Energy requirements and excretion rates of pigs used for reproduction (young sows, young boars, breeding sows and boars) – a compilation and assessment of models

Ulrich Dämmgen*, Hans-Dieter Haenel*, Claus Rösemann*, Heinrich Kleine Klausing**, Jim Webb***, Wilfried Brade****, and Andreas Berk*****

Abstract

In many cases, the assessment of measures to reduce emissions presupposes the screening of the entire production chain, i.e. the fattening of animals, the upstream piglet and feed production including the provision of fertilizer, water and energy carriers.

This paper investigates how energy requirements as well as volatile solids and nitrogen excretions of animals in piglet production (young sows and boars as well as breeding sows and boars) can be described in as much detail as possible. Calculation procedures published in the literature are compared with those used in national emission reporting.

For young sows and boars, the procedures used in German emission reporting can be applied in a modified form, reflecting the animals' gender. The module for breeding sows can be used but has to be applied to each single reproduction cycle.

For breeding boars, their productive lifespan is the determining entity. The module described here allows for the variation of input parameters.

Keywords: *piglet production, breeding pigs, energy requirements, excretions*

Zusammenfassung

Energiebedarf und Ausscheidungsraten von Schweinen für die Zucht (Jungsauen und -eber, Zuchtsauen und -eber) – eine Zusammenstellung und Bewertung von Modellen

Die Bewertung von Maßnahmen zur Emissionsminderung setzt in vielen Fällen die Untersuchung der gesamten Produktionskette voraus, d. h. die Mast von Tieren, die vorgelagerte Ferkelproduktion und die Futtererzeugung einschließlich der Bereitstellung von Dünger, Wasser und Energieträgern.

Diese Arbeit untersucht, wie der Bedarf an umsetzbarer Energie und die Ausscheidungen von organischer Substanz und Stickstoff bei in der Ferkelproduktion zu findenden Tieren (Jungsauen und -eber sowie Zuchtsauen und -eber) möglichst detailliert beschrieben werden kann. Dazu werden in der Literatur beschriebene Berechnungsverfahren mit den in der Emissionsberichterstattung eingesetzten verglichen.

Für Jungsauen und -eber werden die in der deutschen Emissionsberichterstattung benutzten Verfahren in modifizierter Form (geschlechtsspezifisch) eingesetzt; das Sauenmodul der Emissionsberichterstattung wird übernommen, muss aber auf jeden einzelnen Reproduktionszyklus angewendet werden. Bei Zuchtebern ist die Nutzungsdauer das entscheidende Kriterium für Energiebedarf und Ausscheidungen. Das hier dargestellte Modul erlaubt es, Eingangsgrößen zu variieren.

Schlüsselwörter: *Ferkelproduktion, Zuchtschweine, Energiebedarf, Ausscheidungen*

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

** EW Nutrition GmbH, Hogenbögen 1, 49439 Visbek, Germany

*** Faculty of Science and Engineering, MI Building, City Campus - South Wulfruna St, Wolverhampton WV1 1LY, United Kingdom

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

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

Contact: ulrich.daemmgen@daemmgen.de

1 Introduction

Pork production is a major branch of German livestock husbandry. The overall production value of German agriculture is 52.6 bln Euro (DBV, 2015) of which about six bln Euro originate directly from pork production (BMEL, 2016). Pork production (in the strict sense: rearing and manure management, excluding the necessary feed production, fertilizer production and application, etc.) is also a major source of air pollution, in particular of ammonia (NH_3). 124 Gg a^{-1} NH_3 (data for 2014, Haenel et al., 2016) from pork production form a considerable portion of the 740 Gg a^{-1} emitted in Germany (UBA, 2016a). Greenhouse gas (GHG) emissions from enteric fermentation and manure management amount to 4.0 Tg a^{-1} CO_2-eq [1] (data for 2014, Haenel et al., 2016) which is a minor contribution to the overall national emissions of 902 Tg a^{-1} CO_2-eq (UBA, 2016b).

Efforts to identify approaches to emission reduction which leave production intact have to be preceded by a detailed analysis in order to identify and assess the emission reduction potentials along the entire production chain, i.e., the emissions from livestock husbandry (production of breeding animals, piglet production, fattening) as well as those emissions arising from feed production and the provision of energy and water. In pork production, about one third of the GHG emissions from the entire fattening pig production chain can be attributed to feed production and conditioning, fertilizer production and water and energy provision (Dämmgen et al., 2016).

For the purpose of emission reporting within the United Nations Framework Convention on Climate Change (UNFCCC, undated) and the European National Emission Ceilings Directive (EC, 2016), the description of four livestock categories is considered sufficient: weaners, fattening pigs, sows (including piglets up to a weight of 8 kg $piglet^{-1}$) and boars used for reproduction (Haenel et al., 2016). German statistics provide animal numbers which can be transformed so that these categories can be described adequately (Haenel et al., 2011a). For a detailed analysis of emission reduction potentials in pork production the descriptions of weaners and fattening pigs as in emission reporting can be used without additional modifications. However, some animal categories are not needed in the emission inventory, such as young sows and young boars used in sow production. The inventory established for emission reporting can adequately deal with "mean breeding sows". The analysis and the calculation of scenarios, however, will have to deal with varying numbers of litters per lifespan and varying live weights. For breeding boars, the inventory uses default data concerning their metabolizable energy (ME) and feed requirements. With respect to the small numbers of animals affected and the constraints of the availability of statistical data, this is sufficiently accurate (see Haenel et al., 2016, for an overview). However, a detailed analysis of breeding boars' properties and feed requirements remains desirable.

For an in-depth study of emission reduction potentials it is desirable not to use default parameters, but to take the effects of varied animal weights and weight gains or of an extended productive lifespan into account.

This paper includes scenarios of pork production. It has to be able to depict future developments as well as historic trends as pork production is a dynamic business (see Figure 1 as example). For further details on the genetics and breeding of highly fertile sows see e.g. Rothschild and Ruvinsky (2011).

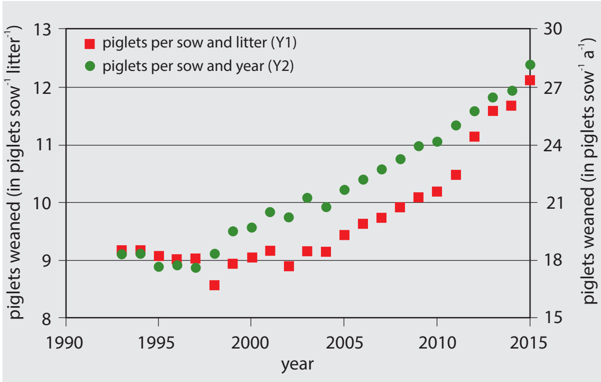

Figure 1
Development of piglet production between 1993 and 2015, example data for Thüringen (Thuringia) (TVL/SKBR, various internal annual reports)

The methodologies describing young sows, young boars, breeding sows and boars should correspond with the existing ones and should, as far as possible, follow the official German recommendations in GfE (2008).

This paper collates the methodologies required to quantify ME requirements as well as emissions from enteric fermentation, volatile solids (VS) and nitrogen (N) excretion in faeces and urine. As the emissions are to be related to the marketable product (pork), an analysis of the carcass composition of slaughtered animals is included.

2 Methods

Animals excrete carbon dioxide (CO_2), methane (CH_4) as well as VS and N in faeces and urine.

The CO_2 released from respiration is not considered an emission. Instead, the agricultural carbon cycle is considered closed: all CO_2 fixed in photosynthesis and fed to animals is finally released with the animals' breath or from decaying organic matter excreted.

The amounts excreted are a function of the feed intake which is itself a function of the energy requirements of the animals. Energy requirements, feed intake and excretions are calculated for each single phase of an animal's lifespan (accumulated amounts for a weaner, each feeding phase in the rearing of a sow or boar, etc., see Section 2.1).

[1] The unit used to quantify GHG emissions is "kg CO_2 equivalents". This reflects the different global warming potentials of the gases considered. With respect to global warming, the effectiveness of methane (CH_4) or nitrous oxide (N_2O) is 25 and 298 times higher than that of CO_2, respectively. (For details see IPCC, 2007.)

Table 1

Terminology used for animals in piglet production

animal category	stage		approx. duration of stage	stage symbol	feeding
	as in this paper	German equivalent			
weaner	weaner	Aufzuchtferkel	2 months	we	2 phases
sow	young sow *	Jungsau	6 months	ys	3 phases
	breeding sow	Zuchtsau **			
	1st litter	1. Wurf	21 weeks	bs1	3 phases
	2nd litter	2. Wurf	21 weeks	bs2	3 phases
	3rd litter	3. Wurf	21 weeks	bs3	3 phases
	etc	usw.			
boar	young boar	Jungeber	5 months	yb	3 phases
	breeding boar	Zuchteber	2 years	bb	1 phase

* English and German terminologies are not standardized. Young sows are also named "gilts". This paper restricts the term "gilt" to female fattening pigs. The terms "Jungsau" and "Jungeber" are equivalent to "weibliche Zuchtläufer" and "männliche Zuchtläufer".

** Breeding sows after their first insemination may be called "Jungsauen" in German.

2.1 Times and terms

The time between weaning and slaughtering of a sow or boar is treated as its lifespan. For animals used for breeding piglets these lifespans (weaning to slaughtering of an animal) are subdivided in stages and phases defined by their respective activity or feeding regime as follows:

2.2 Energy requirements

The requirements of metabolizable energy (ME) are a function of the animal type and are dependent on weight, growth (weight gain), reproduction (numbers of piglets) and the production of milk. The description of each single animal category begins with the derivation of ME requirements.

2.3 Excretion rates

The methodology to calculate excretion rates does not change between animal categories. Any matter that passes the animals' digestive system (VS or N in faeces) or originates from the animal metabolism (N in urine) or transformation within the animal (CH_4 from enteric fermentation) is called an excretion.

