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How does an outdoor yard influence ammonia emissions from fattening pig housings?

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Agricultural livestock farming causes ammonia emissions. However, there have been limited measurements conducted to quantify ammonia emissions from freely ventilated fattening pig housings with outdoor yards. This study presents annual ammonia emission rates and factors related to total ammoniacal nitrogen (TAN) excretion for fattening pig housings with different outdoor yard designs. The research project "Determination of emission data for the assessment of the environmental impact of livestock farming" (EmiDaT) involved conducting ammonia emission measurements over the course of one year at eight fattening pig housings located in different regions of Germany. These housings had varying yard floor designs, including solid and littered yards or yards with slatted floors. No statistically significant difference in ammonia emission rates was found between the two outdoor yard variants. The average annual ammonia emission rate was determined to be 2.6 kg NH_3-N AP^{-1} a^{-1}. The results of the "EmiDaT" project indicate that fattening pig barns with outdoor yards are generally not associated with higher NH_3 emission rates compared to forced-ventilated houses.

Keywords
Emissions, ammonia, fattening pig houses, outdoor yard, emission rate, emission factor

Within the framework of European agreements on air pollution control (Directive EU 2016), Germany has committed to complying with specified emission limits and reporting annual nitrogen emissions from various sectors, including agriculture. Animal husbandry is a significant contributor to total ammonia (NH_3) emissions, accounting for approximately 70% of the emissions. NH_3 emissions originate from livestock buildings as well as storage and application of farm manure (slurry, solid manure etc.).TierAccurate annual emission rates are necessary to estimate NH_3 emissions on an annual basis, considering animal type, production direction, and husbandry method. The current annual emission rates for ammonia used in Germany (VDI 2011) are based on older studies, some dating back to the 1990s, and mostly rely on conventional values. It is therefore logical to systematically review and update these conventional values due to changes in production conditions and advancements in measurement techniques. Additionally, husbandry methods, such as barns with outdoor yards for fattening pigs, should be recorded, as limited test results are available for these scenarios, leading to solid-rate surcharges being applied to outdoor yard emissions.

The project „Determination of emission data for the assessment of the environmental impact of livestock farming" (EmiDaT) aimed to determine NH_3 emission rates from freely ventilated fattening pig housings with outdoor yards in different regions of Germany. The objective of the study was to estimate NH_3 emissions from fattening pig housings with different yard designs, including solid and

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littered outdoor yards, as well as yards with slatted floors. Furthermore, as part of the project, the plausibility of previously used ammonia emission values for closed, forced-ventilated barns was examined.

Material and methods

Investigated housing systems and locations

Ammonia emissions from fattening pig barns with outdoor yards (free ventilation) were investigated for two housing variants: 1. solid, littered yard ("solid") and 2. yard with a slatted floor ("slatted"). Care was taken to select study barns where there were no significant NH_3 emission sources in the immediate vicinity. The barns were mostly standalone structures, allowing for good airflow throughout. The selected farms adhered to good professional practices in farm management.

The "solid" and "slatted" variants differ in the structural design of the housing system and the design of the outdoor yard, with or without bedding.

In the "solid" variant, fattening pig houses had solid, littered outdoor yards. Ventilation in the enclosed barns occurred through windows, doors, and passages into the freely ventilated yard or housing. During the measurements, three out of the four farms had 100% of their outdoor areas covered with litter, while one farm had 50% of the total outdoor area covered. Manure removal from the outdoor yards was done manually using a farm tractor, at least twice a week for all four farms.

In the „slatted" variant, the barns were freely ventilated outdoor climate housings, inside the housings lying boxes with lids; outdoor yards with slatted floors. Ventilation inside the housing was regulated by curtains and passages leading to the yard. Two out of the four farms had underfloor sliders, and manure removal from under the slats was carried out daily. In the other two farms, manure drainage from the channel under the slats of the yard was done regularly and as needed.

Additionally, the housing variants differed in the structural design of the yard roofing. The proportion of roofing for the outdoor yards varied from 50% to 100%. One farm had installed a sun awning as an alternative to yard roofing.

For each of the "solid" and "slatted" variants, four representative practice housings were selected. Ammonia emissions were measured in the outdoor yards. The locations of the housings are illustrated in Figure 1.

