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Anticipated changes in the emissions of greenhouse gases and ammonia from pork production due to shifts from fattening of barrows towards fattening of boars

Ulrich Dämmgen*, Andreas Berk**, Caroline Otten**, Wilfried Brade***, Nicholas J. Hutchings****, Hans-Dieter Haenel*, Claus Rösemann*, Sven Dänicke**, and Manfred Schwerin*****

Abstract

Greenhouse gases and of ammonia emissions from pork production will change when fattening of barrows switches towards to fattening of (intact) boars. The results of an accurate feeding experiment allow for the differentiation of the effects on emissions of gender (differentiating in boars, barrows and gilts) and of diet composition.

The modified fattening pig module of the agricultural emission model GAS-EM was used to estimate emissions in 2020 when the fattening of barrows will no longer be common practice. The scenarios also reflect the effect of the expected increased weight gains and the related effect of increased numbers of animals produced.

The fattening of intact boars as compared to barrows is associated with a reduction of emissions of greenhouse gases and of ammonia per animal. For ammonia, all scenarios result in reduced emissions, most markedly when this shift is combined with increased weight gains. To a lesser extent, this also applies to nitric and nitrous oxide emissions. Methane emissions are less affected; increased weight gains result in increased emissions.

As the greenhouse gas balance is dominated by methane emissions, the overall emission of greenhouse gases (expressed as CO_2 equivalents) is likely to increase slightly in 2020 despite the reductions in nitrous oxide emissions.

Keywords: *boars, barrows, gilts, emission, methane, ammonia, nitrous oxide, greenhouse gases*

* Johann Heinrich von Thünen Institute, Institute of Climate-Smart Agriculture, Bundesallee 50, 38116 Braunschweig, Germany

** Friedrich Loeffler Institute (FLI), Federal Research Institute for Animal Health, Institute of Animal Nutrition, Bundesallee 50, 38116 Braunschweig, Germany

*** University of Veterinary Medicine Hannover, Institute for Animal Breeding and Genetics, Bünteweg 17p, 30559 Hannover, Germany

**** Aarhus University, Dept. of Agroecology, PO Box 50, Research Centre Foulum, 8830 Tjele, Denmark

***** Leibniz Institute for Farm Animal Biology (FBN), Wilhelm-Stahl-Allee 2, 18196 Dummerstorf, Germany

Contact: ulrich.daemmgen@daemmgen.de

Zusammenfassung

Geschätzte Änderungen der Emissionen von Treibhausgasen und von Ammoniak bei der Umstellung der Schweinefleischerzeugung von Börgen- auf Ebermast

Treibhausgas- und Ammoniak-Emissionen werden sich als Folge der bevorstehenden Umstellung der Mast von Börgen auf (intakte) Eber ändern. Die Ergebnisse eines Exaktversuchs erlauben eine Differenzierung zwischen den Einflüssen des Geschlechts (unterschieden werden Eber, Börge und Sauen) und der Futterzusammensetzung auf die Emissionen.

Das modifizierte Mastschweine-Modul des landwirtschaftlichen Emissionsmodells GAS-EM wird dazu benutzt, Emissionen für 2020 vorherzusagen. Das Mästen von Börgen wird dann nicht mehr üblich sein. Der Einfluss erwarteter erhöhter Gewichtszunahmen und die sich daraus ergebende Steigerung der Zahl der gemästeten Tiere werden berücksichtigt.

Das Mästen intakter Eber ist im Vergleich zu Börgen mit verringerten Emissionen von Treibhausgasen und Ammoniak pro Tier verbunden. Bei Ammoniak wird eine deutliche Abnahme berechnet, insbesondere dann, wenn der Wechsel zur Ebermast mit erhöhten Gewichtszunahmen einhergeht. Dies trifft auch für Stickstoffmonoxid- und Lachgas-Emissionen in geringerem Ausmaß zu. Die Methan-Emissionen nehmen geringfügig ab; erhöhte Gewichtszunahmen haben aber erhöhte Emissionen zur Folge.

Die Emission von Treibhausgasen wird in erster Linie von den Methan-Emissionen bestimmt. Für die Gesamtemission von Treibhausgasen (ausgedrückt in CO_2-Äquivalenten) im Jahr 2020 wird eine geringfügige Zunahme berechnet, obwohl die Emissionen von Lachgas abnehmen werden.

Schlüsselwörter: *Eber, Börge, Sauen, Emission, Methan, Ammoniak, Lachgas, Treibhausgase*

1 Background and goal

In European pork production, surgical castration of boars has been the most common procedure to avoid boar taint. About 80 % of all male piglets were castrated (Frederiksen et al., 2009). In Germany, the majority of male piglets were castrated without anaesthetization in the first week of their lives. However, it is good practice to apply analgesic agents after castration. [1] Boars were not fattened (Weiß et al., 2005; Brade and Flachowsky, 2006). The problems of surgical castration of pigs (pain, risk of infection) have long been known (see Hagmüller, 2006, and literature cited therein). Interest in the improvement of animal welfare led to a decision of the German government to ban the castration of piglets without anaesthetization with effect from 1 January 2017 (BMELV, 2012).

Alternatives to castration without anaesthetization are the fattening of boars (intact male pigs), boars castrated under anaesthetization or immunocastrated boars. [2] Of these, the fattening of boars (intact male pigs) seems to be the most likely alternative. In fact the numbers of boars slaughtered in Germany has been increasing steadily (e.g. Quaing, 2012).

The shift from fattening of castrated males (barrows) to boars will have an effect on emissions of greenhouse gases and ammonia: It has been known that there are differences in the feed conversion ratio (FCR, i.e. the ratio of overall feed intake to overall weight gain) of barrows and boars. Dunshea et al. (2001) measured 11 % to 20 % higher feed conversion ratios of boars as compared to barrows, depending on their age. In modern pig production, it is common to offer feed *ad libitum* to achieve a high performance at low costs. Fuller et al. (1995) reported that voluntary feed intake (VFI) is influenced by type of pig (breed, gender) (Kanis and Koops, 1990; Quiniou et al., 2000; Müller et al., 2012). Reduced feed intake rates normally result in reduced emission rates.