2.3.1 Methane excretion

CH_4 from enteric fermentation originates almost entirely from bacterial action in the pigs' hind gut. Various attempts have been made to quantify this CH_4. As described in Dämmgen et al. (2012), the method derived by Kirchgeßner et al. (1991) was chosen for the derivation of the methane conversion rate (MCR) to be used in the German agricultural emission inventory. It relates the daily CH_4 emission rates to the amount of bacterially fermentable substrate (BFS) as in Equation (1):

$$E_{\mathrm{CH4,\,ef}} = a_{\mathrm{ef}} + b_{\mathrm{ef}} \cdot m_{\mathrm{BFS}} = a_{\mathrm{ef}} + b_{\mathrm{ef}} \cdot DM \cdot \eta_{\mathrm{BFS}} \qquad (1)$$

where

- $E_{\mathrm{CH4,\,ef}}$ — CH_4 emission rate from enteric fermentation (in kg animal^{-1} d^{-1} CH_4)
- a_{ef} — constant (in kg animal^{-1} d^{-1})
- b_{ef} — coefficient (in kg kg^{-1} CH_4)
- m_{BFS} — rate of BFS available for fermentation (in kg animal^{-1} d^{-1})
- DM — dry matter intake rate (in kg animal^{-1} d^{-1})
- η_{BFS} — mean BFS content of feed (dry matter) (in kg kg^{-1})

The rate of BFS supplied in the diet is calculated from the diet composition using Equation (2) (see Kirchgeßner et al., 2008, pg 169).

$$m_{BFS,i} = \eta_{BFS,i} \cdot m_{DM,i} = m_{OM,i} \cdot x_{D,OM,i} - m_{XP,i} \cdot x_{D,XP,i} - m_{XF,i} \cdot x_{D,XF,i} - \left(m_{st,i} + m_{su,i}\right) \quad (2)$$

where

$m_{BFS,i}$	rate of BFS available for fermentation in a feed constituent i (in kg animal^{-1} d^{-1})
$\eta_{BFS,i}$	BFS content of a feed constituent i (in kg kg^{-1})
$m_{DM,i}$	intake rate of dry matter of a feed constituent i (in kg animal^{-1} d^{-1})
$m_{OM,i}$	intake rate of organic matter of a feed constituent i (in kg animal^{-1} d^{-1})
$x_{D,OM,i}$	digestibility of organic matter of feed constituent i (in kg kg^{-1})
$m_{XP,i}$	intake rate of crude protein of a feed constituent i (in kg animal^{-1} d^{-1})
$x_{D,XP,i}$	digestibility of crude protein of feed constituent i (in kg kg^{-1})
$m_{XF,i}$	intake rate of crude fat of a feed constituent i (in kg animal^{-1} d^{-1})
$x_{D,XF,i}$	digestibility of crude fat of feed constituent i (in kg kg^{-1})
$m_{st,i}$	intake rate of starch of a feed constituent i (in kg animal^{-1} d^{-1})
$m_{su,i}$	intake rate of sugars of a feed constituent i (in kg animal^{-1} d^{-1})

Values for $m_{BFS,i}$ used in this paper were calculated according to Equation (2) or taken from the literature as listed in Dämmgen et al. (2012).

Both constant and coefficient in Equation (1) vary between growing pigs and sows, for sows also with the mean BFS content η_{BFS}. Kirchgeßner et al. (1991) propose differentiating between three cases:

- growing pigs:
  in any case a_{ef} = 0.00000 kg animal^{-1} d^{-1};
  b_{ef} = 0.020 kg kg^{-1}
- sows and boars:
  if η_{BFS} < 0.08 kg kg^{-1} then
  a_{ef} = 0.00000 kg animal^{-1} d^{-1};
  b_{ef} = 0.020 kg kg^{-1}
  if η_{BFS} ≥ 0.08 kg kg^{-1} then
  a_{ef} = 0.00285 kg animal^{-1} d^{-1};
  b_{ef} = 0.013 kg kg^{-1}

A modified Equation (1) can be used to quantify the CH_4 emissions from enteric fermentation for the entire stage, assuming constant DM intake rates:

$$\sum_{\theta_B}^{\theta_E} E_{CH4,ef} = \left(a_{ef} + b_{ef} \cdot DM \cdot \eta_{BFS}\right) \cdot t_{stage} \quad (3)$$

with

$$t_{stage} = \theta_E - \theta_B \quad (4)$$

where

$\sum_{\theta_B}^{\theta_E} E_{CH4,ef}$	CH_4 emission rate from enteric fermentation from the beginning (θ_B) to the end (θ_E) of a stage (in kg animal^{-1} stage^{-1} CH_4)
a_{ef}	constant (in kg animal^{-1} d^{-1})
b_{ef}	coefficient (in kg kg^{-1} CH_4)
DM	dry matter intake rate (in kg animal^{-1} d^{-1})
η_{BFS}	mean BFS content of feed (dry matter) (in kg kg^{-1})
t_{stage}	duration of the respective stage (in d stage^{-1})
θ_B	beginning of the stage (in d)
θ_e	end of the stage (in d)

2.3.2 Volatile solids

2.3.2.1 Excretion rates

VS excretion rates are used to quantify CH_4 emissions from excreta. In principle, VS excretions of faeces, VS_{faeces}, urine, VS_{urine}, and decaying bedding, VS_{bed}, have to be taken into account to quantify CH_4 emissions.

VS_{faeces} equals the amount of undigested organic matter (OM) and is obtained by subtracting the proportion of digestible organic matter (DOM) from the total OM and the ash content:

$$VS_{faeces} = DM_{feed} \cdot \left(1 - X_{DOM}\right) \cdot \left(1 - X_{ash}\right) \quad (5)$$

where

VS_{faeces}	VS excretion of faeces (in kg animal^{-1} stage^{-1})
DM_{feed}	DM intake of feed (in kg animal^{-1} stage^{-1})
X_{DOM}	apparent digestibility of organic matter (in kg kg^{-1})
X_{ash}	ash content of dry matter (in kg kg^{-1})

VS in urine can be neglected: 90 to 95 % of the OM in urine is urea and allantoin. Both are hydrolyzed within hours after excretion to CO_2 and NH_3. They do not form degradable organic matter as defined and do not account for any CH_4 formation (Monteny and Erisman, 1999).

2.3.2.2 Volatile solids in bedding material

VS in bedding may produce CH_4 under anaerobic conditions. Motte et al. (2013) reported that the amount of VS in wheat straw can be obtained from the dry matter input according to Equation (6).

$$VS_{bedding} = DM_{bedding} \cdot x_{VS,bedding} \quad (6)$$

where

$VS_{beddibg}$	VS in bedding material (in kg animal^{-1} stage^{-1})

$DM_{bedding}$ DM input of bedding (in kg animal^{-1} stage^{-1})
$x_{VS, bedding}$ VS content of bedding material ($x_{VS, bedding}$ = 0.89 kg kg^{-1})

2.3.3 Nitrogen excretion rates

The quantification of N excretion rates is a prerequisite for the determination of emissions of N compounds. The emissions of various N species (di-nitrogen, N_2; ammonia, NH_3; nitric oxide, NO; nitrous oxide, N_2O) occur during the decay of excreta. However, only N in urine is responsible for NH_3 emissions (hence its name TAN, total ammoniacal nitrogen).

The amounts of N excreted with faeces and urine during a stage are:

$$m_{excr} = m_{feed} - (m_l + m_g + m_p) \quad (7)$$

$$m_{excr, TAN} = m_{feed} \cdot X_{DXP} - (m_l + m_g + m_p) \quad (8)$$

where

m_{excr} amount of N in excreta (in kg animal^{-1} stage^{-1})
m_{feed} amount of N contained in feed (in kg animal^{-1} stage^{-1})
m_l amount of N contained in milk (in kg animal^{-1} stage^{-1})
m_g amount of N retained in the animal (in kg animal^{-1} stage^{-1})
m_p amount of N in piglets produced (in kg animal^{-1} stage^{-1})
$m_{excr, TAN}$ amount of N in urine (in kg animal^{-1} stage^{-1})
X_{DXP} digestibility of crude protein (in kg kg^{-1})

Retained N is the whole protein deposition of the animal in form of edible protein and physiological vital protein (e.g. the digestible tract, fetuses, milk).

2.4 Marketable products

Pork is the commodity sold. As an approximate value we use the carcass weight obtained from the animals' slaughter weights and the respective carcass dressing percentage for each animal category.

2.5 Reproduction of sows for piglet production

The sows used in piglet production are generally hybrid sows, i.e. they are cross-breeding products of the two mother breeds / lines of landrace or Edelschwein (Large White, Yorkshire). At the age of about 180 d and a weight of about 100 kg animal^{-1}, they are subjected to a so-called self-performance test (external training and performance assessment). On average, one fourth of the animals tested are excluded from breeding and slaughtered (for details see e.g. Müller et al., 2011).

3 Young sows

Young sows comprise female pigs between weaning and first (artificial) insemination, normally at the third oestrus. Typical start weights range between 28 and 30 kg animal^{-1}, final weights between 130 and 140 kg animal^{-1} at an age of 220 to 230 days (GfE, 2008).

3.1 Daily and cumulative ME requirements

Two publications (GfE, 1987 and 2008) deal with the requirements of metabolizable energy (ME) of young sows as a function of their weights and weight gains. They differ with respect to the details provided. We assess their *feasibility and applicability*; the results are then compared with those from the (fattening) gilt module used for emission reporting. A data set providing a set of animal weights with a daily resolution (Norsvin ZN70, 2015) was used to examine the use of mean weight gains instead of variable ones.

GfE (1987) gives a detailed data set (Table 11) for the raising of young sows. Daily weight gains range between 470 and 650 g animal^{-1} d^{-1}, with a maximum between animal weights of 50 and 70 kg animal^{-1}, and a mean gain of 562 g animal^{-1} d^{-1}.

GfE (2008) provides a recommendation for intake rates of ME. Here, a constant growth rate of 700 g animal^{-1} d^{-1} is assumed for weights between 60 and 150 kg animal^{-1}, and reduced gains of 650 g animal^{-1} d^{-1} between 30 and 60 kg animal^{-1}. For a final weight of 120 kg animal^{-1}, the mean weight gain amounts to 677 g animal^{-1} d^{-1}. In comparison with GfE (1987) its supporting information is less detailed.

A third paper, Norsvin ZN70 (2015), informs in tabular form about weekly data for animal weights. Norsvin TN70 (2015) provides net energy input data as a function of the animal development. As feed constituents are not listed, these data cannot be "translated" to ME requirements.

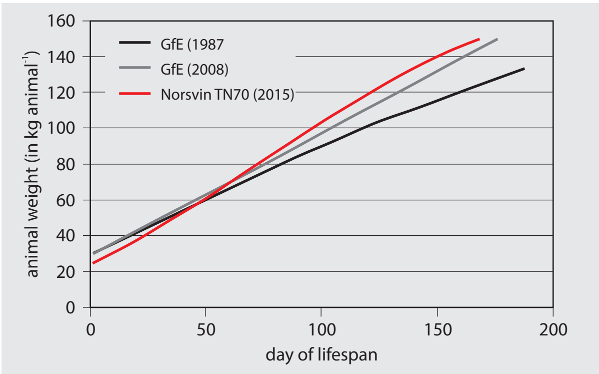

Figure 2
Weight development of young sows according to recommendations in GfE (1987 and 2008) and Norsvin TN70 (2015)

Figure 2 illustrates the principle differences of these three publications regarding the weight development. They suggest that weight gains have increased during the past decades. Furthermore, the weight gain presented by GfE (2008 is almost linear, whereas the other weight gains are slightly non-linear. For the most modern data set (Norsvin TN70, 2015), details regarding weights and weight gains are shown in Figure 5.