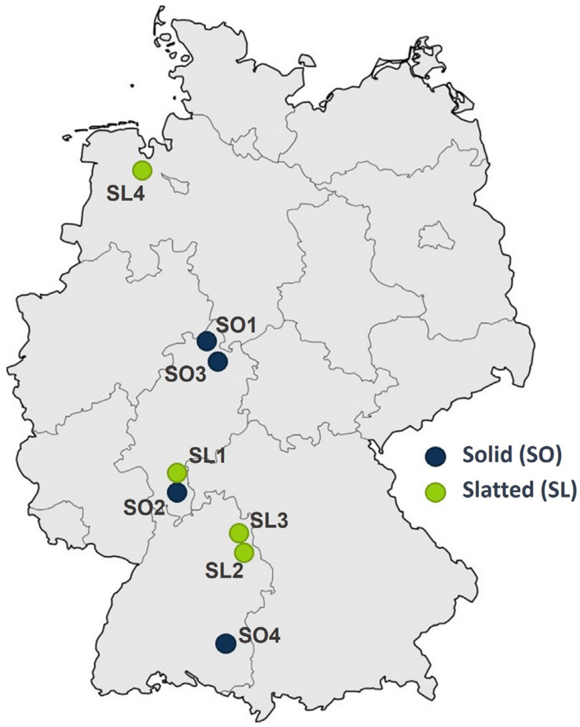

Figure 1: Locations of the 8 fattening pig housings investigated in Germany

The feeding of the fattening pigs followed the feeding recommendations according to DLG (2021) and consisted of up to three phases, as outlined in Table 1. Consequently, it can be assumed that similar levels of nitrogen (N) excretion per fattening pig were observed with comparable animal performance.

The measurements were conducted from 2019 to 2021. Table 1 and Table 2 provide an overview of the housing facilities that were investigated, summarizing relevant information about them.

Table 1: Overview of the fattening pig houses investigated for the variant "solid"

Feature	**Reference unit**	**Variant "solid"**			
		Housing			
		SO1	**SO2**	**SO3**	**SO4**
Buildings and animals					
Year of construction	Year	2006, reconstruction 2015	2000	2016	2006
Animal places (AP)	Quantity	204	120	200	600
Breed	-	Hybrid x Pietrain	Hybrid x Pietrain x Duroc	German Hybrid x Pietrain	90% CH LR[1] x Pietrain; 10% Duroc x Iberico
Mast procedure		in-out	in-out	continuously	continuously
Occupancy time in the housing	Days	345	345	365	365
Area/AP total[2]	m^2	2.4	1.6	1.1	1.7

The table continues on the next page

Feature	Reference unit	Variant “solid” Housing			
		SO1	SO2	SO3	SO4
Outdoor yard					
Floor design outdoor yard	-	solid (with bedding material)	solid (with bedding material)	solid (with bedding material)	solid (with bedding material)
Yard area/animal MW[3)]	m^2	1.3	0.8	0.5	0.7
Alingment yard at building	-	one-sided	one-sided	one-sided	both sides
Proportion Roofing	%	50	100	100	100
Management					
Bedding bay in stable[4)]	-	completely littered	minimum bedding	minimum bedding	minimum bedding
Bedding outdoor yard	-	50% littered	completely littered	completely littered	completely littered
Bedding material	-	straw	straw	straw	straw
Floor cleaning of yard	-	farm tractor	farm tractor	farm tractor	farm tractor
Cleaning frequency	-	3 times per week	2 times per week	2 times per week	2 times per week
Type of feed/Number of fedding phases	-	dry feed/ 1	mash feed/ 2	dry feed/ 1	dry feed/ 3
Number of fedding phases					
NH_3-N	kg AP^{-1} a^{-1}	4.2	3.5	3.8	1.4

[1)] Landrace. [2)] Based on the number of approved animal places. [3)] Mean value over all measurement weeks (MW).
[4)] Minimum bedding: manipulable material

Table 2: Overview of the fattening pig houses investigated for the variant “slatted”

Feature	Reference unit	Variant “slatted” Housing			
		SL1	SL2	SL3	SL4
Buildings and animals					
Year of construction	Year	2017	Housing 1: 2017, Housing 2: 2019	Housing 1: 2016, Housing 2: 2020	2002; reconstruction 2019
Animal places (AP)	Quantity	408	995	1296	64
Breed	-	Dt. Hybrid x Pietrain x Duroc	SH[1)] x Pietrain; BW Hybrid[2)] x Pietrain	Dt. Hybrid	db. Viktoria x Pietrain
Mast procedure	-	continuously	continuously	continuously	in-out
Occupancy time in the housing	Days	365	365	365	345
Area/AP total[2)]	m^2	1.7	1.3	1.2	1.6

