RESEARCH ARTICLE

Pork production in Thuringia – management effects on ammonia and greenhouse gas emissions. 2. Reduction potentials and projections

Ulrich Dämmgen[1], Wilfried Brade[2], Hans-Dieter Haenel[1], Claus Rösemann[1], Heinrich Kleine Klausing[3], J. Webb[4], and Andreas Berk[5]

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HIGHLIGHTS

- **Analysis of the mass flows within the entire pork production chain reveals several minor emission reduction potentials for ammonia**
- **Diets with reduced protein content improve health and reduce ammonia emissions significantly without additional costs**

KEYWORDS **pork production, ammonia, greenhouse gases, area under cultivation, fertilising, energy, water**

Abstract

Measures to reduce emissions from pork production have been evaluated for fattening pigs in Thuringia, where fattening dominates emissions. Next, an expert team provided data sets for emission scenarios for the entire pork production chain (including breeding, piglet production, fattening as well as feed production, fertiliser use and production, provision of water and energy) in 2020 and 2025.

Moderate increases in performance and reduction of animal losses had almost no effect. Substantial emission reductions were found for feeds with reduced protein contents, filtering exhaust air from buildings through scrubbers and reduced emission slurry application procedures. Manure systems using solid farmyard manure emit greater quantities than slurry based systems.

A combination of the measures anticipated for 2025 in a comprehensive (fictive) reference enterprise could result in a NH_3 emission reduction by about one fifth as compared to 2015. A minor reduction of greenhouse gas emissions is a welcome side effect.

1 Introduction

Compared with other German regions, pork production in Thuringia (Thüringen) is characterised by a low livestock density (expressed as pigs per unit of productive land). Major changes occurred due to the restructuring of agricultural production after the German unification. Currently about 750.000 animal places with about 320.000 fattening places can be regarded as standard (StatBA, 2017).

During the past two decades, numerous new livestock buildings have been erected that comply with the regulations on best available techniques, including measures to reduce environmental pollution. Thuringian production units are larger than the German mean (StatBA, 2017) which contributes to the competitiveness of its respective enterprises. Hence, pork production will have a promising future within Thuringian agricultural production.

However, pork production will have to adapt to restrictions imposed by German and European legislation on atmospheric emissions and ground water pollution, such as EU (2016) or the Thuringian enactment on air scrubbers (TMfUEN, 2016). At present, German administrations are reluctant to enforce these regulations. For agriculture, the overall nitrogen

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[1] Johann Heinrich von Thünen Institute, Institute for Climate-Smart Agriculture, Germany
[2] Norddeutsches Tierzucht-Beratungsbüro, Germany
[3] Gesellschaft für Tierernährung mbH, Germany
[4] University of Wolverhampton, Faculty of Science and Engineering, United Kingdom
[5] Friedrich Loeffler Institute, Institute of Animal Nutrition, Federal Research Institute for Animal Health, Germany
CONTACT ulrich.daemmgen@daemmgen.de

problem (eutrophication and acidification of ecosystems, nitrate pollution of drinking water sources) will remain of immense importance. If a reduction of livestock numbers is to be avoided, these ambitious emission reduction goals can only be achieved by introduction of greatly advanced techniques not only in livestock husbandry itself, but also in feed production and the provision of water and energy.

Pork production is a complicated multi-stage process. Earlier investigations showed that the entire production chain has to be analysed in order to identify and assess reduction potentials (e.g. Dämmgen et al., 2016). The preceding paper (Dämmgen et al., 2018a) elucidated that in pork production ammonia (NH_3) from livestock buildings and from feed production has to be addressed with priority. In comparison, emission reductions of greenhouse gases (GHG) from pork production are minor. However, their reduction is a welcome side effect.

This paper reports a detailed systematic analysis of those factors that are related to herd management, with a clear emphasis on fattening. Productive lifetime and fertility of sows were the subject of a separate paper (Dämmgen et al., 2018b). Estimates of future emissions related to pork were estimated using information provided by a Thuringian expert team.[6]

2 Methods

Investigations make use of a fictive 'reference enterprise' which comprises the fattening of pigs, raising of piglets and weaners, basic production (boars) and pure breeding (altogether named 'the herd') as well as production of feed and fertilisers and the provision of water and energy.

2.1 The herd

1,000 pigs (30 to 122 kg pig^{-1}) are fattened at a time (all in all out). Piglet production supplies the right number of piglets at the right time with the necessary number of sows (as a function of the number of piglets weaned per sow). Basic production and pure breeding are taken into account to provide the sows and breeding boars.

As a whole, the example of a comprehensive pork production enterprise reflects the mean Thuringian situation. For details see section 4.2 and Dämmgen et al. (2018b).

2.2 Emission modelling

The quantification of emissions relies on mass flow modelling. Internationally accepted methods (EMEP, 2016; IPCC, 2006) are used to generate comparable results. In addition, national approaches deal with the determination of livestock excretion rates as a function of livestock performance and feed properties. For German pork production these can be found in Haenel et al. (2011) and Dämmgen et al. (2011, 2012, 2017). The work at hand makes use of many data describing non-agricultural processes. Data and methods were described in Dämmgen et al. (2016). The Thuringian data set used was described in detail in the first paper of this series (Dämmgen et al., 2018a).

3 Identifying and assessing reduction potentials – a systematic analysis

The rearing of fattening pigs (fattening hybrids) dominates both NH_3 and GHG emissions in Thuringia (Dämmgen et al., 2018b). Hence, the following detailed examination of reduction potentials is restricted to fattening, including the related direct emissions from feed and fertiliser production as well as indirect emissions resulting from the deposition of reactive N species emitted during this part of the entire production chain. It should be kept in mind that any reduction in NH_3 emissions results in reduced requirements for N fertilisers, and thus at the same time in less emissions from fertiliser production and application.

Reduction potentials are discussed for each single aspect of the production process. They are then compared with the respective projections made by the Thuringian expert team for 2020 and 2025. Drawings contain the absolute emissions for the entire herd of fattening pigs (fp-herd) and the emissions per unit of carcass produced.

3.1 Assumptions for a baseline

Assumptions are similar to the state of pork production in Thuringia in 2015 using statistically available data for animal performance and losses, as well as information provided by the expert panel. However, figures are rounded, and numbers of options are reduced (e.g. for feed, housing, spreading and incorporation).

Animal performance:
- daily weight gain 845 g pig^{-1} d^{-1}, start weight 30 kg pig^{-1}, final weight 122 kg pig^{-1}, carcass dressing percentage 79 %

Animal losses:
- 4 % of fattening pigs housed initially

Feed:
- standard feed only

Housing:
- fully slatted floor only, no exhaust air scrubbers

Storage:
- conventional round tank without cover or natural crust, no fermentation for biogas

Slurry spreading and incorporation:
- trailing hose only; 50 % to bare soil, incorporation within 4 h, rest to short vegetation

N lost to surface and ground waters:
- 5 % of the amount actually available

3.2 Structure of figures

Figures 1 to 10 show the effect of systematic changes of input parameters, such as weight gain, on the left hand side, and the emissions resulting from the mix of parameters for 2015, 2020 and 2025 on the right hand side. The situation for 2015 is *not* the baseline.

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[6] Thuringian State Institute for Agriculture (TLL), Germany: Thomas Bauer, Simone Müller, Jürgen Müller, Gerd Reinhold, Hubert Schröter, Wilfried Zorn. Thuringian Ministry for Infrastructure and Agriculture: Michael Mußlick. Qnetics GmbH: Brigitte Neues

3.3 Effects of animal performance

Usually, enhanced performance and reduced final weights help reduce product related emissions. Cumulative energy requirements and thus feed intake rates increase with decreasing daily weight gains, as the requirements for maintenance (energy, nutrients) increase. This affects emissions, as can be seen from *Figures 1* and *2* (left columns: weight gains in g pig^{-1} d^{-1}, right columns projections for 2015, 2020 and 2025 as in Table 1). The Thuringian expert team expect a very limited increase of daily weight gains in the coming decade. The present final weights remain unchanged.

TABLE 1

Animal performance as proposed by the expert team

performance parameter	unit	year		
		2015	2020	2025
daily weight gain	g pig^{-1} d^{-1}	845	845	850
final live weight	kg pig^{-1}	122	122	122

Table 1 summarizes the assumptions with respect to the development of animal performance.