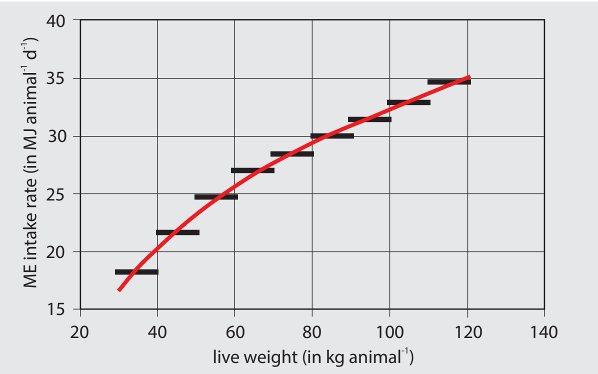

Figure 3
ME intake rate of young sows according to GfE (1987) as a function of animal weights and the derived steady function (Equation (9)) derived ($R^2 = 0.98$)

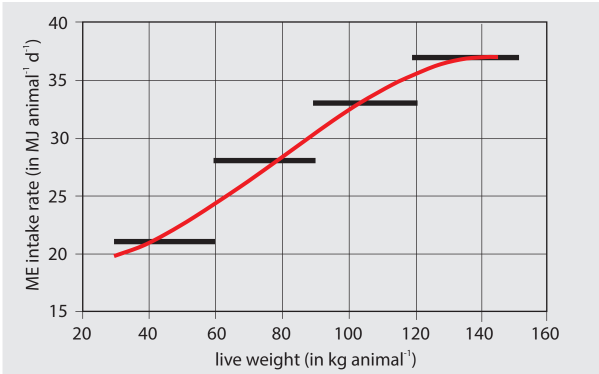

Figure 4
ME intake rate of young sows according to GfE (2008) as a function of animal weights and the derived and steady function (Equation (9)) derived ($R^2 = 0.94$)

Figures 3 and 4 visualize the different ME data listed in GfE (1987, Table 12), and GfE (2008, Table 4.12) and steady functions deduced from these ME data. The horizontal bars visualize the ME intake rates for a given live weight span. In contrast to Figure 2, the simplified integration procedure (see below) relies on constant weight gains. It has to be proved that the error from simplification is tolerable. Figure 5 shows the weight gains used in this comparison (The final weight of young sows in Figure 5 is set to 140 kg animal^{-1}, i.e.

The ME values provided in GfE (1987) and GfE (2008) were transformed to yield the steady functions (polynomials) shown in Figures 3 and 4. These functions can be integrated to obtain the cumulative ME requirements between start weight and final weight. when their stage as breeding sows begins in our calculations. (see Table 1.)

$$ME_{ys} = a_{ys} \cdot w_{ys}^3 + b_{ys} \cdot w_{ys}^2 + c_{ys} \cdot w_{ys} + d_{ys} \qquad (9)$$

and

$$\sum_{w_B}^{w_E} ME_{ys} = \frac{1}{12} \cdot \left(\begin{array}{l} 3a_{ys} \cdot \left(w_{ys,E}^4 - w_{ys,B}^4 \right) + 4b_{ys} \cdot \left(w_{ys,E}^3 - w_{ys,B}^3 \right) \\ + 6c_{ys} \cdot \left(w_{ys,E}^2 - w_{ys,B}^2 \right) + 12d_{ys} \cdot \left(w_{ys,E} - w_{ys,B} \right) \end{array} \right) \qquad (10)$$

where

ME_{ys} ME requirements of a young sow at a given weight (in MJ kg^{-1} animal^{-1} d^{-1})

$w_{ys,B}$ animal weight at the beginning of the respective stage (θ_B) (in kg animal^{-1})

$w_{ys,E}$ animal weight at the end of the respective stage (θ_E) (in kg animal^{-1})

$\sum_{w_B}^{w_E} ME_{ys}$ cumulative ME requirements of a young sow for the weight gained between the beginning and end of the respective stage (θ_B) to its end (θ_E)

Coefficients and constant for GfE (1987):

a_{ys} coefficient (a_{ys} = 0.00001669 MJ kg^{-4} animal^2 d^{-1})

b_{ys} coefficient (b_{ys} = - 0.00506095 MJ kg^{-3} animal d^{-1})

c_{ys} coefficient (c_{ys} = 0.64826297 MJ kg^{-2} d^{-1})

d_{ys} constant (d_{ys} = 1.31122260 MJ kg^{-1} animal^{-1} d^{-1})

Coefficients and constant for GfE (2008):

a_{ys} coefficient (a_{ys} = - 0.00001667 MJ kg^{-4} animal^2 d^{-1})

b_{ys} coefficient (b_{ys} = 0.00391571 MJ kg^{3} animal d^{-1})

c_{ys} coefficient (c_{ys} = - 0.09723102 MJ kg^{-2} d^{-1})

d_{ys} constant (d_{ys} = 19.63844878 MJ kg^{-1} animal^{-1} d^{-1})

An ME requirement model dealing with variable start and final weights as well as weight gains was developed by Dämmgen et al. (2013) for fattening gilts. This model describes ME requirements as a function of time, and requires information about weight gains. For the calculation (i.e. analytic integration) of the cumulative ME requirements for the entire stage of a young sow, the principal approach described in detail in Haenel et al. (2011b) is used that requires a constant (i. e. mean) weight gain. A comparison of cumulative ME requirements using the actual weight gains supplied in Norsvin TN70 (2015) (see Figure 5) and mean weight gains shows that the latter can be used instead of actual weight gains, as is proved by the application of Equation (9) with coefficients and constant for GfE (2008) to the Norsvin TN70 (2015) data set of weights and weight gains.

The comparison of cumulative ME requirements for constant and non-constant weight gains and a final weight of 140 kg animal^{-1} yields 4964 and 4966 MJ animal^{-1} for the use of non-constant and constant weight gains, respectively.

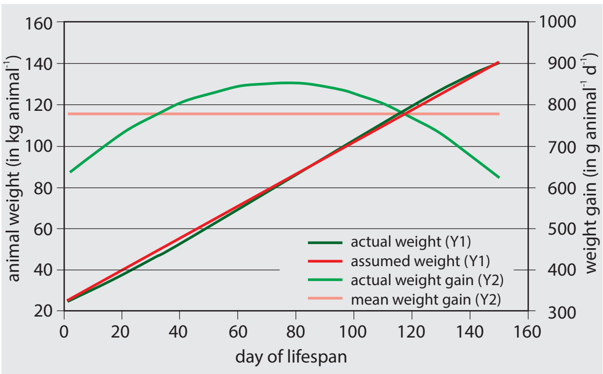

Figure 5
Animal weights and weight gains as a function of animal development as reported in tabular form in Norsvin TN70 (2015), converted to steady functions

The application of the gilt model of Dämmgen et al. (2013) and the young sow model derived from GfE (2008) with the weight gain data by Norsvin TN70 (2015) to varying final weights reveals that both models calculate very similar ME requirements (Table 2). A comparison with GfE (1987) is inadequate as the weight gains are smaller and hence the cumulative ME requirements higher. For a final weight of gilts of 120 kg animal^{-1} as it is assumed for the work at hand the deviation of ME requirements is less than 1 %. As the subsequent calculations aim at establishing relative changes rather than absolute figures, and as the gilt model is reflecting a wider data base than both GfE approaches, the gilt model will be used for the quantification and assessment of excretion rates of young sows even if it is based on the simplifying assumption of mean weight gain.

Table 2
Comparison of cumulative ME requirements using the polynomial derived from Table 4.12 in GfE (2008), and the gilt model in Dämmgen et al. (2013) for a mean weight gain of 677 g animal^{-1} d^{-1}.

		cumulative ME required	
start weight kg animal^{-1}	final weight kg animal^{-1}	GfE (2008) MJ animal^{-1}	Dämmgen et al. (2013) MJ animal^{-1}
30	110	3144	3103
30	120	3634	3608
30	130	4139	4141

3.2 Cumulative nitrogen retention

Dämmgen et al. (2013) analyzed literature data with respect to N contents of the weight gain of fattening gilts, and derived a value of 0.0259 kg kg^{-1} N. However, feeding young sows aims at considerable backfat and sidefat reserves which reduce the overall N content. Gill (2006) gives 0.0246 kg kg^{-1} N for high lysine levels and 0.0222 kg kg^{-1} N for low lysine levels in the diet. Gill (2006) also points out the difference between genotypes (0.0244 kg kg^{-1} N for Large White x Landrace F_1 hybrids and 0.0224 kg kg^{-1} N for Landrace x (Meishan x Large White) gilts. GfE (2008) allows for a determination of N retained from the amounts of fat and protein in weight gain which amounts to 0.0255 kg kg^{-1} N. This value is assumed to be valid for young sows. Hence, cumulative N retention is quantified according to Equation (11):

$$m_{\mathrm{g,\,ys}} = \frac{1}{t_{\mathrm{stage}}}\left(w_{\mathrm{E,\,ys}} - w_{\mathrm{B,\,ys}}\right) \cdot x_{\mathrm{N,\,ys}} \qquad (11)$$

where

$m_{\mathrm{g,\,ys}}$	amount of N retained in the young sow (in kg animal^{-1} stage^{-1})
t_{stage}	duration of the stage (in stage)
$w_{\mathrm{E,\,ys}}$	live weight of the young sow at the end of the stage (in kg animal^{-1})
$w_{\mathrm{B,\,ys}}$	live weight of the young sow at the beginning of the stage (in kg animal^{-1})
$x_{\mathrm{N,\,ys}}$	N content of the live animal ($x_{\mathrm{N,\,ys}}$ = 0.0255 kg kg^{-1})

3.3 Feeding young sows

Young sows are phase-fed. The phases are characterized by live weight spans (30 to 60 kg sow^{-1}, 60 to 100 kg sow^{-1}, > 100 kg sow^{-1}) with diets with decreasing ME and crude protein (XP) contents. For essentials of a respective diet composition see Kleine Klausing and Riewenherm (2012).

3.4 Marketing young sow carcasses

Young sows that do not pass the obligatory performance test (BMELF, 1994) successfully will be slaughtered. A carcass dressing percentage of 79.5 % is used (derived from Adam, undated).

4 Young Boars for reproduction

Boars especially produced for the replacement of breeding boars are called young boars. At the beginning of their lifespan they weigh 28 to 30 kg animal^{-1}. When they are about 100 kg animal^{-1}, they are tested for confirmation, their offspring used to be tested on daily gain, confirmation and body composition (for details see e.g. Müller et al., 2011). However, a genomically assisted selection of young boar piglets has been established in practice (Tribout et al., 2013; Tusell et al., 2016; Xiang et al., 2016; Le et al., 2017).

Those animals that are accepted for the breeding process will continue their life as breeding boars. The rest will be fattened (as boar or castrated as barrow) and slaughtered.

4.1 Daily and cumulative ME requirements

For young boars, the data base is even smaller than for young sows. GfE (1987) present data. GfE (2008) are quite undecided, providing mean weight gains and ME contents of feed, but no recommendation other than *ad libitum* feed intake.

The GfE (1987) data are treated by analogy to those for young sows, yielding Figure 6.