The table continues on the next page

Feature	Reference unit	Variant “slatted” Housing			
		SL1	SL2	SL3	SL4
Outdoor yard					
Floor design outdoor yard	-	50 % solid with bedding; 50 % slatted	slatted	slatted	slatted
Yard area/animal MW[3)]	m^2	1.1	0.4	0.5	0.6
Alignment outdoor yard on building	-	one-sided	one-sided	one-sided	one-sided
Proportion Roofing	%	75	50	0[5)]	100
Management					
Bedding bay in housing[4)]	-	minimal bedding lying box	minimal bedding lying box	minimal bedding lying box	minimal bedding lying box
Bedding outdoor yard	-	solid part littered	-	-	-
Type of bedding	-	straw	straw	straw	straw
Floor cleaning of yard	-	farm tractor plane-fixed/ underfloor scrapper	manually above ground; scrapper underfloor	manually above ground; slurry channel after passage	manually above ground; slurry channel after passage
Cleaning frequency	-	littered area: once per week underfloor scrapper: once per day	above ground: as required; underfloor scrapper: 2 times per day	as needed	above ground: once per day
Type of feeder/ Number of phases	-	mash feed/ 2	mash feed/ 2	dry feed/ 3	dry feed/ 2
Mittlere Jahresemissionsraten					
NH_3-N	kg AP^{-1} a^{-1}	3.5	1.4	2.1	0.9

1) Schwäbisch-Hällische. 2) Based on the number of approved animal places. 3) Mean value over all measurement weeks (MW).
4) Sun awning over entire outdoor yard. 5) Minimum bedding = manipulable material

Calculation of “Total Ammonical Nitrogen” in the excreta

“Total Ammoniacal Nitrogen” (TAN = NH_3-N + NH_4^+-N) refers to the nitrogen component in excreta that can potentially be rapidly converted into ammoniacal nitrogen, including urea in the excreta. The calculation of TAN content in excreta was based on the KTBL (2014) guidelines. In this approach, the nitrogen ingested through feed is allocated to nitrogen excreted in urine and feces using a substance flow model that takes into account digestibility and animal performance.

By considering TAN contents in the excreta (ranging from 5–20% TAN in feces and 60–95% TAN in urine relative to their respective total nitrogen content), average TAN contents in the excreta can be calculated based on the feeding regime and animal performance. For the investigated fattening procedures, the calculated proportion of TAN in total nitrogen excretion was approximately 76%. The European Environment Agency (EEA 2019) assumes an average TAN content of around 70%.

Emission measurements in freely ventilated outdoor yards

At each location, emissions from the outdoor yards were measured during at least six weeks distributed throughout the year. The measurements followed a standardized protocol based on VERA (2018), ensuring consistent measurement procedures.

The ventilation and emission rates of the yards were determined using the tracer ratio method (VERA 2018). Tracer gas dosing and gas sampling for NH_3 and SF_6 measurements were conducted exclusively in the outdoor yards (Figure 2). During the study, a tracer gas (in this case sulfur hexafluoride, SF_6) was released into the outlet area at a constant flow rate. The dosing was performed in the outdoor yard, employing nozzles installed in the floor area at the grid partitions, strategically positioned to avoid disturbance by the fattening pigs. Due to variations in farm structures and management practices, customized adjustments to the dosing technology were necessary.

In the measurement room of the freely ventilated outdoor yards, air was drawn in above the tracer gas sampling points using a manifold located at approximately 1.8 meters height (Figure 2). The air samples were combined to create a composite sample. The concentration of the tracer gas was determined using GC-ECD (gas chromatography with an electron capture detector), while the ammonia concentration was measured using FTIR (Fourier-transform infrared spectroscopy). Tracer gas concentration measurements were conducted every 20 minutes. Background ammonia concentration in the ambient air was determined using passive samplers followed by wet chemical analysis.

Regular inspections and photographic documentation were carried out during the measurement weeks to assess soiling both inside and outside the barns.

