



Berner
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Ammonia emissions from pig housings

**Focusing on systems with outdoor yard
and outdoor climate houses**

Literature review

Ammoniakemissionen aus Mastschweinställen

mit Fokus auf Label- und nicht wärmegeämmte Ställe

Literaturstudie

Report in English with summary in German

Bericht auf Englisch mit Zusammenfassung auf Deutsch

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Summary

Within the ongoing evaluation of the technical parameters of the Agrammon model, a literature review on emissions from housings for fattening pigs was conducted. The focus was on animal friendly systems with an outdoor yard which potentially increases the emitting surfaces. New measurement data from the EmiDat project suggest lower emissions for systems with an outdoor yard compared to conventional systems with a closed barn, fully slatted floors, and mechanical ventilation. This is opposite to the emission factors (EFs) of these housing systems implemented in Agrammon. To evaluate if the emission data from housings with outdoor yards from EmiDat can be extrapolated to Swiss conditions and adopted in the Agrammon model, the systems of the latter have been characterized regarding floor properties and surface per animal of the closed part of the system and the outdoor yard, roofing of the outdoor yard, building insulation and ventilation. The roofing and the floor of the outdoor yard differed between the houses investigated in EmiDat and typical label barns in Switzerland. These differences as well as methodological restrictions of EmiDat which include duration of measurements, emission measurement of the outdoor yard only, determination of excreted N and comparability of the EFs for the two housing types with and without outdoor yard suggest that an extrapolation of the EFs determined in EmiDat to label barns of Switzerland could be problematic.

Based on these key differences, we thus believe that lower emissions from label housings than from conventional barns cannot be assumed. However, since the current EFs as implemented in Agrammon for label barns are double of those of conventional housings, further investigation is warranted. Especially the assumption of an emissions distribution of 1:1 in the closed part of the housing and in the outdoor yard must be revised as this was not found in the other comparable studies which suggests that the EF for label barns as implemented in the Agrammon model could be overestimated. To date, reliable measurement data allowing a revision of the current EFs for both label and conventional barns are still required.

Zusammenfassung

Im Rahmen der laufenden Überprüfung der Modellgrundlagen von Agrammon wurde ein Literaturreview über Emissionen aus Ställen für Mastschweine durchgeführt. Der Schwerpunkt lag dabei auf tierfreundlichen Systemen mit einem Auslauf, der die Emissionsflächen potenziell vergrössert. Neue Messdaten aus dem EmiDat-Projekt deuten darauf hin, dass die Emissionen von Ställen mit Auslauf im Vergleich zu konventionellen Systemen mit geschlossenem Stall, Vollspaltenböden und mechanischer Belüftung geringer sind. Dies steht im Gegensatz zu den Emissionsfaktoren (EF) dieser in Agrammon abgebildeten Stallssysteme. Um zu prüfen, ob die Emissionsdaten von Ställen mit Auslauf aus EmiDat auf Schweizer Verhältnisse extrapoliert und in das Agrammon-Modell übernommen werden können, wurden die Systeme des letzteren hinsichtlich Bodenbeschaffenheit und Fläche pro Tier des geschlossenen Teils des Systems und des Auslaufs, Überdachung des Auslaufs, Wärmedämmung und Lüftung charakterisiert. Die Überdachung und der Boden des Auslaufs unterschieden sich zwischen den in EmiDat untersuchten Ställen und typischen Labelställen in der Schweiz. Diese Unterschiede sowie die methodischen Einschränkungen von EmiDat, nämlich die Messdauer, die Emissionsmessung nur vom Auslauf, die Bestimmung des ausgeschiedenen N und die Vergleichbarkeit der EF für die beiden Stalltypen mit und ohne Auslauf, deuten darauf hin, dass die in EmiDat ermittelten EF nicht direkt auf Labelställe der Schweiz übertragen werden können.

Aufgrund dieser wesentlichen Unterschiede sind wir der Meinung, dass bei Labelställen nicht von geringeren Emissionen ausgegangen werden kann im Vergleich zu konventionellen Ställen. Da aber die aktuellen EF von Agrammon für Labelställe doppelt so hoch sind wie die von konventionellen Ställen, sind weitere Untersuchungen notwendig. Insbesondere die Annahme einer Emissionsverteilung von 1:1 im geschlossenen Teil des Stalls und im Auslauf sollte revidiert werden, da diese in den anderen Vergleichsstudien nicht gefunden wurde. Dies deutet darauf hin, dass der EF für Labelställe in Agrammon überschätzt sein könnte. Derzeit fehlen verlässliche Messdaten, die eine Revision der aktuellen EF sowohl für Label- als auch für konventionelle Ställe erlauben.