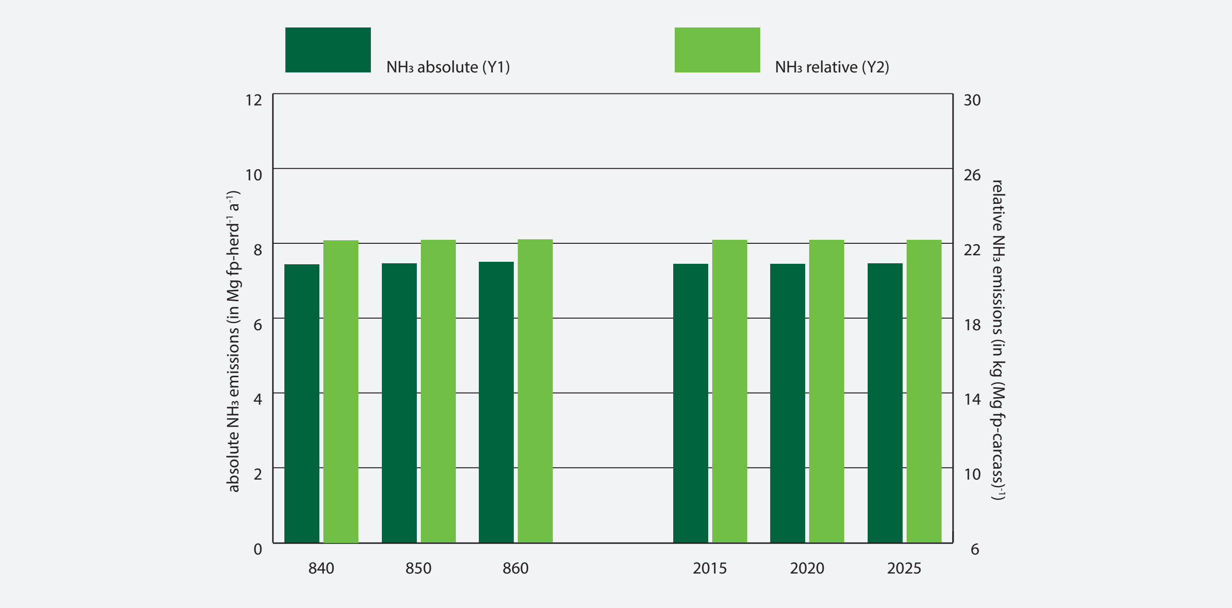

FIGURE 1

Impact of varying daily weight gain on NH$_3$ emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy)

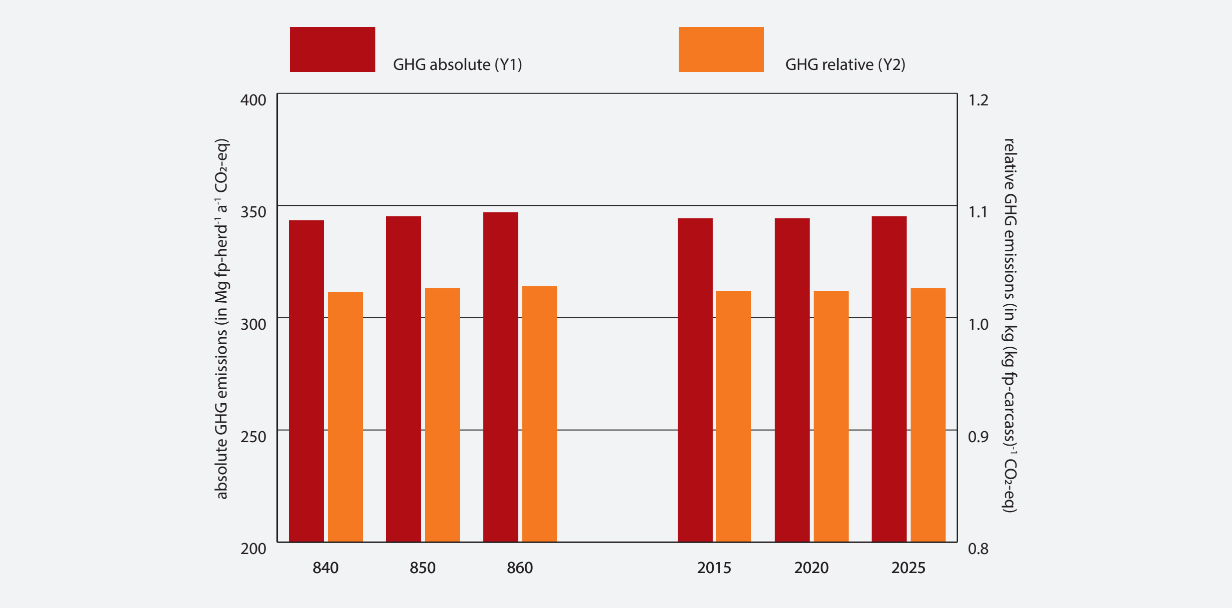

FIGURE 2

Impact of varying daily weight gain on GHG emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy)

The minor changes in animal weight gains have no visible effect on emissions of NH_3 or GHG. Higher daily weight gains result in reduced cumulative energy requirements for maintenance, hence less feed and less excretions. They also result in increased number of animal rounds and thus increased carcass weights per place and year.

Absolute emissions increase slightly whereas relative emissions decrease. Overall emission reductions due to the reduced emission per animal produced are partly compensated by the effect of increased number of animal rounds per year.

Minor changes in daily weight gain can be ruled out as effective measures in emission reduction.

3.4 Effects of animal health

Improved animal health and welfare result in decreased losses of animals whose carcasses cannot be marketed. Our calculations differentiate between those pigs that can be sold at the end of their lives, and those that go to the knacker's yard. For the latter we assume that they have to be fed until half way through their intended lifespan, as we presuppose stochastic deaths over the production period.

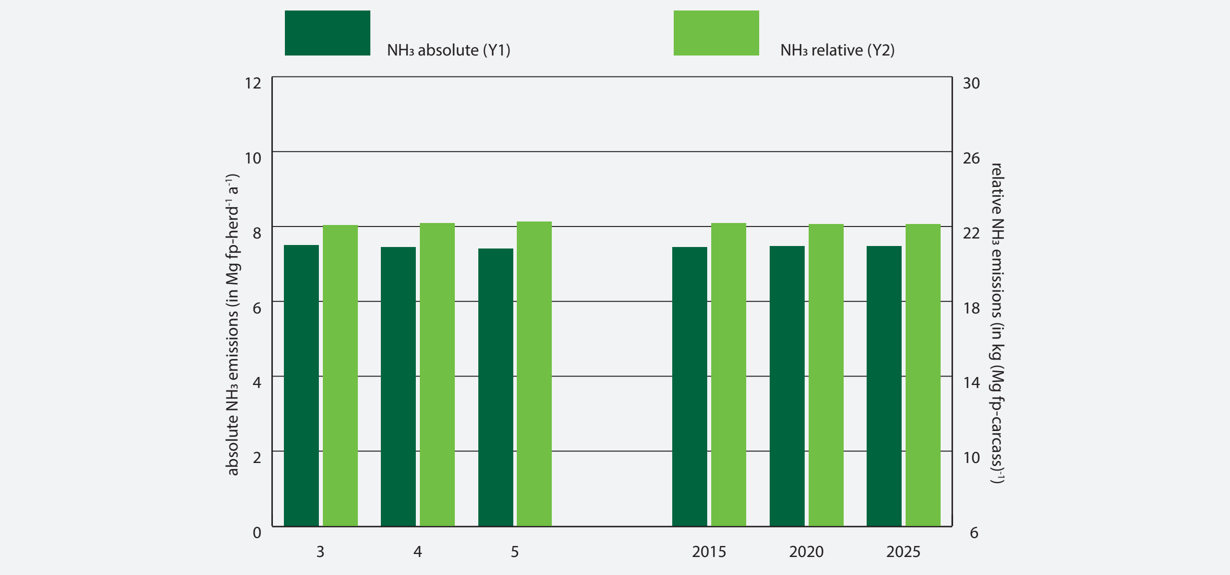

FIGURE 3

Impact of animal losses on NH_3 emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy). Left columns: animal losses in %, right columns projections for 2015, 2020 and 2025 as in Table 2