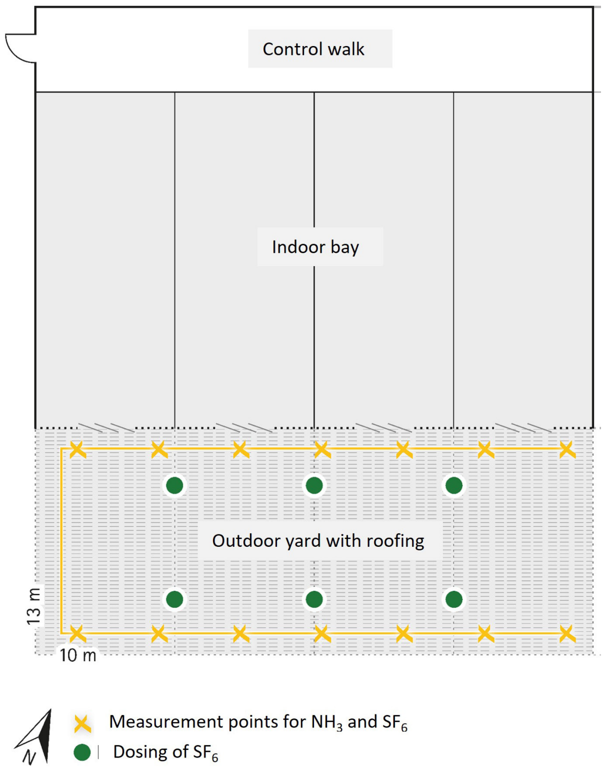

Figure 2: Schematic measurement setup for an operation of the variant “slatted”. Tracer gas SF_6 was added near the ground in the outdoor yard (green dots), while sampling for SF_6 and NH_3 concentration was conducted in the air space above using a manifold (highlighted in yellow).

Meteorological data, including temperature, humidity, wind speed, wind direction, and other relevant parameters, were gathered using a weather station located near the housing. Following a rigorous quality control process and plausibility check of all collected data, a temporal alignment was established (with a maximum deviation of one minute) between the measured gas concentrations of ammonia (NH_3) in the outdoor yard and the injection rates of the tracer gas (SF_6). This alignment was performed using a specialized database application.

Calculation of emission and ventilation rates

The volume flow rates and NH_3 emission rates were calculated using the mass balance equation of the tracer ratio method. As an example, the calculations for the reference units of $m^3\ h^{-1}$ (volume flow rate) and $g\ h^{-1}$ (emission rate) are illustrated in Equations 1a and 1b:

$$VR = \frac{E_{SF_6}}{\Delta C_{SF_6}} \qquad \text{(Eq. 1a)}$$

$$E_{NH_3} = \frac{\Delta C_{NH_3}}{\Delta C_{SF_6}} \cdot E_{SF_6} \qquad \text{(Eq. 1b)}$$

with

E_{NH_3} = Emission rate NH_3 in $g\ h^{-1}$

E_{SF_6} = Emission rate SF_6 in $g\ h^{-1}$

ΔC_{NH_3} = NH_3-concentration difference (outdoor yard air - background) in $g\ m^{-3}$

ΔC_{SF_6} = SF_6-concentration difference (outdoor yard air - background) in $g\ m^{-3}$

VR = Ventilation rate in $m^3\ h^{-1}$

The calculation of the emission factors for the reference unit “animal place and year” is illustrated in Equation 2 as an example:

$$EF_{NH_3} = \frac{E_{NH_3(AP,a)}}{TAN-amount} \qquad \text{(Eq. 2)}$$

with

$EF_{NH_3(AP,a)}$ = emission factor, dimensionless ($0 \leq EF_{NH_3(AP,a)} \leq 1$)

$EF_{NH_3(AP,a)}$ = emission rate in kg NH_3-N $AP^{-1}\ a^{-1}$

TAN-amount = amount of TAN in excrementin kg TANexcr $AP^{-1}\ a^{-1}$

The average ammonia concentrations obtained from the passive samplers during each measurement period were considered as background concentrations. Since SF_6 is typically challenging to detect in ambient air (approximately 10 ppt mass fraction, NOAA 2023), and preliminary studies indicated SF_6 concentrations below the detection limit, the SF_6 concentration in ambient air was assumed to be zero.

To capture various weather conditions, especially temperature ranges throughout the year, measurements were conducted multiple times across all seasons. Additionally, the measurement periods were set to cover different stages of the fattening cycle, corresponding to different animal masses.