1. Introduction and aim of the study

Within the Gothenburg Protocol of the UNECE Convention on Long-Range Transboundary Air Pollution, Switzerland is obliged to regularly report the current state of ammonia (NH₃) emissions. The emission numbers are estimated with the Agrammon model. This is a Tier 3 mass flow model. Within the framework of the emission calculations for the compilation of the inventories, the models used by the parties must be based on valid scientific principles and on the current state of knowledge regarding the technical parameters used. In addition, Agrammon is increasingly used for individual farm applications, e.g., in the context of building permits. This implies increasing requirements for the model bases since the parties concerned expect congruency between the results of the model calculations and the real world.

The share of NH₃ emissions from pigs relative to the total emissions from livestock production is approximately 9%, with fattening pigs accounting for ca. 6%. After dairy cows, fattening pigs are thus the second most important source of emissions at the housing level. The emission factors (EFs) used in Agrammon are based on Keck (1997) for conventional barns and on a Swiss study (Berry et al., 2005) for label housings with a multi-area pen with a littered area or combined lying and feeding cubicles connected to an outside yard. In addition to these systems, Agrammon includes a housing type which exhibits a natural ventilation and microclimate areas but no outdoor yard (outdoor climate houses; Gallmann, 2003; Niebaum, 2001; Rathmer, 2001). The data available for label housings and outdoor climate houses are very limited.

A literature study was conducted with the aim to improve the data basis related to the EFs of these systems.

2. Material and methods

A literature search was conducted using Web of Science¹ with the following search terms: (barn* or hous*) and (outdoor* or yard*) (All Fields) and ammonia (All Fields) and emission* (All Fields) and (pig* or sow* or finisher*) not poultry not broiler* not cattle (All Fields). The search did not yield additional results to those included in Kupper (2022a). The primary data source was therefore Wolf et al. (2023) which reported the results of the EmiDat project². This project investigated housings for fattening pigs with outdoor yards. This study was critically analyzed and compared with available data compiled by Kupper (2022a) for label housings included in Agrammon. The data from the EmiDat project was not appropriated to evaluate EFs from outdoor climate houses since this system does not have outdoor yards.

¹ <https://www.webofscience.com/wos/woscc/basic-search> (24.09.2023)

² <https://www.ktbl.de/themen/EmiDat> (24.09.2023)

3. Results and discussion

3.1 Emissions determined in the EmiDat project

3.1.1 Investigated housing systems and experimental design

The investigated housings and the employed measuring methods are briefly described. Ammonia emissions from housings for fattening pigs with natural ventilation and outdoor yards were investigated. This included 4 barns with 2 types of outdoor yards: 1. yard with a solid floor littered with straw (denoted “solid”) and 2. yard with a slatted floor (denoted “slatted”). The closed part of the houses had a natural ventilation and a solid floor with some litter material to allow the animals root (7 housings), while one house had a fully littered surface.

In three out of the four farms with a solid floor in the yard, 100% of their outdoor areas were covered with litter and one farm had 50% of the outdoor area covered with litter. Manure removal from the outdoor yards was done manually, at least twice a week for all four farms. The barns with slatted floors in the yard exhibited slats on 100% of the yard surface (3 barns) or 50% solid floor with litter and 50% slatted floor (1 barn). The proportion of the outdoor yards covered with a roof varied from 50% to 100%. One farm had installed a sun awning which covered 100% of the yard instead of a roof.

Ammonia emissions were only measured in the outdoor yards since excretions were exclusively deposited there. The ventilation and emission rates thereof were measured with the tracer ratio method (VERA, 2018) using sulfur hexafluoride (SF₆) as a tracer gas.

The NH₃ loads were calculated by combining the measured NH₃ concentrations in the sampled gas with the volumetric flow rates in the sampling line. Subsequently, the NH₃ emission rates per animal place (in kg NH₃-N AP⁻¹ a⁻¹) were calculated considering the number of days the housings were occupied by the animals per year (i.e. 345 days for systems with all-in all-out, 2 farms, and 365 days for those with continuous occupancy, 6 farms), the number of animals during the measurement period, and the average weight of the animals. Since the weight of the animals differed during the measuring periods, the weight was normalized to a mean live weight of 67 kg over the fattening period considering a sigmoidal growth curve for the fattening period.

To capture the meteorological conditions over the year, the 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 means. For calculating annual emission rates, the hourly means were weighted based on the frequencies of long-term temperature hourly means from a nearby weather station. The calculated NH₃ emission rates from the outdoor areas were attributed to the entire housing system. Reference values for conventional housings with a mechanical ventilation and a fully slatted floor were obtained from control measurements conducted by LUFA³ Nord-West study investigating air scrubbers between 2005 and 2017. The complete results of this study can be obtained from Wolf et al. (2023).

