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Exploring Implications of New EU Legislation for Animal Welfare and of Trends in Organic Farming on Ammonia Emissions

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Interim Report **IR-09-004**

Exploring implications of new EU legislation for animal welfare and of trends in organic farming on ammonia emissions

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Approved by

Markus Amann
Project Leader, APD

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%	percent
AT	Austria
BE	Belgium
BG	Bulgaria
cm²	square centimeter
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EC	European Community
EE	Estonia
ES	Spain
FI	Finland

FR	France
g	gram
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
kg	kilogram
LNF	Low Nitrogen Feed
LT	Lithuania
LU	Luxemburg
LV	Latvia
m^2	square meters
mio	million(s)
MT	Malta
N	Nitrogen
NECD	National Emissions Ceilings Directive
NH_3	Ammonia
NL	Netherland
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
TSAP	Thematic Strategy on Air Pollution
UAA	Utilized Agricultural Area
UBA	Umweltbundesamt (der Bundesrepublik Deutschland)
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe

Abstract

Animal welfare legislation in the EU, i.e., the EU Directives for the protection of farm animals coming into force by 2013 the latest, and the EU Regulation on organic farming might lead to an increase in ammonia (NH_3) emissions. A review of the available, although rather limited, literature reveals that animal-friendly housings systems, in line with welfare legislation, are not ammonia-neutral compared to the conventional housing systems. NH_3 emissions per pig from animal-friendly pig houses vary considerably. Emissions from houses that comply with the EU directives differ between -25 percent and +50 percent, while emissions from organic pig houses range from about -10 percent to +170 percent compared to the reference values for conventional houses. The main reason for higher emissions is associated with additional outdoor area required in organic farming. Careful design of housing area and appropriate management can lead to lower emissions than in conventional systems. NH_3 emissions from animal-friendly aviary systems for laying hens were around threefold the emission per hen from battery cages. For organic cattle, emissions from housing are about 50 percent higher than from conventionally kept cattle.

The impact of increased penetration of animal-friendly houses and organic farming on NH_3 emissions was analyzed with the GAINS model. We have developed two scenarios using low and high emission factors and applied them to the recent national agricultural projections for 2020. For EU-27, we calculate that such a development could lead to a slight decrease or to an increase of NH_3 emissions by around five percent by 2020, compared to baseline scenario. However, larger variations occur for specific animal types and countries. An increase in emissions would counteract the EU air pollution policy that calls for a reduction of NH_3 emissions by 27 percent in 2020, compared to the 2000 level. Bearing that in mind, development in animal housing systems and their impacts on NH_3 emissions need to be analyzed further with more field studies and measurements.

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Exploring implications of new EU legislation for animal welfare and of trends in organic farming on ammonia emissions

Susanne Wagner, Zbigniew Klimont

1 Introduction

Ammonia (NH_3) has adverse effects on the environment and on human health. In order to reduce the negative impacts of NH_3 emissions, the European Union (EU) adopted various legislations that require reductions of NH_3 emissions. Agriculture is the main source of NH_3 emissions, the largest share originating from livestock.

In recent years the well-being of farm animals has been of increasing public concern. Intensive livestock production methods were considered inappropriate for animal welfare. Hence, the EU passed legislation with respect to animal welfare for farm animals. Also, the regulation on organic farming contains provisions considering animal welfare.

Animal welfare legislation has an impact on housing conditions, compared to conventional housing systems currently in use. A change in housing systems may be beneficial for animal welfare, but might also affect NH_3 emissions and control options. The objectives of this study were (1) to examine implications of a change in housing systems due to animal welfare legislation on NH_3 emissions by comparing NH_3 emissions factors from animal-friendly and conventional housing systems, and (2), based on the comparison of NH_3 emission factors, to assess the impact on total NH_3 emissions at national and EU level and to evaluate the relevance of the potential change in NH_3 emissions.

After summarizing information on the environmental impacts of NH_3 emissions, the report discusses animal welfare legislation and the relevance of organic livestock production. Further, ammonia emissions from conventional and animal-friendly housing systems for pigs, laying hens and cattle are compared drawing on a literature review on NH_3 emissions from different housing systems. Finally, the impact on NH_3 emissions at sectoral and national levels is assessed in two newly developed scenarios applying the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model.

2 Present state

In the last decades intensification of animal production has caused environmental problems and raised increased awareness of those. At the same time, public concern increased about the well-being of animals. Thus, the EU adopted directives to improve animal welfare for farm animals. Organic farming has not only the reputation of being extensive and more environmentally-friendly, but also organic livestock production is regarded as more animal-friendly than conventional agriculture. According to the EU (2006), “organic farming shall observe the highest level of animal welfare”. Thus, regarding animal welfare issues, organic livestock farming is also to be considered.

2.1 Ammonia – background information

Emissions of NH_3 to the atmosphere have been recognized as an environmental issue for several decades. NH_3 deposition contributes to eutrophication of freshwater and marine ecosystems resulting in a loss of biodiversity. It can also increase acidification and nutrient-nitrogen (N) enrichment of soils. By 2010, NH_3 is probably the major contributor to acidifying gaseous nitrogen emissions in Europe. Moreover, atmospheric NH_3 can react with sulphuric and nitric acids forming secondary particles. Particulate matter is known to have detrimental effects on human health (Kirchmann et al., 1998; Krupa, 2003; Webb et al., 2005; Brunekreef & Holgate, 2002).

The EU considered NH_3 emissions and their adverse impacts in its European Commission Acidification Strategy (EC, 1997) and the EU Directive on national emission ceilings for certain atmospheric pollutants (EC, 2001a), which have called for a limitation of NH_3 emissions from all EU Member States. Existing legislation was regarded as insufficient to prevent negative environmental and health impacts. As a consequence, the Commission of the European Communities adopted the Thematic Strategy on Air Pollution (TSAP) in order to achieve “levels of air quality that do not give rise to significant negative impacts on, and risks to human health and the environment” (EC, 2005). This strategy sets emission reduction targets for the main air pollutants. NH_3 emissions should be reduced by 27 percent by 2020 compared to the situation in 2000.

Agriculture is the major source of NH_3 emissions contributing about 80 to 90 percent of NH_3 emissions in Europe, followed by biomass burning and fossil fuel combustion. Within agriculture, about 80 to 90 percent of NH_3 emissions in Europe originate from nitrogen compounds in livestock excreta, mainly from urea in the urine. Emissions occur at all stages of manure management; that is, during livestock housing, manure storage and from manure application to land, as well as from manure from livestock on pastures. Remaining sources in agriculture include application of mineral N fertilizer to land (Webb et al., 2005; UNECE, 2007).

As agriculture is the largest contributor to NH_3 emissions, the greatest reductions are likely to be achieved within this sector. Emissions and reduction potentials have been widely investigated.

The issue examined in this report is whether animal welfare legislation could have a (positive or negative) impact on NH_3 from agriculture.

2.2 Legislation considering animal welfare in the European Union

The EU Scientific Veterinary Committee and the Scientific Committee on Animal Health and Animal Welfare concluded that current housing conditions for farm animals are inadequate as regards animal welfare and that higher standards are required. Experimental studies have proven that loose housing systems and minimal standards such as enlargement of the exercise area and provision of litter bedding are of substantial benefit for animal welfare (Herlin, 1994; Hinhede et al., 1996; Ernst, 1995; Horne & Niekerk, 1998). Taking these findings into account, the EU adopted various directives laying down minimum standards for the protection of pigs, laying hens, calves and chickens kept for meat production.

In organic farming, the share of loose housing systems is higher (Krutzinna et al., 1996), and organic farms provide larger feeding and exercise areas compared to conventional farms (Hörning, 1998). Sundrum (2001) concluded that living conditions for organic livestock are better than in conventional farming.

The EU Directives for the protection of farm animals, and the regulation for organic farming comprise various prescriptions to ensure animal welfare, such as housing condition, feeding routines, or tooth clipping. As this study focuses on NH_3 emissions, only rules with an expected impact on NH_3 emissions will be presented.

2.2.1 EU Directives for the protection of farm animals

Recognizing that animals are sentient beings, the Council and the Commission of the EU have adopted Directives with minimum standards for the protection of pigs (EC, 2001b; EC, 2001c; EC, 1991), laying hens (EC, 1999a) and chickens kept for meat production (EC, 2007). Legislations for calves are already in force and thus not included in the analysis.

EC (2001b) is based on the conclusion of the Scientific Veterinary Committee “that pigs should benefit from an environment corresponding to their needs for exercise and investigatory behavior and that the welfare of pigs appeared to be compromised by severe restrictions of space.” It prescribes a minimum of unobstructed floor area for weaners and fattening pigs according to their live weight, e.g., 0.65 m^2 per pig from 85 to 110 kg, and for sows kept in groups an area of at least 2.25 m^2 per sow. Sows and gilts shall be kept in groups during pregnancy. According to EC (2001c), pigs must have “access to a lying area physically and thermally comfortable” and “permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, (…)”. These provisions apply to newly or rebuilt farms from 2003, and to all farms from 2013.