The results obtained from individual measurement points were initially aggregated into arithmetic hourly mean values. For calculating annual emission rates, the hourly mean values were weighted based on the frequencies of long-term temperature hourly mean values from a weather station near each study site (DWD 2020). Furthermore, the calculated NH_3 emission rates were adjusted to an average live weight of 67 kg, considering a sigmoidal growth curve for the fattening period. The calculated NH_3 emission rates from the outdoor area were attributed to the entire housing system "outdoor climate barn with outdoor yard."

The annual mean NH_3 emission rates for each site, weighted by temperature and live weight, were categorized into the variants "solid" and "slatted". Significant differences between the variants were tested using analysis of variance (ANOVA) with a simple t-test.

Emission measurements in forced-ventilated, closed housings

The mean annual NH_3 emission rates from forced-ventilated housings in northern Germany were calculated using data obtained from the inspection of exhaust air purification systems conducted by LUFA Nord-West. Measurements of volume flow rates and NH_3 concentrations in the air were conducted in the exhaust stacks of the enclosed barns. Details regarding feeding, housing type, and the number of animals during the measurements can be found in Table 3. The available space per animal, which was 0.75 m^2, met the minimum requirements outlined in the German Animal Welfare Livestock Ordinance (TierSchNutztV 2006). According to DIN EN 18910, the air exchange rates in summer and winter ranged from 36 to 98 m^3 h^{-1} $animal^{-1}$ and 14 to 51 m^3 h^{-1} $animal^{-1}$, respectively, depending on the average weight of the animals. In total, data from 8 locations were evaluated, encompassing the period between 2005 and 2017, and including different seasons with more than 22,000 individual measurements.

Table 3: Overview of the investigated forced-ventilated, closed fattening pig housings

Feature	**Operation**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of animals 1)	312	1,158	3,740	520	1,276	1,512	189	960
Mast method	in-out	continu-ously	in-out	continu-ously	in-out	in-out	in-out	continu-ously
Number of feeding phases	2	3	2	2	6	2	2	3
RAM 2) - feeding	n. s. 3)	yes	n. s. 3)	n. s. 3)	yes	n. s. 3)	n. s. 3)	yes
Average annual NH_3-N emission rate in kg AP^{-1} a^{-1}	2.9	3.3	2.1	2.6	2.3	3.8	2.4	2.8

1) At the time of the measurements. 2) RAM = low crude protein. 3) n. s. = not specified.

The NH_3 loads were calculated by combining the measured NH_3 concentrations in the raw gas with the directly determined volumetric flow rate using measuring fans. Subsequently, the NH_3 emission rates (in kg NH_3-N AP a^{-1}) were calculated considering the number of fattening days per year, the number of animals during the measurement period, and the average weight of the animals. It was assumed that all farms had 330 fattening days per year. To facilitate comparability between the different farms, a weight normalization was also conducted, using a mean live weight of 67 kg.

Results

Ammonia emissions – freely ventilated housings with outdoor yards

The NH_3 emission rates of the individual measurements were extrapolated to annual values to provide a comprehensive representation. These values showed variation both between the different housings and within the measurement weeks (Figure 3). The variation can be attributed to factors such as variations in cleaning practices and soiling levels of the outdoor yards, as well as differences in temperature conditions and animal weights throughout the year.

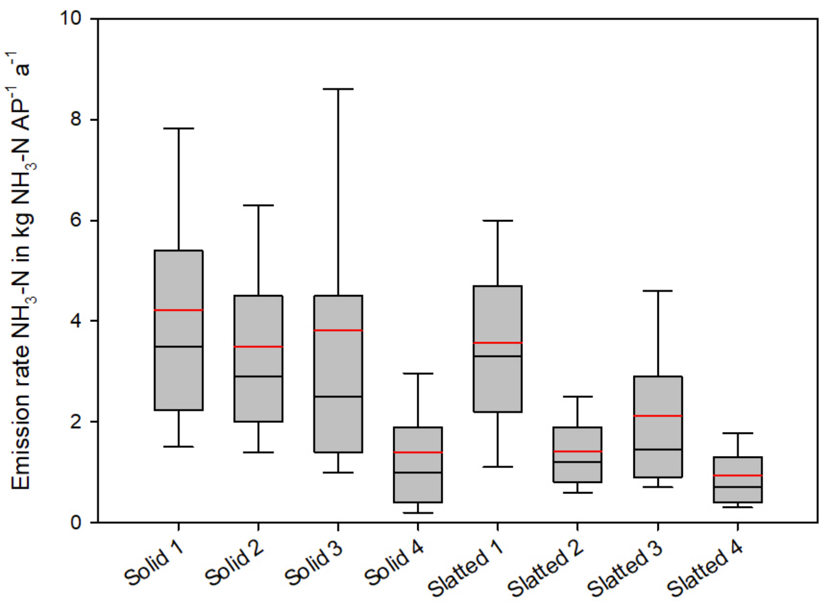

Figure 3: Calculated ammonia emission rates (kg NH_3-N AP^{-1} a^{-1}) for the variants "solid" and "slatted" based on unweighted hourly averages. The red and black lines represent the arithmetic mean and median, respectively (AP = animal place).