However, until recently, no feeding experiments investigating these differences under commercial production conditions had been carried out in Germany. In 2010, the German Agricultural Society stated that reliable results from experiments with the fattening of boars that justified feeding recommendations were not available in Germany (DLG, 2010). Since then, numerous experiments have been carried out comparing the fattening of boars to that of barrows (see Preinersdorfer et al., 2010; and Table 3). They agree with the findings obtained abroad: in general, boars have a lower FCR and a higher ratio of lean meat to fat (e.g. Barton-Gade, 1987; Babol and Squires, 1995; Kallweit et al., 1999) and hence a higher nitrogen (N) content. Ratios, however, vary between experiments. This is attributed to the influence of different factors such as genetic origin, diet composition and feeding system or slaughter weight.

Many results describing the performance of fattening are available but no studies have yet considered the impact on emissions. This work assesses the emission changes to be expected from a move to fattening boars rather than barrows. It comprises five steps:

Step 1 makes use of the results of a feeding experiment with boars and barrows comparing VFI and growth performance of boars and barrows and verifies that gender has a significant effect.

Step 2 modifies the input parameters of the fattening pig module in the German agricultural emission model GAS-EM so that gender specific feed intake and nitrogen retention can be described, exploiting the literature available from feeding experiments with gilts, barrows and boars.

Step 3 derives gender specific individual excretion rates applying the modified input parameters.

Step 4 aims at an estimate of typical gender specific emissions per animal at the present performance level.

Step 5 estimates potential future national emission rates taking into account an increase in animal places and progress in animal breeding, in particular increased daily weight gains.

2 Evaluation of a feeding experiment at the Friedrich Loeffler Institute (Step 1)

A feeding experiment comparing barrows and boars was performed at the Institute of Animal Nutrition of the Friedrich Loeffler Institute (FLI) in Braunschweig, Germany.

2.1 Experimental details

In the FLI experiment, a total of 95 pigs (48 boars and 47 barrows; Piétrain x (Large White x Landrace)) were used. The feeding regime was a two-phase regime ("grower" and "finisher" diets, with "grower" and "finisher" weights of 27 to 77 kg animal^{-1} and 77 to 120 kg animal^{-1}, respectively). Four diets with two different lysine (Lys) to metabolizable energy (ME) ratios were fed, with Lys/ME of 1.0 and 0.94 g MJ^{-1} for grower and 0.78 and 0.73 g MJ^{-1} for finisher diets. The experimental design was a 2 x 2 x 2 factorial design with the factors gender, energy and lysine contents. To reflect German farming practice, the experimental period spanned the live weight range from an average of 27 kg animal^{-1} to a slaughter weight of about 120 kg animal^{-1}. Boars and barrows were allocated alternately in the experimental barn to avoid housing effects. They were kept individually in 3.1 m^2 boxes on concrete floors. Water was provided *ad libitum* via nipple drinkers. All

[1] More than 95 % of German pig producers are members of the German Quality Scheme for Food (QS, 2012) and have committed themselves to use analgesics.

[2] Immunocastration using the formation of antibodies after vaccination against gonatropin releasing factor is one alternative. With respect to their performance, immunocastrated boars do not differ significantly from intact boars (e.g. Götz et al., 2009; Hagmüller and Gallnböck, 2010; Müller et al., 2010; Škrlep et al., 2010; Gispert et al., 2010; Fuchs et al., 2011).
Furthermore, the reduction of the likelihood of boar taint is object of breeding (e.g. Frieden et al., 2011) and feeding experiments (e.g. Lindermayer et al., 2012).
Reduced slaughter weights also reduce the risk of losses due to boar taint. In countries where the fattening of boars has been common practice, slaughter weights are below those in Germany (c.f. BPEX, undated: 2011 carcass weights of 80.1, 80.4, and 82.3 kg animal^{-1} in the United Kingdom, Ireland and Denmark, respectively, as compared to 94 kg animal^{-1} in Germany).

Table 1
Diet compositions (related to fresh matter)
SBEM: soy bean extraction meal, 48 % crude protein (XP); SBO: soy bean oil; MV: mineral feed mixture (Min.Vit.TraceE); Cell: cellulose; Lys: lysine HCl; Met: DL-methionine; Thr: L-threonine; Trp: L-tryptophan (Otten et al., 2013)

	wheat kg kg^{-1}	barley kg kg^{-1}	SBEM kg kg^{-1}	SBO kg kg^{-1}	MV kg kg^{-1}	Cell kg kg^{-1}	Lys kg kg-1	Met kg kg^{-1}	Thr kg kg^{-1}	Trp kg kg-1
phase 1										
feed 1	0.3000	0.3819	0.2200	0.0200	0.0300	0.0330	0.0066	0.0050	0.0030	0.0005
feed 2	0.3000	0.3987	0.2200	0.0340	0.0300	0.0000	0.0075	0.0055	0.0035	0.0008
feed 3	0.3000	0.3845	0.2200	0.0200	0.0300	0.0330	0.0055	0.0040	0.0025	0.0005
feed 4	0.3000	0.4017	0.2200	0.0340	0.0300	0.0000	0.0064	0.0047	0.0027	0.0005
phase 2										
feed 1	0.3200	0.4170	0.1750	0.0200	0.0250	0.0350	0.0040	0.0025	0.0015	0.0000
feed 2	0.3200	0.4375	0.1750	0.0330	0.0250	0.0000	0.0048	0.0027	0.0017	0.0003
feed 3	0.3200	0.4190	0.1750	0.0200	0.0250	0.0350	0.0032	0.0018	0.0010	0.0000
feed 4	0.3200	0.4400	0.1750	0.0330	0.0250	0.0000	0.0039	0.0020	0.0011	0.0000

pigs were manually fed *ad libitum* with mash feed, refilled twice a day. During the experimental period, the pigs were weighed weekly. Feed refusals were weighed on the same day as the animals to calculate feed intake and weight gain on the same time base. The analysis of feed constituents (Weender analysis) was performed at the institute (see Table 1). For further details see Otten et al. (2013).

The experiment did not include fattening of gilts.

2.2 Experimental results

Barrows and boars differ with respect to their weight gains as well as their feed and ME intake rates (Table 2).

