Technical description of the techniques

Covers impermeable to rain

Fixed covers impermeable to rain (tent roof, concrete cover) offer the best emission reduction effect. However, they also require the highest investments. Fixed covers must allow the store to be ventilated in order to prevent explosive concentrations of fermentation gases.

Slurry silo covers in the form of a concrete cover are particularly durable and low-maintenance units. Underground tanks accessible for vehicles open up additional farmyard space. The additional expenses for the necessary carrying capacity, however, are not included in the reduction costs.

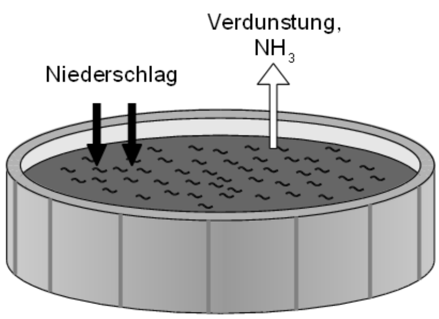
Tent roof constructions are fixed covers with a central support, which serves as a sustainer and a ridge. The central support carries a tent membrane which is attached to the silo edge using belts. This construction also requires little maintenance. Rainwater is effectively kept out of the liquid manure.



Niederschlag – rain, Entlüftung - ventilation

Floating covers permeable to rain

Generally, a natural floating cover consisting of litter and undigested crude fibre of the feedstuff develops on cattle slurry (in contrast to pig slurry). In order to enhance the emission-reducing effect of this floating cover or to generate such a cover, natural substrates, such as chopped straw, light bulk material like swelling clay, and artificial floating bodies out of plastic are used. The effect of the floating covers depends on their physical properties and their thickness. A chopped straw cover should be at least 10 cm thick, while light bulk material (e.g. swelling clay) should have a minimum thickness of 20 cm. The straw cover is mixed in during stirring and removed with the slurry during distribution. Therefore, straw covers must be replaced partially or entirely several times per year. In floating covers out of light bulk material, however, only slight losses must be replaced every year.



Niederschlag – rain, Entlüftung - ventilation

Floating bodies made of plastic, such as the hexagonal recycling product Hexa-Cover, form a closed floating cover on the slurry surface. They are currently used only for pig slurry without a natural floating cover.

The individual ribs in the bodies prevent the elements from being pushed one on top of the other. The homogenization and the sucking-off of the liquid manure require particular care in order to avoid potential clogging or damage to the technical equipment.

Floating film out of plastic is either filled with floating elements featuring a sandwich design, or it is kept on the surface by swimmers. The film has maintenance openings, which can be opened when necessary (e.g. during homogenization). The tanks are filled underneath the surface.

7.2 Emission reduction and fertilizer value

The assumptions for the emission reduction of store covers correspond to the calculation basis of the National Emission Report (NIR, HAENEL ET AL. 2010). When the slurry is homogenized and spread, covers consisting of straw and light bulk materials are mixed in. This decreases the emission-reducing effect until the floating covers form again or until they are rebuilt. This effect was considered by lowering the reduction values indicated in HAENEL ET AL. (2010) by a margin of 4% per year (light bulk materials, straw cover) or 1% (floating bodies) of the reductions listed in Table 10 for slurry spread twice a year.

According to these calculations, store covers can be expected to reduce emissions by 75 to 80%. The nitrogen boni consider later losses during distribution. For this purpose, the actual N-value of the conserved nitrogen was reduced by the reference value of the spreading losses in the present study, which amounts to 50% for cattle slurry and 25% for pig slurry.

Table 10: Relative NH_3 emission reduction due to slurry covers and bonus for the conserved nitrogen

Variant	***Reduction***	***N-bonus****	
		Cattle slurry	***Pig slurry***
	[%]	***[€/m³]***	***[€/m³]***
Concrete cover	90	0.04-0.06	0.29-0.43
Tent roof	90	0.04-0.06	0.29-0.43
Floating film	85	0.04-0.06	0.27-0.41
Light bulk material	80	0.04-0.05	0.26-0.38
Floating body	85	-	0.27-0.41
Straw cover	80	0.03-0.05	0.24-0.36

* Later losses during slurry application included.

7.3 Costs of store coverage and emission reduction

In the reference system without covers, the annual expenses for slurry storage range between € 1.1 (earth tank) and € 1.8 per m³ (small round tank variant, usable storage capacity 500 m³ (Table **11**). Assumed storage duration was 6 months so that these expenses are based on an annual slurry quantity which is twice as large as the usable capacity. The investment requirements of the round tanks include a residual volume of 0.5 m (depth). In all stores, a freeboard of 0.2 m is considered.