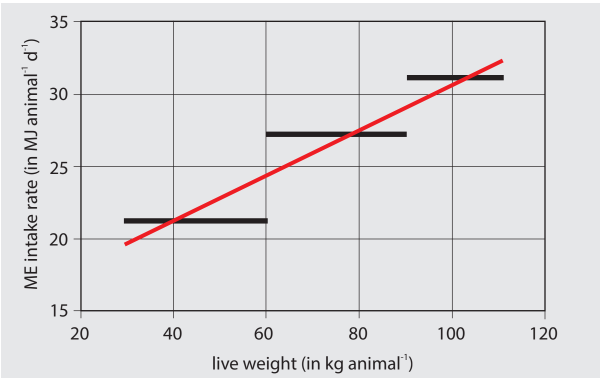

Figure 6
ME intake rate of young boars according to GfE (1987) and steady function derived (Equation (9); $R^2 = 0.88$)

The data in Figure 6 allow for the derivation of a linear regression. Table 15 in GfE (1987) was converted into a polynomial:

where

ME_{yb} daily ME requirements of a young boar (in MJ kg^{-1} animal^{-1} d^{-1})

w_{yb} animal weight (in kg animal^{-1})

$\sum_{w_B}^{w_E} ME_{yb}$ cumulative ME requirements of a young boar for the weight gained between the beginning of the respective stage (B) to its end (E)

Coefficients and constant for GfE (1987):

b_{yb} coefficient (b_{yb} = 0.0002430 MJ kg^{-3} animal d^{-1})

c_{yb} coefficient (c_{yb} = 0.1267103 MJ kg^{-2} d^{-1})

d_{yb} constant (d_{yb} = 15.4514201 MJ kg^{-1} animal^{-1}) d^{-1})

Both these treatments of the ME requirements of young boars are considered unsatisfactory. GfE (2008) because of its poor data background, and GfE (1987) as outdated.

Dämmgen et al. (2013) also proposed a variant of the Haenel model (Haenel et al., 2011b) to quantify emissions from boars for fattening, again correcting the ME requirements using an improved feed conversion rate. As the treatment of these boars does not deviate in principle from young boars for reproduction, the boar model in Dämmgen et al. (2013) is used in the present paper. Keeping in mind that the number of these animals is small in comparison to the other pig categories, this is suggested as a compromise.

4.2 Cumulative nitrogen retention

For German fattening boars, Dämmgen et al. (2013) determined an N content of the weight gained during its lifespan (see Table 1) of 0.0270 kg kg^{-1}. This value is also used in the treatment of young boars. For the calculation of the cumulative N retention see Equation (11).

4.3 Feeding young boars

Young boars are phase-fed. Phases being weight dependent (30 to 60 kg boar^{-1}, 60 to 90 kg boar^{-1}, 90 to 120 kg boar^{-1}) ME and XP contents decreasing with increasing weights. Example properties are provided in Table 7. For the principles behind the respective diet composition see Kleine Klausing and Riewenherm (2012).

4.4 Marketing young boar carcasses

Young boars that are not accepted for breeding (BMELF, 1979) will normally be castrated, fattened and slaughtered. A carcass dressing percentage of 79.5 % is used (as per Adam, undated).

$$ME_{yb} = b_{yb} \cdot w_{yb}^2 + c_{yb} \cdot w_{yb} + d_{yb} \quad (12)$$

and

$$\sum_{w_B}^{w_E} ME_{yb} = \frac{1}{6} \cdot \left(2b_{yb} \cdot \left(w_{yb,E}^3 - w_{yb,B}^3\right) + 3c_{yb} \cdot \left(w_{yb,E}^2 - w_{yb,B}^2\right) + 6d_{yb} \cdot \left(w_{yb,E} - w_{yb,B}\right)\right) \quad (13)$$

5 Breeding sows

Breeding sows comprise female pigs between first insemination and slaughtering. Typical start weight is 130 to 140 kg animal^{-1}, final weights depend on the number of pregnancies. It is common practice to regard a sow and her respective litter as a unit that has to be fed and that excretes at the same time and location. Piglets are weaned after 28 days with a weight of 8 kg piglet^{-1}.

5.1 ME requirements

GfE (2008), Table 4.13, provides information on the ME requirements of breeding sows. The method used in the national emission inventory makes use of a mean weight of sows irrespective of the number of lactations. It considers the number of piglets raised as a variable (Haenel et al., 2011b). GfE (2008) confines its recommendations to four litters.

However, GfE (2008) also provide the basic information which allows us to extend to more litters. Equation (14) names the different terms which can be quantified using the subsequent relations (Equations (15) to (19), derived from the context of Table 4.13 in GfE, 2008). Table 4.13 of GfE (2008) (zero weight losses during lactation [2]) is converted to produce a steady function. This function allows for adjustments of sow weights and weight gains as well as of piglet numbers.

The Equations have to be applied to each single reproduction cycle (stage).

$$\Sigma ME_{\text{bs}} = \Sigma ME_{\text{bs, m}} + \Sigma ME_{\text{bs, grav,1}} + \Sigma ME_{\text{bs, grav, 2}} + \Sigma ME_{\text{bs, lact}} + \Sigma ME_{\text{bs, empty}} \qquad (14)$$

$$\Sigma ME_{\text{bs, m}} = a_{\text{bs, m}} \cdot w_{\text{unit}} \left(\frac{1}{2} \cdot \frac{w_{\text{start}} + w_{\text{fin}}}{w_{\text{unit}}} \right)^{0.75} \cdot t_{\text{bs, lac}} \qquad (15)$$

$$\Sigma ME_{\text{bs, grav 1}} = ME_{\text{bs, grav 1}} \cdot t_{\text{bs, grav 1}} \qquad (16)$$

$$\Sigma ME_{\text{bs, grav 2}} = ME_{\text{bs, grav 2}} \cdot t_{\text{bs, grav 2}} \qquad (17)$$

$$\Sigma ME_{\text{bs, lact}} = n_{\text{piglet}} \cdot c_{\text{milk}} \cdot \frac{\eta_{\text{ME. milk}}}{x_{\text{milk}}} \cdot \left(w_{\text{piglet, fin}} - w_{\text{piglet, start}} \right) \qquad (18)$$

$$\Sigma ME_{\text{bs, empty}} = ME_{\text{bs, empty}} \cdot t_{\text{bs, empty}} \qquad (19)$$

where

ΣME_{bs} ME requirements of a breeding sow (in MJ animal^{-1} stage^{-1})
$\Sigma ME_{\text{bs, m}}$ ME requirements for maintenance (in MJ animal^{-1} stage^{-1})
$\Sigma ME_{\text{bs, grav, 1}}$ ME required for the development of conception products, gestation phase 1 (in MJ animal^{-1} stage^{-1})
$\Sigma ME_{\text{bs, grav, 2}}$ ME required for the development of conception products, gestation phase 2 (in MJ animal^{-1} stage^{-1})
$\Sigma ME_{\text{bs, lact}}$ ME required for lactation (in MJ animal^{-1} stage^{-1})
$\Sigma ME_{\text{bs, empty}}$ ME requirements between weaning and insemination (in MJ animal^{-1} stage^{-1})
$a_{\text{m, bs}}$ coefficient ($a_{\text{m, bs}}$ = 0.44 MJ kg^{-1})
w_{unit} unit weight (w_{unit} = 1 kg animal^{-1})
$w_{\text{bs, B}}$ weight at the time of insemination, see Table 3 (in kg animal^{-1})
$w_{\text{bs, E}}$ weight at the beginning of the subsequent insemination, see Table 3 (in kg animal^{-1})
$t_{\text{bs, lac}}$ duration of the lactation period ($t_{\text{bs, lac}}$ = 28 d stage^{-1})
$ME_{\text{bs, grav 1}}$ daily ME requirements during gravidity phase 1, see Table 3 (in MJ animal^{-1} d^{-1})
$t_{\text{bs, grav 1}}$ duration of gravidity phase 1 ($t_{\text{bs, grav 1}}$ = 84 d stage^{-1})
$ME_{\text{bs, grav 2}}$ daily ME requirements during gravidity phase 2, see Table 3 (in MJ animal^{-1} d^{-1})
$t_{\text{bs, grav 2}}$ duration of gravidity phase 1 ($t_{\text{bs, grav 2}}$ = 30 d stage^{-1})
n_{piglet} number of piglets per litter (in piglet stage^{-1})
c_{milk} amount of milk per kg of piglet weight gained (c_{milk} = 4.1 kg kg^{-1})
$\eta_{\text{ME, milk}}$ ME content of pig milk ($\eta_{\text{ME, milk}}$ = 5.0 MJ kg^{-1})
$x_{\text{ME, milk}}$ share of ME that is used for milk production ($x_{\text{ME, milk}}$ = 0.7 MJ MJ^{-1})
$w_{\text{piglet, fin}}$ weight of the piglet at the time of weaning ($w_{\text{piglet, fin}}$ = 8 kg animal^{-1})
$w_{\text{piglet, start}}$ birth weight of piglets ($w_{\text{piglet, start}}$ = 1.5 kg animal^{-1})
$ME_{\text{bs, empty}}$ daily ME requirements between weaning and insemination, see Table 3 (in MJ animal^{-1} d^{-1})
$t_{\text{bs, empty}}$ time span between weaning and insemination, see Table 3 (in d stage^{-1})

In Table 3, GfE (2008) provide a set of input data and the consequent ME requirements.

[2] If weight losses are taken into account, these have to be compensated between weaning and insemination. The net effect with respect to ME intake is zero.

Table 3
Recommended ME intake rates for breeding sows for animal weights, weight gains and piglet numbers as listed (GfE, 2008, modified)

		number of litter			
	unit	1	2	3	4
live weight at insemination $w_{bs, B}$	kg animal^{-1}	140	185	225	255
maternal weight gain	kg animal^{-1}	45	40	30	0
piglets expected per litter	animal animal^{-1}	12	13	13	13
time between weaning and insemination	d stage^{-1}	11	11	11	0 *
ME intake rate, gravidity phase 1	MJ animal^{-1} d^{-1}	29	32	34	31
ME intake rate, gravidity phase 2	MJ animal^{-1} d^{-1}	39	42	43	39
ME intake rate, weaning to insemination	MJ animal^{-1} d^{-1}	39	42	43	39

* The final stage before slaughtering ends after weaning.

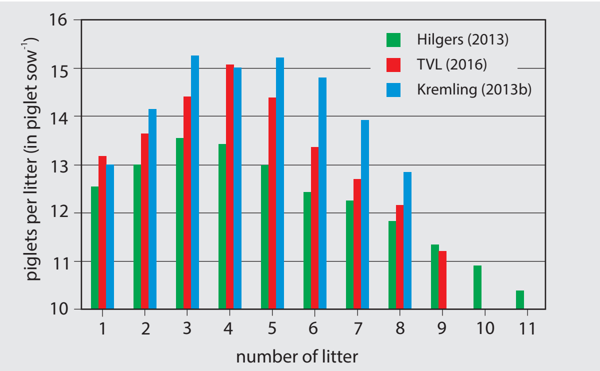

Figure 7
Example numbers of live-born piglets per sow as a function of the number of litters. Hilgers (2013): mean of 106 Rhenish piglet producers; Kremling (2013b): data for a single farm. TVL (2016): 22 farms in Thuringia. Note that the ordinate starts with 10 piglets per litter.

In contrast to GfE (2008), Schnurrbusch (2004) and Wähner (2012) considered more than four litters per sow as standard with more than 50 weaners per sow and life-time. Hilgers (2016, private communication) report that sows have 12.6 weaners per litter and 5.6 litters per productive lifespan, with top farms producing 14 piglets per litter with 6.1 litters before slaughtering (mean values). Hilgers (2013) illustrated that the largest number of piglets is produced between the third and fifth litters (Figure 7). A mean number of litters above six can be obtained in practice (Kremling, 2013a).