Considering the welfare of laying hens, the Scientific Veterinary Committee concluded that current battery cages (“unenriched cages”) are inadequate and that “certain of the hens’ needs cannot be met”. EC (1999a) prohibits rearing hens in unenriched cage systems, with an area of about 550 cm^2 per hen, with effect from 2012. From then on, it permits only enriched cages with at least 750 cm² per hen, as well as nests, litter for pecking and scratching, and perches. Alternatively, non-cage systems are allowed providing a minimum of 1111 cm² (maximum nine hens per m²) usable area per hen, at least one nest for every seven hens, perches and at least 250 cm² of littered area. These can be supplemented by outdoor runs. Minimum requirements for non-cage systems came into force in 2007.

Also rearing conditions for broilers are regarded as unsatisfactory for animal welfare and health. For intensive farming systems (more than 500 chickens), EC (2007) prescribes a maximum stocking density of 33 kg/m²; if extra welfare measures are applied, a stocking density of a maximum of 39 kg/m² is allowed. Additionally, farmers must ensure “permanent access to litter which is dry and friable on the surface” for all chickens, and appropriate ventilation. Member States are to implement legislation in compliance with this Directive by the end of June 2010 the latest.

2.2.2 EC Regulation on organic livestock farming

The EC regulation 1804/1999, supplementing regulation 2092/91 (EC, 1999b), provides standards for organic livestock farming. Amongst others, it includes specifications for housing conditions and animal nutrition for all species of animals kept on organic farms. Housing conditions as regards ventilation, light, space and comfort should meet the animals’ biological and ethological needs. Sufficient area to permit freedom of movement and natural social behavior should be provided. Dry litter bedding and group housing are mandatory for all organic livestock. Additionally, all animals should have access to outdoor exercise areas or grazing.

For fattening pigs, depending on the live weight, a minimum indoor area of 1.3 m² and a minimum outdoor area of 1 m² per pig from 85 kg up to 110 kg are prescribed. For dairy cows, at least 6 m² of indoor and 4.5 m² of outdoor area are required. The minimum area for breeding and beef cattle relates to their live weight, e.g., up to a weight of 100 kg at least 1.5 m² indoor and 1.1 m² outdoor are required. For laying hens, a maximum stocking density of six animals per m² indoor (i.e., at least 1667 cm² per hen), and 4 m² minimum outdoor area per hen are prescribed. Stocking density of fattening poultry in fixed housing is limited to 21 kg per m² indoor, with at least 4 m² of outdoor area per broiler, in mobile housing to 30 kg per m² with at least 2.5 m² of outdoor run. Animal feed has to be of organic origin. Feeding of synthetic amino acids and growth promoters is prohibited.

Table 1: Overview of EU legislation with respect to animal welfare

Animal category	Legislation	Provisions	Date of compliance[1]
Pigs	2001/88/EC	Space, group-housing for sows	1 January 2013
	2001/93/EC	Litter	1 January 2003[2]
Laying hens	1999/74/EC	Battery cages prohibited	1 January 2012
		Alternative systems	1 January 2007
Broilers	2007/43/EC	Space and litter	30 June 2010[2]
Organic farming - all animals	1804/1999/EC	Space and litter, outdoor area	31 December 2010

* Legislation already applies to new and rebuilt buildings. Date of compliance refers to all buildings

[1] Member States to bring legislation into force

2.3 Development in organic livestock production

Since the early 1990s, organic farming has rapidly developed in most European countries. In 2003, 5.7 million hectares representing 3.6 percent of the Utilized Agricultural Area (UAA) in EU-25 were managed organically by 149 000 farms (1.4 percent of total farms) (European Commission, 2005). In the year 2005, organic area reached about 6.3 million hectares (3.9 percent of UAA), cultivated by 160 000 farms (1.7 percent). Figure 1 shows the development of organic farming in the past years.

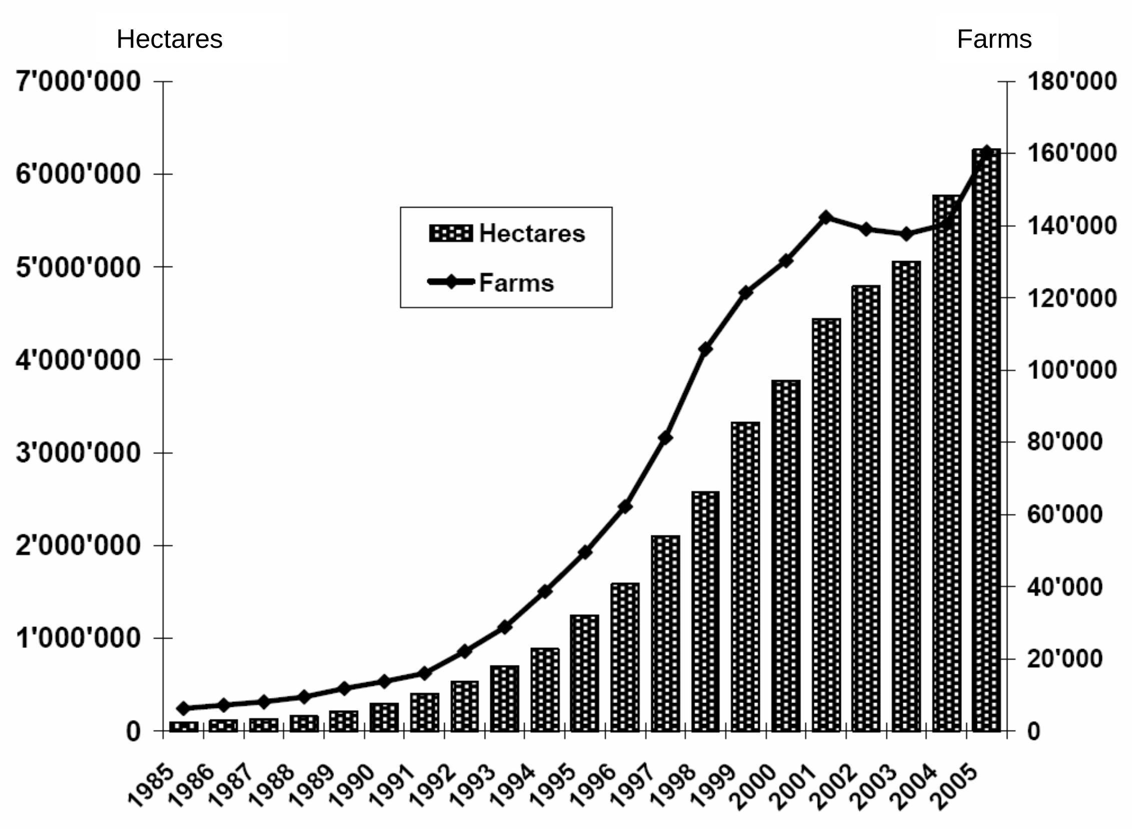

Figure 1: Development of organic farming in the European Union 1985 – 2005; *Source:* Willer & Yussefi (2007)

Ireland, Greece, Spain, Italy, Cyprus, Lithuania and Slovakia have reported growth rates of more than ten percent between 2004 and 2005. There were, however, decreases in the UK, Denmark, Finland, and a slight reduction in Sweden. (Willer & Yussefi, 2007; Eurostat, 2007). Highest growth rates occurred in the Member States with low shares in the past.

The importance of organic farming differs considerably between countries. Italy is the country with the highest number of organic farms and the largest organic area. The country with the highest proportion of organic area is Austria, with more than 14 percent of agricultural land managed organically, followed by Italy with eight percent. Finland, Sweden, Latvia, the Czech Republic and Greece have a share of about seven percent organic area. In many countries the share of organic area is around one percent (Eurostat, 2007)

Organic livestock amounted to about three million livestock units or 2.3 percent of the total livestock in EU-25 in 2003 (European Commission, 2005). The percentages of organic livestock in total livestock production by Member States show that some countries produce a considerable amount of organic livestock (Figure 2).