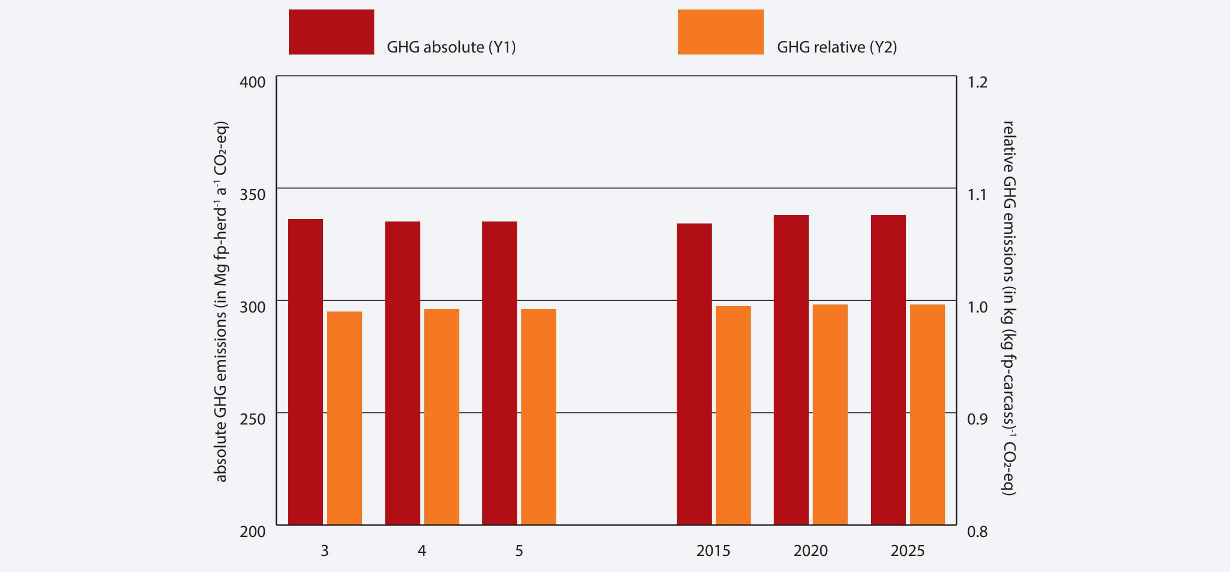

FIGURE 4

Impact of animal losses on GHG emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy). Left columns: animal losses in %, right columns projections for 2015, 2020 and 2025 as in Table 2

TABLE 2
Animal losses proposed by the expert team

loss parameter	unit	year		
		2015	2020	2025
losses of fatteners	% *	4.0	3.5	3.5
* of pigs housed initially				

Figures 3 and *4* indicate that absolute emissions decrease with increasing losses; less animals have to be fed to the end of their lives. However, relative emissions increase with increasing losses, again due to the decreasing number of useful carcasses.

Small improvements of animal welfare and health have no noticeable effect on emissions.

3.5 Effects of feed composition

At present standard feed and N P reduced feeds are taken into consideration. The use of a special feed improving animal welfare ('Gesundfutter') with reduced protein contents and increased amounts of fibre has been discussed. However, no projections could be made with respect to its use.

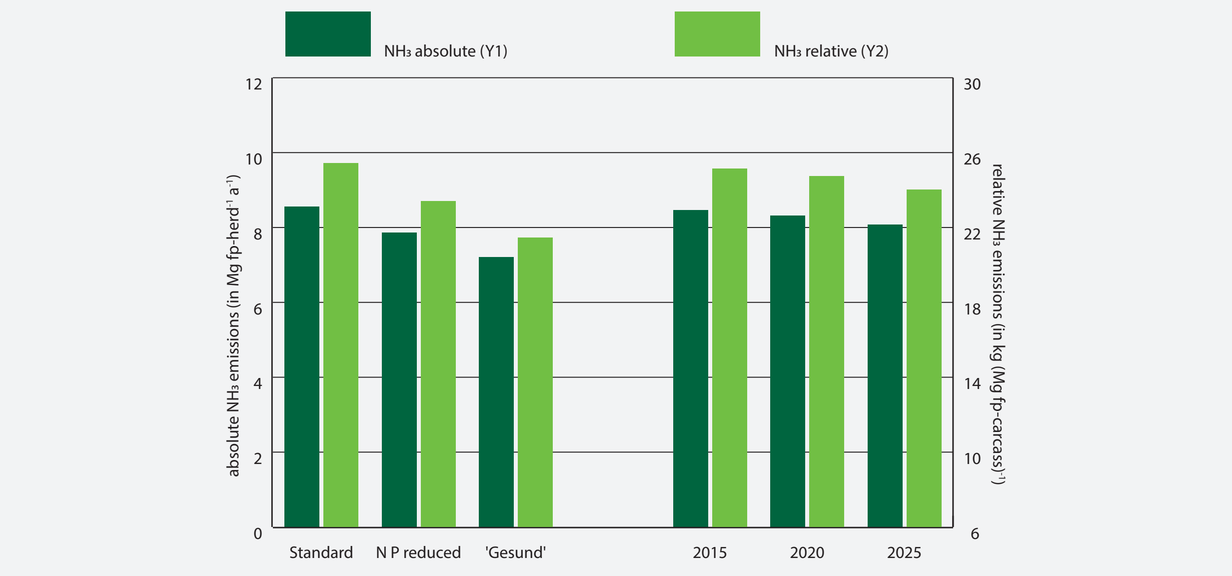

FIGURE 5
Impact of varying feed on NH_3 emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy). Left: 100 % of respective feed, right: proportions of standard and N P reduced feed for 2015, 2020 and 2025 as in Table 3

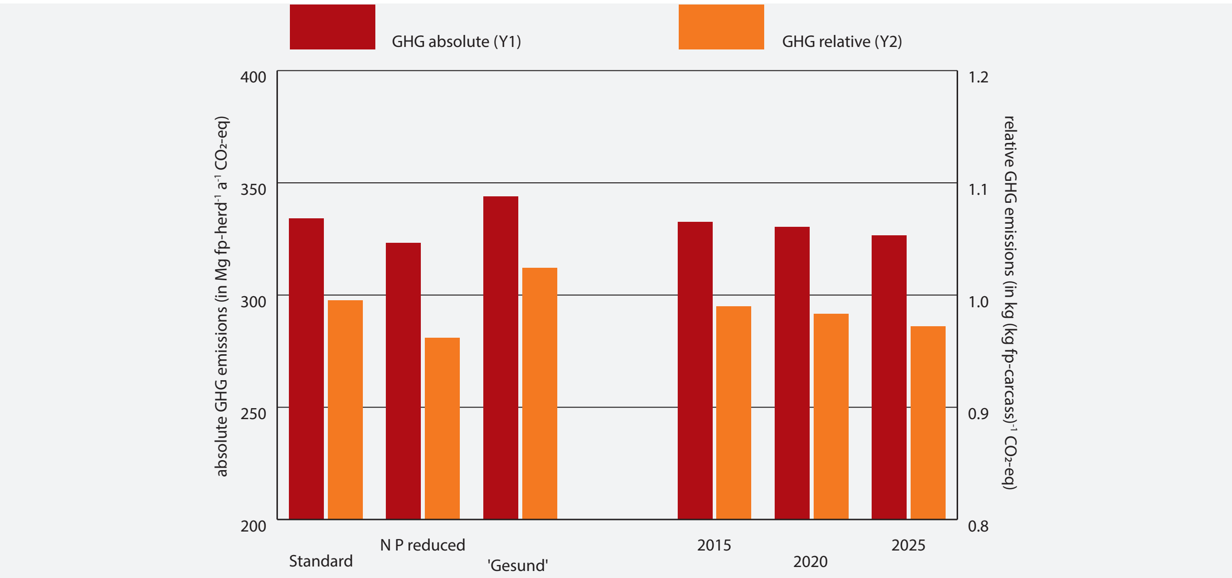

FIGURE 6
Impact of varying feed on GHG emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy). Left: 100 % of respective feed, right: proportions of standard and N P reduced feed for 2015, 2020 and 2025 as in Table 3

TABLE 3

Feeding of fatteners as proposed by the expert team

feed	unit	year		
		2015	2020	2025
standard	% of pigs fed	85	65	30
N P reduced	% of pigs fed	15	35	70

With less crude protein in the diet[7], feeding N P reduced and healthy ('Gesund') diets yield considerable reductions in NH_3 emissions from manure management and from fertiliser application and production occur. Also the fibre rich 'Gesund' diet leads to increased CH_4 emissions from enteric fermentation and from storage (*Figures 5* and *6*).