It is obvious from Figure 7 that Table 3 needs to be extended. Equations (14) to (19) can be used, if the respective input data (animal weight, weight gain, number of piglets per litter) can be supplied.

Table 3 also needs updating with respect to heavier animals: From literature data, Heinze et al. (2008) concluded that the GfE (2008) data for animal weights are underestimated. Their own experimental data confirm this. Two experiments with different lactation periods, different breeds and 220 to 287 sows per litter, varying with the number of litters, were performed the results of which are collated in Table 4. If one uses the additional information on weights and weight gains provided in Hühn and Gericke (2000) and Close and Cole (2000), smoothed relations between number of litters and animal weights and weight gains can be derived (Figure 8). The weight gains decrease by 5 kg sow^{-1} litter^{-1} and become zero after the sixth litter.

Table 4
Experimental data for animal weights and weight gains of breeding sows in Heinze et al. (2008). Group A: lactation period 3 weeks; group B: lactation period 4 weeks.

	group A			group B		
number of litter	start (kg animal^{-1})	end (kg animal^{-1})	gain (kg animal^{-1})	start (kg animal^{-1})	end (kg animal^{-1})	gain (kg animal^{-1})
1	153	186	33	165	184	19
2	186	213	37	184	218	34
3	213	225	12	218	243	25
4	225	239	14	243	258	15
5	239	261	22	258	265	7
≥ 6	261	269	7	265	276	11

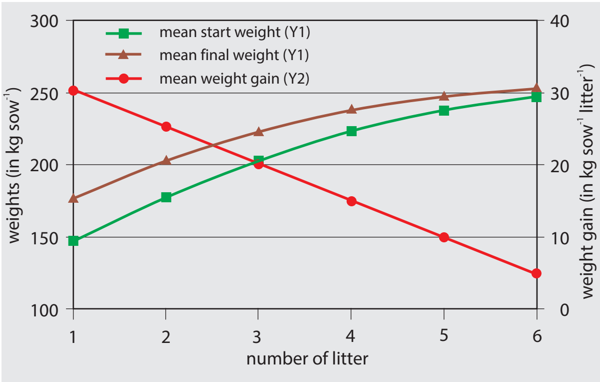

Figure 8
Mean animal weights and weight gains of breeding sows as a function of the number of litters. Smoothed experimental and literature data (arithmetic means of the data sets from Heinze et al., 2008, Hühn and Guericke, 2000, and Close and Cole, 2000; second order polynomial for weights; R^2 = 0.999; linear relation for weight gains, R^2 = 1.00), see text.

GfE (2008) lists ME requirements for gravidity and weaning to insemination for four lactations. DLG (2008) recommend larger ME intake rates and differentiate between first and subsequent litters only.

An extended and updated data set of ME intake rates for breeding sows for animal weights, weight gains and piglet numbers combining the above mentioned details is given in Table 5.

5.2 Cumulative nitrogen retention

Various procedures for quantifying N retention can be found in the literature:

- LfL (2013) lists N contents of fattening pigs and pigs for reproduction of 0.0256 kg kg^{-1} irrespective of the animals' gender. This value (whose origin is unknown) may be treated as default value if data for sows cannot be derived.
- Dämmgen et al. (2013) derived different N contents in the weight gain of fattening gilts, boars and barrows. This suggests that N retention for sows should differ from the LfL (2013) mean.
- Everts and Dekker (1995) report a mean N content of 0.0255 kg kg^{-1} N, depending on feed protein contents. This value supports the LfL (2013) N content.
- Beyer et al. (1993) measured N contents of sows' empty bodies for various stages in the production cycle. However, these values cannot be extrapolated to entire animals.
- Hansen et al. (2014) presuppose an ME intake model with a resolution in time of one day to calculate N contents. As the ME intake model at hand does not have the required resolution, the model cannot be used in this work.
- Gill (2006) and Dourmad et al. (2008) relate the protein content of a breeding sow to its empty body weight and its back fat thickness where Gill (2006) covers the first litter only. However these data can be used to explain the LfL (2013) N content.

The Equation used in the sow model given by Dourmad et al. (2008) for N retained can be re-written as:

$$m_{\mathrm{g,\,sow}} = x_{\mathrm{N}} \cdot m_{\mathrm{CP,\,g,\,sow}} = x_{\mathrm{N}} \cdot \left(a_{\mathrm{BF}} + b_{\mathrm{BF}} \cdot x_{\mathrm{EW}} \cdot w_{\mathrm{sow}} + c_{\mathrm{BF}} \cdot T_{\mathrm{BF,\,sow}}\right) \qquad (20)$$

where

$m_{\mathrm{g, sow}}$	N retained in a sow (in kg sow^{-1} $stage^{-1}$)
x_{N}	N content of crude protein (x_{N} = 1/6.25 kg kg^{-1})
$m_{\mathrm{CP, g, sow}}$	CP content of a sow (in kg kg^{-1})
a_{BF}	constant (a_{BF} = 2.28 kg sow^{-1} $stage^{-1}$)
b_{BF}	coefficient (b_{BF} = 0.178 kg kg^{-1} $stage^{-1}$)
x_{EW}	body weight correction factor relating body weight to empty body weight (x_{EW} = 1/0.96 kg kg^{-1})
w_{sow}	body weight of a sow (in kg sow^{-1})
$c_{\mathrm{BF, sow}}$	coefficient ($c_{\mathrm{BF, sow}}$ = - 0.333 kg mm^{-1} sow^{-1} $stage^{-1}$)
$T_{\mathrm{BF, sow}}$	backfat thickness at standard measuring point 2 (in mm)

Table 5
Example input parameters and ME intake rates for breeding sows for animal weights, weight gains and piglet numbers using information described in text.

		number of litter						
	unit	1	2	3	4	5	6	7
live weight at insemination $w_{\mathrm{bs, B}}$	kg $animal^{-1}$	146.7	177.4	202.8	223.0	237.8	247.3	251.6
maternal weight gain	kg $animal^{-1}$	30.3	25.2	20.1	15.0	9.9	4.8	0.0
piglets per litter	animal $animal^{-1}$	13	14	15	14	13	12	11
time between weaning and insemination	d $stage^{-1}$	11	11	11	11	11	11	0
ME intake rate, gravidity phase 1	MJ $animal^{-1}$ d^{-1}	31	35	35	35	35	35	35
ME intake rate, gravidity phase 2	MJ $animal^{-1}$ d^{-1}	39	43	43	43	43	43	43
ME intake rate, weaning to insemination	MJ $animal^{-1}$ d^{-1}	39	43	43	43	43	43	0
maintenance and lactation	MJ $animal^{-1}$ d^{-1}	108	118	127	121	115	109	103

Table 6
Compilation of backfat thicknesses of breeding sows

time of measurement	backfat thickness (in mm)	remarks, conditions	source
insemination	18 to 20	1st litter	Close and Cole (2000)
	20 to 24	≥ 2nd litter	Close and Cole (2000)
	18		Whittemore (1993)
	13 to 16		Jeroch et al. (1999)
after birth	20 to 24		Close and Cole (2000)
	14 to 25	1st litter	Whittemore (1993)
	18 to 22		Jeroch et al. (1999)
	7.8 to 20	BCS 2*	Spanlang (2011)
	10.2 to 25.8	BCS 3	Spanlang (2011)
	15.5 to 31.3	BCS 4	Spanlang (2011)
at weaning	18.5	1st litter, 159 kg sow^{-1}	Kornblum (1997)
	18.5	2nd litter, 170 kg sow^{-1}	Kornblum (1997)
	18.1	3rd litter, 173 kg sow^{-1}	Kornblum (1997)
	17.5	4th litter, 179 kg sow^{-1}	Kornblum (1997)
	17.5	5th litter, 188 kg sow^{-1}	Kornblum (1997)
	10.9 to 12.6	1st litter, diet varied	Derking (2014)
losses during lactation	< 1 1.5 to 6.5		Aherne and Williams (1992) Spanlang (2011)

* BCS: body condition score

Spanlang (2011) collated literature data for backfat thickness and gives results of her own measurements. Together with data from Kornblum (1997) and Derking (2014) these are listed in Table 6.

The N content at respective final weaning relates to the N content at the time of slaughtering. However, the data given in Kornblum (1997) were obtained for lightweight sows and can hardly be transferred.

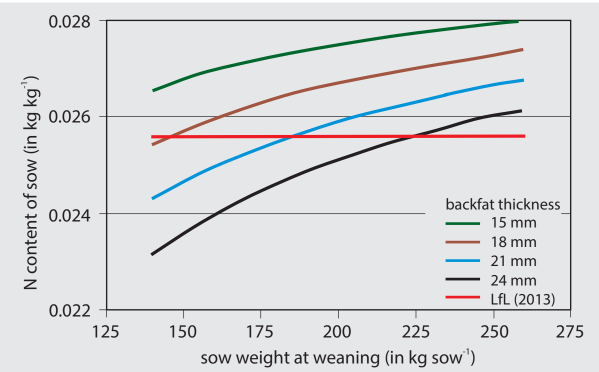

Figure 9
N content of sows as obtained after Dourmad et al. (2008) for various backfat thicknesses and the LfL (2013) default value

If one assumes a relevant backfat thickness of 21 mm, this results in a reduction of crude protein of 7 kg sow^{-1} or about 1 kg sow^{-1} N. Figure 9 depicts sows' N contents for various assumed backfat thicknesses and compares them to the weight independent value in LfL (2013).

The model in Dourmad et al. (2008) does not refer to any uncertainties. However, its source (Dourmad et al., 1997) reveals considerable uncertainties, in particular for a_{BF}, even for a given backfat thickness. It is therefore inappropriate to prefer this procedure to the use of the LfL (2013) constant.

Our model calculations will use the LfL (2013) recommendation. It is obvious from Figure 9 that this value does not contradict the findings in Dourmad et al. (2008).

For the calculation of the cumulative N retention with the LfL (2013) constant see Equation (11).

5.3 *Feeding breeding sows*

The energy and nutrient requirements of breeding sows vary with animal weight, the state of pregnancy and the number of piglets raised. This is reflected by the diet composition which differentiates between empty sows, two gravidity phases and the lactation period. Normally, two diets are supplied where empty and lactation sows are differentiated from gravid sows. Table 7 gives example diet properties that take the recommendations in DLG (2008) into account.

5.4 *Marketable products*

Dressed body weight is considered to be an adequate measure for the marketable product.

A carcass dressing percentage of 79.5 % is used (Adam, undated).

Table 7
ME intake recommendations for breeding boars (from Wilson et al., 2004, after Kemp and Soede, 2001)

live weight	kg animal^{-1}	150	200	250	300	350
weight gain	g animal^{-1} d^{-1}	500	400	300	200	100
overall ME intake rate	MJ animal^{-1} d^{-1}	34.19	35.18	35.92	36.46	36.86
ME for maintenance	MJ animal^{-1} d^{-1}	17.79	22.07	26.09	29.91	33.58
ME for growth	MJ animal^{-1} d^{-1}	16.40	13.11	9.83	6.55	3.28

6 Breeding boars

Young boars of 8 to 9 months undergo a selection process, after which they are either used for breeding or slaughtered. Breeding boars have an overall life expectancy of about 2 years - about 16 months of which is their productive stage. They will then be slaughtered and replaced by younger ones. At that time they have a live weight of about 300 kg animal^{-1}.