Table 11: Annual costs of slurry storage

	Round tank				Earth tank
	Usable storage capacity [m^3]				
	500	1000	3000	5000	7500
	Diameter [m]				Length x Width [m]
	13.7	17.7	27.9	35.5	75 x 25
	Annual storage costs [€/(m^3•a)]				
Open (reference)	1.78	1.57	1.29	1.17	1.08
Concrete cover	2.74	2.38	1.96	1.82	-
Tent roof	3.67	2.74	2.00	1.74	-
Floating film	2.70	2.14	1.66	1.47	1.34
Light bulk materials	2.03	1.73	1.43	1.30	1.23
Floating bodies (Hexa-Cover)	2.42	2.11	1.73	1.60	-
Straw	2.20	1.86	1.49	1.35	1.35

Including the covers, the 500 m³ round tank under a tent roof causes the highest annual storage expenses in the amount of € 3.67 per m³. Due to the long period of use, even the annual costs of a tank with a concrete cover are € 0.9 lower in this case. As the size of the store grows, however, the specific investment requirements for tent roofs decreases from ca. € 100 per m² to € 46 per m² so that they fall below the costs of a concrete cover when storage capacity reaches 5,000 m³. Floating film shows similarly high economies of scale (€ 34 per m² for a capacity of 500 m³, € 16 per m² for 5,000 m³, and € 11.50 per m² for the earth tank). For light bulk material and floating bodies, economies of scale with growing surface are smaller or negligible (swelling clay: € 10.20 per m² to € 7.60 per m², floating body "Hexa-Cover": € 39.50 per m²). The expenses for the spreading of these long-lived floating covers with the aid of a front loader and/or a telescopic loader are very low as compared with the material costs (< 1%). In the case of light bulk material, it has been taken into account that annually approximately 10% of the material gets lost during the homogenization and distribution of the slurry and must be replaced periodically. Nevertheless, light bulk material causes the lowest additional expenses as compared with storage without covering.

Store coverage with chopped straw causes expenses of € 0.40 to 0.60 per m² depending on the thickness of the layer. These are by far the lowest material expenses. Here, the calculated machinery and work expenses for spreading with a front loader and a forage harvester exceed the costs of straw collection and supply by the 2.6-fold amount. Since the floating cover gets lost during the homogenization and distribution of the slurry, two coverings per year were calculated.

The resulting reduction expenses for NH_3 emission for cattle and pig slurry are listed in Table **12** and Table **13**. The difference in reduction costs between the storage of cattle and pig slurry is significant. Given costs of € 1.3 to 12 per kg NH_3, the reduction expenses for cattle slurry with a natural floating layer exceeded those for pig slurry without a floating cover (€ 0.26 – 2.5 per kg NH_3) by the fivefold amount. These differences in reduction expenses are caused by the reference emissions. For cattle slurry, which generally has a floating cover, these emissions were assumed to be 3.3 g/(m^2•d). Pig slurry generally does not form an emission-reducing natural floating cover. Therefore, reference emissions are considerably higher at 16 g/(m^2•d). For this reason, reduction measures lead to a significantly stronger reduction of NH_3 emissions from pig slurry, making them more cost-effective.

Light bulk material is the most cost-effective form of covering followed by straw and floating bodies in smaller stores. Despite high investment costs, light bulk material and floating bodies are cost-effective for emission reduction during storage due to their long service life and the low expenses for repairs and maintenance. In the large store variants, tent roofs and floating film catch up due to their large economies of scale. However, they remain relatively expensive reduction measures if the boni for rainwater and N are not included in the calculation like in this case (cf. chapter 7.4). Floating covers out of chopped straw are an alternative in particular for tanks which cannot be equipped with solid covers without greater technical requirements. If the N-value and expenses for the distribution of rainwater are included, their reduction costs are higher than those of floating bodies. However, they have the advantage that they are easily available on many farms and require small investments.

Table 12: Emission reduction costs of cattle slurry

	Round tank				Earth tank
	Usable storage capacityt [m^3]				
	500	1,000	3,000	5,000	7,500
	Reduction costs [€/kg NH_3]				
Concrete cover	6.16	6.16	6.16	-	-
Tent roof	12.07	8.90	6.55	5.38	-
Floating film	6.26	4.62	3.58	2.96	2.09
Light bulk material	1.76	1.38	1.38	1.34	1.30
Straw	3.12	2.59	2.12	2.00	2.35

Table 13: Emission reduction costs of pig slurry

	Round tank				Earth tank
	Usable storage capacity [m^3]				
	500	1,000	3,000	5,000	7,500
	Reduction costs [€/kg NH_3]				
Concrete cover	1.25	1.25	1.25	-	-
Tent roof	2.45	1.81	1.33	1.09	-
Floating film	1.27	0.94	0.73	0.60	0.42
Light bulk material	0.36	0.28	0.28	0.27	0.26
Floating body (Hexacover)	0.88	0.88	0.88	0.88	-
Straw	0.63	0.53	0.43	0.41	0.48

7.4 Sensitivity of the calculation

The value of the conserved nitrogen was not included in the reduction costs (**Table** 10). For cattle slurry, for which relatively low reference emissions were assumed, this value only accounts for 2 to 3% of the storage costs. For pig slurry with higher reference emissions, however, this share reaches 15 to 25%. The assumption of NH_3 losses during subsequent spreading in the amount of 25% for pig slurry also leads to a corresponding increase in reduction costs here (cf. 5.3 and 6.3).