2.3 The influence of gender and diet composition on daily weight gains and feed conversion rates – results of an analysis of variance

An analysis of variance (ANOVA; $P < 0.05$) indicates that boars and barrows had significantly different performance and feed intake rates ($p < 0.001$). The average daily weight gain over the whole experimental period of boars was 1188 g d^{-1} in contrast to 1107 g d^{-1} for barrows. Although boars grew slightly faster, they consumed 10 % less feed (2.66 kg d^{-1}) than barrows (2.95 kg d^{-1}). Accordingly, the feed conversion ratio of boars was found to be reduced by approx. 16 % as compared to barrows (2.25 kg kg^{-1} and 2.69 kg kg^{-1}, respectively) (Otten et al., 2013).

Table 2
Animal weights, weight gains and intakes of feed and ME – experimental data. numbers in brackets are standard deviations (Otten et al., 2013)

	initial weight kg animal^{-1}	final weight kg animal^{-1}	weight gain g animal^{-1} d^{-1}	total feed intake kg animal^{-1} DM	total ME intake MJ animal^{-1}
boars					
feed 1	27.65 (1.07)	123.03 (3.30)	1153	215.7 (13.6)	2791
feed 2	27.99 (1.30)	126.00 (3.83)	1193	219.3 (13.9)	3023
feed 3	27.44 (0.21)	127.77 (4.09)	1221	229.3 (16.7)	3009
feed 4	27.67 (0.63)	125.02 (3.41)	1185	214.9 (13.8)	2958
barrows					
feed 1	27.92 (1.31)	121.89 (8.18)	1130	244.8 (30.3)	3169
feed 2	28.03 (1.42)	124.35 (4.90)	1107	256.2 (28.8)	3532
feed 3	27.22 (0.22)	124.33 (3.99)	1093	269.2 (24.0)	3535
feed 4	27.38 (0.23)	120.30 (3.40)	1097	249.8 (17.9)	3438

2.4 Representativeness of the experimental findings

The conditions and results of the FLI experiment reflect the state of the art in pig breeding and science rather than the situation in German commercial fattening pig production.

- The experimentally achieved weight gains (see Table 3) exceed those obtained in common practice; according to information of the pig breeders' associations (ZDS) mean daily weight gains in 2010 amounted to about 750 g animal^{-1} d^{-1} (see Rösemann et al., 2013).
- The slaughter weights are slightly higher than those dominating the German market.
- Measured FCR are in the range of data published from scientific experiments and therefore lower than FCR obtained for practice oriented weight gains (see Table 4).
- A comparison with diet compositions obtained from a national survey (Dämmgen et al., 2011b) shows that the diets used in the experiment are slightly richer in ME and crude protein than in current German practice.

Furthermore, no N contents of the carcasses were available from the experiment so far. Hence, their representativeness cannot be checked.

Thus we conclude that the results of this experiment cannot be extrapolated directly to quantify anticipated changes in emissions for future pork production. The additional information needed has to be extracted from the literature.

3 Derivation of gender specific parameters for the GAS-EM fattening pig module (Step 2)

3.1 Modelling of excretion rates

It is common practice to model feed intake and excretion rates in animal husbandry starting with the assessment of ME requirements as determined by animal type and performance. For fattening pigs, animal weights and weight gains are considered. Calculations follow the official national recommendations provided in GfE (2008) where standard assumptions are made for protein and fat contents of the animals. ME intake and diet composition then allow for the assessment of feed intake rates, including the intake rates of those feed constituents that govern the emissions of CH_4 from enteric fermentation and from manure management. The quantification of the amount of N excreted in faeces and urine presupposes the knowledge of the amount of N retained. This can be obtained from the weight gain and the N content of that gain. [3]

Table 3
Example experimental results of the fattening of boars and barrows in Germany. Data originating from well-described experiments only.

Daily weight gain g animal^{-1} d^{-1}		Feed conversion ratio (FCR) kg kg^{-1}		Carcass lean meat content [A] (%)		Remarks	Source
boars	barrows	boars	barrows	boars	barrows		
848	860	2.46	2.81			slaughter weight 95 kg animal^{-1}	Hoppenbrock (1995)
860	866	2.99	2.59			slaughter weight 115 kg animal^{-1}	Hoppenbrock (1995)
1043	1053	1.98	2.21	59.6	58.5	slaughter weight 102 kg animal^{-1}	Schön and Janssen (2010)
1065	1032	2.06	2.36	59.5	57.2	slaughter weight 115 kg animal^{-1}	Schön and Janssen (2010)
898	919	2.30	2.61	57.7	55.2		Matthes and Brüggemann (2010)
1022	1012	2.23	2.69	58.4	56.6		Müller (2010a, b)
796	834	2.50	2.76	56.2	55.4		Müller (2010b)
802	830	2.87	2.97			without additional amino acid supply	Walgern et al. (2011)
889	816	2.66	3.10			with additional amino acid supply	Walgern et al. (2011)
798	797	2.50	2.95	59.3	56.5		Meyer (2011)
906 893 901	851	2.41 2.49 2.46	2.80	61.5 61.2 61.0	58.8	experimental variation in the feeding of boars (3 groups)	Schulze Langenhorst et al. (2011)
1188	**1107**	**2.24**	**2.67**				Otten et al. (2013)

[A] estimated according to SchwHKIV (1986)

[3] Is it assumed that the N content of growth is constant for the whole of the pig's life.

The model used in this work is the fattening pig module of the German agricultural emission model GAS-EM that was developed to serve national emission reporting in compliance with international obligations [4], as well as to provide a tool to evaluate emission reduction measures. For fattening pigs in particular, the module is able to reflect the national situation using an approach to assess emission from so-called mass flow considerations. However, the present version of the GAS-EM fattening pig module does not differentiate between gilts, barrows and boars. For the purpose of this work, sub-modules for the treatment of gilts, barrows and boars were derived that made use of gender specific N contents and feed intake rates.