3.1.2 Emission rates

The calculated mean annual NH₃ emission rate for all measured housing systems was 8.6 g NH₃ animal⁻¹ d⁻¹ or 2.6 kg NH₃-N animal place⁻¹ a⁻¹ as reported by Wolf et al. (2023). The emissions were 6.7 g NH₃ animal⁻¹ d⁻¹ (2.0 kg NH₃-N animal place⁻¹ a⁻¹) for the houses

³ LUFA stands for Landwirtschaftliche Untersuchungs- und Forschungsanstalt. LUFA Nord-West is the accredited service laboratory of the Lower Saxony Chamber of Agriculture (<https://www.lufa-nord-west.com> 25.09.2023).

with slatted yards (“slatted”) and $10.6 \text{ g NH}_3 \text{ animal}^{-1} \text{ d}^{-1}$ ($3.2 \text{ kg NH}_3\text{-N animal place}^{-1} \text{ a}^{-1}$) for the houses with solid yards (“solid”). Due to the high variability of the average emission rates between the four houses ranging from 2.3 to $12.0 \text{ g NH}_3 \text{ animal}^{-1} \text{ d}^{-1}$, the difference between the two systems was not statistically significant.

It should be noted that the solid floor with litter tended to exhibit higher emissions. The housing with the highest emissions among the “slatted” group had 50% solid floor with litter in the outdoor yard. In addition, the lowest emissions were observed for the housings with a 100% roofed yard and vice versa for the <100% roofed yards except for one housing with a 50% covered yard and slatted floor.

Table 1 shows the emissions measured in the study of Wolf et al. (2023) for housings with outdoor yards compared with those for conventional housings based on measurements by LUFA Nord-West. The housings with outdoor yards exhibited slightly lower values. The emission from the housings with outdoor yards from Wolf et al. (2023) were lower by ca. 30% than those used in the Agrammon model. The emissions from the reference system (i.e., conventional housings with slatted floor and mechanical ventilation without outdoor yard) are in contrast lower by ca. 40% in the Agrammon model. The amount of N and TAN excreted by the animals according to the estimates from Wolf et al. (2023) and according to the agricultural NH_3 emission inventory only slightly deviated from each other. N excretion is one of the major drivers of NH_3 emissions. The good agreement of the numbers from Wolf et al. (2023) and the Agrammon model suggest that the difference in emission levels were not due to discrepancies in N excretion.

Table 1: Ammonia emissions (in % TAN, by animal, an, or animal place, AP) measured in the EmiDat project (Wolf et al., 2023) for housings with outdoor yards, for conventional housings (slatted floor, mechanical ventilation, without outdoor yard; reference system) based on measurements by LUFA Nord-West (8 farms, 2005-2017) and assumed values for N and TAN excretion. For comparison, the corresponding numbers implemented in the Agrammon Model are shown.

	Wolf et al. (2023)	Model Agrammon	Unit	Difference
Emissions from housings with outdoor yards	2.6	3.8*	$\text{kg NH}_3\text{-N AP}^{-1} \text{ a}^{-1}$	32%
	8.6	12.8*	$\text{g NH}_3 \text{ an}^{-1} \text{ d}^{-1}$	32%
	31	48.6*	% of TAN	37%
Emissions from conventional housings	2.8	1.9*	$\text{kg NH}_3\text{-N AP}^{-1} \text{ a}^{-1}$	-46%
	9.3	6.4*	$\text{g NH}_3 \text{ an}^{-1} \text{ d}^{-1}$	-46%
	33	24.3*	% of TAN	-36%
N excreted	11.0	11.3**	kg N a^{-1}	2%
TAN excreted	8.5	7.9**		-8%

* Calculated based on Kupper (2021) for housing types denoted “label barn” and “conventional barn”, respectively

** Calculated for the Swiss agricultural ammonia emission inventory (Kupper et al., 2022)

While the absolute differences were within the expected range reflecting the variability of different measurements and methods for emission estimates, the discrepancy between the systems, i.e., emissions from the housing system with outdoor yard was lower or equal than from the conventional system according to Wolf et al. (2023), whereas this relationship assumed to be inverse in Agrammon, was considerable and requires further analysis:

- The results from Wolf et al. (2023) are probably among the best regarding accuracy of the measurement method (tracer ratio method using SF_6 as a tracer; Hassouna et al., 2023, Ogink et al., 2013) and can be considered as reliable. However, this method implies relatively short measurement periods which were approximately one week which might limit its accuracy considering the large range of conditions occurring at farm scale. This especially applies for fattening pigs in the all-in all-out system where increasing emissions during the production cycle due to the growth of the animals occur. Although

this was considered in the method by Wolf et al. (2023), according to the state of current knowledge (e.g. normalized to a mean live weight of 67 kg over the fattening period; section 3.1.1), uncertainties can occur when data from a relatively short period and representative for a certain state within a production cycle is extrapolated to the entire fattening period.