This paper deals with breeding boars used for sperm production for artificial insemination.

6.1 Daily and cumulative ME requirements

The information on requirements and feeding of breeding boars provided in official recommendations and the Central European literature is sparse. Wilson et al. (2004) reviewed the little literature on ME requirements of breeding boars. The information provided there is collated in Table 7. Here, values include ME required for mating activity and sperm production. They were obtained for a temperature of 20 °C in the animal building. However, no data are available for different temperatures. As a rule, temperature data are not communicated. Due to lack of information, the data obtained at 20 °C are used to quantify ME requirements.

In order to derive a steady function for live weight as a function of time from Table 7, first the weight gain is to be expressed as a function of weight (Equation (21)).

$$\Delta w_{\mathrm{bb}} = a_{\mathrm{bb}} + b_{\mathrm{bb}} \cdot w_{\mathrm{bb}} \quad (21)$$

where

Δw_{bb} weight gain of a breeding boar (in g animal^{-1} d^{-1})
a_{bb} constant (a_{bb} = 800 g animal^{-1} d^{-1})
b_{bb} coefficient (b_{bb} = - 2 g kg^{-1} d^{-1})
w_{bb} live weight of a breeding boar (in kg animal^{-1})

This relation can be used to calculate the weight of a breeding boar at a given time. The result is shown in (Figure 10).

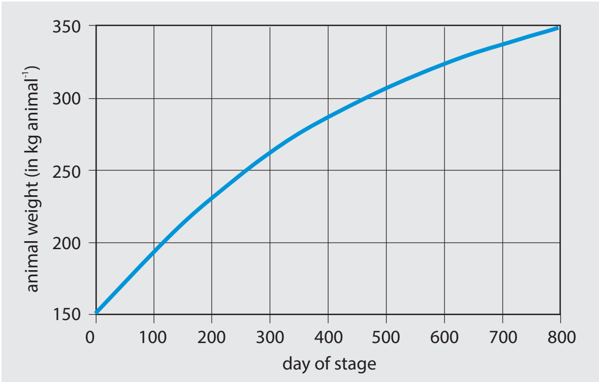

Figure 10
Weight of breeding boars as a function of time according to information provided in Table 7

The relation between weight and time can be approximated by a steady function (Equation (22), R^2 = 1.000):

$$w_{\mathrm{bb},\theta} = a_{\mathrm{bb,w}} \cdot \theta^3 + b_{\mathrm{bb,w}} \cdot \theta^2 + c_{\mathrm{bb,w}} \cdot \theta + d_{\mathrm{bb,w}} \quad (22)$$

where

$w_{\mathrm{bb},\theta}$ weight of a breeding boar at day θ of his lifespan as breeding boar, start weight 150 kg animal^{-1}
$a_{\mathrm{bb,w}}$ coefficient ($a_{\mathrm{bb,w}}$ = 0.000000162 kg animal^{-1} d^{-3})
θ day of life in the lifespan of breeding boar (in d)
$b_{\mathrm{bb,w}}$ coefficient ($b_{\mathrm{bb,w}}$ = - 0.000430390 kg animal^{-1} d^{-2})
$c_{\mathrm{bb,w}}$ coefficient ($c_{\mathrm{bb,w}}$ = 0.491516619 kg animal^{-1} d^{-1})
$d_{\mathrm{bb,w}}$ constant ($d_{\mathrm{bb,w}}$ = 149.938556227 kg animal^{-1})

The quantification of ME for maintenance ($ME_{\mathrm{m,bb}}$) of breeding boars makes use of the linear relation between the metabolic body size [3] and $ME_{\mathrm{m,bb}}$ as provided in Table 6:

$$ME_{\mathrm{m,bb}} = c_{\mathrm{MEm,bb}} \cdot w_{\mathrm{unit}} \cdot \left(\frac{w_{\mathrm{bb}}}{w_{\mathrm{unit}}}\right)^{0.75} \quad (23)$$

where

$ME_{\mathrm{m,bb}}$ daily ME requirements for maintenance of a breeding boar (in MJ animal^{-1} d^{-1})
$c_{\mathrm{MEm,bb}}$ constant ($c_{\mathrm{MEm,bb}}$ = 0.415 MJ kg^{-1} d^{-1})
w_{unit} unit weight (w_{unit} = 1 kg animal^{-1})
w_{bb} live weight of the breeding boar (in kg animal^{-1})

3 The authors name an exponent of 0.665. However, their calculation obviously uses the standard value of 0.75.

The ME required for growth (ME_g) is proportional to the weight gain. Using data from Table 5 results in Equation (24):

$$ME_{g,\,bb} = d_{MEg,\,bb} \cdot \Delta w_{bb} \tag{24}$$

where

$ME_{g,\,bb}$ ME requirements for growth of a breeding boar (in MJ animal^{-1} d^{-1})

$d_{MEg,\,bb}$ constant ($d_{MEg,\,bb}$ = 32.77 MJ kg^{-1})

Δw_{bb} weight gain (in kg animal^{-1} d^{-1})

Using Equations (21) and (22), ME equations (23) and (24) can easily be transformed to time dependent functions the graphs of which are displayed in Figure 11 where also the total daily ME requirements (ME) is shown.

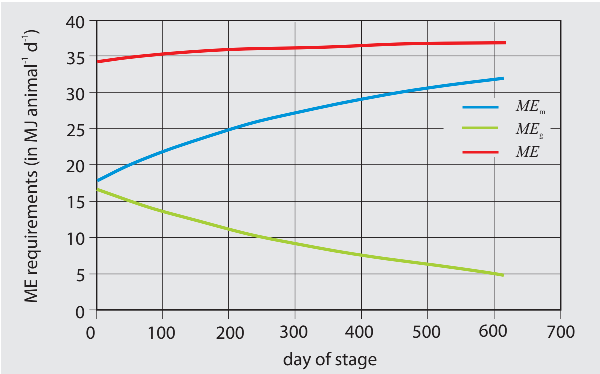

Figure 11

ME requirements of breeding boars as function of the day of stage, data from Table 6, using Equations (25) and (26) for $ME_{m,\,bb}$ and $ME_{g,\,bb}$, respectively

Total daily ME requirements (ME in Figure 11) can be expressed as a function of time (day in the productive lifespan) using a third order polynomial which can be integrated (Equation (26a)). As the time of the beginning θ_B is 0, the simplified Equation (26b) can be used.

where

ME_{bb} daily ME requirements of a breeding boar (in MJ animal^{-1} d^{-1})

$\sum_{\theta_B}^{\theta_E} ME_{bb}$ cumulative ME requirements of a breeding boar between the beginning (θ_B) and the end (θ_E) of his productive stage (in MJ animal^{-1} stage^{-1})

e_{bb} coefficient (e_{bb} = 7.5·10^{-9} MJ animal^{-1} d^{-4})

θ_{bb} day of stage of a breeding boar (in d)

f_{bb} coefficient (f_{bb} = - 0.0000139576 MJ animal^{-1} d^{-3})

g_{bb} coefficient (g_{bb} = 0.00968232 MJ animal^{-1} d^{-2})

h_{bb} constant (h_{bb} = 34.2615348 MJ animal^{-1} d^{-1})

The German agricultural emission inventory uses a constant value of 35 MJ animal^{-1} d^{-1} deduced from GfE (2008) for a mean live weight of 200 kg animal^{-1} (Haenel et al., 2016). This is also in line with PIC (2016). Figure 11 illustrates the compatibility of the results. However, the detailed procedure, Equations (25) and (26), can be used to treat weights and weight gains as variables.

6.2 *Cumulative nitrogen retention*

LfL (2013) lists N contents of fattening pigs and pigs for reproduction of 0.0256 kg kg^{-1} irrespective of the animals' gender. Specific literature data are not available. In view of the comparatively small number of animals the LfL (2013) value is used. For the calculation of the cumulative N retention see Equation (11).

6.3 *Feeding breeding boars*

GfE (2008) do not recommend diet properties for breeding boars. It is customary to provide the same feed as for empty and lactating sows (Kirchgeßner et al., 2008). An example diet composition (expert judgement Kleine Klausing) can be found in Table 8.

6.4 *Marketable products*

Due to its boar taint it is assumed that the carcass is used for pet food production.

$$ME_{bb} = e_{bb} \cdot \theta_{bb}^3 + f_{bb} \cdot \theta_{bb}^2 + g_{bb} \cdot \theta_{bb} + h_{bb} \tag{25}$$

$$\sum_{\theta_B}^{\theta_E} ME_{bb} = \frac{1}{12} \cdot \begin{pmatrix} \left(3\theta_{bb,\,E}^4 - 3\theta_{bb,\,B}^4\right) \cdot e_{bb} + \left(4\theta_{bb,\,E}^3 - 4\theta_{bb,\,B}^3\right) \cdot f_{bb} \\ + \left(6\theta_{bb,\,E}^2 - 6\theta_{bb,\,B}^2\right) \cdot g_{bb} + \left(12\theta_{bb,\,E} - 12\theta_{bb,\,B}\right) \cdot h_{bb} \end{pmatrix} \tag{26a}$$

$$\sum_{\theta_B = 0}^{\theta_E} ME_{bb} = \frac{1}{12} \cdot \left(3\theta_{bb,\,E}^4 \cdot e_{bb} + 4\theta_{bb,\,E}^3 \cdot f_{bb} + 6\theta_{bb,\,E}^2 \cdot g_{bb} + 12\theta_{bb,\,E} \cdot h_{bb}\right) \tag{26b}$$

7 Example overall excretions of sows and boars during their lifespan from weaning to slaughtering

In order to depict the entire lifespan of a sow or a boar for reproduction, their stage as weaners has to be included. Excretion by piglets is incorporated in the calculations of N excretion by their mother sow. For example calculations we make use of the performance data listed in Table 8. Note that the number of piglets produced varies with the litter number.

Feeding of young sows and boars takes the energy and nutrient requirements into account. It is customary to feed in three phases each. For breeding sows, gestation, gravidity and lactation call for different ME and protein contents. In gravidity phase 2, the diet for empty sows is used.

Breeding boars may be fed a special diet. As mentioned above they may also get the same feed as empty and lactating sows.

Diet properties for sows and boars are listed in Table 9.

Figures 12 and 13 show the different "boxes" symbolizing excretions for the two animals. They have different overall lifespans (sows about 41 months, boars about 29 months). They also differ with respect to their main product (pregnancy and energy intensive milk production versus semen production). Whereas sows also produce an edible carcass, that of breeding boars cannot be used for human consumption.