Table 4 presents the reference units and reference values utilized in the study. It indicates that an average nitrogen excretion of 11.0 kg N AP^{-1} a^{-1} can be considered.

Table 4: Reference units and reference values for the results of fattening pig houses with a free outdoor yard

	Reference unit	**Reference value**
Mean animal live weight (LW) of fattening pig over fattening period	kg LM	67
Livestock unit (LU)	kg LM	500
1 fattening pig = 1 animal place (AP)	LU	0.1336
Average growth rate fattening pig	g LM d^{-1}	791
Mean amount of TAN in excrement	kg TANexcr AP^{-1} a^{-1}	8.5
Mean N excretion	kg N AP^{-1} a^{-1}	11.0
Number of farms with outlet	n	8

The average temperature- and live weight-weighted annual NH_3 emission rates are presented in Table 5. The emission rates are 3.2 kg NH_3-N AP^{-1} a^{-1} for the variant “solid” and 2.0 kg NH_3-N AP^{-1} a^{-1} for the variant “slatted”. No statistically significant difference in the weighted annual NH_3 emission rates could be observed between the two variants (Table 5). The average value of both variants is 2.6 kg NH_3-N AP^{-1} a^{-1} (Table 6).

Table 5: Temperature- and live weight-weighted annual NH_3 emission rates for the variants “solid” and “slatted”. Emission rates with the same letters are not significantly different (t-test, $p > 0.05$; AP = animal place).

Variant	**Emission rate kg NH_3-N AP^{-1} a^{-1}**
Solid	3.2[a]
Slatted	2.0[a]

As shown in Table 6, the average NH_3-N emission factor for both variants, relative to the calculated TAN amount, is 0.31 kg NH_3-N kg $TANexcr^{-1}$.

Table 6: Arithmetic mean, standard deviation, and median value of temperature- and live weight-weighted NH_3-N emission rates and NH_3-N emission factors calculated for all investigated fattening pig barns with a free-range (“solid” + “slatted”; n = 8)..

	NH_3-N emission rates in kg a^{-1}		**NH_3-N-emission factors related to**	
	LU	**AP**	**TAN amount in excrements (TANexcr)**	**Amount of N in excrements (Nexcr)**
Mean value (arithmetic)	19,9	2,6	0,31	0,24
Standard deviation	9.9	1.3	0.15	0.12
Median	21.0	2.8	0.32	0.25

Ammonia emissions – closed, forced-ventilated fattening pig housings

Table 7 presents the reference units and reference values used for the closed barns with forced ventilation.

Table 7: Reference units and reference values for the results of closed, forced-ventilated fattening pig housings

	Reference unit	**Reference value**
Mean animal live weight (LW) "fattening pig" over fattening period	kg LW	67
Livestock unit (LU)	kg LW	500
1 fattening pig = 1 animal place (AP)	LU	0.1336
Number of farms with fully slatted floor	n	8

As presented in Table 8, the calculated mean annual NH_3 emission rate, weighted by live weight, is 2.8 kg NH_3-N AP^{-1} a^{-1} (with an average animal live weight of 67 kg over the fattening period). Unfortunately, accurate data for mean daily gain rate (g LW d^{-1}), mean annual N excretion (kg N AP^{-1} a^{-1}), and mean annual TAN excretion in feces (kg TANexcr AP^{-1} a^{-1}) were not available for the farms. However, it can be assumed that these values fall within the range of a typical fattening operation.

Table 8: Arithmetic mean, standard deviation, and median value of temperature- and live weight-weighted NH_3-N emission rates and NH_3-N emission factors calculated for all investigated closed, forced-ventilated fattening pig barns (n = 8).