- Wolf et al. (2023) only measured the emissions from the outdoor yard and attributed them to the entire system including the closed barn and the outdoor yard. Berry et al. (2005) found concentrations between 3.2 and 30 ppm in the closed part of a label barn. In winter, the closed part contributed 82% and in summer 13% to the total emissions. Kupper (2022a) suggests an average distribution of 67:33 for the outdoor yard and the closed part of the system. This considerable contribution indicates that omitting emission measurements from the closed part of the barn could lead to an underestimation of the emissions from the entire system.
- Two institutes conducted the measurements of barns with outdoor yard and conventional systems⁴. It cannot be ruled out that different institutes produce measurement results which exhibit systematic differences, similar to the institute effect found for emission data from slurry application (Hafner et al., 2018). An intercomparison campaign, e.g. by the release of a known amount of the target gas (Gao et al., 2010; Twigg et al., 2022), to evaluate the comparability of the measurement results from the two institutes has not been done.
- The N-excretions of the animals have a high influence on the emission levels (Dai, Karring, 2014; Lengling et al., 2020). N-excretions were not measured or specifically calculated based on e.g. protein contents of the rations fed in the farms, but instead estimated based on norm values. This constitutes a shortcoming even if the estimates of N in the excretions seemed to be reasonable.
- The reference values for the conventional housing originated from earlier measurements. Again, an uncertainty might occur due to the use of different measurement methods or devices (even if the same DIN standard method was employed) and higher N excretions of the earlier measurements⁵.
- The emissions for the reference system (i.e., conventional housings with fully slatted floors and mechanical ventilation without an outdoor yard) used in EmiDat were higher than those for housings with outdoor yards. These data originated from housings with a fully slatted floor. The data compiled by Kupper (2022a) suggest that emissions from fully slatted floors are higher than those from partly slatted floors (see Annex 1 for the data compilation). In Switzerland, fully slatted floors are not allowed. Various studies comparing the emissions from pig houses with fully slatted floors with those from partly slatted floors have found NH₃ emissions being lower by ca. 20 to 49% for the latter. However, it has also been shown that in many studies the opposite was observed (Kupper, 2022a). Philippe et al. (2011) explain this discrepancy by the altered behavior of the pigs, which, depending on the conditions (barn temperature and/or animal density), preferentially defecated on the solid floor to cool down their bodies. This could offset the advantage of having partly slatted floors (i.e., a smaller emitting surface of the slurry pit) regarding emissions if the housing is properly managed.
- Assuming that housings with partly slatted floors emit less NH₃ than fully slatted floors it can be hypothesized that the reference system used in EmiDat exhibits higher NH₃

⁴ LUFA Nord-West, Müller BBM <https://www.ktbl.de/themen/EmiDat> (03.10.2023)

⁵ Although, the latter might be of lower importance: e.g. the decrease in N excretion estimated within the Swiss emission inventory is approximately 5% between the period of 2005-2017 and the 2020s.

emissions compared to the reference system of Switzerland which has partly slatted floors.

3.2 Characterization of housing systems in Switzerland

The housing systems implemented in Agrammon are as follows:

1. Conventional barn: exclusive production of slurry, no outdoor yard.
2. Label barn: multi-area pen with littered area or combined lying and feeding cubicles connected to outside yards, exclusive production of slurry.
3. Outdoor climate house: non-insulated housing, exclusive production of slurry.
4. Deep litter: entire housing surface covered with deep litter, exclusive production of solid manure.
5. Outdoor: the animals are kept on a pasture, the emissions are entirely allocated to the emission stage “pasture”, i.e., there is no “housing” stage that produces manure also omitting the subsequent storage and field-application stages.

It must be noted that the distinction between these systems is only based on the production of slurry or solid manure. In addition, for ‘label barn’ the presence of an outdoor yard and for ‘outdoor climate house’ the absence of an insulation of the housing and of a mechanical ventilation are necessarily part of this system. Other characteristics have not been defined and are not provided in the technical description of the model (Kupper, 2021, 2022b). This is an obstacle for the present task, i.e. to evaluate if emissions determined in a given housing type as done, e.g. in the EmiDat project (Wolf et al., 2023), can be extrapolated to a housing type in the Agrammon model due to a lack of appropriate system characterization.

In the following section, we therefore attempt to bridge this gap and provide ex post a more detailed characterization of the five housing types. To do this, the descriptions of the housings are obtained from the studies which were used to determine the EFs of the systems. In a subsequent step, the characteristics of the systems are compared with the actual state of pig housing systems. The actual state was defined based on an interview with an expert who has information of approx. 500 pig barns due to his involvement in planning, constructing or control of the barns. This corresponds to ca. 25% of the existing houses in Switzerland with more than 200 pigs. Therefore, the information based on this expert judgment can be considered as reliable. Table 2 provides an overview of the most important characteristics of the housing types in Agrammon. More details are given below.