3.2 Gender specific nitrogen contents

It is customary in Germany to use a standard N content of adult pigs of 2.56 % or 0.0256 kg kg^{-1} N. [5] Due to an increased ratio of lean meat to fat (see Table 1), boars should have a higher N content than both barrows and gilts. However, there are currently no German data that differentiate the N contents of boars, barrows and gilts. [6]

Barton-Gade (1987) published experimental data of protein contents of Danish boars, barrows and pigs of 4.7 %, 3.6 % and 4.0 %, respectively. Various breed combinations were tested. Slaughter weights were about 70 kg animal^{-1}. No weight gains were reported. The resulting N contents of the carcasses were low compared to the German situation.

Lawlor et al. (2005) quantified N contents of whole carcasses of Irish boars, barrows and gilts of 2.286 %, 2.144 % and 2.197 %, respectively. The experiment dealt with hybrids Landrace x (Landrace x Large White). Daily weight gains were in the same order of magnitude as German weight gains (710 to 750 g animal^{-1} d^{-1}). Slaughter weights of 120 kg animal^{-1} agree with German practice. For slaughter weights of 100 kg animal^{-1}, N contents were very similar to those used in Germany. Hence, this data set was preferred to estimate the respective N contents of fattening pigs as described subsequently.

The N content of a carcass is defined as

$$X_{\mathrm{N,c,}} = \frac{m_{\mathrm{N,c}}}{w_{\mathrm{c}}} \quad (1)$$

where

$X_{\mathrm{N,c}}$ overall N content of a carcass (in kg kg^{-1} N)
$m_{\mathrm{N,c}}$ mass of N in the carcass (in kg N)
w_{c} mass of the carcass (in kg)

Assuming that the mean carcass weights of the pigs of various genders are about equal and that the overall N content of German pigs ($X_{\mathrm{N,mean,de}}$) currently used in the GAS-EM model was established for a population consisting of equal shares of barrows and gilts, the N contents of boars, barrows and gilts carcasses can be estimated by Equations (2) to (4):

$$X_{\mathrm{N,boar,de}} = X_{\mathrm{N,mean,de}} \cdot \frac{X_{\mathrm{N,c,boar,ie}}}{\frac{1}{2}\cdot\left(X_{\mathrm{N,c,barrow,ie}} + X_{\mathrm{N,c,gilt,ie}}\right)} \quad (2)$$

$$X_{\mathrm{N,barrow,de}} = X_{\mathrm{N,mean,de}} \cdot \frac{X_{\mathrm{N,c,barrow,ie}}}{\frac{1}{2}\cdot\left(X_{\mathrm{N,c,barrow,ie}} + X_{\mathrm{N,c,gilt,ie}}\right)} \quad (3)$$

$$X_{\mathrm{N,gilt,de}} = X_{\mathrm{N,mean,de}} \cdot \frac{X_{\mathrm{N,c,gilt,ie}}}{\frac{1}{2}\cdot\left(X_{\mathrm{N,c,barrow,ie}} + X_{\mathrm{N,c,gilt,ie}}\right)} \quad (4)$$

where

$X_{\mathrm{N,boar,de}}$ overall N content of German boar (in kg kg^{-1} N)
$X_{\mathrm{N,mean,de}}$ overall N content of German pig (official mean) ($X_{\mathrm{N,mean,de}}$ = 0.0256 kg kg^{-1} N)
$X_{\mathrm{N,c,boar,ie}}$ overall N content of a Irish boar carcass ($X_{\mathrm{N,boar,ie}}$ = 0.02286 kg kg^{-1} N)
$X_{\mathrm{N,c,barrow,ie}}$ overall N content of a Irish barrow carcass ($X_{\mathrm{N,barrow,ie}}$ = 0.02144 kg kg^{-1} N)
$X_{\mathrm{N,c,gilt,ie}}$ overall N content of a Irish gilt carcass ($X_{\mathrm{N,gilt,ie}}$ = 0.02197 kg kg^{-1} N)
$X_{\mathrm{N,barrow,de}}$ overall N content of German barrows (in kg kg^{-1} N)
$X_{\mathrm{N,gilt,de}}$ overall N content of German gilts (in kg kg^{-1} N)

One obtains N contents of German boars, barrows and gilts of 0.0270 kg kg^{-1} N, 0.0253 kg kg^{-1} N and 0.0259 kg kg^{-1} N respectively. These estimates were used for the subsequent excretion calculations.

3.3 Gender specific feed intake rates

FCR is a function of gender. However, the methodology used in GAS-EM does not allow for differentiation of genders. Instead, it calculates mean energy requirements and feed intake rates for a mixed population of gilts and barrows according to GfE (2008). Currently GAS-EM calculates a mean feed intake for a population of gilts and barrows. In this work we need to separately estimate the feed intakes of gilts, barrows and boars. Gender specific feed intake rates are here derived using feed conversion ratios deduced from published experiments (Table 4).

[4] UNECE Convention on Long-Range Transboundary Air Pollution (EMEP, 2008), UN Framework Convention on Climate Change (IPCC, 1996, 2006), EU National Emission Ceilings Directive (Eionet, 2012)

[5] This generally accepted value (DLG, 2005; LfL, 2006) is poorly documented but likely to be adequate; see data collated in Wesseling (2003) and GfE (2008). In principle, X_{N} should be a function of the share of lean meat content and thus depend on progress in breeding.

[6] Kirchgeßner et al. (1989) investigated sows and barrows only.