	NH_3-N emission rates in kg a^{-1}	
	LU	**AP**
Mean value (arithmetic)	21.0	2.8
Standard deviation	3.7	0.5
Median	20.2	2.7

Discussion

The calculated mean annual NH_3 emission rates for housing systems with outdoor yards of 2.6 kg NH_3-N AP^{-1-} a^{-1} fall between the emission rate of 3.0 kg NH_3-N AP^{-1} a^{-1} reported by VDI (2011) for forced-ventilated barns with fully slatted floors, and the emission rate of 2.0 kg NH_3-N AP^{-1} a^{-1} for outdoor climate housings without outdoor yards. It should be noted that the emission rates reported by VDI (2011) are considered convention values, with the emission rate for outdoor climate barns derived from studies by Niebaum (2001) among others, on outdoor climate barns without yards (emission rates of 1.3 and 1.9 kg NH_3-N AP^{-1} a^{-1} at 330 housing days). In current licensing practice, barns with outdoor yards are typically given a 30% surcharge on the corresponding VDI value (Brandenburg State Office for the Environment 2020).

Comparing the convention values according to VDI (2011) with the results of the EmiDaT studies has limitations since the emission rates refer to different types of barns or husbandry methods: closed, forced-ventilated barns without outdoor yards (3.0 kg NH_3-N AP^{-1} a^{-1}; VDI 2011) and outdoor climate barns without yards (2.0 kg NH_3-N AP^{-1} a^{-1}; VDI 2011). However, the results of the current study specifically refer to the housing system “barn with freely ventilated outdoor yard”.

In addition to presenting NH_3 emission rates, expressing NH_3-N emissions as emission factors related to mean N or TAN excretion per animal or animal place and time unit (Table 3) allows for their use in emission inventories (Dämmgen et al. 2010, EEA 2019, Sommer et al. 2019) or farm-specific estimation of ammonia emissions.

Ammonia emissions – temperature influence

Ammonia emissions are influenced by various factors, including the quantity of feces and urine produced, the distribution of excrements, surface air flow, temperature, and more. On livestock farms, in addition to these factors, structural elements such as area sizes and floor design, as well as barn management practices, can also impact NH_3 emissions.

The effect of temperature on NH_3 release has been extensively studied in previous research (Hempel et al. 2016, Monteny 2000, Ni 1999, Sanchis et al. 2019, Ye et al. 2011). Higher air and surface temperatures generally promote NH_3 emissions (Ye et al. 2011, Monteny 2000). However, in the current study, the temperature effect could not be clearly demonstrated for all the farms investigated. This is likely due to the overriding influence of farm management practices (Table 1, Table 2), which can mask the direct impact of temperature on measured NH_3 emissions.

To account for the temperature effect, it was assumed that the (outdoor) air temperature mainly influences the temperature of urine puddles and urine absorbed in straw. Hourly averages of emission rates were normalized based on the frequency of long-term temperature hourly averages from a nearby weather station (DWD 2020). This approach reduces the weight given to measurements taken on warmer-than-average days compared to the overall long-term average. Consequently, more realistic results are obtained regarding the total annual emissions of ammonia.

Ammonia emissions – influence of the outdoor yard area

The outdoor yards of the eight barns under investigation, ranging from 0.4 to 1.3 m^2 per animal, were measured. Regular soiling monitoring conducted in both the yards and the barn buildings revealed that the animals predominantly defecate and urinate in the outdoor yards (Figure 4, Figure 5). As a result, the contribution of ammonia emissions from the barn buildings can be considered low for the housings examined. Therefore, the ammonia emission rates determined from the outdoor yards were applied to the entire housing system referred to as "barn with freely ventilated outdoor yard."

Figure 4: Outdoor run of the variant "solid" with solid bay and straw bedding; the manure area is located at the grid adjacent to the neighbouring bay in the outdoor yard (© KTBL)

Typically, animals tend to concentrate their waste in specific areas within the outdoor yards, creating defecation sites (Figure 4). This localized soiling of yard areas has been documented in previous studies (Mielke et al. 2015, Gilhespy et al. 2009, Ivanova-Peneva 2008). Particularly in longitudinally rectangular yards, the separation of lying and defecation/urination areas has been observed. Ammonia is primarily formed from urea found in excrements, particularly urine, through the action of the enzyme urease. Therefore, the formation of manure/urination areas plays a crucial role in reducing NH_3 emissions. By confining the potentially emitting area to urine puddles, even in larger yard spaces, emissions are reduced compared to scenarios where the entire area is contaminated with urine. As a result, no linear relationship between the size of the yard and NH_3 emission rates could be established for the studied fattening pig housings. Aarnink et al. (2015) also found no correlation between NH_3 emissions and the available area per animal in their study on fattening pig barns with different yard sizes. Overall, the extent of soiled area plays a crucial role in NH_3 emissions, as surface contamination allows for direct NH_3 release (Aarnink 2015). Therefore, proper management of the soiled areas is very important. Regular cleaning and keeping the surfaces dry are effective measures in reducing NH_3 release. Additionally, the use of a roofing above the outdoor yard can help to maintain dry conditions in the areas.