Conventional barn:

- Characterization based on barns investigated by Berry et al. (2005): the barns have fully or partly slatted floors, production of slurry, insulated buildings, mechanical ventilation, dry or liquid feeding. Straw pellets are often provided as manipulable material. The production system is mainly operated as all-in all-out by compartment. The surface per animal is between 0.75 and 1.03 m².
- Characterization according to current practice: the characteristics are as described as above. In addition, barns built before 2008 and modified to comply with the ban of fully slatted floors after 2018⁶ have 0.6 m² per animal with a reduced share of slits in the floor (max. 5% perforation) and 0.3 m² slats with a higher share of slits (in general >15% - ≤50%). The total surface per animal is 0.9 m². Due to additional surface for the feeding equipment and drinking systems, the total surface per animal is approximately 1 m² per animal. The entire surface exhibits an underneath slurry pit.

⁶ <https://www.blv.admin.ch/dam/blv/de/dokumente/tiere/nutztierhaltung/schweine/fachinformationen-schwein/fi-schwein-uebergangsfrist-vollspaltenboden-schweinemast.pdf.download.pdf/8-11-1-d-Vollspaltenbodenverbot.pdf> (26.09.2023)

Barns built after 2008 have 0.6 m² per animal with a solid floor and 0.3 m² slats with >15% - ≤50% share of slits. The slurry pit is located at the slatted area only.

Label barn:

- Characterization based on barns investigated by Berry et al. (2005): the closed part of the house exhibited a solid floor littered with cut straw, insulated walls, mechanical ventilation, liquid or dry feeding. Straw pellets were provided as manipulable material. The outdoor yard exhibited 50-100% solid floor and 0-50% slatted floor which was manually cleaned. This system exclusively produced slurry. The production system was operated with continuous occupancy of the housing. The total area per animal ranged from 1.66 to 1.84 m². The surface inside of the barn was between 0.51 and 0.56 m² per animal and that of the outdoor yard 1.15-1.28 m² per animal with a share of 0% or 55% perforated floor. 50% of the outdoor yard was covered by a roof.
- Characterization according to current practice: the closed part of the house has a solid floor with 0.6 m² lying area per animal without slatted floor or an additional area of slatted floor with a channel underneath of ca. 0.2 m² per animal. The floor is covered with a thin layer of litter. The buildings are insulated, ca. 2/3 of these houses have a mechanical ventilation and 1/3 a natural ventilation, respectively, liquid or dry feeding, an outdoor yard with 100% slatted floor or 66% solid floor and 34% slatted floor. According to the RAUS specifications, fully slatted floors are allowed, but since the first program which launched animal friendly systems⁷ allowed a maximum of one third slatted floor, ca. 80 to 90% of the label barns are constructed according to this standard and only 10 to 20% have fully slatted outdoor yards. In this system, exclusively slurry is produced, and the amount of solid manure is negligible. Fattening can be operated as continuous occupancy or all-in all-out. The total surface per animal is 1.60 m² separated across the inside of the barn with 0.6 m² per animal and the outdoor yard with a minimum of 0.65 m² per animal of which at least 0.325 m² must be uncovered. The remaining difference of 0.35 m² per animal of the required 1.60 m² per animal can be distributed across the closed part of the house and the outdoor yard; the share between these two compartments is often 50:50. 50% of the outdoor yard is covered.

Most label housings have been constructed over the last 20 years. Therefore, the systems have benefitted from a technically correct design and if properly operated, the animals deposit the excretions at the intended sites, i.e. onto the perforated floor of the outdoor yard and if present in the closed part of the housing. Usually, during 95% of the production cycles, the areas outside the perforated floor remain clean since the feces are not deposited in the closed part of the housing. Here, only drinking water is collected and in the wintertime, also urine during periods with low temperatures when the animals tend to stay in the warmer part of the housing (personal communication, M. Bucheli, Kanton Lucerne)⁸.

Outdoor climate house:

- No specific study has been used to determine the EF of this system or more precisely, no emission reduction has been determined relative the conventional barn reference system. The implemented emission reduction was rather the result of an expert judgment based on several studies (Gallmann, 2003; Niebaum, 2001; Rathmer, 2001). Rathmer (2001) provided an overview with 4 types of outdoor climate houses (see Annex 2) which can either have: a solid or a partly slatted floor, no litter, or a littered floor or

⁷ Coop Naturafarm.

https://www.coop.ch/content/dam/labels/naturafarm/RL_Naturafarm%20Basisstandards.view.r-cnf-d.pdf (29.09.2023)

⁸ Examples of label housings are provided at

<https://www.krieger-ag.ch/de/stalleinrichtungen/schweine.html#references> (04.10.2023)

deep litter, a barn without insulation, natural ventilation, and no outdoor yard. The total surface per animal ranges from 1.0 to 1.25 m²; the lying area per animal is between 0.4 and 0.8 m².

- Characterization according to current practice: these housings hardly exist in Switzerland (personal communication, M. Bucheli, Kanton Lucerne).