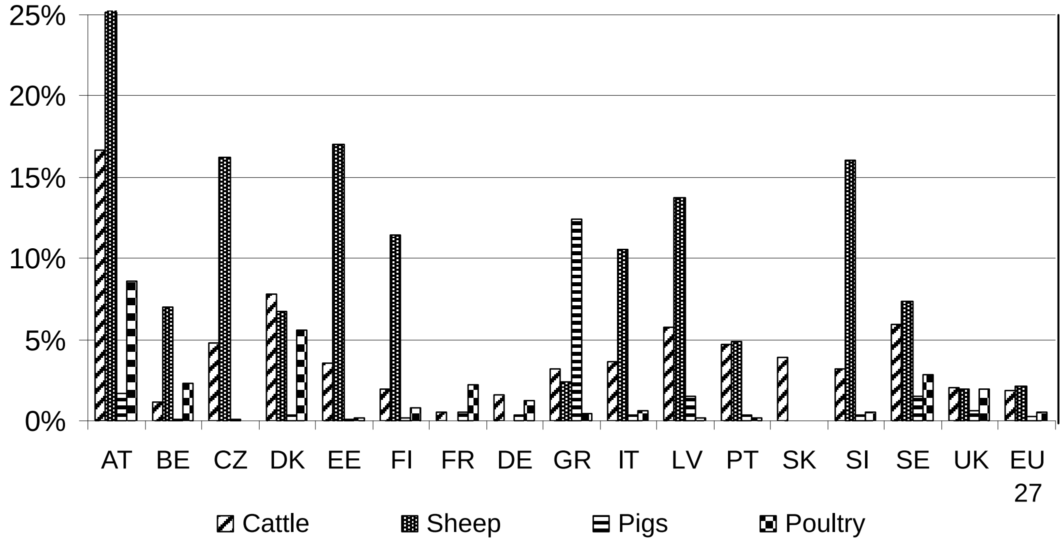

Figure 2: Organic livestock out of total livestock in 2005 (%); *Source:* Eurostat (2007), European Commission (2005)

In most of the Member States, sheep and cattle are the most popular species in organic farming. In Austria, 25 percent of sheep and 17 percent of cattle were produced organically in 2005. Organic cattle accounted for more than five percent in the Czech Republic, Denmark, Latvia and Sweden. Generally, pigs and poultry were of minor importance. With 13 percent organic pigs of total pig production, Greece was the only country with a high share of organic pigs. Broilers and laying hens amounted to a noticeable number in France, with 5.1 and 1.3 millions, respectively; in the UK, laying hens amounted to 1.4 millions. Looking at the share of organic laying hens in total number of hens, Denmark exceeded the EU-15 average, at 1.7 percent, significantly with a share of 22 percent, followed by Sweden (seven percent), Austria (six percent) and Luxembourg (four percent).

The number of animals and developments in individual Member States vary according to species. In some Member States, organic species are on the increase whereas in others they are declining. The trend in the organic livestock sector diverges significantly between Member States (see Table 2).

Table 2: Organic livestock numbers (heads), 2005 and relative changes (%) 2004-2005.

Country	**Cattle**		**Pigs**		**Sheep**		**Poultry**	
	Numbers	**Changes**	**Numbers**	**Changes**	**Numbers**	**Changes**	**Numbers**	Changes
AT	333826	1%	52170	6%	79551	0%	1025331	21%
BE	30116	-6%	8090	-3%	10636	50%	818109	2%
CZ	67956	-32%	3108	129%	24230	-23%	2946	72%
DK	122760	-2%	53541	-8%	11609	-1%	979241	.
EL	22900	55%	126003	353%	218293	63%	144098	94%
ES	56701	6%	10665	26%	137831	-4%	105756	18%
FI	19048	6%	3046	19%	9948	132%	84116	13%
IE	21950	.	700	.	38000	.	73000	.
IT	222516	3%	31338	18%	738737	48%	977537	-55%
LT	3843	-42%	70	-16%	3658	-3%	363	-59%
LV	21439	114%	6580	217%	6109	210%	7356	22%
NL	36269	4%	26200	-10%	9340	-8%	559984	24%
PT	62218	14%	6763	-30%	124408	8%	45377	-4%
SE	91515	.	27299	23%	34700	-9%	410919	5%
SI	14539	11%	1966	59%	21071	17%	17642	24%
SK	20133	58%	206	565%	57830	114%	76	55%
UK	214276	7%	29995	-46%	691000	0%	3439548	29%

Source: Eurostat (2007); European Commission (2005)

3 Ammonia emissions from conventional and animal-friendly housing systems – a comparison

Animal welfare and organic farming legislation affect housing conditions. Requirements for more space and litter might influence NH_3 emissions and the manure systems. For instance, a change from liquid to solid systems also affects NH_3 emissions and the available options for emissions controls. Emissions from conventional housing systems have been widely investigated, and emission factors are rather well documented. Information and data from alternative, animal-friendly housing systems at farm level, however, are limited. A literature search of peer-reviewed articles, complemented by research project reports, has been carried out to collect emission factors from animal-friendly housing systems for pigs, laying hens, and cattle, and to compare them to conventional housing systems.

3.1 Ammonia formation and control options

NH_3 formation and emissions are influenced by many different factors. Main factors are urea and NH_3 concentrations in the slurry, pH and temperature of the slurry, and the air velocity over the manure surface. NH_3 emissions from houses also depend on the area of the floor covered with excreta and the area of the manure pit. Elzing et al. (1992) found a linear relation between area of NH_3 source and emissions. Moreover, temperature and humidity in the house are important. NH_3 emissions from straw-based systems may depend on the amount of straw used.

NH_3 emissions can be reduced by technical measures during all stages of the manure chain, or by adjustments to livestock diets that result in less nitrogen in excreta available for NH_3 formation.

Emissions from animal houses can be substantially lowered if the emitting surface area is reduced. For slurry, frequent removal out of the building into closed storage outside avoids emissions with exhaust air. Another option is the lowering of the pH and the temperature of the slurry. Keeping floors and manure dry also helps to reduce NH_3 emissions. Especially for poultry houses, drying of manure, for example by application of a manure belt, reduces NH_3 emissions significantly. In mechanically ventilated houses, filtration techniques such as bioscrubbers can be applied (Weiske, 2005; UNECE, 2007; Peet-Schwering et al., 1999). In straw-based systems, a high amount of straw used can reduce emissions not only from housing but also from storage and spreading (Pain & Jarvis, 1999). Urea concentration in the urine and NH_3 in the slurry can be influenced by feeding. Particularly for pigs, phase-feeding and a low protein diet, additionally fortified with synthetic amino acids, reduces NH_3 emissions (Peet-Schwering et al., 1999).

NH_3 loss from slurry storage can be decreased if storages are covered, for instance by formation of a natural crust, mainly for cattle slurry, or with rigid plastic covers. Also, lagoons could be replaced by tanks. For solid manure storage no proven control measures are available (UNECE, 2007; Weiske, 2005).

NH_3 emissions from manure application account for a large share of total NH_3 emissions. Control options are very important at this stage as much of the benefit of abating during housing and storage can be lost without abatement at the final stage. For slurry, band spreading techniques where the slurry is discharged at ground level or injected can reduce NH_3 emissions substantially. These techniques are mainly applicable to grassland. Incorporation of slurry or solid manure into the soil by plough or disc is only applicable to arable land and is the only control option for solid manure (UNECE, 2007; Weiske, 2005).

3.2 Ammonia emissions from conventional and animal-friendly housing systems

3.2.1 Pig housing

The most common system for conventional pig fattening are mechanically ventilated houses with fully-slatted floors without separation in lying and dunging area. A manure storage pit underneath the floor collects the slurry and may connect to a central channel for emptying. Farrowing sows are usually kept in crates on slatted floors.

A housing system regarded as more animal-friendly is the deep litter system. In general, deep litter housing systems are applicable to cattle, pigs and poultry. Animals are kept in groups on solid floors on a thick layer of bedding material such as straw or sawdust. No separate dunging and lying areas are offered. Litter is added regularly so that the bedding layer increases over time, and manure accumulates on it. The litter is removed from the house one to two times per year as farmyard manure. Deep litter houses may be naturally ventilated (UNECE, 2007; Pain & Menzi, 2003). Alternatively, pigs can be kept in a straw flow house (Amon et al., 2007) which is separated into several pens. Each pen is divided into a concrete lying area with a slight slope towards the excretion area in the rear of the pen. Straw for manipulation is supplied in a rack in the front of the pen. The straw flow house can be forced or naturally ventilated and can be run as a straw-based system with a mixture of straw and excreta in the dunging area, or slurry-based with a slatted excretion area and a dung channel underneath (Figure 3). Organic pigs can be kept in straw flow or deep litter systems with obligatory access to an outdoor run. Floors in the outdoor run can be solid or partially perforated (Olsson et al., 2005; Wachenfelt & Jeppsson, 2006; Ivanova-Peneva et al., 2006; Keck et al., 2004).