The kind of coverage of the storage containers influences the evaporation and the input of precipitation water. This results in differences in the slurry quantities to be spread and the application costs which are not included in the reduction expenses listed under 6.3. In the case of floating covers which allow for rainwater input but reduce evaporation, this causes additional expenses of € 0.17 to 0.26 per m³. Solid covers, however, can record a slight bonus of € 0.05 to 0.08 per m³ because they are impermeable to precipitation.

If measures are realized which completely prevent precipitation input, a slightly lower storage volume and therefore lower construction costs can additionally be assumed when a new store is built. This reduces storage costs by 5 to 6%.

For straw covers, stirring twice per year was assumed in chapter 6.3. The straw cover must be renewed after each stirring process. If more frequent application of slurry to the land and, hence, stirring are necessary, the costs increase.

Table **14** lists the mitigation expenses for pig slurry which result if the value of the conserved nitrogen, the expenses for the application of precipitation water on to land, and the costs of a freeboard for precipitation water are considered. For straw, additionally the reduction expenses caused if slurry is spread four times per year are shown. Light bulk materials remain particularly favourable in this consideration and can be used in a virtually cost-neutral manner. As compared with the other covers, reduction by means of solid covers is considerably more cost-effective. If straw is spread on the container four times per year, it is a relatively expensive reduction technique.

Table 14: Emission reduction costs of pig slurry given different assumptions*

	Round tank				Earth tank
	Usable storage capacity [m3]				
	500	1,000	3,000	5,000	7,500
	Reduction costs [€/kg NH3]				
Concrete cover	0.44	0.45	0.47	-	-
Tent roof	1.64	1.01	0.55	0.32	-
Floating film	1.07	1.29	0.52	0.40	0.22
Light bulk material	0.17	0.09	0.09	0.08	0.07
Floating body (Hexacover)	0.67	0.67	0.67	0.67	-
Straw, 2 times per year	0.47	0.36	0.26	0.24	0.31
Straw, 4 times per year	1.17	0.94	0.74	0.69	0.84

*The value of the conserved nitrogen, the costs of application of precipitation water on to land, and the expenses for the freeboard for precipitation water have been considered. Straw: Additionally, the costs of slurry application four times per year are shown.

8 Mitigation costs: Slurry application

Five techniques were defined which approximately reflect the spread of slurry application techniques used in practice with annual process outputs of 1,000 to 100,000 m³ (Table 15). The 1,000 m³ technique characterizes an economically suboptimal variant realized on a single farm which owns the necessary equipment. 3,000 m³ correspond to a slightly larger farm or a cooperative of several smaller farms which use the distribution equipment cooperatively. The quantity of 10,000 m³ justifies investments in more efficient equipment and characterizes a cooperative or a larger farm. 30,000 and 100,000 m³ represent contractors and large farms. These quantities are applied to the land in an economically profitable manner using efficient techniques divided into transport and spreading units. The assumptions used as the basis for the calculations are listed. The application of cattle and pig slurry is considered at the beginning of the vegetation period and on areas without a plant cover or covered by low plants. Given a temperature of approximately 15°C at the time of distribution, an NH_3 loss of 50% of the ammonium nitrogen must be expected for cattle slurry if broadcast application is applied as a reference technique. In the case of pig slurry, expected NH_3 losses reach 25%.

Table 15: Characterization of the calculated spreading techniques

Total slurry quantity spread per year m^3/a	Technique	Components of the technique / procedure
1,000	continuous	Tractor-drawn pump tanker, 10 m^3
3,000	continuous	Tractor-drawn pump tanker, 10 m^3
10,000	continuous	Tractor-drawn pump tanker, 15 m^3
30,000	divided	Transport: tractor-drawn pump tanker, 21 m^3 Distribution: tractor-drawn pump tanker, 10m^3
100,000	divided	Transport: tractor-drawn pump tanker, 21 m^3 Distribution: Carrier vehicle, 21 m^3

8.1 Technical description of the techniques

Tankers and carrier vehicles

Tankers feature the following two common designs:

- Vacuum tankers
- Pump tankers

The vacuum tanker actively sucks slurry into the tank by inducing a vacuum. The pump tanker also actively generates suction. Due to their functional reliability, their high filling capacity, and more precise metering in particular during the application of emission-reducing spreading techniques, pump tankers are often preferred in practice.

