We thank the reviewer for their useful and insightful comments. Here we outline our responses in blue.

The paper presents an extensive and well detailed model for NH3 emissions from chickens. As mentioned in the manuscript, most of the current global emission inventories for livestock are based on emission factors without any consideration for regional climate conditions and farming practices. The introduction of a few regional dependent parameters should greatly improve the spatial and temporal variations in the NH3 emissions which is of great value in for example in air quality modelling. The manuscript is well written, structured and easy to read.

Major comments

1. Hourly and Daily timescales; the authors describe in section 2.1 that their model operates at an hourly timescale for outdoors emissions while only at a daily level for in- door emissions. While variations in temperatures inside can reasonably be expected to be small, emissions will show some variations as a function of the inside temperature, which will lead to variations in the emissions to the outside. If possible add a sentence about the choice for two different timescales and the potential impact.

We agree with the reviewer that variations in the indoor temperature of the houses will lead to variations in the emissions. The reason why the housing simulation was calculated at daily timescales is because the generalised relationship between indoor and natural temperature was derived from daily measurement data, and we want to keep the modelling structure consistent. Since the inside temperature is controlled, with variations typically smaller than diurnal variations of the outside temperature, we think simulating housing emissions with daily resolution can provide reasonable outcomes. In contrast, simulations of emissions from land spreading and backyard chickens were run with hourly timesteps in order to replicate the meteorological effects to capture diurnal variations. We propose to add a sentence in the methodology (Section 2.4.2 Global upscaling under Section 2.4 Global applications) to address this point.

2. Section 3.1.3; line 17. I would argue that the model does an average job at capturing the overall level of emissions but that some of the major changes at the start of the measurement period seem to be over and underestimated by up to a factor 2 (figure 5 May-June and ~

September). Add some discussion on the main cause for the discrepancy between the modeled and measured emissions.

We thank the reviewer for pointing out the discrepancy between modelled emissions and measurements in Fig 5. The model overestimated NH_3 emissions from early April to early July and then underestimated the emissions in September for House B. Following the suggestion of the reviewer, we propose to add a sentence noting this in the Results (Section 3.1.3 Resistance within chicken houses and site simulations). We know the discrepancies are mainly caused by the use of a fixed housing resistance, R*. In reality, R* will vary with the environmental conditions within chicken houses. However, we consider it well-justified to use a constant value of R* in order to keep simple the overall fit of the dataset to the measured emissions, which also simplifies the global application. We agree that the value of R* and its variation across chicken house designs is a significant source of uncertainty in our results. For this reason, we have given attention to discussing the model uncertainty related to the R* value in the revised manuscript.

3. Uncertainties; the various uncertainties within the model are discussed to great extent but what is missing is a final summary and overall estimate of uncertainty. If possible add a table summarizing the various errors and uncertainties, including an expected (back of the envelope) range of uncertainty for each individual error. Similarly add a summary/discussion on the total expected uncertainty, and a summary for the uncertainties in the spatial and temporal distributions (similar to the ranges, at a back of the envelope level).

We thank the reviewer for this invaluable comment. We agree that there is substantial uncertainty in modelling NH_3 emission from livestock farming. Here, we focus on discussing the uncertainty related to model parameterizations. As stated by the reviewer, it is helpful to include a "back of the envelope" calculation of the overall uncertainty and uncertainties for individual components. The model parameters may influence the emissions interactively with non-linear consequences. We find that it is probably impossible to estimate the error based on mathematical approaches because the uncertainty distribution for many of the model terms is not well known. Instead, we conduct sensitivity analysis by simulating the effect of changes in parameters on NH_3 emissions. By doing this, we are able to indicate the ranges of uncertainty and also to highlight which parameters are most important and need to be further investigated. Based on prior test, we find that indoor resistance R*, rearing density, manure pH, runoff coefficient and amount of N excreted are most important and examine these in the sensitivity tests. In addition, the uncertainty arising from the parameterization of UA hydrolysis is represented by the differences between Fig. 8 and Fig. S9. Uncertainty related to human management and processes that are not included in the model are not quantitatively investigated here but has been discussed in the manuscript.