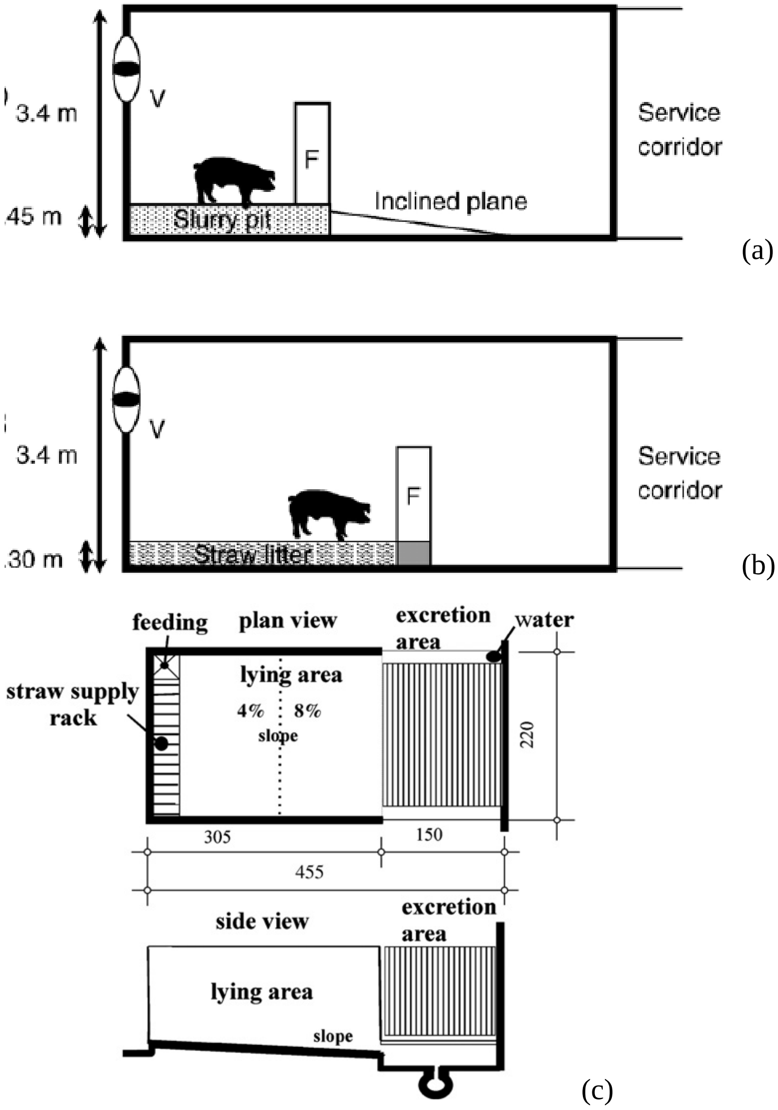

Figure 3: Designs of pig houses: conventional fully-slatted-floor house (a), deep litter house (b), straw flow house (c); *Source:* Philippe et al. (2007); Amon et al. (2007)

For fattening pigs kept in conventional, i.e., fully-slatted, floor systems, a number of emission factors are available. Döhler et al. (2002) and UBA (2001) give a reference factor for fully-slatted floor systems equalling three kg NH_3 per pig place per year for a housing period of 330 days. From an experiment, Philippe et al. (2007) reported a mean emission rate of 6.22 g NH_3 per pig per day. Assuming the same housing period of 330 days, emissions summed up to 2.1 kg NH_3 per pig per year. Groenestein & Faassen (1996) cite the result of measurements done by Hoeksma et al. (1993) who determined an average emission rate of 0.3 g NH_3-N per pig per hour which results in around 2.9 kg NH_3 per pig per year.

Considering animal-friendly housing systems, Groenestein & Faassen (1996) measured NH_3 emissions from fattening pigs kept on deep litter. Emission rates varied between 0.12 and 0.24 g NH_3-N per pig per hour, resulting in 1.1 kg and 2.3 kg NH_3 per pig and year, depending on the amount of litter used and the treatment of the bed, and thus were lower than the results of Hoeksma et al. (2003) for conventional houses. Philippe et al. (2007) found a mean emission rate of 13.10 g NH_3 per pig per day on deep litter, which is equivalent to 4.3 kg per pig per year. Directly compared to the results for conventional housing from the same experiment, emissions from the deep litter system were significantly higher. Amon et al. (2007) investigated emissions from a slurry-based straw flow system in Austria. Emissions were 2.1 kg per pig per year from a dung channel system, and 1.9 kg per pig per year from a system with daily manure removal. Rathmer (2001) reported emission rates of 2.6 to 4.2 g NH_3 per livestock unit and hour for straw flow systems, i.e. around 2.4 to 4 kg NH_3 per pig per year.

Looking into pig housing systems with outdoor runs as required in organic farming, Keck et al. (2004) and Berry et al. (2005) compared emissions from traditional pig housing systems with animal-friendly systems with outdoor runs in Switzerland. Traditional housing systems with slatted floors and including straw for manipulation emitted around 2.69 kg NH_3 per pig per year, whereas emissions from housing systems with outdoor yards summed up to 5.55 kg NH_3 per pig per year, with about 4.5 kg NH_3 from the outdoor area. In a study in the Netherlands, Ivanova-Peneva et al. (2008) measured NH_3 emissions from three organic pig farms. Emission rates were 8.0, 2.0 and 0.4 g NH_3 per pig per day for the inside area, and 14.5, 7.6 and 4.7 g NH_3 per pig per day for the outdoor run, for each farm respectively. These figures result in total NH_3 emissions of 7.4, 3.2 and 1.7 kg NH_3 per pig per year. Olsson et al. (2007) determined NH_3 emissions from organic pig production in Sweden to be about four times higher than those from conventional farms. They estimated the higher crude protein content of the organic feed and the poorer feed conversion to contribute by a factor of about 1.75 times, and the larger fouled areas by a factor of about 2.25 times.

Referring to sows, Peet-Schwering et al. (2001) investigated NH_3 emissions from ad libitum fed pregnant sows in group houses in accordance with the welfare legislation. Applying simple housing measures concerning floor features and manure removal, emissions were limited to 2.3 kg per pig place per year and were below the threshold of 2.6 kg NH_3 per pig place per year for conventional low emission houses. Bos et al. (2003) reported NH_3 emissions from sows in an animal-friendly straw-based group-housing system to be 2.6 kg per sow per year, due to intelligent housing design, compared to emissions of 1.8-4.2 kg per sow per year from conventional crate housing.

In another Dutch study, Ivanova-Peneva et al. (2006) determined NH_3 emissions from three organic farms with pregnant sows. Emissions from the indoor pens were 6.3, 0.5 and 2.8 kg per pig per year; emissions from the outdoor runs equalled 0.4, 1.8 and 1.8 kg NH_3 per pig per year respectively. A significant effect of location (inside or outside) on NH_3 emissions was not found. Total emissions, including those from manure pits, amounted to 7.4, 4.4 and 4.6 kg NH_3 per pig per year, respectively. Compared to the Dutch standard for conventional pig production with a limit of NH_3 emissions of 4.2 kg per pig place per year, all farms exceeded the standard, with one farm exceeding by far.

In Figure 4, NH_3 emission factors from animal-friendly pig housing systems are shown in relation to the reference values from conventional houses (reference value = 100). Emission factors from houses in line with the EU Directives (welfare) (see 2.2) range from 50 to 150 percent of conventional references. In most of the studies, emission factors were lower. For organic farming, emission factors are predominantly higher than the conventional reference values, with up to 400 percent of conventional emission factors.

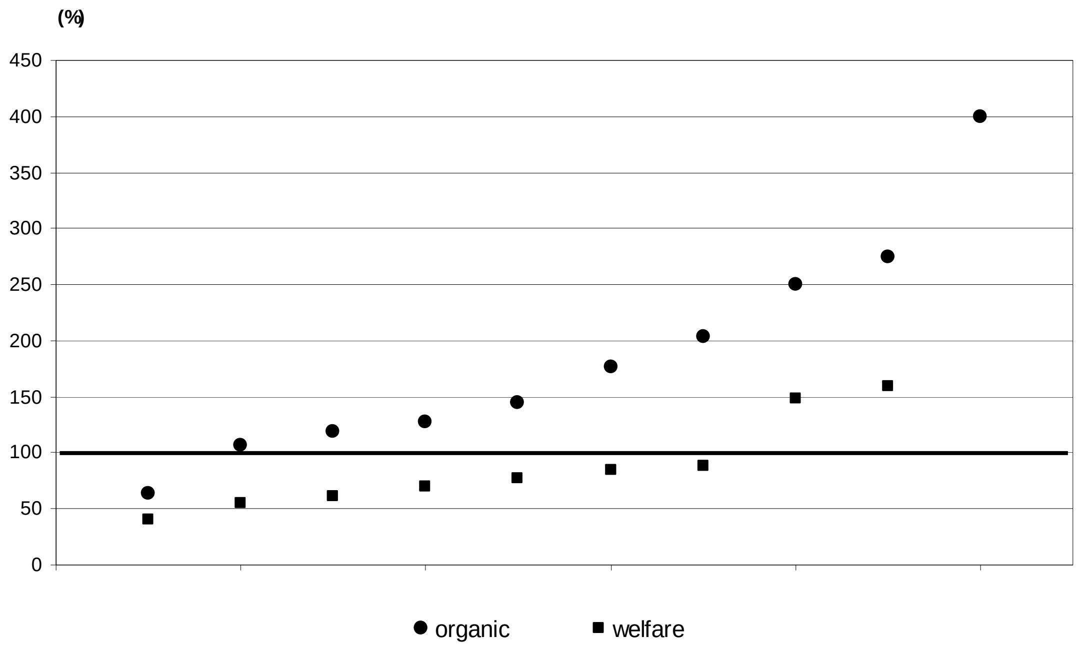

Figure 4: Pigs: Emissions from animal-friendly houses in relation to conventional references (%)

3.2.2 Poultry housing

Laying hens are mainly housed in conventional tiered cages in closed buildings with forced ventilation. Droppings fall through the bottom of the cages into open manure storage underneath and are removed once a year. In some houses, manure pits are ventilated to dry the manure and thus reduce NH_3 emissions. Stilt houses have a valve between cages and manure pit so that manure can be removed regularly without disturbing the birds. In houses with movable belts under the cages, droppings are collected and removed of the house into closed storage outside. Manure can also be dried on the belts through forced ventilation.