The reduction of emissions with increasing shares of N P reduced feed is obvious. (NH_3 N P reduced 8 %, 'Gesund' 16 %; GHG N P reduced 3 %, 'Gesund' – 1 %, as compared to standard, absolute and relative reductions).

Changing to feeds with reduced protein contents is definitely a useful tool for NH_3 reduction and is likely to be applied in future.

3.6 Effects of housing

Fully slatted floors have been state of the art for decades. However, they are considered inferior with respect to animal health. Partially slatted floors are assumed to be more animal friendly. Different emission factors were used for both types, assuming a reduction of 20 % for partially slatted floors (judgement of the expert team, based on a literature review described in Dämmgen et al., 2018c, Annex 5.4.) The overall frequency of partially slatted floors is assumed to be constant.

For the same reason, fatteners should have more space than provided at present. This will result in larger soiled areas and increased NH_3 emissions. (The expert team assumes 25 % more emissions than 'normal' partially slatted floors on extended partially slatted floors. For details of this decision we refer to Dämmgen et al., 2018c, Annex 5.4). However, no assumptions could be made for their future frequency.

A small proportion of pigs are kept in straw based systems, mainly in organic pork production. Their share is assumed to increase slightly.

Air scrubbers are to be installed in bigger livestock buildings (> 1500 places for fatteners, > 560 places for sows and > 4500 places for weaners (TMfUEN, 2016)). An efficiency of 80 % for NH_3 reduction was used in this study (Dämmgen et al., 2010).

TABLE 4

Housing of fatteners as proposed by the expert team

housing	unit	year		
		2015	2020	2025
fully slatted floors	% of places	65	64	63
partially slatted floors	% of places	30	30	30
plane floor with bedding	% of places	5	6	7
air scrubbers	% of places	18	30	60

For NH_3 and GHG, partially slatted floors reduce absolute emissions by 11 and 2 % respectively, as related to fully slatted floors. However, smaller emissions in the building increase the emission potential in the subsequent processes. The use of farmyard manure (FYM) reduces GHG emissions by 4 %,

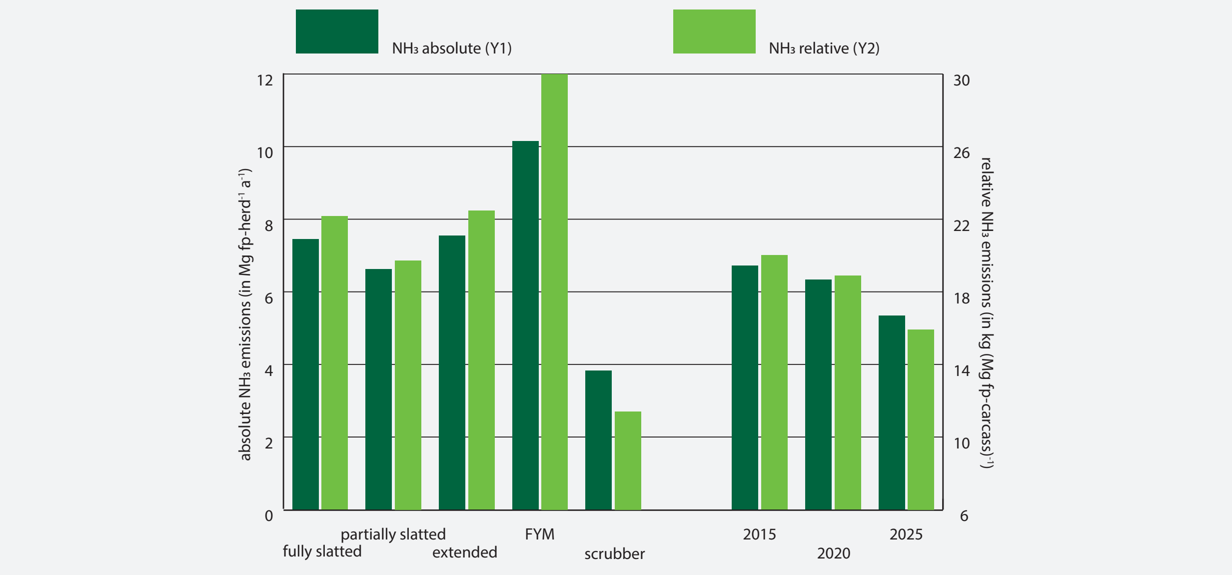

FIGURE 7

Impact of housing systems on NH_3 emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy). Left columns: frequency 100 %, respectively (FYM: farmyard manure), right columns with proportions of housing systems for 2015, 2020 and 2025 as in Table 4

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[7] Three phase feeding with crude protein contents in standard feed: 175, 165 and 155 g kg^{-1}, in N P reduced feed: 170, 150, and 140 g kg^{-1}, in 'Gesund' feed 155, 145 and 140 g kg^{-1} for feeding stages 1, 2 and 3, respectively.

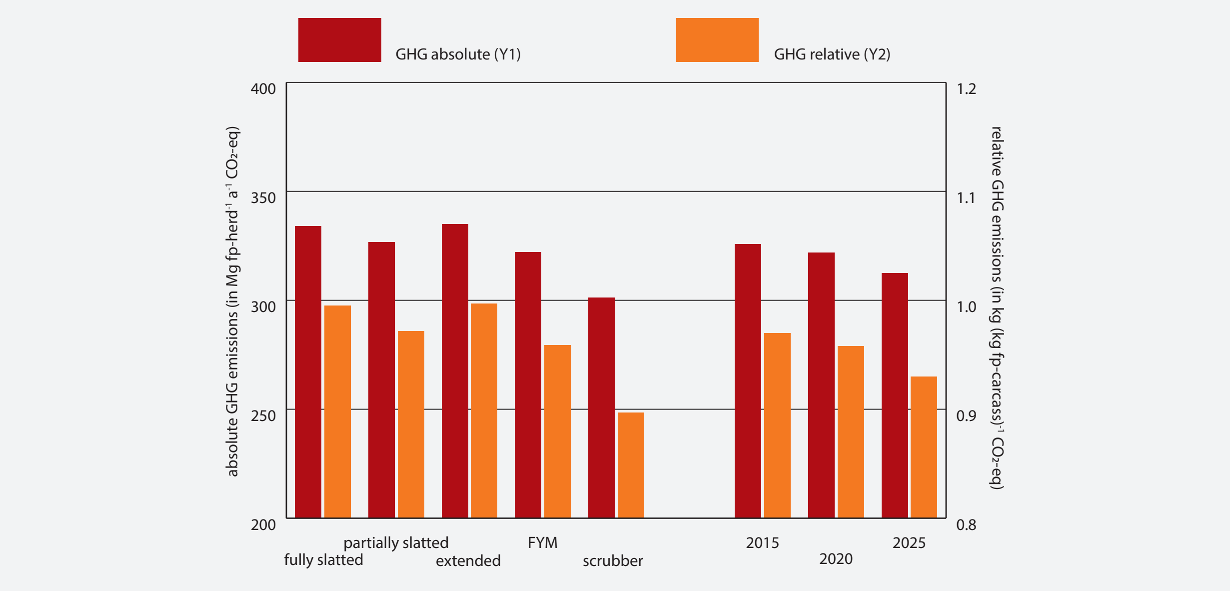

FIGURE 8
Impact of housing systems on GHG emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy). Left columns: frequency 100 %, respectively (FYM: farmyard manure), right columns with proportions of housing systems for 2015, 2020 and 2025 as in Table 4

but increases NH_3 emissions by 36 %. Scrubbers remove N from the system which reduces emissions from the house; the scrubbed N is fed into the slurry system immediately before spreading (see *Figures 7* and *8*.)

The projections for 2020 and 2025 reflect the increase in animal places equipped with active scrubbers.

If fully slatted floors are replaced by partially slatted floors, a considerable emission reduction can be achieved for NH_3. Scrubbers are a very effective (and expensive) means of NH_3 reduction. It is likely that this option is used in future.

3.7 Effects of storage

In Thuringia most slurry is stored in tanks covered with granules wherever slurry is not fermented in biogas plants. Tanks covered with plastic film have the same emission factor as covering with granules.

The expert team agreed that no changes can be anticipated at present. No projections were available for future shares of biogas installations (see *Table 5*). Calculations used the 2015 data for 2020 and 2025.