It is worth noting that the ranges of the parameters are arbitrarily selected based on expert judgement. Indoor resistance and runoff coefficient are considered to be uncertain by a factor of 2, with manure pH uncertain by a factor ±1, which corresponds to a factor of 10x for hydrogen ions concentration. The nitrogen excretion rate is considered to have an uncertainty of 10 %. The global simulation of housing driven by varying indoor resistance values shows that 2x higher R* leads to NH_3 emission decrease by approximately 31 %, and 2x lower R* leads to 27 % higher emissions, which is similar to the result of sensitivity test at the site scale. The R* values directly influence the magnitude of housing emissions, but only to a limited extent (as discussed in the manuscript, the primary limiting factor is the hydrolysis rate of UA). The R* values also impact NH_3 emissions from land spreading of chicken manure by limit the available amount of nitrogen that is applied to land. In total, doubling R* leads to a reduction of NH_3 emissions by 6.4 %, and half R* leads to an increase of emissions by 8.5 %. The manure (system) pH, which affects the hydrolysis rate of UA and the chemical equilibria between NH_4^+ and gaseous NH_3, is found to have positive effect on NH_3 emissions that emissions tend to increase as pH increases. We find that increasing pH from 8.5 to 9.5 causes annual NH_3 emission to increase by 5.8 %, while a decrease of pH to 7.5 leads to a decline of emission by 15.9 %. As the model is not able to simulate soil pH, the sensitivity analysis is carried out by changing the manure pH. The runoff coefficient was set to be 1 % mm^{-1} for nitrogen pools in the model (Riddick et al., 2017). By doubling the runoff coefficient, the NH_3 emissions decrease by 11.8 %, while decreasing the coefficient to half lead to emissions increase by 16.5 %. It should be noted that among these parameters, changing the system pH has influences on both housing emissions (from broiler and layer housing) and outdoor emissions (spreading of broiler and layer manure; backyard chicken manure). The runoff coefficient only affects the outdoor emissions, while indoor resistances limit housing emissions directly, but also have impacts on consequent outdoor emissions. Smaller NH_3 emissions from housing indicate a larger potential for outdoor release during the spreading stages under the same farming practices. Conversely, higher housing emissions lead to smaller emission potential for land application because “what has been emitted is not going to be emitted again”. Uncertainty related to the runoff coefficient has both spatial and temporal variations, which is because regions and periods with higher precipitation are more influenced than dry areas and periods. Concerning the nitrogen excretion rate from chicken, find that a 10 % of variation leads to an annual NH_3 emission change of approximately 12 %. The change in NH_3 emission is not proportional to the nitrogen input because of non-linear interactions in the model, e.g., an increase in nitrogen input by 10 % may only lead NH_3 emissions to increase by a negligible amount in regions with heavy rainfall.

Combining these ranges and taking the base run result as the "best estimate", the overall uncertainty is estimated as the square root of the sum of the squares of the individual uncertainties, expressed as mean values of magnitudes of positive and negative changes from the sensitivity tests. For housing emissions, the estimated uncertainty is 33 %, which combines uncertainty from indoor resistance on housing emissions (29 %), manure pH (11 %) and excreted nitrogen (12 %). The uncertainty of emissions from chicken manure land spreading is 18 %, resulting from uncertainty in manure pH (11 %) and runoff coefficient (14 %). The uncertainty of emissions from backyard chicken is 21 %, which combines uncertainty from excreted nitrogen (12 %), manure pH (11 %) and runoff coefficient (14 %). The total expected uncertainty in annual global emissions of NH_3 is estimated to be 22 % of the total global emissions, corresponding to 1.2 Tg N per year. This value is determined by combining all component uncertainties, i.e. indoor resistance for emissions from both housing and land spreading (together 7 %), manure pH (11 %), runoff coefficient (14 %) and excreted nitrogen (12 %), assuming that they are independent. We summarize these results in Tables R.1.1 and R1.2 below, which we propose to include in the revised manuscript in response to the comment from the reviewer.

Table R1.1 Sensitivity test for model parameters for global application of the model.

<table>
<tr><th>Parameter</th><th>Value tested</th><th>Value change</th><th colspan="2">ΔNH_3 emission %</th></tr>
<tr><td rowspan="3">[a, b] Indoor resistance, R*</td><td>16700 s m^{-1} (base)</td><td>1 x</td><td colspan="2">0.0 %</td></tr>
<tr><td>8350 s m^{-1}</td><td>0.5 x</td><td>[a] 27.1 %</td><td>[a, b] 8.5 %</td></tr>
<tr><td>33400 s m^{-1}</td><td>2 x</td><td>[a] -30.6 %</td><td>[a, b] -6.4 %</td></tr>
<tr><td rowspan="3">[a, b, c] Manure pH (H^+)</td><td>8.5 (base)</td><td>1 x</td><td colspan="2">0.0 %</td></tr>
<tr><td>7.5</td><td>0.1 x</td><td colspan="2">-15.9 %</td></tr>
<tr><td>9.5</td><td>10 x</td><td colspan="2">5.8 %</td></tr>
</table>

$^{b, c}$ Runoff coefficient, R_{runoff}	1 % mm^{-1} (base)	1 x	0.0 %
	0.5 % mm^{-1}	0.5 x	16.5 %
	2 % mm^{-1}	2 x	-11.8 %
$^{a, b, c}$ Excreted nitrogen	11.2 Tg N year^{-1} (base)	1 x	0.0 %
	10.1 Tg N year^{-1}	0.9 x	-12.3 %
	12.3 Tg N year^{-1}	1.1 x	12.6 %

[a] Parameters affect NH_3 emissions from housing. [b] Parameters affect NH_3 emissions from land spreading of chicken manure. [c] Parameters affect NH_3 emissions from backyard chicken.