As conventional cages are prohibited from 2012 on, enriched cages or non-cage systems will be used. Enriched cages are a new type of battery cages with more space for the hens and litter. Droppings can be removed via manure belts. In non-cage systems such as aviaries, hens have freedom of movement and different functional areas for feeding, sleeping, scratching and egg laying (UNECE, 2007; Pain & Menzi, 2003). A Tiered Wire Floor aviary system as described by Groot Koerkamp & Bleijenberg (1998) consists of rows of stacked wire floors with rows of laying nests. The concrete floor is completely covered with sand. Manure drops on belts equipped with drying system underneath the floors, but parts of the droppings are deposited in the dry litter.

NH_3 emissions from laying hens kept in conventional battery cages range from 12-42 g per hen per year, in contrast to emissions from typical aviary systems with up to 90 g per hen per year (Bos et al., 2003). In the aviary system, 90 percent of the manure is deposited on the manure belt where it is dried immediately, and ten percent on litter causing these high emissions. However, emissions could be reduced to 20 g per hen per year when measures to keep the litter friable and dry were applied. In various studies comparing emissions from cages and aviary systems, emissions from aviary systems were found to be about three times higher than emissions from battery cages (Groot Koerkamp et al, 1995; Groot Koerkamp, 1994). In these studies, about 80 percent of manure was deposited on the manure belt and dried, and 20 percent was deposited in litter. Emissions from litter were about 80 percent of total NH_3 emissions from the aviary systems. Gustafsson & von Wachenfelt (2000) also confirmed that emissions from loose housing systems were higher than from cage systems due to the accumulation of a higher amount of manure inside the buildings.

At this stage, no studies for broilers useful for our purposes were found.

3.2.3 Cattle housing

Cattle in conventional farming are commonly loose-housed in cubicle houses with natural ventilation. Animals rest in cubicles on a small amount of bedding such as straw or plastic mats. Faeces and urine are excreted in the slatted or solid passage ways between the cubicles. Passage ways are cleaned regularly, for example with a scraper, and the manure is removed as slurry (UNECE, 2007; Pain & Menzi, 2003). In some countries, tied systems are also in use.

In organic livestock farming, cattle are kept in loose housing systems such as cubicle or deep litter houses. The opportunity for grazing or access to an outdoor yard is mandatory.

For cattle, only one report dealing with NH_3 emissions from organic dairy cows housed in a naturally ventilated deep litter house was found (Mosquera et al., 2005). Emissions from organic dairy cows amounted to 13.9 kg NH_3 per cow per year, and thus exceeded emissions from conventional dairy farming in cubicle houses, at nine kg NH_3 per cow per year, as stated in the study.

Table 3 gives an overview of NH_3 emission factors from animal-friendly and conventional housing systems for all animals considered from all studies.

Table 3: NH_3 emissions from different housing systems (in kilogram per animal per year; for laying hens in gram per hen per year)

Animal type	Conventional	Welfare [1]	Organic (whereof outdoor)	Source
Fattening pigs	3			Döhler et al. (2002); UBA (2001)
	2.9	1.1; 2.3		Groenestein & Faassen (1996)
	2.1	4.3		Phillipe et al. (2007)
		1.9; 2.1		Amon et al. (2007)
		2.4; 4		Rathmer (2001)
	2.69		5.55 (4.5)	Keck et al. (2004); Berry et al. (2005)
			1.7; 3.2; 7.4 (1.6; 2.5; 4.8)	Ivanova-Peneva (2008)
			Fourfold compared to conventional	Olsson et al. (2007)
Sows	2.6	2.3		Peet-Schwering et al. (2001)
	1.8-4.2	2.6		Bos et al. (2003)
	4.2		7.4; 4.6; 4.4 (0.4; 1.6; 1.8)	Ivanova-Peneva et al. (2006)
Laying hens	12-42	20-90		Bos et al. (2003)
		Threefold compared to battery cages		Groot Koerkamp et al. (1995); Groot Koerkamp (1994)
Dairy cows	9		13.9	Mosquera et al. (2005)

[1] referring to the EU Directives for the protection of farm animals

4 Impacts of animal-friendly housing systems on ammonia emissions

The literature review of emissions from animal-friendly houses showed that animal housing complying with welfare legislation as well as organic farming requirements can have higher ammonia emissions. It has to be noted that there are several examples of housing design where emission can be reduced. We have developed two sets of emission factors (low and high) and made assumptions on the future penetration of respective housing systems. Employing the recent national agricultural projections used in the development of the scenarios for the review of the National Emission Ceiling (NEC) directive (Amann et al., 2007) and the above assumptions on emission factors and share of animals kept in animal-friendly housing, we constructed two scenarios for each of the discussed animal categories. These were implemented in the GAINS model (Amann, 2004) to evaluate the impact on the overall emissions of ammonia by 2020 in the EU-27.

4.1 Scenarios

Scenarios have been developed for emissions from pigs, cattle and laying hens for the year 2020. In 2020, all non-organic farms must have implemented the EU directives for the protection of farm animals (see 2.2), and impacts on NH_3 emissions should be perceptible. Resulting emissions are compared against the GAINS baseline scenarios that have been developed for the revision of the EU National Emissions Ceilings Directive (NECD) (Amann et al., 2007). In all of the discussed scenarios we have not assumed any changes to animal diets, i.e., excretion rates remain the same as assumed used for the NECD baseline projection.

Baseline scenario

The baseline scenarios for NH_3 emissions from pigs, cattle, laying hens, and total emissions at national levels were taken from the GAINS model database. The database holds projections for animal numbers for 2020, NH_3 emission factors for different animals for all stages of the manure chain, assumptions on emission control measures applied, as well as total NH_3 emissions (Klimont & Brink, 2004). For pigs and cattle, the GAINS model differentiates between animals kept on solid and liquid manure systems. Considered emission control options are house adaption, biofiltration and low-nitrogen feed for housing, covered storage for slurry storage, and low-nitrogen application for solid manure and slurry, respectively. Implementation of these control options varies across countries and animal types. In some countries, we assume no control measures for all or parts of the animal stock. The baseline scenario for pigs considers all control options mentioned. As cattle houses are commonly naturally ventilated, biofilters are not applied. Also for laying hens, application of biofilters is not considered.

For the scenarios, we consider the progressing rate of the implementation of control measures, and neglect the potential impact of a change to animal-friendly housing on the applicability of abatement options along the manure chain. As the penetration of measures is relatively small, we believe that the impact is low and can be neglected for the time being.

Pig scenario

The literature review showed that emissions from animal-friendly pig houses vary considerably. For some animal-friendly houses, emissions are lower compared to conventional houses, for some houses they were higher, particularly from organic pig production. Therefore, we constructed a case with low emissions and one with high emissions. For the low-emissions case, emissions from houses in compliance with the EU Directives were estimated to be 75 percent, and for organic farming 90 percent of emissions from conventional houses. For the high-emission case, emissions from houses in line with the EU Directives have been assumed to be about 150 percent, and for organic farming 270 percent of emissions from conventional houses.

As the amount of NH_3 emitted during housing has an impact on subsequent emissions, adjustments for emissions from storage and application were made. We have estimated that introducing animal-friendly housing will lead to higher emission factors from storage and application. For the low-emissions case we assumed an increase by six percent for houses in line with the EU Directives, and by two percent for organic pigs. For the high-emissions case, we assumed that emission factors from storage and application will be lower by nine percent, and by 35 percent for organic houses. Starting from the pig numbers in the baseline GAINS scenario, we have assumed, for organic pigs, a moderate growth of 0.5 percent per year beginning from 2005. As deep litter systems are seen as animal-friendly, NH_3 emissions from pigs on solid systems in GAINS were taken as they were. It was assumed that conventional liquid systems change into animal-friendly houses and organic production.