Changes in storage systems from the prevailing stores covered with granules are not meaningful. The reduction obtained by using solid covers is expensive and results in just a few percents reduction. Obviously fermentation producing biogas is the option to strive for with respect to GHG emissions. For NH_3, the net mineralization of slurry N increases the TAN[8] content of biogas slurry. The fermentation also results in an increased pH, and thus in an increased NH_3 vapour pressure (see *Figures 9* and *10*.)

TABLE 5
Storage of pig slurry as proposed by the expert team

storage facility	unit	year		
		2015	2020	2025
conventional tank without cover	% of slurry N	0	0	0
conventional tank, granules	% of slurry N	100	100	100
conventional tank, floating plastic film	% of slurry N	0	0	0
biogas tanks (gas tight)	% of slurry N	38	no estimate	no estimate

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[8] TAN: total ammoniacal nitrogen, N in urine

FIGURE 9
Impact of varying storage system on NH_3 emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy). Left columns: frequency of covers or biogas 100 %, respectively, right columns with proportions of storage system for 2015, 2020 and 2025 as in Table 5

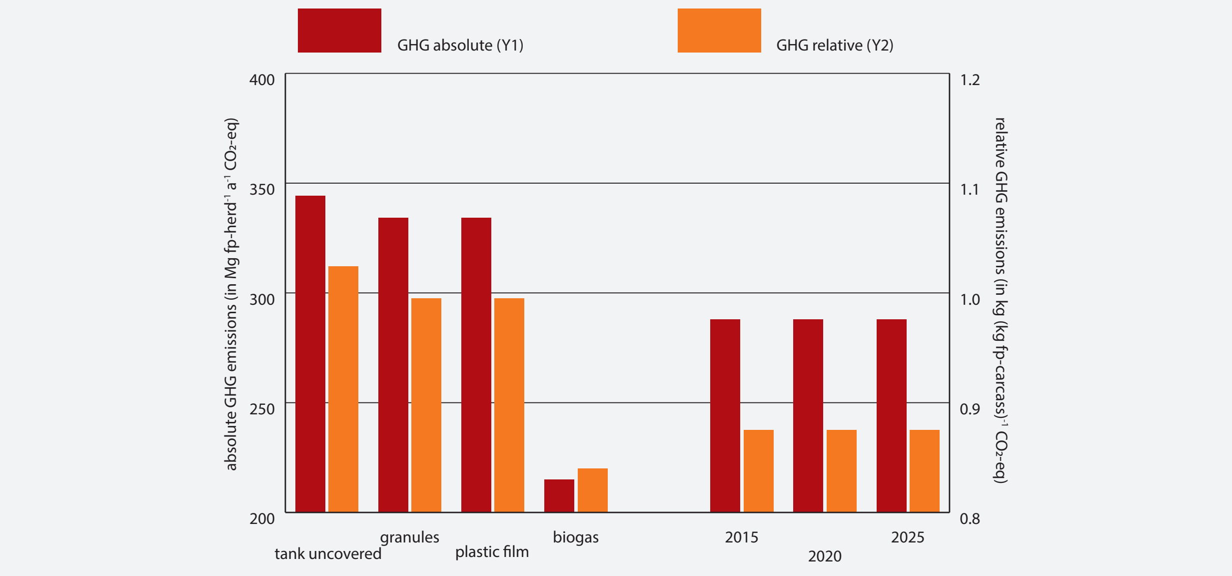

FIGURE 10
Impact varying housing system on GHG emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy). Left columns: frequency of covers or biogas 100 %, respectively, right columns with proportions of storage system for 2015, 2020 and 2025 as in Table 5

3.8 Effects of application techniques and time before incorporation of slurry

For NH_3 emissions, the surface of slurry exposed to the atmosphere controls the speed with which NH_3 is emitted per unit of area. The second important parameter is the duration of exposure.

Emission reduction aims at optimising both parameters. Injection is almost free from emissions whereas the old-fashioned broadcast application without incorporation loses almost all NH_3 to the atmosphere. As shown in *Figures 11* and *12*, NH_3 emissions during and after application of slurry differ greatly with the technique and the times before incorporation. However, in this analysis the overall effect on emission reduction is smaller than expected, as only small quantities of N and TAN are left after housing and storage losses. GHG emissions are also affected. Reductions are calculated for emissions from plant production (less mineral fertiliser) and fertiliser production as well as for indirect emissions.

The experts expect only small future changes. Increased share of injection remains an option.

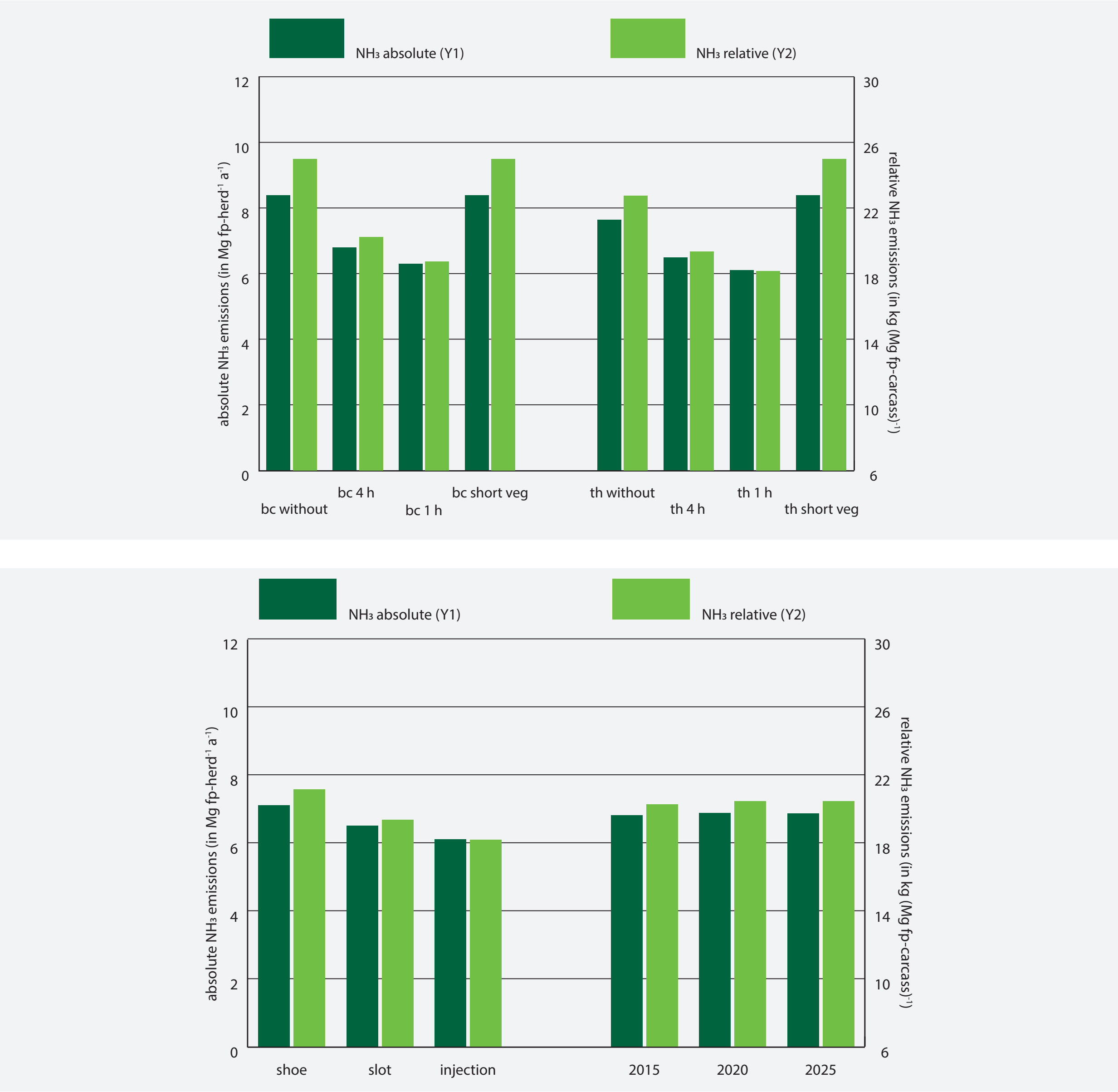

FIGURE 11

Impact of varying application techniques and speed of incorporation on NH_3 emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy).