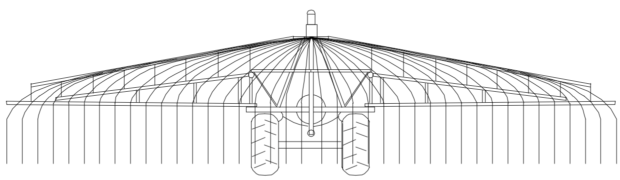
Especially in regions where large fields are predominant, carrier vehicles are increasingly establishing themselves for slurry spreading. The carrier vehicles are equipped with suitable tanks and application equipment. Since they require large investments, these vehicles are only suitable for cooperative use.

While broadcast spreaders (splash plate, rod distributor, swivelling distributor) are still predominant today, they are being replaced more and more by low-emission distributing systems in particular on large farms and in cooperative use.

The following spreading techniques are used for low-loss, precise spreading:

Trailing hose spreaders

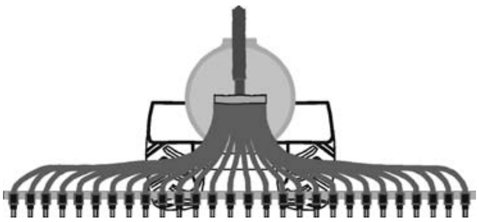
Trailing hose spreaders have a working width of 6 to 24 m. In recent models, working widths even reach 36 m. The individual trailing hoses are generally situated 20 to 40 cm apart. The slurry is deposited on the soil surface in 5-10 cm wide bands.

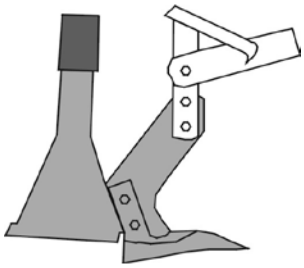


Trailing shoe spreaders

Trailing shoe spreaders have a working width of 3 to 12 and sometimes even 18 m. The individual trailing hoses are generally situated 20 to 30 cm apart. The end of the trailing hose is equipped with special distributing units which are usually designed as a shoe-like reinforcement or a trailing skid and at whose end the slurry is deposited.

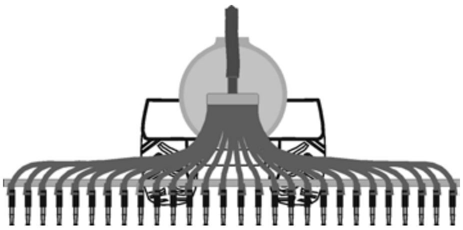
During the spreading process, the distributor is pulled through the crops (if there are any). Due to the design, the crops are slightly pushed aside during the distribution process. The slurry is deposited in the uppermost soil layer (0 to 3 cm) so that crop soiling can largely be avoided.

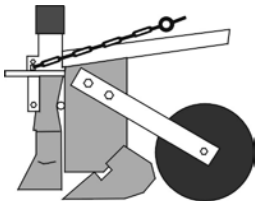




Open slot injectors

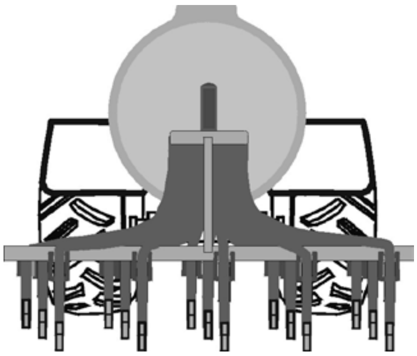
Typical slot injectors have a working width of 6 to 9 m, and the individual trailing hoses are generally situated 20 to 30 cm apart. Application is carried out using a shoe-like reinforcement. A cutting disc (or a steel knife) in front of this reinforcement cuts the soil, and the slurry is deposited into the slot at the end of the trailing shoe.





Direct incorporation with a cultivator and intermittent incorporation

The so-called slurry cultivators have a working width of 3 to 6 m, and the individual trailing hoses are generally situated 20 to 40 cm apart. The soil is cultivated with the aid of a cultivator tine, whose immediate extension is used to deposit the slurry into the soil during cultivation. In addition, disc harrows are available which cultivate the soil using hollow discs and deposit the fertilizer into the soil in the same manner. Incorporation can also be carried out after spreading using an intermittent technique and conventional soil cultivation implements. For efficient emission reduction, it is also important that incorporation takes place briefly after spreading. The thicker the slurry and the higher the temperatures are, the more important this becomes.



Other techniques

Additionally, dilution with water at a 1:1 ratio is considered for cattle slurry.

8.2 Emission reduction and fertilizer value

Table 16 shows the assumptions for the emission reduction of the individual techniques. As compared with broadcast spreaders as a reference, the reduction achieved by trailing hoses is 20%, whereas trailing shoes reduce emissions by 40%. Slot techniques show a reduction of 60%, and the slurry cultivator reaches 90%. The resulting nitrogen conservation provides a bonus of € 0.23 to 1.01 per m³ of cattle slurry. A reduction technique is cost-neutral if the reduction costs are identical or lower than the amount of the bonus. The reduction effect of trailing hoses and trailing shoes is slightly higher for pig slurry because liquid pig manure is more fluid.