Laying hens scenario

Emissions from laying hens kept in aviaries were found to be around 300 percent of emissions from battery cages. We have estimated that the increase in emission from housing will lead about 50 percent lower emission factors from storage and application, respectively.

Cattle scenario

As no new EU directives for the protection of cattle exist, only organic cattle are considered. Based on a study for organic dairy cows kept on deep litter, an increase of NH_3 emissions by 50 percent compared to conventional slurry-based systems was assumed. Similarly to organic pig numbers, we have assumed a growth of 0.5 percent per year starting from 2005. The GAINS model database contains numbers of cows and cattle kept on solid and liquid systems. As solid systems are considered animal-friendly, emissions from cattle on solid systems have not been changed. We have assumed that a proportion of cattle on liquid systems will convert into organic cattle kept on deep litter. For emission factors from storage and application, we have estimated a reduction by 30 percent for storage and by 60 percent for application.

Total NH_3 emissions scenario

Finally, the various scenarios have been compiled, and we examine how changes in emissions from pigs, laying hens and cattle due to animal welfare legislation affect total NH_3 emissions at national levels.

4.2 Results

Animal-friendly pig housing can lead to a change in NH_3 emissions, varying from almost minus 20 percent to plus 30 percent in Ireland, for example (see Figure 5). The relative changes differ across countries according to the applied emission control strategies, but are considerable in nearly all countries. At the level of EU-27, emissions can be reduced by almost ten percent, or can increase by around 15 percent, depending on the assumptions.

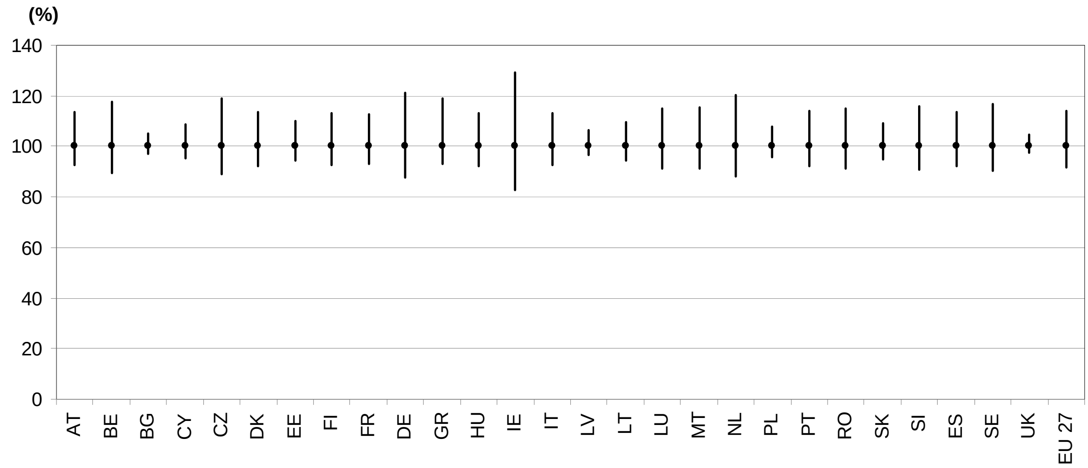

Figure 5: Relative change of NH_3 emissions from pigs (%)

As shown in Figure 6, for laying hens a change from battery cages to aviary systems leads to a significant increase in NH_3 emissions in all countries but Belgium. For some countries such as Denmark and Germany, emissions would more than double. For the EU-27, aviary systems lead to an increase by more than 60 percent. Although emissions from aviary housing are threefold compared to cages, the adjustments made for emissions from storage and applications limit the overall relative change.

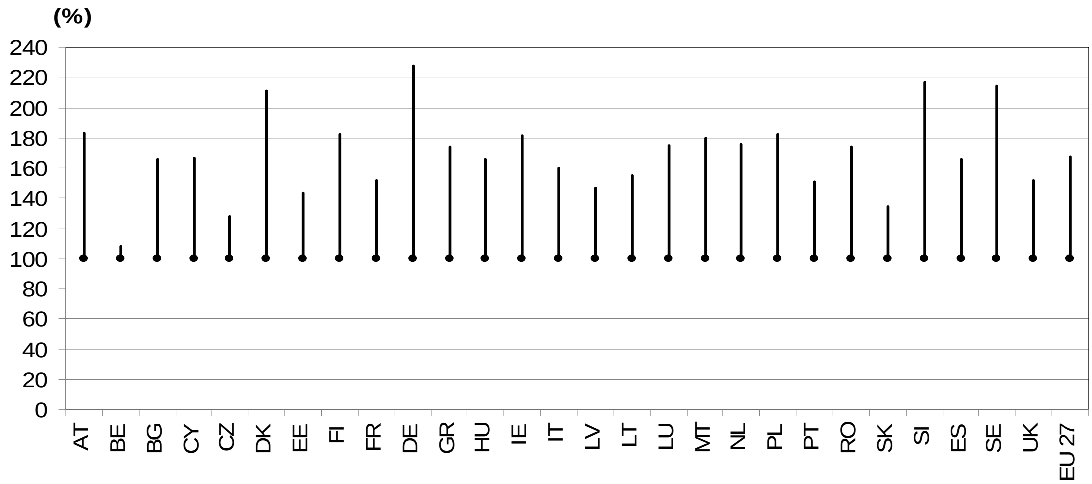

Figure 6: Relative change of NH_3 emissions from laying hens (%)

For organic cattle, an increase of NH_3 emissions during housing by 50 percent compared to conventional houses was found. The adjustments of emission factors for storage and application, however, resulted in lower emissions per head compared to conventionally raised cattle in nearly all countries. Due to the small number of organic cattle, the overall impact on NH_3 emissions from cattle at national levels is barely noticeable (see Figure 7). Only in Austria, the high share of about 19 percent organic cattle leads to a noteworthy reduction of eight percent.

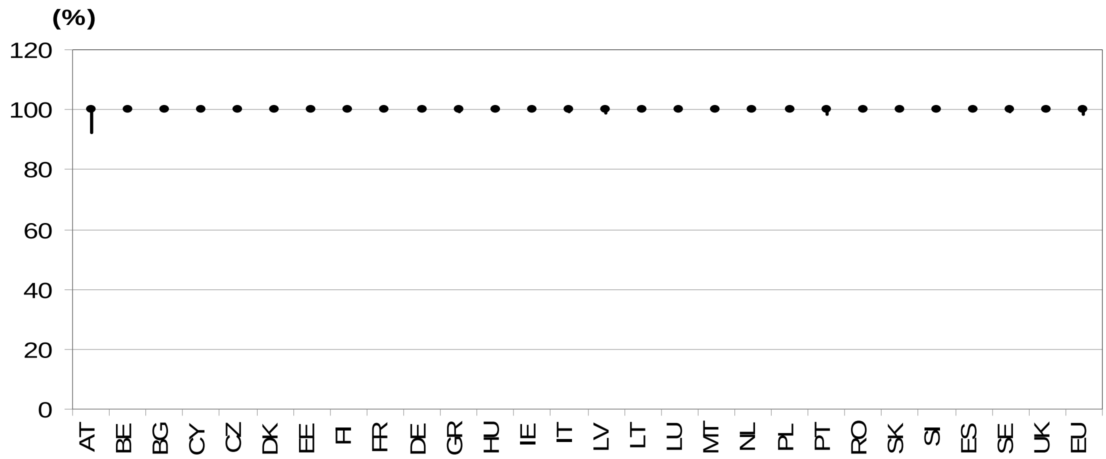

Figure 7: Relative change of NH_3 emissions from organic cattle (%)

The impact on total national NH_3 emissions is shown in Figure 8. Animal-friendly housing can lead to a marginal reduction in NH_3 emissions, or to an increase by up to ten percent in a few countries. At EU-27 level, emissions could increase by up to five percent.