Top: bc without: broadcast on bare soil without incorporation; bc 4 h: broadcast, incorporation within 4 h; bc 1 h: broadcast, incorporation within 1 h; bc short veg: broadcast on short vegetation, th: trailing hose

Bottom left: shoe: trailing shoe in short vegetation; slot: open slot;

bottom right: columns with proportions of application systems for 2015, 2020 and 2025 as in Tables 6 to 8

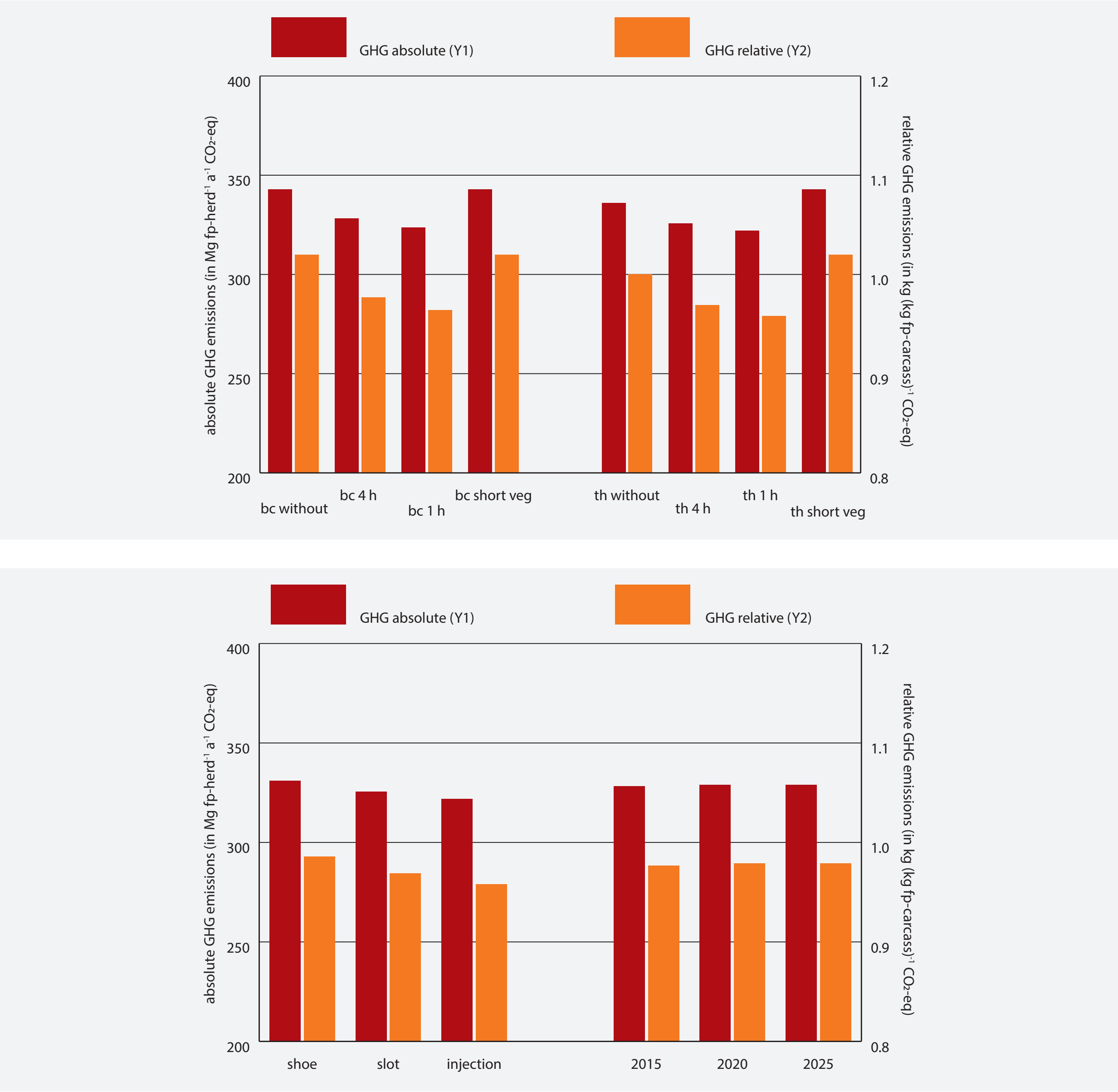

FIGURE 12

Impact of varying application techniques and speed of incorporation on GHG emissions from the herd of fattening pigs (including emissions from feed and fertiliser production, provision of water and energy).

Top: bc without: broadcast on bare soil without incorporation; bc 4 h: broadcast, incorporation within 4 h; bc 1 h: broadcast, incorporation within 1 h; bc short veg: broadcast on short vegetation, th: trailing hose

Bottom left: shoe: trailing shoe in short vegetation; slot: open slot;

bottom right: columns with proportions of application systems for 2015, 2020 and 2025 as in Tables 6 to 8

TABLE 6
Slurry application 1. Broadcast

location and incorporation	unit	year		
		2015	2020	2025
bare soil or stubbles, without incorporation	% of slurry N	0.0	0.0	0.0
bare soil or stubbles, incorporation within ≤ 1 h	% of slurry N	2.5	0.0	0.0
bare soil or stubbles, incorporation within ≤ 4 h	% of slurry N	1.9	0.0	0.0
short vegetation	% of slurry N	2.6	0.0	0.0
subtotal	% of slurry N	7.0	0.0	0.0

TABLE 7
Slurry application 2. Techniques with reduced emission

technique, location and incorporation	unit	year		
		2015	2020	2025
trailing hose				
bare soil, stubbles, without incorporation	% of slurry N	0	0	0
" , incorporation ≤ 1 h	% of slurry N	9	10	10
" , incorporation ≤ 4 h	% of slurry N	6	5	4
short vegetation	% of slurry N	24	30	30
trailing shoe	% of slurry N	1	2	2
open slot	% of slurry N	10	10	10
injection	% of slurry N	43	43	44
subtotal	% of slurry N	93	100	100

TABLE 8
FYM application, broadcast

location and incorporation	unit	year		
		2015	2020	2025
without incorporation	% of FYM N	60	50	40
bare soil, stubbles, incorporation ≤ 4 h	% of FYM N	10	10	10
bare soil, stubbles, incorporation ≤ 8 h	% of FYM N	30	40	50

3.9 Assessment of reduction potentials for fattening pigs

Some of the emission reduction potentials in single links of the production chain discussed above are promising, in particular for diet design in feeding, for the livestock building and for storage. Changing feed properties is a low or even no cost option. The equipment of livestock buildings with scrubbers is legally binding. There is no doubt that the other measures are at least partly feasible, although some of them will mean investments that restrict them to newly built livestock buildings or substantial refurbishments. Subsidies are likely to play a crucial role.

On the other hand, any new livestock building will be built according to modern standards. The experts' estimation is conservative in assuming that new houses are an unlikely option at present.

However, all single measures discussed above add up to considerable overall reductions. *Figure 13* illustrates the results, showing a reduction of almost 26 % for NH_3 and about 6 % for GHG for fattening pigs (absolute values).

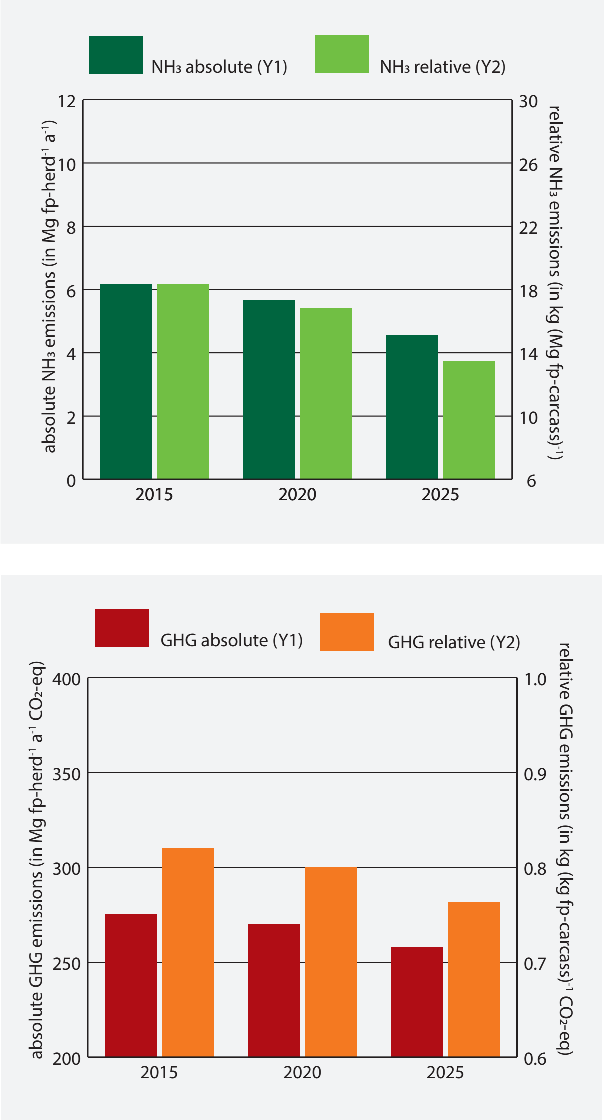

FIGURE 13
NH_3 and GHG emissions taking into account the 2015 data set and the expert projections for 2020 and 2025, fattening pigs only

4 Emission reduction in Thuringian pork production as anticipated for 2020 and 2025

In the following evaluations the scope is widened and covers all emissions from the entire production chain.