Table R1.2 (manuscript Table 1) Excreted nitrogen from housed and backyard chicken, and estimated annual NH_3 emissions from each practice based on 2010

Production system	Total excreted nitrogen (Tg N)	Practice	Total emission (Tg N)	Average P_V (%)
Broiler and layer	9.0 [±0.9]	Housing	2.0 [±0.6]	22 [±7] %
		Land spreading	2.7 [±0.5]	39 [±7]* %
Backyard chicken	2.2 [±0.2]	Left on land	0.7 [±0.2]	32 [±7] %
Total	11.2 [±1.1]		5.5 [±1.2]	49 [±11] %

* Based on the excreted N remaining (i.e., 7.0 Tg N) after NH_3 volatilization from housing.

4. Current inventories; that brings us to a comparison to current inventories which is as of yet missing in the manuscript. Most regional/country scale inventories, to some extent, do have emission totals for chicken housing/open-range chickens. How do the emissions reported in this manuscript compare to some of those emission inventories (for example, UK, Netherlands, *Denmark, US, German inventories. . .etc), and did the added complexity of the model improve the overall uncertainty in the emission totals?*

We thank the reviewer for this comment. We reply to this point together with *Comment 5*, please see our answer below.

5. Similarly, add some discussion on the average Volatilization levels reported in this study compared to those in current literature.

We thank the reviewer for these comments that comparing the results with existing inventories and literature. Here we can compare the results from the AMCLIM model to three other (model-based) studies/reports from Denmark, Netherlands and United Kingdom, respectively. The Danish IDA model (Albrektsen et al., 2017) and the UK NARSES model (Misselbrook et al., 2011) provided 2010 emission data, and the NEMA model (Velthof et al., 2012) from Netherlands estimate emissions in 2009 (see Table R1.3 below). It is important to clarify that all these studies show emissions from poultry rather than chicken. It has been clearly stated that the input used in the AMCLIM from the GLEAM model used here are chicken data, which excluded other poultry such as turkeys, ducks etc. Therefore, we can see that the excreted nitrogen from the GLEAM model (GLEAM FAO, 2018) is generally smaller than other individual studies. For housing, the AMCLIM model shows similar estimates of NH_3 emissions to the other models. The housing emissions given by the AMCLIM model are smaller than the local models in Denmark and Netherlands, partly due to the smaller total excreted N from animals. However, the AMCLIM model suggests larger emissions from land spreading for Netherlands and the UK (spreading-derived emissions are not available from the IDA model), especially in Netherlands where the difference between the two estimates reaches 8 x. This is probably due to the different schemes or assumptions for land spreading practices, i.e. deep injection of manure, in different models. The P_V rates, which indicate the fraction of nitrogen that is emitted as NH_3 are comparable from all models for the housing sector. The AMCLIM model suggests that the P_V rates do not vary significantly between these countries because the indoor conditions are largely controlled and in similar climates, which leads to small variations in house environments. This table will be included in the revised manuscript. It should be noted that there is a lack of published experimental data on emissions from chicken in many climate (e.g. tropical climates), for which future measurements datasets would be useful to further test the model performance. We compare the model performance with experimental field studies in answer to reviewer 2 (see Figure R2.1 in reply 2).

Table R1.3 Estimates of NH_3 emissions from poultry/chicken farming by IDA for Denmark (Albrektsen et al., 2017) and by NARSES (Misselbrook et al., 2011) for the United Kingdom based on 2010, and by NEMA (Velthof et al., 2012) for Netherlands based on 2009*. Ranges given in the P_V-housing represents the geographical variations across the country.

	Ammonia emission from Housing (Gg N yr^{-1})	Ammonia emission from Spreading (Gg N yr^{-1})	Total excreted N (Gg N yr^{-1})	P_V-housing (%)
Denmark	3.0 (IDA)	Not available	11.3 (IDA)	26.5
	1.7 (AMCLIM)	2.4 (AMCLIM)	7.9 (GLEAM)	21.5 (20.4 – 22.9)
Netherlands	11.4* (NEMA)	1.8* (NEMA)	62.9* (NEMA)	18.1*
	10.0 (AMCLIM)	15.0 (AMCLIM)	49.0 (GLEAM)	20.4 (20.0 – 21.0)
United Kingdom	15.0 (NARSES)	14.7 (NARSES)	Not available	17.8
	17.4 (AMCLIM)	23.7 (AMCLIM)	84.1 (GLEAM)	20.7 (18.6 – 22.1)

Minor edits and remarks

a. Figure S1, is there any reasoning behind the choice of a third order polynomial?

We use this third order polynomial equation to represent a generalised relationship between indoor and outdoor temperature because 1) it is roughly consistent with a simplified parameterization proposed by (Gyldenkærne et al., 2005) that the indoor temperature behaves in a “increase-stay-increase” pattern, 2) and it is applicable and convenient for computing. We will add this clarification to the revised manuscript in Section 3.1.1 Temperature of chicken houses.

b. Page 6., line 9, add “of” between lack and knowledge.

Corrected, thanks.

References

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