Deep litter:

- Characterization based on the literature review of Webb et al. (2012): this housing type had a littered area covering 25-100% of the surface which might imply that solid or partly slatted floors were included; the type of litter used was straw or saw dust; the temperature inside of the house was 6.3– 22.7°C which indicates that the houses were probably not insulated.
- Characterization according to current practice: deep litter housings hardly exist in Switzerland (personal communication, M. Bucheli, Kanton Lucerne). This is confirmed by the surveys conducted within the national NH₃ emission inventory which yielded the share of this system for fattening pigs to be <0.1% (Kupper et al., 2022).
It can be concluded that the deep litter system is redundant considering the outdoor climate house system which can have deep litter (see Annex 2).

Outdoor:

- The basis of the EF is the study of Sommer et al. (2001) where sows with piglets were kept on a pasture over the entire year. The description of Sommer et al. (2001) suggest that the pasture was part of a crop rotation. The animal density was approximately 100 m² per sow. Feed was provided near the huts and the animals grazed on the pasture. The NH₃ volatilization was high in the vicinity of the feeding area and of the huts because pigs tend to urinate in those areas (Eriksen, Kristensen, 2001). At a distance of 40 m from the feeding area, no NH₃ emissions were detected.
The characteristics of the outdoor system are provided for the sake of completeness regarding systems included in Agrammon. This system is not part of the discussion in this report.

Table 2: Summary of the properties of the housing systems implemented in the Agrammon model according to current practice.

	Produced manure	Floor	Surface per animal (m ²)*	Building insulation	Ventilation	Outdoor yard
Conventional barn	Slurry	Partly slatted**	0.9 (0.3)	Yes	Mechanical	None
Label barn	Slurry	Partly slatted	1.6 (0.33/0.53)	Yes	² / ₃ me., ¹ / ₃ nat***	Yes
Outdoor climate house	Slurry and/or solid manure	Partly slatted or solid	1-1.25**	None	Free	None
Deep litter	Solid manure	Solid	1.25****	None****	Free****	None
Outdoor	-	-	-	-	-	-

*Left: total surface; right in italics: potentially soiled surface, i.e. perforated surfaces on channels; for label barn: 0.33 m² and 0.53 m² without and with perforated surface in the closed part of the house, respectively.

**Barns built before 2008 and modified to comply with the ban of fully slatted floors after 2018⁹: 0.6 m² with reduced share of slits in the floor (max. 5%), 0.3 m² slats with 20% share of slits.

***²/₃ of the label housings are a mechanically (me.) ventilated and ¹/₃ a naturally (nat.) ventilated (e.g. roof ridge ventilation with the air intake occurring through openings in the side walls and the exhaust air directed through the ridge

****Derived from Rathmer (2001)

⁹ <https://www.blv.admin.ch/dam/blv/de/dokumente/tiere/nutztierhaltung/schweine/fachinformationen-schwein/fi-schwein-uebergangsfrist-vollspaltenboden-schweinemast.pdf.download.pdf/8-11-1-d-Vollspaltenbodenverbot.pdf> (26.09.2023)

3.3 Implications for the Model Agrammon

Based on the mean values of Berry et al. (2005) for conventional housings (2.36-3.0 kg NH₃ per animal and year; mean: 2.69 kg NH₃ per animal and year) and for label housings (3.76-10.39 kg NH₃ per animal and year; median: 5.55 kg NH₃ per animal and year), it is assumed in Agrammon that label housings produce twice as much emissions as conventional housings. For simplification, it was assumed that half of the emissions occur inside the closed house and half in the outdoor area. A 50:50 distribution between indoor and outdoor areas requires closer examination, since neither emission measurements (mainly Berry et al., 2005 and Wolf et al. 2023) nor the housing concept of the label barn and observations in practice (section 3.2) support a 50:50 distribution. Moreover, the assumption of a doubling in the emitting surface due to the presence of an outdoor yard cannot be maintained considering the data shown in Table 2. Reasons for the high emissions from the label barn investigated by Berry et al. (2005) could be:

- the distribution of slatted and solid floor in the outdoor yard which was either 50% or 100% solid floor. The emitting surface from the slurry channel was thus larger compared to the label system as found in Switzerland (33% slatted floor) or higher emissions from the system with 100% solid floor (removal of the excretions once or twice per day) which exhibited a more pronounced soiling compared to the system with 50% of slatted floor (Berry et al., 2005).
- short measurement duration due to the use of the tracer ratio method using SF₆ as a tracer (see section 3.1.2).
- the higher crude protein content (CP) of the rations ranging from 194 to 207 g kg⁻¹ versus the actual average in CP which is 151 g kg⁻¹ (von Wyl et al., 2023).

The question whether the label barn induces higher emissions than conventional barns or vice-versa cannot be definitively answered since a proper comparison of both systems in measurements which include multiple barns of both systems, or a comparison in an experimental barn are not available. There are factors driving emissions in both directions, i.e., Higher emissions for the label barn due to:

- Higher temperatures and air exchange in the outside yard during the warm season when emissions are highest compared to a closed barn, especially if techniques to reduce the temperature are employed in a closed housing.
- Slightly higher emitting surface areas for label barns.
- Higher probability of the label barn producing behavioral changes in the animals inducing excretion onto and soiling of the laying area due to more variable climate conditions compared to the conventional barn.
- Higher emissions for the label barn as evidenced by Berry et al. (2005) compared to the conventional barn.