4.1 Assumptions

The assumptions of the expert team with respect to fattening pigs are listed in the tables above.

4.1.1 Piglet production

Weaners in piglet production (8 to 30 kg weaner^{-1}, *Table 9*) are kept on flat decks. The properties and composition of feeds used in their 3-stage diet are listed in Dämmgen et al. (2018a).

TABLE 9
Daily weight gains and animal losses of weaners as proposed by the expert team

parameter	unit	year		
		2015	2020	2025
daily weight gain	g weaner^{-1} d^{-1}	428	440	455
losses	% of weaners housed initially	2	2	2

Breeding sows: No expert judgement could be obtained for the frequency of housing system for sows. Our calculations suppose that all are kept in slurry based houses. Feeding differentiates between lactating and gestating animals (for properties and composition of the feeds see Dämmgen et al., 2018b). Animal weights are taken into account (see *Table 10* and Dämmgen et al., 2018a). The number of piglets weaned and the share of losses are treated as variables (*Tables 11* and *12*). The fraction of stillborn piglets is constant and assumed to be 5 %.

TABLE 10
Animal weights at the beginning and the end of a production cycle (Dämmgen et al., 2018a)

live weight	unit	litter number							
		1	2	3	4	5	6	7	8
beginning of cycle	kg sow^{-1}	158	189	215	238	254	266	274	277
end of cycle	kg sow^{-1}	189	215	238	254	266	274	277	277

TABLE 11
Performance of breeding sows as proposed by the expert team

performance	unit	year		
		2015	2020	2025
piglets weaned (mean)	piglet sow^{-1}a^{-1}	28.1	29.9	29.9

TABLE 12
Piglet losses as proposed by the expert team

year	unit	litter number							
		1	2	3	4	5	6	7	8
2015	% of piglets born live	16	13	12	12	13	14	15	15
2020	% of piglets born live	16	13	12	12	13	14	15	15
2025	% of piglets born live	15	12	11	11	12	13	14	14

Young sows for breeding have a constant daily weight gain of 700 g sow^{-1} d^{-1}. Losses of 2 % are taken into account. Animals are raised on bedding and fed a special set of diets. Those suitable for breeding are fed to the start weight of breeding sows. The rest are slaughtered.

Barrows are fed standard diets as for fattening pigs. House and manure management reflect those of fattening pigs.

Weaners in basic production and pure breeding are fed the same diets as weaners for fattening. However, they are kept in bedded systems. Manure management is identical with that for young sows.

4.2 Results

4.2.1 Animal numbers and cumulative carcass weights

Changes in daily weight gains and losses for fatteners and weaners for fattening (*Tables 1, 2* and *9*), changes in the performance of sows as well as piglet losses result in changes for almost all livestock numbers (*Table 13*). Increased daily weight gains for fatteners lead to increased overall carcass weights. However, changes in emissions are almost negligible.

TABLE 13

Numbers of animals fed and cumulative carcass weights (rounded values)

animal category	number of animals fed animal herd^{-1} a^{-1}			carcass weight Mg herd^{-1} a^{-1}		
	2015	2020	2025	2015	2020	2025
fattening						
fattening pigs						
standard feed, slaughtered	2,340.9	1,799.5	834.9	286	220	102
standard feed, knackers	97.5	65.3	30.3			
N P reduced feed, slaughtered	413.1	968.4	1,948.1	50	118	238
N P reduced feed, knackers	17.2	35.1	70.7			
subtotal	*2,868.8*	*2,868.8*	*2,883.9*	*336*	*338*	*340*
weaners						
used for fattening	2,868.8	2,868.8	2,883.9			
knackers	57.4	57.4	57.7			
subtotal	2,926.2	2,926.2	2,941.6			
piglet production						
breeding sows	104.1	97.9	98.4	10.7	10.1	10.1
young sows fattened	68.7	64.5	64.9	1.2	1.1	1.1
barrows fattened	68.8	65.0	65.0	6.5	6.1	6.1
weaners	139.7	131.2	131.9			
subtotal				*18.4*	*17.3*	*17.3*
provision of boars for artificial insemination (AI boars)						
AI boars	0.2	0.2	0.2	0.0	0.0	0.0
teaser boars	0.5	0.5	0.5	0.0	0.0	0.0
young boars	1.8	1.6	1.7	0.1	0.1	0.1
sows fattened	1.8	1.6	1.7	0.2	0.2	0.2
weaners	3.5	3.3	3.3			
subtotal				*0.4*	*0.4*	*0.4*
pure breeding						
breeding sows	14.5	13.6	13.7	1.2	1.2	1.2
young sows	44.3	41.6	41.8			
surplus sows fattened	4.4	4.2	4.2	0.4	0.4	0.4
breeding boars	1.4	1.4	1.4	0.4	0.3	0.3
young boars	4.4	4.2	4.2			
barrows fattened	44.3	41.6	41.8	4.2	3.9	4.0
weaners	97.4	91.6	92.1			
subtotal				*6.2*	*5.9*	*6.0*
total				361	362	364

4.2.2 Emissions

Tables 14 to *16* collate emissions for the years 2015, 2020 and 2025, respectively. In order to improve clarity, the absolute totals and the carcass related emissions are listed in *Tables 17* and *18*. For some sources, emissions of GHG are not reported as N_2O, CH_4 or CO_2. Instead the overall figure is given and referred to as 'GHG' in *Tables 14* to *17*.

Tables 17 and *18* indicate that under the given assumptions a considerable emission reduction for NH_3 can be expected. Keeping in mind the importance of agricultural NH_3 emissions this is a major step forward and close to the target reduction of 29 % in 2030 (EU, 2016). The reduction of GHG is considered a welcome by-product.

TABLE 14

Overall emissions 2015 (values rounded)

emissions of	NH_3	N_2O	CH_4	CO_2	GHG*	total GHG
unit	kg herd^{-1} a^{-1}				Mg herd^{-1} a^{-1} CO_2-eq	
fattening						
fattening pigs	6,157	338	3,813	34,317	45.5	275.4
weaners	656	52	794	5,930	17.9	59.1
subtotal	*6,812*	*390*	*4,608*	*40,247*	*63.4*	*334.4*
piglet production						
breeding sows	977	141	680	3,668	32.9	95.6
young sows for breeding	141	12	33	930	3.1	8.6
surplus young sows fattened	31	2	4	126	0.7	1.6
barrows fattened	131	6	77	681	3.3	7.6
weaners	32	4	8	212	6.0	7.6
subtotal	*1,312*	*166*	*802*	*5,618*	*45.9*	*120.9*
provision of boars for artificial insemination (AI boars)						
AI boars	3	0	0	16	0.0	0.1
teaser boars	5	0	1	26	0.0	0.2
young boars	6	1	1	48	0.1	0.3
sows fattened	5	0	2	27	0.1	0.2
weaners	1	0	0	5	0.0	0.1
subtotal	*19*	*1*	*4*	*121*	*0.2*	*0.9*
pure breeding						
weaners	42	10	7	179	4.2	7.5
young boars	14	2	2	129	0.1	0.7
breeding boars	20	1	2	92	0.1	0.7
surplus barrows fattened	84	4	58	516	0.3	3.4
young sows	187	16	26	818	2.4	8.6
breeding sows	64	10	148	816	5.8	13.2
surplus sows fattened	24	1	6	53	0.0	0.6
subtotal	*434*	*43*	*250*	*2,603*	*12.9*	*34.7*