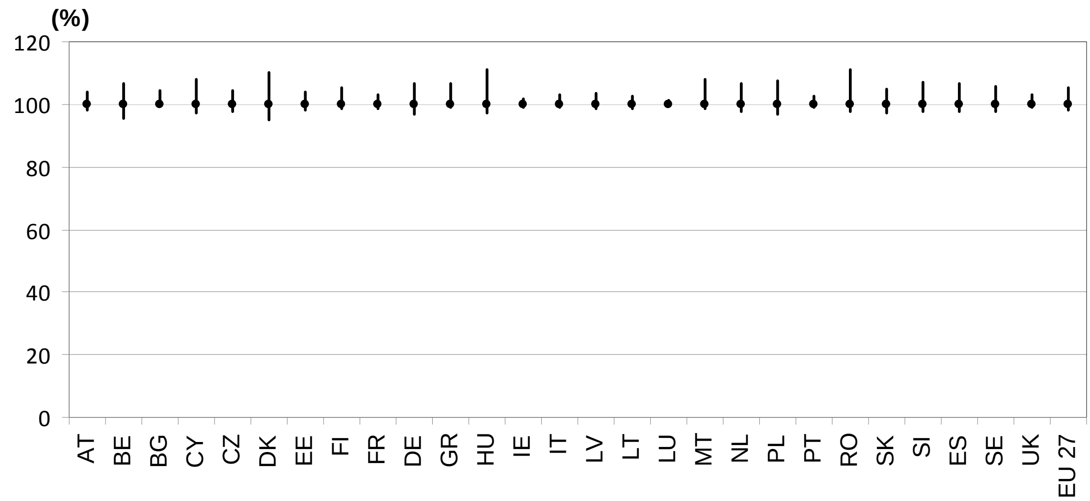

Figure 8: Relative change of total NH_3 emissions (%)

5 Discussion

The literature review confirms an impact of animal-friendly housing on NH_3 emission factors compared to those from conventional houses. It also shows that only little data from on-farm measurements exist. Field studies are available from a few countries only, and measurements were conducted under different climatic conditions and with different techniques. Also, only few studies comparing NH_3 emissions from animal-friendly with conventional houses exist. Hence, it is difficult to compare emission factors from animal-friendly houses across studies, and to emission factors from conventional houses.

As current emission data were considered insufficient for a robust assessment in absolute terms, a relative approach was chosen. For a precise assessment with absolute numbers, more studies and measured data are needed. Starting from the GAINS baseline livestock projections, we assumed, for organic farming (livestock), an annual growth rate of 0.5 percent beginning from 2005. This assumption has been made for all countries and takes into account a slowdown in growth, observed in the recent years in several countries with huge growth rates in the past.

The results of this study can provide only an indication of the potential impact of animal welfare legislation on NH_3 emissions. Results indicate that animal welfare legislation might alter total NH_3 emissions, ranging from a marginal decrease to an increase by around five percent for the EU-27. Considering the 27 percent emission reduction target (in comparison to 2000) that has been set in the EU Thematic Strategy on Air Pollution, the possible increase resulting from animal welfare legislation and organic farming need to be compensated by more and more effective implementation of emission control measures, or by lower livestock numbers. For individual countries even larger effects might occur.

The fact that we assumed the current emission control legislation for this analysis might lead to a slight underestimation of the impact of animal-friendly housing. Although it is believed that the impact will not be large, a separate analysis would be needed.

Regarding pigs, a number of studies on NH_3 emissions from animal-friendly pig houses were found, and current data are considered sufficient for assessment. As NH_3 emission factors from pigs vary considerably, animal-friendly housing can lead to a reduction or to an increase in emissions. Potential reductions are due to animal-houses following the EU Directives for the protection of pigs. Organic pig farming is likely to increase NH_3 emissions, mainly due to emissions from the outdoor run, but also higher crude protein content in organic feed and poorer feed conversion might play a role. Frequent manure removal from the outdoor area may help to limit emissions from organic pigs (Ivanova-Peneva et al., 2008). Low nitrogen feed in combination with amino acids to reduce NH_3 is not applicable to organic pigs. For a better assessment, information on the type of house and manure system is needed. NH_3 from houses with forced ventilation can be reduced by biofilters, but this control option is not applicable to naturally ventilated houses. A change in the manure systems from conventional slurry-based to straw-based systems has an effect on subsequent emissions: for slurry, effective storage and application techniques are available. However, for farmyard manure no proven storage techniques exist, and the only reduction technique for application is incorporation, which is only appropriate for arable land. Animal-friendly houses run with a liquid system are also expected to produce a small amount of farmyard manure due to litter use. The amount of litter used also affects the storage capacity needed. For laying hens, only few studies on aviary systems are available, but all report a significant increase of NH_3 emissions compared to battery cages. The increase goes back to manure dropped on the litter. Aviary systems can be run with belts to remove and possibly dry manure and thus reduce NH_3 emissions. About 20 percent of the manure, however, drops on the litter. At present, no proven control option for NH_3 emissions from the litter is known. Emissions from the litter may be reduced by enhancing the scratching of the hens, and with new ventilation systems to keep the litter dry and friable (Bos et al., 2003). However, laying hens cannot only be kept in aviary systems, but also in enriched cages. Studies on NH_3 emissions from enriched cages are needed, as well as information on the proportion of laying hens kept in either of the systems. Although laying hens are of minor importance in organic farming, data on NH_3 emissions including outdoor area would be useful for a comprehensive assessment.

For organic cattle, only one study was found on NH_3 emissions from a deep litter house. For a reliable assessment across countries, more measurements, both from straw-based and from slurry-based houses including outdoor areas, are needed. Reduction measures for NH_3 emissions from organic cattle are limited. As natural ventilation is common for cattle houses, biofilters cannot be applied. For slurry, effective storage and application techniques are known. For farmyard manure, no control option during storing exists, and for application only incorporation on arable land is an option.

6 Conclusions and outlook

The literature review of NH_3 emission factors from animal-friendly housing systems demonstrates that animal-friendly houses are not ammonia-neutral compared to conventional houses. Emission factors from animal-friendly pig houses vary considerably and can be lower or higher than those from conventional houses. Organic pig production is likely to increase NH_3 emissions, mainly due to emissions from outdoor areas, whereas organic cattle production might lead to a marginal decrease in NH_3 emissions. A change from battery cages to aviary systems for laying hens may increase NH_3 emissions significantly. Overall impacts of a change to animal-friendly housing systems on national ammonia emissions could cause a slight decrease or a noticeable increase in emissions. Thus, the implementation of animal welfare legislation has potentially important implications for the European air pollution policy as it may counteract the NH_3 emission reduction target set in the EU Thematic Strategy on Air Pollution. This potential trade-off between animal welfare legislation and air pollution policy calls for further research. For a more precise assessment, more measurements of NH_3 emissions from animal-friendly houses are needed, particularly for cattle, laying hens and broilers. As a change in housing systems may also affect greenhouse gas emissions, and to avoid pollution swapping, those should be included in a comprehensive assessment.

References

Amann, M. (2004): The RAINS model: Documentation of the model approach prepared for the RAINS peer review 2004. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria. http://www.iiasa.ac.at/rains/review/review-full.pdf.

Amann, M., Asman, W., Bertok, I., Cofala, J., Heyes, C., Klimont, Z. et al. (2007): NEC Scenario Analysis Report Nr. 4: Updated Baseline Projections for the Revision of the Emission Ceilings Directive of the European Union. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria. http://www.iiasa.ac.at/rains/CAFE_files/NEC4-v1.pdf.

Amon B., Kryvoruchko V., Frohlich M., Amon T., Pollinger A., Mosenbacher I., Hausleitner A. (2007): Ammonia and greenhouse gas emissions from a straw flow system for fattening pigs: Housing and manure storage. Livestock Science 112, 199-207.

Berry, N.R., Zeyer, K., Emmenegger, L., Keck, M. (2005): Emissionen von Staub (PM10) und Ammoniak (NH3) aus traditionellen und neuen Stallsystemen mit Untersuchungen im Bereich der Mastschweinehaltung. Vertrag Nr. BUWAL/INT/501.01.16 (5.1.1).

Bos B., Groot Koerkamp P.W.G., Groenestein K. (2003): A novel design approach for livestock housing based on recursive control - with examples to reduce environmental pollution. Livestock Production Science 84, 157-170.

Brunekreef, B., Holgate, S.T. (2002): Air pollution and health. The Lancet 360, 1233-1242.

Döhler, H., Dämmgen, U., Berg, W., Bergschmidt, A., Brunsch, R., Eurich-Menden, B., Lüttich, M., Osterburg, B. (2002): Anpassung der deutschen Methodik zur rechnerischen Emissionsermittlung an internationale Richtlinien und Prognose der Ammoniak-Emissionen der deutschen Landwirtschaft und Szenarien zu deren Minderung bis zum Jahre 2010. Final Report for Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft und Umweltbundesamt, Texte 5/02, Forschungsbericht 299 42 245/02.

EC (1991): Council Directive 91/630/EEC laying minimum standards for the protection of pigs.

EC (1997): Commission of the European Communities. Communication to the Council and the European Parliament on a Community Strategy to Combat Acidification, 88 final, Brussels.

EC (1999a): Council Directive 1999/74/EC laying minimum standards for the protection of laying hens.

EC (1999b): European Commission Council Regulation No 1804/1999 supplementing Regulation (EEC) No 2092/91 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs to include livestock production)

EC (2001a): Directive 2001/81/EC of the European Parliament and of the Council on national emission ceilings for certain atmospheric pollutants.