Table 8
Animal properties and performance data used in example quantifications of excretions

animal category	number of litter	start weight kg animal^{-1}	final weight kg animal^{-1}	weight gain g animal^{-1} d^{-1}	numbers of piglets per litter animal animal^{-1}
weaners		8	30	525	
young sows		30	140	720	
young boars		30	150	780	
breeding sows	1	146.7	177.4		13
	2	177.4	202.8		14
	3	202.8	223.0		15
	4	223.0	237.8		14
	5	237.8	247.3		13
	6	247.3	251.6		12
	7	251.6	251.6		11
breeding boars		150	308 *		

* duration of lifespan as breeding boar 480 d

Table 9
Diet properties used for the calculation of example excretions of sows and boars (Figures 13 and 14)

		young sows			young boars			breeding sows		boars
live weight / phase	kg animal^{-1}	30-60	60-100	>100	30-60	60-90	90-120	gestation	lactation	breeding
feed type		YS 1	YS 2	YS 3	YB 1	YB 2	YB 3	BS 1	BS 2	BB
dry matter	kg kg^{-1}	0.873	0.8749	0.8763	0.8734	0.8723	0.8727	0.8758	0.8771	0.8699
ME content	MJ kg^{-1}	13.24	13.20	13.18	13.00	12.60	12.60	13.17	12.00	12.05
crude protein	kg kg^{-1}	0.165	0.145	0.140	0.170	0.165	0.155	0.165	0.140	0.185
crude fibre	kg kg^{-1}	0.045	0.050	0,055	0,045	0.050	0.050	0.050	0.070	0.0596
ether extract (crude fat)	kg kg^{-1}	0.0426	0.0559	0.0685	0.0409	0.0300	0.0321	0.0575	0.0425	0.0191
crude ash	kg kg^{-1}	0.0532	0.0494	0.0496	0.0534	0.0514	0.0511	0.0577	0.0463	0.0570
BFS	kg kg^{-1}	0.079	0.082	0.083	0.079	0.085	0.083	0.088	0.187	0.100
digestibility crude protein	kg kg^{-1}	0.838	0.815	0.810	0.838	0.826	0.819	0.830	0.748	0.834
digestibility organic matter	kg kg^{-1}	0.854	0.830	0.818	0.856	0.838	0.834	0.836	0.815	0.816

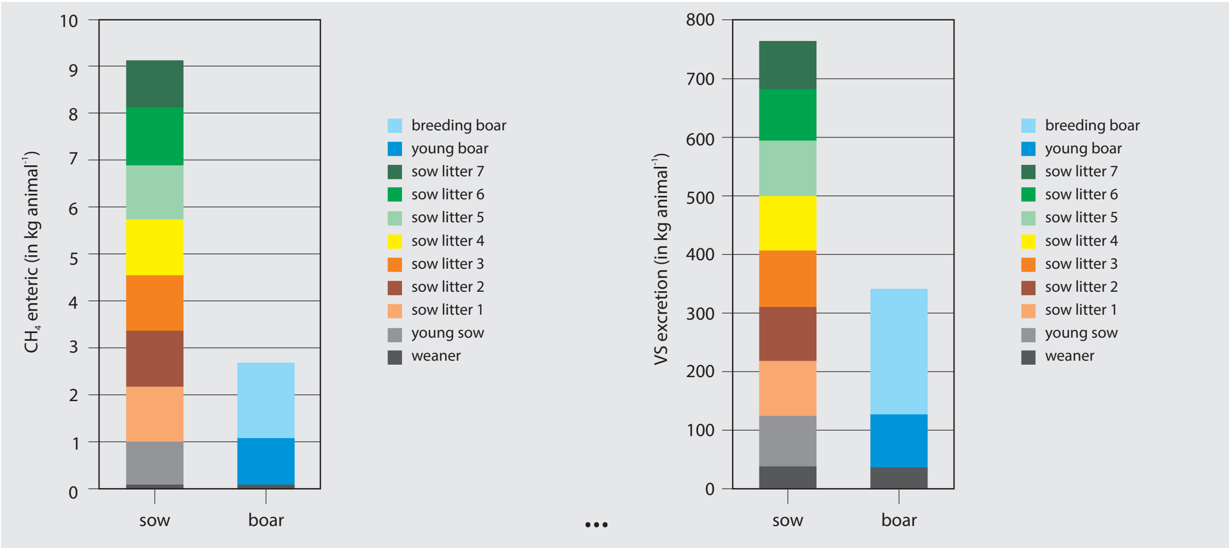

Figure 12
Enteric CH_4 and VS excretions during the entire life spans of a sow and a boar used for reproduction (ME requirements as in Table 5, performance data as in Table 8, diet properties as in Table 9) (CH_4 emissions and VS excretions of sows (sow litter) include those of piglets.)

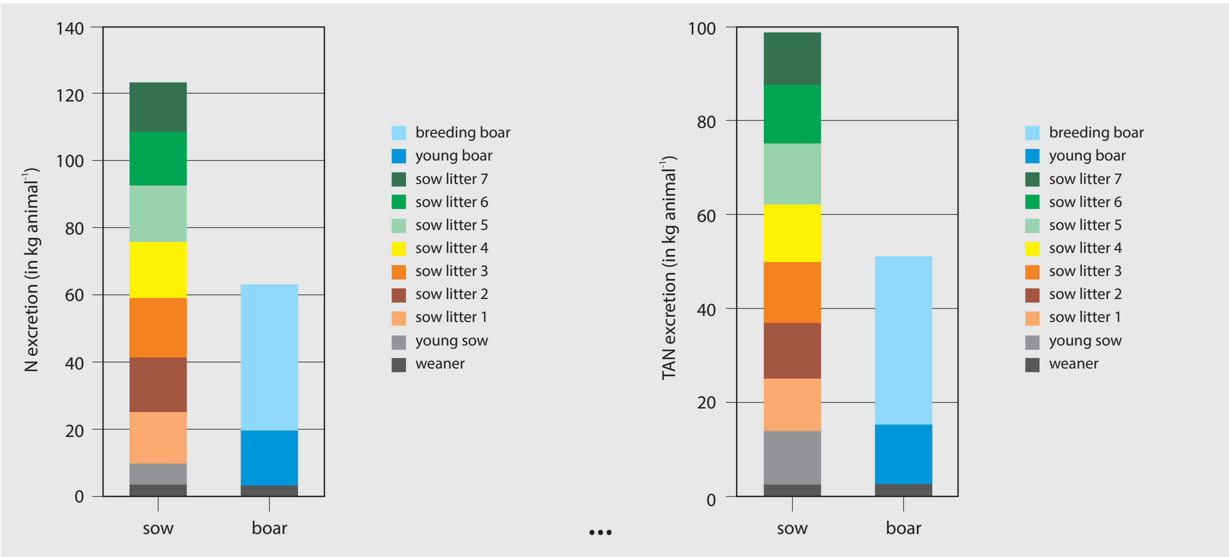

Figure 13
N and TAN excretions during the entire life span of a sow and a boar used for reproduction (ME requirements as in Table 5, performance data as in Table 8, diet properties as in Table 9) (N excretions of sows (sow litter) include those of piglets.)

8 Discussion

8.1 Applicability to present pig production procedures

At present, piglet production is not flourishing in Germany. This increases economic pressure on the respective enterprises. They strive for increased animal performance to reduce costs. The focus is on sows, in particular the overall number of weaners produced per animal (Kremling, 2012; Kecman and Wähner, 2016). Hence the model has to be able to calculate up to ten reproduction cycles and the maximum number of piglets fed per litter.

The sow module allows for any number of litters as it just reflects the ME requirements for milk production. Hence it can also deal with a sow with sixteen active teats. Nurse sows are not provided for.

The modules for young sows and boars are derived from those describing the respective fattening animals which cover a wide range of performances.

8.2 Compatibility of methods with those used in the German agricultural emission inventory

A basic step in the calculations procedure is the quantification of ME requirements. For young sows and boars, as well as for breeding sows, the methods applied are modifications of the respective inventory methods, using different input data reflecting the lower weight gains and higher final weights.

For breeding sows, the inventory sow model is applied to each single litter using specific piglet numbers and weight gains.

For daily ME requirements, our model for breeding boars takes the productive stage of the boar into account where the inventory model uses a constant ME value (Haenel et al., 2016).

Our calculation procedures follow the guidebook recommendations in IPCC (2006) and EMEP (2013) in principle. Where national input data and procedures are used, they were published and accepted by the scientific community.

8.3 Usability for lifecycle analysis or footprint calculations

All models require input of nutritional values which are deduced from diet compositions. Here, the input data use specific feed compositions which can be varied. The amounts of each single feed component can be quantified and are then used as input parameters for feed production calculations, and subsequently for matter and energy flows in the production chain.

8.4 Uncertainties

The information provided in data collections such as GfE (2008), DLG (2014) and Beyer et al. (1993) does not state uncertainties. However, these data are widely used in Germany.

N excretion rates obtained on the basis of the calculations described above are in accordance with those in DLG (2014).

Acknowledgements

Johannes Hilger, Schweinevermarktung Rheinland e. V., provided useful data and background information, which is greatfully acknowledged.

References

Adam F (undated) Was bringen zusätzliche Ausschlachtungsprozente beim Schwein? : Abbildungen [online]. To be found at <https://www.landwirtschaftskammer.de/landwirtschaft/tierproduktion/schweinehaltung/pdf/abbildungen-erloes-schlachtschwein.pdf> [quoted 28.06.2017]

Aherne FX, Williams LH (1992) Nutrition for optimising breeding herd performance. Vet Clin North Am Food Anim Pract 8:589-608

Beyer M, Jentsch W, Hoffmann L, Schiemann R (1993) Untersuchungen zum Energie- und Stickstoffumsatz von graviden und laktierenden Sauen sowie von Saugferkeln : 2. Mitteilung - Chemische Zusammensetzung und Energiegehalt der Tierkörper von graviden, güsten und laktierenden Sauen. Arch Anim Nutr 44:317-338

BMEL - Bundesministerium für Ernährung und Landwirtschaft (2016) Landwirtschaft verstehen : Fakten und Hintergründe [online]. To be found at <http://www.bmel.de/SharedDocs/Downloads/Broschueren/Landwirtschaft-verstehen.pdf;jsessionid=87826B987C043C1367F6FA89C0A-F5A2A.2_cid358?__blob=publicationFile> [quoted 28.06.2017]

BMELF - Bundesminister für Ernährung, Landwirtschaft und Forsten (1994) Verordnung über die Leistungsprüfungen und die Zuchtwertfeststellung bei Schweinen vom 16. Mai 1991 (BGBl. I S. 1130), Fassung vom 17. August 1994 (BGBl. I S. 2133) [online]. To be found at <https://www.gesetze-im-internet.de/bundesrecht/schwzlpv/gesamt.pdf> [quoted 28.06.2017]

BMELF - Bundesminister für Ernährung, Landwirtschaft und Forsten (1979) Verordnung über die Körung von Ebern. Bundesgesetzbl I 1979:1483-1489

Close WH, Cole DJA (2000) Nutrition of sows and boars. Nottingham : Nottingham Univ Pr, 377 p

Dämmgen U, Schulz J, Kleine Klausing H, Hutchings NJ, Haenel H-D, Rösemann C (2012) Enteric methane emissions from German pigs. Landbauforsch 62(3):83-96