Table 4
Data used for the assessment of mean *FCR* ratios

heads			daily weight gain g animal^{-1} d^{-1}			*FCR* kg kg^{-1}				
gilts	barrows	boars	gilts	barrows	boars	gilts	barrows	boars	note	Source
30	30		711	807		2.50	2.56			Biedermann et al. (2000)
57	24		932	1086		2.50	2.48		A	Borchers (2011)
18	60		928	1057		2.42	2.46		B	Borchers (2011)
8	34		904	1073		2.42	2.42		C	Borchers (2011)
4	37		948	1116		2.45	2.50		D	Borchers (2011)
108	108	216	849	902	862	2.39	2.55	2.25		Bünger et al. (2009)
34	34		800	833		2.51	2.66		E	Haus Düsse (2009)
32	34		892	854		2.54	2.68		F	Haus Düsse (2009)
34	32		820	828		5.51	2.67		G	Haus Düsse (2009)
	95	92		860	848		2.81	2.46	H	Hoppenbrock (1995)
				866	860				I	Hoppenbrock (1995)
	26	26		1053	1043		2.21	1.98	J	Schön and Janssen (2010)
	26	26		1032	1065		2.36	2.06	K	Schön and Janssen (2010)
8	8	8	640	670	680	3.44	3.19	3.11		Katurasitha et al. (2006)
120	120		917	943		2.65	2.78			Latorre et al. (2003)
566	561		837	906		2.30	2.43			Littmann et al. (2012)
	62	62		919	898		2.61	2.30		Matthes and Brüggemann (2010)
235	91	132	758	797	798	2.61	2.95	2.50		Meyer (2011)
42	22		938	1008		2.5	2.58			Meyer et al. (2012)
37	35	33	964	1012	1022	2.40	2.69	2.23		Müller (2010a, b)
				834	796		2.76	2.50		Müller (2010b)
45	44	17	864	946	970	2.36	2.58	2.28		Müller (2011)
	47	48		1107	1188		2,69	2,25		Otten et al. (2013)
13	13	13		931	883		2.54	2.34		Pauly et al. (2008)
99	86		746	822		2.57	2.58			Polten et al. (2010)
30	30	30	988	1032	1069	2.48	2.62	2.26		Quiniou et al. (2010)
20	20		892	972		2.46	2.58			Schön et al. (2012)
52	52		1010	979		2.37	2.36			Schön and Clar (2010)
24	19	20	831	958	940	2.88	2.77	2.63	L	Siers (1975)
21	14	16	790	826	894	3.27	3.42	3.07	M	Siers (1975)
165	150		794	832		2.94	3.11		N	Shirali et al. (2012)
117	104		805	829		3.49	3.66		O	Shirali et al. (2012)
18	18		850	925		2.74	3.05			Stupka et al. (2003)
85	85	85		830	802		2.97	2.87	P	Walgern et al. (2011)
85	85	85		816	889		3.10	2.66		Walgern et al. (2011)
	80	80		799	731		2.62	2.48		Xue et al. (1995)

Remarks: A values for 2008; B values for 2009; C values for 2010; D values for 2011; E target weight gain 850 g animal^{-1} d^{-1}; F target weight gain 950 g animal^{-1} d^{-1}; G target weight gain 950 g animal^{-1} d^{-1}, lysine added; H slaughter weight 95 kg animal^{-1}; I slaughter weight 95 kg animal^{-1}; J slaughter weight 102 kg animal^{-1}; K slaughter weight 105 kg animal^{-1}; L spring; M autumn; N weight range 60 to 90 kg animal^{-1}; O weight range 90 to 120 kg animal^{-1}; P without additional amino acid supply; Q without additional amino acid supply

Relative feed conversion rates can be obtained from the weighted means (using animal numbers provided) of the FCR provided in Table 4, for pairs of gilts and barrows (comparison 1) and of boars and barrows (comparison 2), namely

- matching pairs for gilts and barrows (comparison 1, denoted *)

FCR_{gilt}* = 2.62 kg kg^{-1}
FCR_{barrow}* = 2.68 kg kg^{-1}

- matching pairs for boars and barrows (comparison 2, denoted **)

FCR_{boar}** = 2.43 kg kg^{-1}
FCR_{barrow}** = 2.75 kg kg^{-1}

From these FCR values, correction factors can be calculated to assess feed intake rates for gilts, barrows and boars from mean feed intake rates. For comparable overall weight gains the mean FCR of the present pig population consisting of equal shares of gilts and barrows [7] can be derived as arithmetic mean (see denominator of Equations (5) to (7)):

$$f_{gilt} = \frac{FCR_{gilt}\,*}{\frac{1}{2}\cdot\left(FCR_{gilt}\,* + FCR_{barrow}\,*\right)} \quad (5)$$

$$f_{barrow} = \frac{FCR_{barrow}\,*}{\frac{1}{2}\cdot\left(FCR_{gilt}\,* + FCR_{barrow}\,*\right)} \quad (6)$$

$$f_{boar} = \frac{FCR_{barrow}\,*}{\frac{1}{2}\cdot\left(FCR_{gilt}\,* + FCR_{barrow}\,*\right)} \cdot \frac{FCR_{boar}\,**}{FCR_{barrow}\,**} \quad (7)$$

where

f_{gilt} correction factor relating FCR_{gilt} to the mean FCR
FCR_{gilt}* feed conversion ratio of gilts in comparison 1 (in kg kg^{-1})
FCR_{barrow}* feed conversion ratio of barrows in comparison 1 (in kg kg^{-1})
f_{barrow} correction factor relating FCR_{barrow} to the mean FCR
f_{boar} correction factor relating FCR_{boar} to the mean FCR
FCR_{boar}** feed conversion ratio of boars in comparison 2 (in kg kg^{-1})
FCR_{barrow}** feed conversion ratio of barrows in comparison 2 (in kg kg^{-1})

[7] Shares of newborn females and males are 0.50 and 0.50 animal animal^{-1}, respectively, in Hühn et al. (2002), and 0.49 and 0.51 animal animal^{-1} in Górecki (2003).

The correction factors as derived in the above equations are

f_{gilt} 0.989
f_{barrow} 1.011
f_{boar} 0.893

The feed intake rates of gilts, barrows and boars can then be deduced from those calculated with the present GAS-EM procedure using Equations (8) to (10)

$$M_{feed,\,gilt} = M_{feed,\,present} \cdot f_{gilt} \quad (8)$$

$$M_{feed,\,barrow} = M_{feed,\,present} \cdot f_{barrow} \quad (9)$$

$$M_{feed,\,boar} = M_{feed,\,present} \cdot f_{boar} \quad (10)$$

where

$M_{feed,\,gilt}$ feed intake of gilts (in kg animal^{-1})
$M_{feed,\,present}$ present feed intake as calculated with GAS-EM (in kg animal^{-1})
f_{gilt} correction factor relating FCR_{gilt} to $FCR_{present}$
$M_{feed,\,barrow}$ feed intake of barrows (in kg animal^{-1})
f_{barrow} correction factor relating FCR_{barrow} to $FCR_{present}$
$M_{feed,\,boar}$ feed intake of boars (in kg animal^{-1})
f_{boar} correction factor relating FCR_{boar} to $FCR_{present}$

4 Gender specific excretion rates in present German pig production (Step 3)

German pork production varies considerably with regions and years (Dämmgen et al., 2011b). For simplicity, a data set was constructed that represents typical conditions for the dominating production regions.