EC (2001b): Council Directive 2001/88/EC amending Directive 91/630/EEC laying minimum standards for the protection of pigs.

EC (2001c): Commission Directive 2001/93/EC amending Directive 91/630/EEC laying minimum standards for the protection of pigs.

EC (2005): Commission of the European Communities. Communication from the Commission to the Council and the European Parliament. Thematic Strategy on Air Pollution, 446 final, Brussels.

EC (2006): Commission of the European Communities. Commission working document on a Community Action Plan on the Protection and Welfare of Animals 2006-2010. Strategic basis for the proposed actions. 14 final, {SEC (2006) 65}, Brussels.

EC (2007): Council Directive 2007/43/EC laying down minimum rules for the protection of chickens kept for meat production.

Elzing, A., Kroodsma, W., Scholtens, R., Uenk, G.H. (1992): Ammoniakemissiemetingen in een modelsysyeteem van een rundveestal: theoretische beschouwingen. Report No. 92-3, IMAG-DLO, Wageningen.

Ernst, E. (1995): Die Bedeutung von Stroh für die Haltung von Mastschweinen. Betriebswirtschaftliche Mitteilungen der LWK Schleswig-Holstein 480, 17-24.

European Commission (2005): Organic farming in the European Union. Facts and Figures. Report. Brussels.

Eurostat (2007): Different organic farming patterns within EU-25. An overview of the current situation. Statistics in focus. Agriculture and fisheries 69.

Groenestein C.M., Van Faassen H.G. (1996): Volatilization of ammonia, nitrous oxide and nitric oxide in deep-litter systems for fattening pigs. Journal of Agricultural and Engineering Research 65, 269-274.

Groot Koerkamp, P.W.G, Keen, A., van Niekerk, Th.G.C.M., Smits, C. (1995): The effect of manure and litter handling and indoor climatic conditions on ammonia emissions from a battery cage and an aviary housing system for laying hens. Netherland Journal of Agricultural Science 43, 351-373.

Groot Koerkamp, P.W.G. (1994): Review on emissions of ammonia from housing systems for laying hens in relation to sources, processes, building design and manure handling. Journal of Agricultural Engineering Research 59, 73-87.

Groot Koerkamp, P.W.G., Bleijenberg, R. (1998): Effect of type of aviary, manure and litter handling on the emission kinetics of ammonia from layer houses. British Poultry Science 39, 379-392.

Gustafsson, G., von Wachenfelt, E. (2000): Ammonia extraction by ventilation of loose-housing systems for laying hens. Journal of Agricultural Engineering Research 75, 17-25.

Herlin, A.H., 1994: Effects of tie-stalls or cubicles on dairy cows in grazing or zero-grazing situations. Dissertation, Swedish University of Agricultural Science, Upssala, Report 228.

Hindhede, J., Sorensen, J.T., Bak Jensen, M.B., Krohn, C.C., 1996: Effect of space allowance, access to bedding, and flock size in slatted floor systems on the production and health of dairy heifers. Acta Agric. Scand., Sect. A. Animal Science 46, 46-56.

Hoeksma, P., Oosthoek, J., Verdoes, N., Voermans, J.A.M., 1993: Reduction of ammonia emission in pig housing by flushing with aerated slurry. Report 93-23, IMAG-DLO, Wageningen, The Netherlands, 1993.

Horne, P.L.M. van, Niekerk, T.G.C.M. van (1998): Volieren- und Käfighaltung im Vergleich – Produktqualität, Gesundheit und Wirtschaftlichkeit von Legehennen. DGS-Mag. 6, 14-17.

Hörning, B. (1998): Tiergerechtheit und Tiergesundheit in ökologisch wirtschaftenden Betrieben. Deutsche Tierärztliche Wochenschrift 105, 313-321.

Ivanova-Peneva S.G., Aarnink A.J.A., Verstegen M.W.A. (2008): Ammonia emissions from organic housing systems with fattening pigs. Biosystems Engineering 99, 212-222.

Ivanova-Peneva, S.G., Aarnink, A.J.A., Verstegen, M.W.A. (2006): Ammonia and mineral losses on Dutch organic farms with pregnant sows. Biosystems Engineering 93, 221-235.

Keck, M., Zeyer, K., Emmenegger, L. (2004). Emissions of NH3 and PM10 from closed housing and housing combined with open exercise yards for growing-finishing pigs. Proceedings of AgEng 2004, p.6, 12-16 September 2004, Leuven.

Kirchmann, H., Martti, E., Morken, J., Ferm, M., Bussing, W., Gustavsson, J., Jakobsson, C. (1998): Ammonia emissions from agriculture. Nutrient Cycling in Agroecosystems 51, 1-3.

Klimont, Z. and Brink, C. (2004): Modelling of Emissions of Air Pollutants and Greenhouse Gases from Agricultural Sources in Europe. International Institute for Applied Systems Analysis (IIASA), 02-142, Laxenburg, Austria.

Krupa, S. (2003): Effects of atmospheric ammonia (NH3) on terrestrial vegetation: a review. Environmental Pollution 124, 179-221.

Krutzinna, C., Boehncke E., Hermann, H-J. (1996): Die Milchviehhaltung im Ökologischen Landbau. Berichte über Landwirtschaft 74, 461-480.

Mosquera, J., Hol, J.M. G., Huis in't Felt, J.W.G. (2005): Onderzoek naar de emissies van een natuurlijk geventileerde potstal voor melkvee I Stal. Rapport 324. Agrotechnology & Food Innovations B.V., Wageningen.

Olsson, A.-C., Jeppsson, K.-H., Botermans, J., Andersson, M., Wachenfelt, H. von, Svensson, G., Svendsen, J. (2007): Ekologisk slaktgrisproduktion. Del 2 – Produktion, djurrhälsa, välfärd, funktion och miljö (Organic growing-finishing pig production. Part 2. Production, animal health, welfare, function and environment). Rapport 147. Swedish University of Agricultural Science, Alnarp.

Pain, B., Menzi, H. (2003): Glossary of terms on livestock manure management 2003. www.ramiran.net.

Peet-Schwering, C.M.C. van der, Aarnink, A.J.A., Rom, H.B., Dourmad, J.Y. (1999): Ammonia emissions from pig houses in The Netherlands, Denmark and France. Livestock Production Science 58, 265-269.

Peet-Schwering, C.M.C., van der, Plagge, J.G., Verdoes, N. (2001): Ammonia emission in pregnant sows fed ad libitum. Rapport – Praktijkonderzeoek Veehouderij, 2001 (No. 209).

Philippe F.-X., Laitat M., Canart B., Vandenheede M., Nicks B. (2007): Comparison of ammonia and greenhouse gas emissions during the fattening of pigs, kept either on fully slatted floor or on deep litter. Livestock Science 111, 144-152.

Rathmer, B. (2001): Vergleich klima- und umweltrelevanter Emissions aus Haltunssystemen für Mastschweine. Dissertation, Lehrstuhl für Landtechnik der Technischen Universität München.

Sundrum, Albert (2001): Organic livestock farming. A critical review. Livestock Production Science 67, 207-215.

UBA (Umweltbundesamt der Bundesrepublik Deutschland) (2001): Beste verfügbare Techniken in der Intensivtierhaltung (Schweine- und Geflügelhaltung), UBA-Text 75/02, UBA Vorhaben FKZ 360 08 001, Forschungsbericht 360 08 001, UBA-FB 000284 ISSN 0722-186X; http://www.umweltdaten.de/publikationen/fpdf-1/2213.pdf.

UNECE (2007): Guidance document on Control Techniques for Preventing and Abating Emissions of Ammonia (EB.AIR/WG5/2007/13)
http://www.unece.org/env/lrtap/ExpertGroups/aa/welcome.htm.

Wachenfelt, H. von, Jeppsson, K.-H. (2006): Nitrogen losses from Organic Housing Systems for Fattening Pigs. In: Proceedings of the Workshop on Agricultural Air Quality: State of the Science, 1192-1199, 5-8 June, Washington, D.C.

Webb, J., Menzi, H., Pain, B.F., Misselbrook, T.H., Dämmgen, U., Hendriks, H., Döhler, H. (2005): Managing ammonia emissions from livestock production in Europe. Environmental Pollution 135, 399-406.

Weiske, A. (2005): Survey of technical and management-based mitigation measures in agriculture. Project report MEACAP WP3 D7a. SSPE-CT-2004-503604.

Willer, H., Yussefi, M. (eds.) (2007): The World of Organic Agriculture. Statistics and Emerging Trends 2007. 9th edition, totally revised and updated. International Federation of Organic Agriculture Movements IFOAM Bonn, Germany & Research Institute of Organic Agriculture FiBL, Frick, Switzerland.