Table 16: Relative NH_3 emission reduction of the individual application techniques and bonus for conserved nitrogen

Variant	Cattle slurry		Pig slurry	
	Reduction %	Bonus €/m³	Reduction %	Bonus €/m³
Broadcast spreader (reference)	-	-	-	-
Trailing hose	20	0.23	30	0.27
Trailing shoe	40	0.45	50	0.45
Slot injector (discs)	60	0.68	60	0.54
Cultivator	90	1.01	90	0.81
Incorporation within 1h	90	1.01	90	0.81
Incorporation within 4h	50	0.56	70	0.63
Dilution 1:1	50	0.56	-	-

8.3 Costs of application and emission reduction

Both the costs of application (Table **17**) and emission reduction (Table **18** and Table **19**) significantly depend on the capacity exploitation of slurry application and emission reduction equipment.

While the technique causes expenses of approximately € 9 per m² when applied on single farms (1,000 m³/a), these costs decrease to about € 4 to 8 per m³ for process capacities of 3,000 m³/a, € 3 to 6.5/m³ for 10,000 m³/a and € 2.5 to 5 per m³ for 100,000 m³/a. The consideration of the variant with process capacities of 3,000 m³/a shows that different hourly capacities influence total costs, which can range between € 1 and 2 per m³. Techniques for single farms, however, have the advantage that they always allow the best times to be used. These farms can wait for good weather conditions (humid and cool) or daytimes (evening hours).

Under the considered conditions, the costs of emission reduction range between € 0.30 and € 7 per kg NH_3 for cattle slurry (Table 18) and between € 0.30 and € 9 per kg NH_3 for pig slurry (Table 19). The total emission reduction expenses for pig slurry are higher than those for cattle slurry. The absolute costs of emission reduction remain the same. However, emissions from pig slurry are lower, which also reduces the effect of emission reduction.

A very cost-efficient technique also for single farms, which produce small slurry quantities, is incorporation with a separate tractor and incorporation equipment (cultivator, disc harrow). Depending on the allocation of the expenses to soil cultivation and emission reduction, these techniques cause expenses of considerably less than € 1 to 1.5 per kg of NH_3.

The dilution of cattle slurry with water, however, is an effective, though very expensive variant because increased volumes must be transported and spread.

Table 17: Application expenses for slurry

Variant	Annual process capacity [m³/a]					
	1,000	3,000		10,000	30,000	100,000
	Process capacity [m³/a]					
	low	high	low	low	-	-
	Distribution costs					
	€/m³	€/m³	€/m³	€/m³	€/m³	€/m³
Broadcast spreader (reference)	6.61	3.22	4.31	3.04	3.19	2.49
Trailing hose	8.76	3.99	5.08	3.38	3.32	2.57
Trailing shoe	9.68	4.63	5.87	4.11	4.10	-
Slot injector (discs)	9.97	4.89	6.16	4.37	4.67	2.89
Cultivator	10.38	5.71	7.49	4.96	5.30	3.04
Incorporation within 1h	7.43	4.04	5.13	3.86	4.02	3.31
Incorporation within 4h	7.10	3.71	4.80	3.53	3.69	2.98
Dilution 1:1	11.11	6.08	8.81	6.49	5.95	4.40

Table 18: NH_3 emission reduction expenses for cattle slurry

Variant	Annual process capacity [m³/a]					
	1,000	3,000		10,000	30,000	100,000
	Process capacity [m³/h]					
	low	high	low	low	-	-
	Reduction costs [€/kg NH_3]					
	€/kg	€/kg	€/kg	€/kg	€/kg	€/kg
Trailing hose	7.08	2.54	2.54	1.14	0.41	0.28
Trailing shoe	5.06	2.33	2.57	1.77	1.50	-
Slot injector (discs)	3.70	1.83	2.04	1.47	1.63	0.44
Cultivator	2.76	1.82	2.33	1.41	1.54	0.40
Incorporation within 1h	0.60	0.60	0.60	0.60	0.60	0.60
Incorporation within 4h	0.65	0.65	0.65	0.65	0.65	0.65
Dilution 1:1	5.93	3.77	5.93	4.55	3.63	2.52

Given costs of approximately € 3 to 7 per kg NH_3, techniques for single farms (1,000 m³/a) with mounted equipment (e.g. trailing hoses) are only conditionally suitable for cost-efficient emission reduction. Techniques for single farms, however, in particular allow optimal time periods to be used, which can usually only be realized during a few hours of a work day.

Given annual capacities of 3,000 m³/a, the costs are lower, though still at a level of approximately € 2 to 3 per kg of NH_3. Apart from intermittent incorporation techniques, a cost level of € 1 to 2 per kg NH_3 is only reached at process capacities of 10,000 m³/a. The cost level of the boni (Table 16) requires process capacities of 100,000 m³/a.