Higher emissions for the system conventional barn due to:

- Higher average temperatures over the year in a closed barn (which is supported by lower emissions observed for outdoor climate houses (Gallmann, 2003; Niebaum, 2001; Rathmer, 2001)).

To determine whether housings with outdoor yards as investigated by Wolf et al. (2023) are comparable to those in Switzerland and if this study can be used to revise the EFs for pig housings in Agrammon, some main characteristics listed in Table 3 need to be considered. Except for the roofing and the floor of the outdoor yard, the characteristics of the housings investigated by Wolf et al. (2023) are comparable to the label barns in Switzerland. 100% roofed yards as mostly present in the barns in Wolf et al. (2023) could shade the floor thus reducing emissions during high ambient temperatures compared to the 50% covering in

Switzerland. This is supported by Oettl et al. (2023) who found low emissions for an animal friendly pig barn with a 100% roofed outdoor yard. However, the 100% slatted floor in the outdoor yard of the latter induces the opposite. These restrictions as well as those mentioned in section 3.1.2 regarding the study of Wolf et al. (2023) suggest that an extrapolation to Swiss label barns could be problematic.

Table 3: Comparison between the housings with outdoor yards investigated in the EmiDat project (Wolf et al. 2023) and the label barns in the Agrammon model.

	Housings with outdoor yards (Wolf et al., 2023)	Label barn Agrammon (Kupper, 2021; 2022b)	Outdoor climate house Agrammon (Kupper, (2021;2022b)
Roofing % of outdoor yard	50% - 100%	≤50% but mostly 50%	Not applicable
Floor type of outdoor yard	100% solid floor with litter or 100% slatted floor	Max. 33% slatted floor in 80-90% of cases; 10-20% of houses have 100% slatted floor	Not applicable
Floor of the closed part of the housing	100% solid floor	≤100% solid floor; channel covered with slats is present in most cases	<100% solid floor; channel covered with slats present
Sites of excretion	100% outdoor yard	Closed part of the house and outdoor yard*	Closed part of the house
Total surface**	1.2-1.7 m ² per animal	1.6 m ² per animal	Not applicable
Surface outdoor yard**	0.4-1.1 m ² per animal	0.65 m ² per animal	Not applicable

* 100% of the feces end up in the outdoor yard and also the major part of the urine (see also section 3.2).

**Only barns with slatted floor in the outdoor yard

The available data do not allow to determine robust EFs for these systems but suggest that the EF for label barns as implemented in the Agrammon could be overestimated. Dedicated measurement campaigns are needed, which include both systems as found in Switzerland, i.e. for label barns with 50% roofing and partly slatted floor of the outdoor yard and partly slatted floor for the conventional barn.

4. Conclusions

The study of Wolf et al. (2023) provides the most complete data for pig housing systems with outdoor yards, despite the criticism from section 3.1.2. Still, we believe that their results cannot be fully extrapolated to label housings as occurring in Switzerland due to roofs covering ≥50% of the outdoor yards and outdoor yards with a littered surface or 100% slatted floors which do not or rarely occur in Switzerland. However, since the current EFs implemented in Agrammon for label barns are double those of the conventional housing, their results indicate cause to re-evaluate the current EFs. Especially the assumption that emissions are produced 1:1 in the closed part of the house compared to the outdoor yard which suggests that the EF for label barns as implemented in the Agrammon model could be overestimated and need revision, as this is not supported by any of the available studies. To date, robust measurement results allowing a revision of the current EF for both systems are lacking, and more data are needed.

The ex-post characterization of housings for pigs implemented in Agrammon suggests that the type 'deep litter' can be deleted since it is redundant to the type 'outdoor climate house'.

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Annex 1

Overview on EFs from pig housings with partly slatted floor, fully slatted floor and deep litter

Table 4: Emission factors of the literature study of Kupper (2022a) which are mainly based on Vigan et al. (2019) for housings for fattening pigs of the systems fully slatted, partly slatted floor and deep litter, comparative values and emission factors of the Agrammon model based on a nitrogen excretion (N_{ex}) according to the standard value as well as according to the emission inventory 2007 and 2019.

	Partly slatted floor	Fully slatted floor	Deep litter
Data literature study (Kupper, 2022a)	g NH ₃ animal ⁻¹ d ⁻¹		
n	140	82	49
Mean	9.2	6.1	10.8
Median	8.2	5.6	11.7
Min.	1.0	1.4	1.1
Max.	26.3	17.6	18.6
Groenestein et al. (2014), Rav (2021)		8.2*	
Rav (2021)	12.3**		
Rav (2021)		12.3***	
Bitman et al. (2014): Standardvalue UNECE	8.2#	6.6##	
Berry et al. (2005)		8.8	
Agrammon 13 kg N _{ex}	6.1	6.1	12.1
Agrammon N _{ex} 2007	5.5	5.5	11.0
Agrammon N _{ex} 2019	5.3	5.3	10.5

* System D3.100, reference system of the Netherlands; area: 0.9 m² per animal Tier (Overige systemen voor vleesvarkens); partly slatted floor; slurry present under perforated floor only.