Dämmgen U, Berk A, Otten C, Brade W, Hutchings NJ, Haenel H-D, Rösemann C, Dänicke S, Schwerin M (2013) Anticipated changes in the emissions of greenhouse gases and ammonia from pork production due to shifts from fattening of barrows to fattening of boars. Landbauforschung Appl Agric Forestry Res 63(1):47-60

Dämmgen U, Liermann W, Böschen V, Berk A, Dänicke S (2016) Der Einfluss der Futterkonfektionierung bei Mastschweinen und Broilern auf die Emission von Treibhausgasen und Ammoniak : Betrachtung der gesamten Produktionskette. Landbauforsch Appl Agric Forestry Res 66(1):45-70

DBV - Deutscher Bauernverband (2015) Situationsbericht 2015/2016 : landwirtschaftliche Gesamtrechnung [online]. To be found at <http://www.bauernverband.de/53-landwirtschaftliche-gesamtrechnung-664078> [quoted 28.06.2017]

Derking S (2014) Feldstudie an hochproduktiven Sauen zu Fütterungseinflüssen auf die Entwicklung der Körpermasse und Rückenspeckdicke in der Laktation sowie auf die Leistung der Ferkel (Wurfzuwachs) [online]. To be found at <http://elib.tiho-hannover.de/dissertations/derkings_ss15.pdf> [quoted 28.06.2017]

DLG - Deutsche Landwirtschaftsgesellschaft (2008) Empfehlungen zur Sauen- und Ferkelfütterung. Frankfurt a M : DLG Verl, 56 p, DLG Inform 1/2008

DLG - Deutsche Landwirtschaftsgesellschaft (2014) Bilanzierung der Nährstoffausscheidungen landwirtschaftlicher Nutztiere. Frankfurt a M : DLG Verl, 120 pp

Dourmad J-Y, Étienne M, Noblet J, Casseur D (1997) Prédiction de la composition chimique de la truie reproductrice à partir du poids vif et de l'épaisseur de lard dorsal. Journéee Rech Porcine France 29:255-262

Dourmad J-Y, Étienne M, Valancogne A, Dubois S, van Milgen J, Noblet J (2008) InraPorc : a model and decision support tool for the nutrition of sows. Anim Feed Sci Technol 143:372-386

EC - European Commission (2016) National Emission Ceilings [online]. To be found at <http://ec.europa.eu/environment/air/pollutants/ceilings.htm> [quoted 28.06.2017]

EMEP - EMEP-EEA air pollutant emission inventory guidebook (2013) : Technical Report 12/2013 [online]. To be found at <http://www.eea.europa.eu//publications/emep-eea-guidebook-2013> [quoted 28.06.2017]

Everts H, Dekker RA (1995) Effect of protein supply during pregnancy and lactation on body condition of sows during three reproductive cycles. Livest Prod Sci 43:137-147

GfE - Gesellschaft für Ernährungsphysiologie, Ausschuss für Bedarfsnormen (1987) Energie- und Nährstoffbedarf landwirtschaftlicher Nutztiere : 4: Schweine. Frankfurt a M : DLG-Verlag, 153 p

GfE - Committee for Requirement Standards of the Society of Nutrition Physiology (2008) Recommendations for the supply of energy and nutrients to pigs. Frankfurt a M : DLG-Verl 245 p

Gill BP (2006) Body composition of breeding gilts in response to dietary protein and energy balance from thirty kilograms of body weight to completion of first parity. J Anim Sci 84:1926-1934

Haenel H-D, Dämmgen U, Laubach P, Rösemann C (2011a) Update of the calculation of metabolizable energy requirements for pigs in the German agricultural emission inventory. Landbauforsch 61(3):217-228

Haenel H-D, Dämmgen U, Rösemann C (2011b) Estimating numbers of piglets, weaners and fattening pigs for the German agricultural emission inventory. Landbauforsch 61(3):229-236

Haenel H-D, Rösemann C, Dämmgen U, Freibauer A, Döring U, Wulf S, Eurich-Menden B, Döhler H, Schreiner C, Osterburg B (2016) Calculations of gaseous and particulate emissions from German agriculture 1990 – 2014 : report on methods and data (RMD) submission 2016. Braunschweig : Johann Heinrich von Thünen Inst, 409 p, Thünen Rep 39

Hansen AV, Strathe AB, Theil PK, Kebreab E (2014) Energy and nutrient deposition and excretion in the reproducing sow : model development and evaluation. J Anim Sci 92:2458-2472

Heinze A, Rau K, Ochrimenko W, Gernand E (2008) Untersuchungen zur Lebendmasseentwicklung und zur Konditionsbewertung bei Sauen im Reproduktionszyklus : Abschlussbericht [online]. To be found at <http://www.tll.de/ainfo/pdf/saur0608.pdf> [quoted 28.06.2017]

Hilgers J (2013) Lang lebe die Sau [online]. To be found at <http://www.topagrar.com/archiv/Lang-lebe-die-Sau-1183590.html> [quoted 28.06.2017]

Hühn U, Gericke R (2000) Lebendmasseentwicklung und Fruchtbarkeit bei Sauen. VeredlungsProduktion 2000(1):17-18

IPCC – Intergovernmental Panel on Climate Change (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories : vol: 4 Agriculture, forestry and other land use [online]. To be found at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html> [quoted 28.06.2017]

IPCC – Intergovernmental Panel on Climate Change (2007) Climate change 2007: Working Group I: the physical science basis : 2.10.2 Direct global warming potentials [online]. To be found at <http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html#table-2-14> [quoted 05.07.2017]

Jeroch H, Drochner W, Simon O (1999) Ernährung landwirtschaftlicher Nutztiere : Ernährungsphysiologie, Futtermittelkunde, Fütterung. Stuttgart : Ulmer, 544 p

Kecman J, Wähner M (2016) Management großer Würfe in der Ferkelerzeugung. Tierärztl Prax G 44:318-325

Kemp B, Soede NM (2001) Feeding of developing and adult boars. In: Lewis AJ, Southern LL (eds) Swine nutrition. Boca Raton : CRC Pr, pp 771-782

Kirchgeßner M, Kreuzer M, Müller HL, Windisch W (1991) Release of methane and carbon dioxide by the pig. Agribiol Res 44:103-113

Kirchgeßner M, Roth FX, Schwarz FJ, Stangl G (2008) Tierernährung : Leitfaden für Studium, Beratung und Praxis. Frankfurt a M : DLG Verl, 635 p

Kleine Klausing H, Riewenherm G (2012) Fütterung von Zuchtschweinen. In: Hoy S (ed) Schweinezucht und Ferkelerzeugung. Stuttgart : Ulmer, pp 153-176

Kornblum E (1997) PIC Futterecke : Rückenspeck und Leistung. PIC Spiegel 1/97

Kremling R (2012) Große Würfe - Fluch oder Segen? Top agrar 11:S10-13

Kremling R (2013a) Frühzeitig Körperfett anfüttern. Top agrar 7:S8-S9

Kremling R (2013b) Nach dem 8. Wurf ist Schluss. Top agrar 7:S10

Le TH, Christensen OF, Nielsen B, Sahana G (2017) Genome-wide association study for conformation traits in three Danish pig breeds. Genet Sel Evol 49:12

LfL - Bayerische Landesanstalt für Landwirtschaft (2013) Basisdaten Stand: 2013 [online]. To be found at <www.lfl.bayern.de/iab/duengung/031245/> [quoted 30.06.2017]

Monteny GJ, Erisman JW (1999) Ammonia emission from dairy cow buildings : a review of measurement techniques, influencing factors and possibilities for reduction. Neth J Agric Sci 46:225-247

Motte J-C, Trably E, Escuidié R, Hamelin J, Steyer J-P, Bernet N, Delgenes J-P, Dumas C (2013) Total solids content : a key parameter of metabolic pathways in dry anaerobic digestion. Biotechnol Biofuels 6:164

Müller S, Reimann G, Gottschall U, Braun U, Kallenbach K (2011) Jahresbericht 2010 über die Leistungsprüfung bei Schweinen in Thüringen [online]. To be found at <www.tll.de/ainfo/pdf/jbls0311.pdf> [quoted 28.06.2017]

Norsvin (2015) TN70 Gilt feeding and management [online]. To be found at <http://tn70.tint-tn.nl/wp-content/uploads/2016/03/TN70-gilt-manual.pdf> [quoted 28.06.2017]

PIC (2016) PIC nutrient specifications manual [online] To be found at <http://na.picgenus.com/tech_support/nutrition/nutrient_specifications_manual_download.aspx> [quoted 28.06.2017]

Rothschild MF, Ruvinsky A (2011) The genetics of the pig. Wallingford : CABI, 520 p

Schnurrbusch U (2004) Bedeutung des Körperfetts für die Fruchtbarkeit von Sauen. Lohmann Informationen 4/2004:1-6

Spanlang U (2011) Zusammenhang zwischen BCS (Body Condition Score) und weiteren Körpermerkmalen sowie der Aufzuchtleistung von laktierenden Zuchtsauen. Wien : Univ Bodenkultur, 89 p

Tribout T, Larzul C, Phocas F (2013) Economic aspects of implementing genomic evaluations in a pig sire line breeding scheme. Genet Sel Evol 45:40

Tusell L, Gilbert H, Riquet J, Mercat M-J, Legarra A, Larzul C (2016) Pedigree and genomic evaluation of pigs using a terminal-cross model. Genet Sel Evol 2016 48:32

TVL/SKBR - Thüringer Verband für Leistungs- und Qualitätsprüfungen in der Tierzucht (2016) Bericht über Arbeit und Ergebnisse : Prüfungsjahr 2015 [online]. To be found at <http://www.tvlev.de/cms/sites/default/files/downloads/publikationen/TVL%20Jahresbericht%202015_Endfassung_01-04-16.pdf> [quoted 28.06.2017]

UBA - Umweltbundesamt (2016a) Ammoniak [online]. To be found at <http://www.umweltbundesamt.de/themen/luft/luftschadstoffe/ammoniak> [quoted 28.06.2017]

UBA - Umweltbundesamt (2016b) Treibhausgas-Emissionen in Deutschland [online]. To be found at <www.umweltbundesamt.de/themen/klima-energie/klimaschutz-energiepolitik-in-deutschland/treibhausgas-emissionen/emissionsquellen> [quoted 28.06.2017]

UNFCCC - United Nations Framework Convention on Climate Change (undated) First steps to a safer future: introducing the United Nations Framework Convention on Climate Change [online] To be found at <http://unfccc.int/essential_background/convention/items/6036.php> [quoted 28.06.2017]

Wähner M (2012) Zucht- und Produktionsziele in der Schweinezucht. In: Hoy S (ed) Schweinezucht und Ferkelerzeugung. Stuttgart : Ulmer, pp 17-59

Whittemore CT (1993) The science and practice of pig production. Harlow : Longmann, 661 p

Wilson ME, Rozeboom KJ, Crenshaw TD (2004) Boar nutrition for optimum sperm production. Adv Pork Prod 15:295-306

Xiang T, Nielsen B, Su G, Legarra A, Christensen OF (2016) Application of single-step genomic evaluation for crossbred performance in pig. J Anim Sci 94:936-948