* Some sources do not report single GHGs (N_2O, CH_4, CO_2), but the respective sum. This column contains such emissions *reported* as GHG, whereas total GHG is the sum of the weighted emissions of CO_2 (global warming potential GWP 1 kg kg^{-1}), CH_4 (GWP 25 kg kg^{-1}), N_2O (GWP 298 kg kg^{-1}) and GHG (GWP 1 kg kg^{-1})

TABLE 15
Overall emissions anticipated for 2020 (values rounded)

emissions of	NH_3	N_2O	CH_4	CO_2	GHG	total GHG
unit	kg $herd^{-1}$ a^{-1}				Mg $herd^{-1}$ a^{-1} CO_2-eq	
fattening						
fattening pigs	5,673	333	3,797	31,205	45.3	270.3
weaners	640	51	786	5,865	17.6	58.3
subtotal	*6,313*	*385*	*4,583*	*37,070*	*62.9*	*328.6*
piglet production						
breeding sows	934	140	639	3,668	31.2	92.7
young sows for breeding	140	12	33	875	3.1	8.4
surplus young sows fattened	31	2	4	118	0.6	1.5
barrows fattened	120	5	76	639	3.3	7.4
weaners	32	4	8	200	6.0	7.6
subtotal	*1,258*	*164*	*761*	*5,500*	*44.1*	*117.5*
provision of boars for artificial insemination (AI boars)						
AI boars	3	0	0	16	0.0	0.1
teaser boars	5	0	1	26	0.0	0.2
young boars	6	1	1	48	0.1	0.4
sows fattened	4	0	2	25	0.1	0.2
weaners	1	0	0	5	0.0	0.1
subtotal	*18*	*2*	*4*	*119*	*0.2*	*1.0*
pure breeding						
weaners	34	3	6	167	3.9	5.2
young boars	13	1	2	121	0.1	0.7
breeding boars	20	1	2	87	0.1	0.7
surplus barrows fattened	86	4	57	485	0.3	3.3
young sows	177	15	25	769	2.3	8.1
breeding sows	63	9	144	801	5.7	12.9
surplus sows fattened	24	1	6	50	0.0	0.6
subtotal	*417*	*35*	*242*	*248*	*12.4*	*31.4*

TABLE 16

Overall emissions anticipated for 2025

emissions of	NH_3	N_2O	CH_4	CO_2	GHG	total GHG
unit	kg herd^{-1} a^{-1}				Mg herd^{-1} a^{-1} CO_2-eq	
fattening						
fattening pigs	4,559	317	3,783	25,719	44.3	258.5
weaners	629	50	780	5,811	17.2	57.4
subtotal	*5,188*	*367*	*4,564*	*31,530*	*61.5*	*315.9*
piglet production						
breeding sows	917	140	643	3,643	31.3	92.8
young sows for breeding	140	12	33	879	3.1	8.4
surplus young sows fattened	32	2	4	119	0.6	1.6
barrows fattened	95	5	76	638	3.2	7.2
weaners	33	4	8	201	6.0	7.6
subtotal	*1,216*	*164*	*764*	*5,480*	*44.2*	*117.5*
provision of boars for artificial insemination (AI boars)						
AI boars	3	0	0	16	0.0	0.1
teaser boars	5	0	1	26	0.0	0.2
young boars	6	1	1	48	0.1	0.4
sows fattened	3	0	2	25	0.1	0.2
weaners	1	0	0	5	0.0	0.1
subtotal	*18*	*2*	*4*	*120*	*0.2*	*1.0*
pure breeding						
weaners	34	3	6	168	3.9	5.2
young boars	14	1	2	121	0.1	0.7
breeding boars	20	1	2	87	0.1	0.7
surplus barrows fattened	72	3	56	485	0.3	3.2
young sows	179	15	25	773	2.3	8.1
breeding sows	56	9	145	804	5.7	12.9
surplus sows fattened	23	1	6	50	0.0	0.5
subtotal	*397*	*35*	*242*	*2,489*	*12.4*	*31.3*

TABLE 17
Compilation of subtotals and totals

emissions of	NH_3	N_2O	CH_4	CO_2	GHG	total GHG
unit	kg herd^{-1} a^{-1}				Mg herd^{-1} a^{-1} CO_2-eq	
2015						
fattening	6,812	390	4,608	40,246	63	334
piglet production	1,312	166	802	5618	46	121
provision of boars	19	1	4	121	0	1
pure breeding	434	43	250	2,603	13	35
total	*8,577*	*600*	*5,664*	*48,588*	*122*	*491*
2020						
fattening	6,313	385	4,583	37,070	63	329
piglet production	1,258	164	761	5,500	44	118
provision of boars	18	2	4	119	0	1
pure breeding	417	35	242	2,479	12	31
total	*8,006*	*586*	*5,590*	*45,168*	*120*	*478*
% of 2015	93	98	99	93	98	97
2025						
fattening	5,188	367	4,564	31,530	62	316
piglet production	1,216	164	764	5,480	44	118
provision of boars	18	2	4	120	0	1
pure breeding	397	35	242	2,489	12	31
total	*6,819*	*567*	*5,574*	*39,619*	*118*	*466*
% of 2015	80	94	98	82	97	95

TABLE 18
Carcass related NH_3 and GHG emissions

gas	unit	year		
		2015	2020	2025
NH_3	kg (Mg carcass)$^{-1}$ NH_3	30.1	28.0	23.7
GHG	kg (kg carcass)$^{-1}$ CO_2-eq	1.72	1.67	1.62

5 Discussion

5.1 General remarks

Future agriculture will have to face a host of problems. However, agriculture is the vitally essential food producer. More people have to be fed from a shrinking agriculturally usable land area. An increasing demand for meat and milk reduces the overall efficiency of agricultural production, i.e. the ratio of output to input of energy. Restrictions are in force or planned that aim to reduce agriculture's impact on the environment and to improve animal health and welfare. The obvious solution to many constraints is an increase in plant and animal performance and increased efficiency in the use of resources. Improving performances in every link of the chain is indispensable, which applies to increased daily weight gains in particular.

This paper is to a large extent based on expert projections. One might call the experts' team's proposals cautious, conservative or even unambitious. It is definitively not describing maximum technical feasibility, but reflects the potential social feasibility in a densely populated area. And: agricultural enterprises have to be profitable. This work could provide a methodical tool to look for serious compromises and proposals to further improve the efficiency of pork production with reduced environmental impact.

5.2 Methods

Pork production is a complex process. Its description mainly reflects the energy needs of animals, coupled with the fluxes of nutrients and water. Energy is also used in the entire production chain. However, energy requirements other than in farm management such as for the construction of buildings and machines or for transport are not treated as variables in this paper.

The description of energy and matter fluxes also forms the base of emission reporting to the various international bodies. A complex way of interlinking the various calculation procedures provided there had to be found that was able to depict pork production in Thuringia correctly – at least in principle. Some models had to be improved or refined to achieve the tool needed to quantify and assess those emission reductions which are in the scope of the livestock farmer.

In most cases, the methods provided in the respective guidebooks are best approximations. In some cases they are 'rules of thumb'. However, it is better to use them than not to use them; they are at least internationally accepted tools.

5.3 Uncertainties

General remarks on the uncertainty of model calculations of emissions can be found in Part 1 of this work (Dämmgen et al., 2018a). The number of digits in the above tables does not reflect the uncertainty. It allows for an easy comparison of the emissions originating from the various animal categories.

5.4 Comparability and comparative data

As shown in the respective Chapter in Part 1 (Chapter 4.2), the results obtained in this work are in line with most other similar investigations. However, a direct intercomparison suffers from inadequate information on details. For example, this paper uses the official German recommendations for the application of mineral fertilisers. However, the basis for these recommendations has not been fully documented. For example, there is no mention of the impacts on atmospheric deposition of N and no adjustments in the recommendations according to the risks of run-off and leaching.

Furthermore, the Thuringian results for 2015, 2020 and 2025 illustrate the range of potential variations. This is what this paper wants to emphasize: changes to management practices in order to reduce emissions are feasible, and they are likely to be required in order to meet commitments to reduce emissions.

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