If annual process capacities are low, the reduction expenses for sophisticated techniques (slurry slot) are lower than for the trailing hoses. If annual process capacities are high, trailing hoses cause the lowest expenses.

Table 19: NH_3 emission reduction expenses for pig slurry

Variant	Annual process capacity [m^3/a]					
	1,000	3,000		10,000	30,000	100,000
	Process capacity [m^3/h]					
	low	high	low	low	-	-
	Reduction costs					
	€/kg	€/kg	€/kg	€/kg	€/kg	€/kg
Trailing hose	8.80	3.16	3.16	1.42	0.50	0.34
Trailing shoe	6.29	2.89	3.20	2.20	1.86	-
Slot injector (discs)	4.60	2.28	2.53	1.82	2.02	0.55
Cultivator	3.43	2.27	2.89	1.75	1.91	0.50
Incorporation within 1h	0.75	0.75	0.75	0.75	0.75	0.75
Incorporation within 4h	0.81	0.81	0.81	0.81	0.81	0.81
Dilution 1:1	7.37	4.69	7.37	5.65	4.52	3.13

9 Mitigation costs: Urea

9.1 Technique

The reduction expenses for NH_3 losses from urea during the fertilizing of grassland as well as growing silo maize and winter wheat were calculated. The quantity of N-fertilizer was assumed to be 108 or 86 kg N/ha respectively for silo maize and winter wheat in the form of urea granulate. The assumed NH_3 losses were based on the emission factors of the National Emission Report (HAENEL ET AL. 2010), which are 12% of the urea-N on fields and 23% on grassland. The use of an urease inhibitor and fertilizer incorporation in arable farming as an additional technique were considered as a reduction measure.

In maize cultivation, incorporation with a rolling-type row hoe was assumed. The roller-type hoe provides good mixing of the soil layer close to the surface, for which an emission reduction of 90% in the cultivated part of the area between the maize rows is assumed. If 70% of the entire area is cultivated, this leads to a reduction effect of 63%.

In winter wheat, combing as an incorporation measure was taken into consideration. Since this results in only limited mixing of the uppermost soil layer, an emission reduction of 25% was supposed.

For emission reduction by urease inhibitors, 60% for the field variants and 80% for the grassland were assumed according to SCHMIDHALTER ET AL. (2010).

9.2 Mitigation costs

In relation to the quantity of N distributed in the form of urea, incorporation is twice to three times more expensive (€ 0.2 per kg of N for winter wheat and € 0.3 per kg of N for maize) than if NBTPT is used (€ 0.1 per kg N). Accordingly, the reduction expenses for incorporation range between € 4 to 6 per kg NH_3 as compared with € 1.1 per kg NH_3 and € 0.5 per kg NH_3 respectively for the application of urease inhibitors on fields and grassland (Table **20**). If the value of the conserved NH_3 is considered, reduction costs on grassland decrease by almost 40%. On the field, this N-bonus would only range between less than 1% and 5% of the reduction costs.

Table 20: Calculation results for emission reduction during urea application

		Incorporation*		Urease inhibitor**		
		Silo maize	Winter wheat	Silo maize	Winter wheat	Grassland
Additional costs	€/kg urea-N	0.33	0.21	0.10	0.10	0.10
Emissions reduction	%	63	25	60	60	80
Value of conserved N	€/kg urea-N	0.07	0.03	0.06	0.06	0.17
Reduction costs	€/kg NH_3	3.62	5.72	1.14	1.14	0.45

* Silo maize: Roller-type hoe, winter wheat, comb
** N-(n-butyl) thiophosphoric acid triamide (NBTPT, “Agrotain“)