4.1 Performance data and N content of animals

Animal weights are used as typical for Niedersachsen (see Rösemann et al., 2013), i.e. begin of fattening: 30 kg animal^{-1}; final live weight 120 kg animal^{-1}. Feeding phases switch at 60 kg animal^{-1} (see Rösemann et al., 2013).

The **mean weight gain** of the whole pig population is estimated to be approx. 750 g animal^{-1} d^{-1} (Rösemann et al., 2013).

The **N contents of the weight gains** derived in Chapter 3.2 were used throughout.

4.2 Feed properties and intake rates

In accordance with the data used in the German agricultural emission inventory, the feed properties listed in Table 5 are assumed to reflect the present reality. For the assessment of this data see Rösemann et al. (2013) and Dämmgen et al. (2011a). These data are listed in Table 5.

Table 5
Feed properties (related to dry matter) η_{ME}: ME content; x_{ash}: ash content; x_N: N content; X_{DE}: digestibility of energy; X_{DOM}: digestibility of organic matter

	η_{ME} MJ kg^{-1}	x_{ash} kg kg^{-1}	x_N kg kg^{-1}	X_{DE} MJ MJ^{-1}	X_{DOM} kg kg^{-1}
phase 1	13.4	0.053	0.0280	0.8307	0.86
phase 2	13.0	0.057	0.0275	0.8170	0.84

ME requirements and feed ME contents allow for the assessment of feed intake rates. These intake rates are calculated for pigs (50 % gilts and barrows each) and then modified using the factors derived in Chapter 3.3.

4.3 Individual gender specific methane, volatile solids and nitrogen excretion rates

The excretion rates of CH_4 from enteric fermentation and the excretion rates of volatile solids (VS) [8] are dependent on feed intake rates and feed properties (Dämmgen et al., 2011 a, b, 2012). Furthermore, the calculation of N excretion rates with faeces and urine [9] presupposes the knowledge of the amount on N retained in growth. The ME intake rate is proportional to the feed intake rate. Data for the various genders and the 2010 situation are collated in Table 6.

All excretion and emission rates are given per animal and relate to the fattening period only, i. e. the excretion and emission rates of piglets and weaners are not included. They are proportional to excretions and emission rates per unit of weight gained.

In 2010, the pigs' excretion rates are the arithmetic means of the gilts' and barrows' excretion rates. As expected, all excretion rates for boars fall below those of gilts. It is also visible that CH_4 emission and VS excretion rates are directly related to ME intake rates, whereas the reductions for N and TAN are definitively larger due to N retention.

Percentage changes in ME intake rates, CH_4 emission and N excretion rates per animal are identical to the respective changes per unit of weight gained.

5 Example gender specific methane, ammonia, nitric and nitrous oxides emission rates - present situation (Step 4)

Manure management practices have an influence on emissions of CH_4, from storage and of NH_3, NO and N_2O. In order to allow for an extrapolation to the national scale, management was chosen to closely follow current German practices as used in the German inventory. If management practices are kept constant, then the relative emission reduction can be calculated.

Table 6
Modelled excretion rates per animal for the present situation with equal populations of gilts and barrows, no boars, and a weight gain of 750 g animal^{-1} d^{-1}, as compared to gender specific excretion rates (Percentage increases [10] and reductions as compared to pigs in brackets)

	ME intake rate MJ animal^{-1} ME		CH_4 emission rate from enteric fermentation kg animal^{-1} CH_4		VS excretion rate kg animal^{-1} VS		N excretion rate (faecal and renal) kg animal^{-1} N		TAN excretion rate (renal) kg animal^{-1} N	
pigs (2010)	3493		0.363		39.0		5.06		3.74	
gilts	3456	(-1.1)	0.359	(-1.1)	38.5	(-1.1)	4.96	(-2.1)	3.65	(-2.5)
barrows	3531	(1.1)	0.367	(1.1)	39.4	(1.1)	5.17	(2.1)	3.83	(2.5)
boars	3118	(-10.7)	0.324	(-10.7)	34.8	(-10.7)	4.14	(-18.1)	2.96	(-20.7)

[8] "Volatile solids" (VS) are used to calculate CH_4 emissions from manure management. They are the organic dry matter excreted without its ash content. Technically, VS comprise the organic material in livestock manure that is oxidised during combustion at 800 °C. For details see Dämmgen et al. (2011a).

[9] Renal N excretion contains compounds that are rapidly degraded to ammonium. Hence this fraction is called "total ammoniacal nitrogen" (TAN).

[10] The percentage change of an excretion rate is calculated as follows:

$$R_X = \frac{E_{X,\,gilt}}{E_{X,\,pig}} \cdot 100 - 100$$

where

R_X change of the excretion rate of X from gilts as compared to pigs (2010) (in %)

$E_{X,\,gilt}$ excretion rate of X from gilts (in kg animal^{-1} X)

$E_{X,\,pig}$ excretion rate of X from pigs (in kg animal^{-1} X)

etc.

The following conditions were selected:

NH_3 emissions from houses vary with the housing type. A house with partially slatted floor without bedding was assumed typical. According to the IPCC methodology, emissions of N_2O, NO and CH_4 (from VS) are included in the emissions from storage. For CH_4 emissions from enteric fermentation see Table 6.

All emissions from storage depend on the storage type and on a potential cover. This work assumes that all slurry is stored in conventional tanks, half of which develop an effective natural crust. Air scrubbers and fermentation for biogas production are not considered.

NH_3 emissions from slurry application depend on the application technique, the plant-soil system and - for bare soil - the duration between application and incorporation. Here, trailing hoses are assumed to be used throughout. One half of the slurry is assumed to be applied to bare soil and incorporated within 4 hours, the other half applied to vegetation.

Direct N_2O and NO emissions originate from storage and from N application to the soil and are closely related to N excretions. They are included in the comparison. [11]

Indirect N_2O emissions resulting from manure management (stemming from the deposition of emitted NH_3 and NO, and from N applied contaminating surface and ground waters) are also related to N excretions and included in the comparison.