Figure 5: Indoor area of the variant “solid” with solid bay and straw bedding (© KTBL)

Ammonia emissions – influence of floor design and cleaning

No statistically significant difference in mean annual NH_3 emission rates could be observed between the different barn or outdoor yard variants (Table 5). The variation in NH_3 emission rates among the investigated housingns can be partly attributed to differences in cleaning frequencies, particularly with regard to manure removal.

The “slatted” outdoor yard variant shows NH_3 emission rates for three out of the four investigated barns that fall within the range of outdoor climate housings without an outdoor yard, as specified in VDI (2011). However, even in the “solid” variant, there is one farm that achieves a similarly low emission rate. By consistently managing litter and cleaning practices, in combination with urine drainage, NH_3 emissions can also be effectively controlled in outdoor systems with litter.

In general, regular cleaning of soiled areas, including the removal of feces and urine, reduces potential NH_3 emission sources. The use of an adequate amount of bedding material is crucial for solid-surfaced, bedded areas (Gilhespy et al. 2009, Misselbrook and Powell 2005). According to KTBL (2014), the recommended amount of litter required to fully absorb urine in fattening pigs ranges from 0.8 to 1.0 kg AP d^{-1}, depending on the daily weight gain. It should be noted that this value represents an average over the fattening period, making control of litter quantity a key focus of farm management.

The choice of bedding material can influence NH_3 emissions in various ways. Firstly, the physical structure of the bedding material is important as it determines the extent to which urine is adsorbed or absorbed. Secondly, emissions are reduced when urine sites are shielded from air turbulence by a layer of bedding, resulting in longer diffusion paths and reduced gas transfer to the bedding surface. However, if the urine sites meet the litter surface, the increased surface area can lead to higher emissions.

In the case of slatted floor systems, the rapid drainage of urine into the slurry channel below promotes the immediate separation of excrement into feces and urine. This results in a drier surface, leading to a general reduction in NH_3 release. However, under high air temperatures and strong irradiation, increased evaporation can cause drying and, depending on animal stocking density and outlet size, can result in clogging of the slats. Therefore, regular cleaning of the perforated surface is necessary. Additionally, the rapid removal of slurry from underneath the slats into an external, preferably closed, storage facility is essential for emission reduction (Chowdhury et al. 2014). Practical measures such as the separation of feces and urine using urinary flumes and under-floor sliders can be employed as effective emission control measures (Lachance et al. 2005).

Ammonia emissions from forced-ventilated barns

By analyzing the measurement data from closed, forced-ventilated barns, it was possible to confirm and update the previous convention value of 3.0 kg NH_3-N AP^{-1} a^{-1} (VDI 2011) using current production data. The determined emission rate of 2.8 kg NH_3-N AP^{-1} a^{-1} represents a range of different feeding regimes, including variations in the number of feeding phases and the optional use of raw protein and low-phosphorus fattening feed (RAM feeding). Unfortunately, it was not possible to estimate the potential effect of feeding on the level of NH_3 emissions due to a lack of data.

Conclusions

The “EmiDaT” project aimed to establish a comprehensive database for calculating NH_3 emission rates from housing systems using standardized measurement methods and evaluation procedures. The primary objective was to assess the current state of NH_3 emissions in housing systems with outdoor yards for fattening pigs. By analyzing data from practical farms, an average annual emission rate could be calculated. However, due to the limited sample size, certain factors that influence NH_3 emissions, such as cleaning frequency or structural conditions (e.g. yard roofing), could not be thoroughly investigated. It should be noted that housings for fattening pigs with outdoor yards, as studied in the “EmiDaT” project, are not necessarily associated with higher NH_3 emission rates compared to forced-ventilated barns. The evaluation of data from closed, forced-ventilated fattening pig barns under current production conditions revealed slightly lower NH_3 emission rates than the previously used convention values.

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