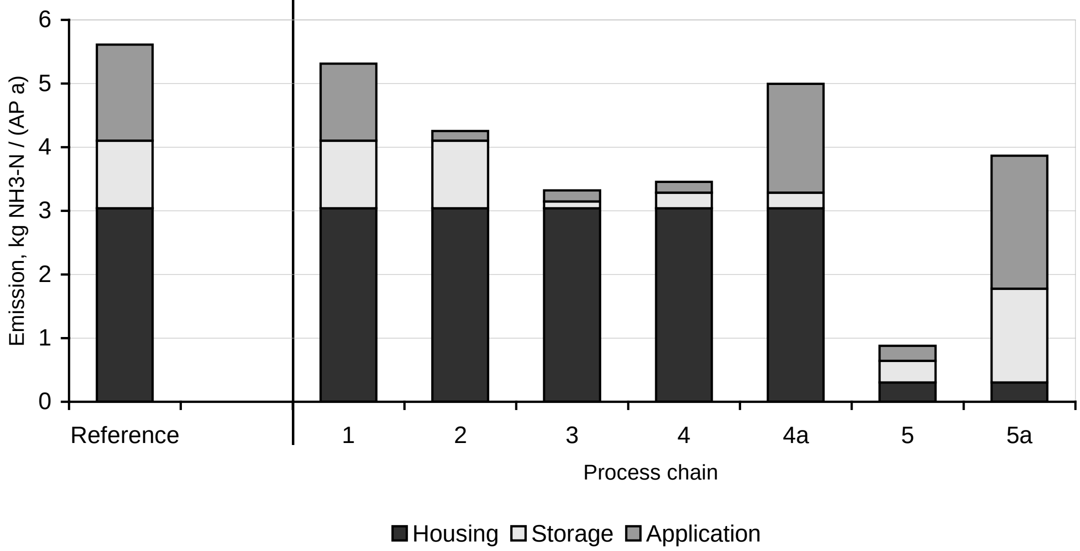
The actual quantity of NH_3 emissions from urea fertilizers is strongly influenced by soil properties and climatic factors. The emission factors used in the emission inventory, which serve as data for the calculations described here, are largely based on studies carried out in England. Few studies are available for German locations. Their results, however, indicate significantly lower emission factors (SCHMIDHALTER ET AL. 2010). If one uses the emission factors listed there, which are only half as high, reduction costs are twice as high.

Research is necessary for both the consideration of NH_3 emission from urea fertilizers in the emission inventories and the estimation of NH_3 reduction costs in urea fertilizing.

10 Mitigation costs in the process chain

The calculations described above were carried out for individual techniques. In general, emission reduction in one technique influences the nitrogen quantity in the following technique and therefore also the quantity of potential NH_3 emissions there. If ammonia emissions in a pig house are reduced, for example, more ammonium reaches the slurry store. This increases the ammonia emissions from the store. As a result, part of the reduction effect in the animal house is lost. At the same time, however, the reduction measures in the store become more cost-effective. In order to model these interrelationships, animal husbandry must be shown as an entire process chain. For this purpose, nitrogen emissions in the individual process steps feeding, housing, as well as slurry storage and application are combined into an entire chain. The quantity of N per animal place and year, for example, can be used as a permanent reference unit. The reduction expenses for the process chain are calculated as the sum of the additional costs per technique as compared with a reference process chain and divided by the total emission reduction. The total reduction can be described as the difference of the remaining nitrogen quantity at the end of the process chain of reference and reduction techniques. Figure 7 shows results for a process chain in pig fattening as an example.

		1	2	3	4	4a	5	5a
NH_3 mitigation costs	€/kg NH_3	1.39	0.75	0.88	0.64	0.58	3.41	8.46
Additional costs	€/ (TP a)	0.51	1.23	2.45	1.67	0.44	19.58	17.91
NH_3 mitigation	%	5	24	41	38	11	84	31



Process chains
1 Trailing hose
2 Incorporation within one hour
3 Concrete cover; incorporation within one hour
4 Straw cover; incorporation within one hour
4a Straw cover
5 Three-stage exhaust air purification system; straw cover; incorporation within one hour
5a Three-stage exhaust air purification system

Figure 7: Process chain: additional costs due to individual and combined techniques for ammonia reduction, the reduction of ammonia emissions, and resulting reduction costs

A fattening house with 1,000 animal places, a slurry store with a storage volume of 1,000 m³, and spreading techniques with a capacity of 10,000 m³/a were combined. Slurry incorporation as the last element in the process chain is a cost-effective reduction measure also as a single technique. Exhaust-air cleaning and straw covering, however, lose in effectiveness due to the following losses if no emission-reducing techniques are used in the following stages of the process chain. The combination of the measures provides maximum emission reduction.

11 Literature

AARNINK, A.J.A.; SMITS, M.C.J.; BAKKER, G.C.M.; VERSTEGEN, M.W.A. (2003): Manipulating the diet to reduce environmental pollution from pigs. Wageningen University and Research Center Publications. Unveröffentlicht.

AMON, B.; FRÖHLICH, M. (2006): Ammoniakemissionen aus frei gelüfteten Ställen und Wirtschaftsdüngerlagerstätten für Rinder. In: KURATORIUM FÜR TECHNIK UND BAUWESEN IN DER LANDWIRTSCHAFT e.V. (KTBL) (Hrsg.): Emissionen der Tierhaltung. Messung, Beurteilung und Minderung von Gasen, Stäuben und Keimen. KTBL-Schrift 449: 69-74. ISBN 978-3-939371-19-9. Darmstadt, 2006

CANH, T.T.; AARNINK, A.J.A.; SCHUTTE, J.B.; SUTTON, A.; LANGHOUT, D.J.; VERSTEGEN, M.W.A. (1998): Dietary protein affects nitrogen excretion and ammonia emission from slurry of growing–finishing pigs. Livestock Production Science 56(3): 181-191.