National ***emission factors*** were used as in emission reporting as listed in Rösemann et al. (2013). For details see Dämmgen et al. (2012) (enteric fermentation), Dämmgen et al. (2010) (NH_3) and Dämmgen et al. (2011a) (greenhouse gases from manure management).

The gender specific emission rates obtained for fattening pigs are listed in Table 7.

Emissions per animal are closely related to the excretion rates listed in Table 6. The percentage increase and reduction of CH_4 both from enteric fermentation and from manure management equals that of ME intake rates. Direct N_2O and NO emission rates from manure storage are proportional to the N excretion rates. The respective direct emissions from soil and the indirect emissions are final products of the N flow through the production system. Table 7 provides the total of the N_2O and NO emissions. For NH_3, slight deviations from the percentage originate from transformation processes during storage.

As in Table 6, percentage changes in emission rates per animal are identical to the respective changes per unit of weight gained.

6 Estimating potential emission rates in future German pork production (Step 5)

An estimate of potential emission changes resulting from the restructuring of herds (shift from barrow to boar production) should be as close to the German reality as possible. Hence, it should also reflect anticipated animal numbers (numbers of **animal places**) and the potential progress in animal breeding, in particular increased daily weight gains. This in turn has an effect on the duration of production cycles and subsequently the number of animals produced per place (animal rounds).

Initial and final weights as used in 2010 are kept for 2020, assuming that consumers' attitudes do not change. Feeding regimes and feed composition are also kept unchanged, as are all assumptions regarding housing systems and manure management.

6.1 Additional assumptions concerning animal numbers, animal performance data and herd management

The **number of animal places** provided in the official statistics has to be modified for the purpose of the inventory (Haenel et al., 2011). The inventory uses 14947.7 and 15370.7 thousand places for 2010 and 2020 respectively (Rösemann

Table 7
Modelled emission rates per animal for the present situation with equal populations of gilts and barrows, no boars, and a weight gain of 750 g animal^{-1} d^{-1}, as compared to gender specific emissions (Percentage increases and reductions as compared to pigs in brackets)

	CH_4 emission rate (enteric fermentation) kg animal^{-1} CH_4		CH_4 emission rate (manure management) kg animal^{-1} CH_4		NH_3 emission rate kg animal^{-1} NH_3		N_2O emission rate kg animal^{-1} N_2O		NO emission rate kg animal^{-1} NO	
pigs	0.363		1.57		1.99		0.299		0.0894	
gilts	0.359	(-1.1)	1.55	(-1.1)	1.94	(-2.4)	0.293	(-2.1)	0.0877	(-1.9)
barrows	0.367	(1.1)	1.58	(1.1)	2.04	(2.4)	0.305	(2.1)	0.0912	(1.9)
boars	0.324	(-10.7)	1.40	(-10.7)	1.58	(-20.6)	0.245	(-18.0)	0.0742	(-17.0)

[11] In the IPCC (1996) methodology, N_2O emissions originating from the application of manure are dealt with as emissions from soils.

Table 8
Pig production scenarios – variables.

	Shares in fattening pig population			Animal places	Overall weight gain	Resulting animal rounds
	gilts	barrows	boars			
Scenario	animal animal^{-1}			million places	g animal^{-1} d^{-1}	animal place^{-1} a^{-1}
baseline	0.50	0.50	0.00	15.0	750	2.70
A	0.50	0.00	0.50	15.0	750	2.70
B	0.50	0.00	0.50	15.0	900	3.17
C	0.50	0.00	0.50	15.4	750	2.70
D	0.50	0.00	0.50	15.4	900	3.17

et al., 2013). For the subsequent calculations, 15.0 million places are used to describe the situation in 2010, and 15.4 million places are anticipated for 2020. Half of these are males (barrows in 2010, boars in 2020), see footnote 7.

With respect to future fattening of gilts and boars expert judgement on **housing** is ambiguous. Both joint and separate feeding scenarios are being discussed at present. In the past, differences in weight gains of gilts and barrows did not result in separate fattening. With the shift from barrows to boars the differences in weight gains between males and females even decrease (weighted means derived from Table 4; note also the inconsistencies in Table 4 with respect to the ratios of weight gains). Hence we do not consider separate fattening as a scenario.

Table 8 contains the scenarios chosen to identify changes in emission rates. The baseline reflects the situation in 2010, with fattening of gilts and barrows only.

Animal rounds are calculated from weight gains assuming 15 days of vacancy (see Dämmgen et al., 2011b) between fattening cycles.

6.2 Enteric methane, volatile solids and nitrogen release rates of fattening pigs in 2010 and 2020

Table 9 collates the data needed to estimate future emissions. Excretion rates per place are obtained from excretions per animal (Table 6) multiplied by the number of animal rounds (Table 8).

Scenario D is the most likely scenario. Scenarios A to C help to interpret changes.

Scenario A considers the shift in the pig population from gilts and barrows to gilts and boars. The reductions in excretions are considerable as both gilts and boars have smaller excretion rates than the "mean pig" in 2010.

Scenario B introduces increased weight gains. The number of animals produced per place increases with the number of animal rounds. For enteric CH_4 and VS, the increase of excretion rates more than compensates the reduction due to changes in the herd composition (comparison with scenario A). It lessens the reduction for N and TAN.

Scenario C takes increased numbers of animal places into account. Reductions in excretion rates are identical to those in scenario A.

Scenario D combines changes in herd composition, animal weight gain and numbers of animal places. The reductions in excretion rates are identical to those in scenario B.

Potential changes in feeding (low N diets, increased number of feeding phases), housing (e.g. air scrubbers) manure management (e.g. increased share of low emission techniques) are not included in this paper.

6.3 National emission rates in 2020

Table 10 combines the number of animal places with the emission rates listed in Table 9. The number of animals produced is provided for comparison.