** System D3.1; at least 71% slatted floor relative to the total surface (system number: BWL 2001.21.V1)

*** System D3.2.1 (system number: BWL 2001.23.V1); at least 30% solid floor relative to the total surface; the total housing surface located on a slurry pit; this differs to system D3.100

Standard value for the reference system according to UNECE defined as a full slatted floor with a slurry pit underneath and mechanical ventilation

Assumption of a emission reduction by 20% for systems with a reduced share of slatted floor (Bittman et al., 2014)

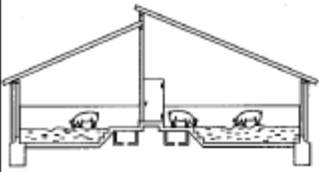

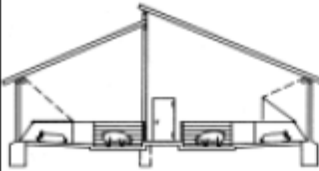
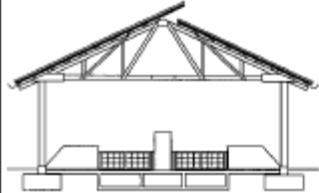
Lower emissions for systems with partly slatted floors are supported by measurement data obtained within the control of air scrubbers: old barns with previously fully slatted floor which replaced the perforated floor with elements with a share of 5% perforation but still had the slurry pit over the entire barn area exhibited substantially higher concentrations at the inlet of the scrubber compared to partly slatted floors without a slurry pit (personal communication, M. Bucheli, Kanton Lucerne).

Annex 2

Characterization of outdoor climate housings

The figure has been published by Rathmer (2001).

Tabelle 2: Außenklimaställe für Mastschweine (HAIDN ET AL., 2000)

Stallsystem	Verfahrensbeschreibung	Verfahrenskennndaten	
 <p>Tiefstreu stall</p>	Funktionsbereichstrennung Liegen/Koten und Fressen Anwachsende Mistmatratze, auf die alle 10 bis 14 Tage ein Großballen Stroh gesetzt wird Entmistung am Ende der Mastperiode Fütterung über Breifutterautomaten am angehobenen Fressplatz Merkmal: hohe Mistmatratzentemperaturen	Hauptmastplätze / Bucht Buchtenfläche / Tier Liegefläche / Tier Einstreu / Tier u. Tag Mist / Tier u. Tag Jauche / Tier u. Tag	24 1,25 m ² 0,8 m ² 0,8-1,2 kg 3-4 kg 0,05 kg
 <p>Schrägboden stall</p>	Funktionsbereichstrennung Liegen/Fressen und Koten Geneigte Buchtenfläche (6-8%) Einstreuen durch Selbstbedienen der Tiere an einer Strohraufe kontinuierlicher Stroh-Mist-Fluss stationäre Entmistung unter dem Spaltenboden Merkmal: Liegeflächenabdeckung im Winter erforderlich	Hauptmastplätze / Bucht Buchtenfläche / Tier Liegefläche / Tier Einstreu / Tier u. Tag Mist / Tier u. Tag Jauche / Tier u. Tag	14 1,1 m ² 0,8 m ² 0,1-0,3 kg 2-3 kg 0,8-1,0 kg
 <p>Kisten stall - eingestreut -</p>	Funktionsbereichstrennung Liegen, Fressen, Koten Einstreuen alle 2-3 Tage durch Ausrollen von Großballen am Kontrollgang Entmisten alle 2-3 Tage mit dem Schlepper nach Wegsperren der Schweine durch Schwenken der Buchtentrenngitter Merkmal: Wärme gedämmte Ruhelkisten	Hauptmastplätze / Bucht Buchtenfläche / Tier Liegefläche / Tier Einstreu / Tier u. Tag Mist / Tier u. Tag Jauche / Tier u. Tag	14 1,1 m ² 0,4 m ² 0,1-0,2 kg 2-3 kg 0,8-1,0 kg
 <p>Kisten stall - strohlos -</p>	Funktionsbereichstrennung Liegen, Fressen, Koten Flüssigmisterzeugung Spaltenboden über den Güllekanälen Merkmal: Wärme gedämmte Ruhelkisten	Hauptmastplätze / Bucht Buchtenfläche / Tier Liegefläche / Tier Einstreu / Tier u. Tag Gülle / Tier u. Tag	14 1,0 m ² 0,4 m ² 0 kg 4-5 kg