DÖHLER, H.; EURICH-MENDEN, B.; DÄMMGEN, U.; OSTERBURG, B.; LÜTTICH, M.; BERGSCHMIDT, A.; BERG, W.; BRUNSCH, R. (2002): BMELV/UBA-Ammoniak-Emissionsinventar der deutschen Landwirtschaft und Minderungsszenarien bis zum Jahr 2010. Forschungsbericht 299 42 245/02. Texte 05/02. Umweltbundesamt, Berlin

EMEP/EEA (2010): Emission inventory guidebook 2009, updated June 2010. 4.B Animal husbandry and manure management. http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/part-b-sectoral-guidance-chapters/4-agriculture/4-b/4-b-animal-husbandry-and-manure-management.pdf; retrieved on 05/05/2011

EURICH-MENDEN B.; DÖHLER H.; VAN DEN WEGHE H. (2011): Ammoniakemissionsfaktoren im landwirtschaftlichen Emissionsinventar – Teil 2: Geflügel und Mastschweine. Landtechnik 66/1: 60-63

EUROPEAN COMMISSION (2003): Integrated Pollution Prevention and Control (IPPC): Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (ILF). 341 S., http://eippcb.jrc.ec.europa.eu/reference/brefdownload/download_IRPP.cfm; retrieved on 06.01.2011

GESELLSCHAFT FÜR ERNÄHRUNGSPHYSIOLOGIE (GFE) (2006): Empfehlungen zur Energie- und Nährstoffversorgung von Schweinen. DLG Verlag, Frankfurt a.M.

HAENEL H.D.; RÖSEMANN C.; DÄMMGEN U.; DÖHLER H.; EURICH-MENDEN B.; LAUBACH P.; MÜLLER-LINDENLAUF M.; OSTERBURG B. (2010): Berechnung der Emissionen aus der deutschen Landwirtschaft – Nationaler Emissionsbericht (NIR) 2010 für 2008. Landbauforschung, Sonderheft 334: 428 S. ISBN 978-3-86576-060-9, Braunschweig, 2010

HAEUSSERMANN A. (2006):Minderungsmaßnahmen in der Mastschweinehaltung. In: KURATORIUM FÜR TECHNIK UND BAUWESEN IN DER LANDWIRTSCHAFT e.V. (KTBL) (Hrsg.): Emissionen der Tierhaltung. Messung, Beurteilung und Minderung von Gasen, Stäuben und Keimen. KTBL-Schrift 449: 69-74. ISBN 978-3-939371-19-9. Darmstadt, 2006

INTERNATIONALE BODENSEEKONFERENZ (IBK) (2008): Emissionsmindernde Gülleausbringung. IBK Positionspapier. Antrag an die Regierungen. Unveröffentlicht.

MÜLLER, H.J.; BRUNSCH, R.; BERG, W. (2006): Ammoniakemissionsmassenströme in und um Tierhaltungsanlagen. In: KURATORIUM FÜR TECHNIK UND BAUWESEN IN DER LANDWIRTSCHAFT e.V. (KTBL) (Hrsg.): Emissionen der Tierhaltung. Messung, Beurteilung und Minderung von Gasen, Stäuben und Keimen. KTBL-Schrift 449: 69-74. ISBN 978-3-939371-19-9. Darmstadt, 2006

OSTERBURG B.; RÖSEMANN C.; HAENEL H.D.; DÖHLER H.; WULF S. (2010): Bewertung von Maßnahmen im Bereich der Landwirtschaft zum Erreichen der Emissions-obergrenze für Ammoniakemissionen gemäß EU-NEC-Richtlinie im Jahr 2010. Unveröffentlichter Bericht zur Unterstützung der Ressortgespräche zwischen BMELV/BMU vor dem Hintergrund der EU-NEC-Richtlinie. Berichtsfassung vom 26.05.2010, Braunschweig und Darmstadt, im Mai 2010

SCHMIDHALTER U.; SCHRAML M.; WEBER A.; GUTSER R. (2010): Ammoniakemissionen aus Mineraldüngern – Versuchsergebnisse auf mitteleuropäischen Standorten. In: KURATORIUM FÜR TECHNIK UND BAUWESEN IN DER LANDWIRTSCHAFT e.V. (KTBL) (Hrsg.): Emissionen landwirschaftlich genutzter Böden. KTBL-Schrift 483: 92-102. ISBN 978-3-941583-45-0. Darmstadt, 2010

SCHULTE-SUTRUM, R. (2010): Fütterungsanlagen für Schweine – Mischen und Transportieren. DLG-Merkblatt 361. 1. Auflage.

UN/ECE (2007): Guidance Document on Control Techniques for Preventing and Abating Emissions of Ammonia. 35 S.; http://www.unece.org/env/documents/2007/eb/wg5/WGSR40/ece.eb.air.wg.5.2007.13.e.pdf; retrieved on 23.09.2010