Table 9
Modelled excretion rates per animal place (percentage increases and reductions as compared to pigs 2010 as baseline in brackets)

	Animals places 10^6 places		CH_4 emission rate (enteric) kg place^{-1} CH_4		VS excretion rate kg place^{-1} VS		N excretion rate kg place^{-1} N		TAN excretion rate kg place^{-1} N	
baseline	15.0		0.98		105.3		13.68		10.11	
A	15.0	(0.0)	0.92	(-5.9)	99.1	(-5.9)	12.30	(-10.1)	8.94	(-11.6)
B	15.0	(0.0)	1.01	(2.9)	108.4	(2.9)	12.94	(-5.4)	9.26	(-8.4)
C	15.4	(2.7)	0.92	(-5.9)	99.1	(-5.9)	12.30	(-10.1)	8.94	(-11.6)
D	15.4	(2.7)	1.01	(2.9)	108.4	(2.9)	12.94	(-5.4)	9.26	(-8.4)

Table 10
Modelled national emissions in the year 2020 (in brackets: percentage changes [12] and reductions as compared to the baseline)

Scenario	Parameters changed *			Animals produced		CH4 emission rates (enteric)		CH_4 emission rates (manure management)		NH_3 emission rates		N_2O emission rates		NO emission rates		GHG emission rates, present *GWP* **		GHG emission rates, future *GWP* **	
	HC	WG	NP	10^6 animals a^{-1}		Gg a^{-1} CH_4		Gg a^{-1} CH_4		Gg a^{-1} NH_3		Gg a^{-1} N_2O		Gg a^{-1} CO_2-eq		Gg a^{-1} CO_2-eq			
Baseline				40.6		14.7		63.5		80.6		4.48		3,63		3032		3291	
A	X			40.6	(0.0)	13.8	(-5.9)	59.8	(-5.9)	71.4	(-11.5)	4.03	(-10.0)	3.28	(-9.5)	2796	(-7.8)	3042	(-7.6)
B	X	X		47.6	(17.4)	15.1	(2.9)	65.3	(2.9)	74.0	(-8.2)	4.25	(-5.3)	3.48	(-4.1)	3006	(-0.9)	3277	(-0.4)
C	X		X	41.6	(2.7)	14.2	(-3.4)	61.3	(-3.4)	73.3	(-9.1)	4.14	(-7.6)	3.37	(-7.0)	2870	(-5.3)	3123	(-5.1)
D	X	X	X	48.9	(20.5)	15.5	(5.7)	67.1	(5.7)	76.0	(-5.8)	4.36	(-2.8)	3.57	(-1.6)	3087	(1.8)	3365	(2.2)

* HC: herd composition (shift from borrows to boars); WG weight gain; NP: number of animal places
** see footnote 13

7 Discussion and conclusions

Excretion and emission rates per individual fattening pig as listed in Tables 6 and 7 clearly show that the changes in excretion and emission are affected by feed intake rather than the body composition. These results show that if the change in gender composition occurred without changes in the production system there would be a significant reduction in the emissions of both GHG and NH_3. However, the simultaneous changes expected in the production system as reflected in scenario D are likely to counteract these changes.

The future **number of animals produced** will increase by more than 20 % between 2010 and 2020 (scenario D)., with the major contribution being the improved performance (i. e. increased weight gains resulting in increased numbers of animals produced per place and year, scenario B) rather than the projected increase in animal places (scenario C).

In comparison to the number of animals produced, the increase in emission rates for **CH_4** is low (scenario D: 5.7 % for both enteric and manure management emissions). The effect of the shift from barrows to boars (scenario A) is clearly visible. Increased weight gains and increased numbers of animal places reduce this effect. As a result, future changes in pork production are unlikely to be beneficial to CH_4 emission reductions.

For **NH_3**, a considerable emission reduction can be achieved by replacing barrows with boars despite the increased numbers of animals produced. Likewise, the emissions of **N_2O** and **NO** will be reduced, albeit less than NH_3 and with different percentages. For N_2O, both direct and indirect emissions are considered. NO emissions originate directly from manure management and N applied to soils. Hence, their reduction potentials are different.

Overall **greenhouse gas** (GHG) emissions (calculated from CH_4 and N_2O emissions using the global warming potentials, *GWP*, see footnote [13] are also affected. They are clearly reduced in Scenario A. With increased numbers of animals produced, the reductions in N_2O emissions only partly compensate the effect of increased CH_4 emissions.

The emission rates calculated for the baseline differ from those published in Rösemann et al. (2013). The calculations for this paper make use of simplifying assumptions without regional differentiation of weights, weight gains, manure management systems and service times. Furthermore an updated emission factor for CH_4 from enteric fermentation was applied.

With respect to national totals of GHG emissions (in the order of magnitude of 1 million Gg a^{-1} CO_2-eq; UBA, 2012a), the changes in fattening pig production have little effect. However, the reduction of 4 to 5 Gg a^{-1} NH_3 as compared to the national total of about 550 Gg a^{-1} NH_3 (UBA, 2012b) is likely to be a most welcome contribution to the mitigation of agricultural NH_3 emissions – a reduction obtained without additional costs!

The results obtained in this work indicate that the shift from barrow to boar production has significant impact on NH_3 emissions. However, the assessment of the amounts of N retained is based on a German data set is poorly documented. That should lead to an evaluation of data and methods that include the progress in animal breeding with respect to changes in carcass composition.

[12] The percentage change is calculated as follows:

$$R_X = \frac{E_{X,\,pig\_scen}}{E_{X,\,pig\_base}} \cdot 100 - 100$$

where

R_X change of the emission rate of X from future pigs (pigs 2020) as compared to the baseline (pigs 2010) (in %)
$E_{X,\,pig\_scen}$ emission rate of X from future pigs (scenario) (in kg $animal^{-1}$ X)
$E_{X,\,pig\_base}$ emission rate of X from present pigs (baseline) (in kg $animal^{-1}$ X)

[13] GWP_{CH4} of 21 and GWP_{N2O} of 310 kg kg^{-1} CO2-eq to be used in the present emission reporting according to IPCC (1996); GWP_{CH4} of 25 and GWP_{N2O} of 298 kg kg^{-1} CO_2-eq as in the IPCC Fourth Assessment report to be used in future (IPCC, 2007)

It is recommended that the changes in the herd composition of fattening pigs from gilts and barrows to gilts and boars be included in emission reporting.

Irrespective of any these changes in herds or carcass composition, likely changes in the production system should be included in the emission projections.

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