Reviewer 3’s comments:

This study utilizes both regional (CMAQ) and local (ADMS) modeling approaches to evaluate the impact of agricultural ammonia mitigation scenarios on PM2.5 concentrations in the UK. Specifically, it assesses the effectiveness of varying uptake measures for the year 2030 and investigates the dispersion of pollutants near specific livestock farms. However, upon reviewing the manuscript alongside the comments from other reviewers and the corresponding author responses, it is evident that several critical scientific issues remain adequately unresolved. Consequently, I recommend that the authors provide direct responses and implement necessary modifications regarding the following key concerns.

We sincerely thank the reviewer for his thorough review and valuable feedback. Our responses to the comments are provided in green below, and the manuscript has been revised accordingly.
It is worth noting that despite the concern raised by the reviewer on the underestimation in $PM_{2.5}$ concentrations calculated with CMAQ, this bias is consistent with the values found in the literature. More details are provided in the following responses.
We have also updated the manuscript by providing more details on the local modelling.

1. The systematic underestimation of PM2.5 concentrations by approximately 50% in the regional simulation remains a critical issue that has not been adequately resolved. Such a significant negative bias implies that the model fails to accurately capture essential internal physical or chemical processes governing aerosol formation. Consequently, the reliability of the sensitivity analysis results—specifically the conclusion that ammonia reduction has a negligible impact on PM2.5—is substantially compromised, as the model may be operating under a chemical regime that does not reflect reality. The authors must provide a more targeted and rigorous attribution of these uncertainties beyond general statements about missing processes. If the root causes of this discrepancy cannot be clarified or corrected, the validity of the study’s core conclusions regarding regional air quality improvements remains questionable.
We agree this underestimation can be a limiting factor in our modelling and will impact the analysis of the emission scenarios. This is for this reason we have been transparent in showing this evaluation of the concentrations.

However, it is worth noting that:

1) we decided to do not tweak the emission inventories to improve the calculation of modelled concentrations while Kelly et al. (2023) and Marais et al. (2023) - two studies cited in the manuscript - homogenously increased the NAEI NH_3 emission by 50% and decrease the SO_2 emissions by 60% in the whole UK. Despite scaling the emissions with large numbers, they only found a correlation of 0.66 and still had a bias of -11% in $PM_{2.5}$.

Our results are consistent with previous studies:

2) Appel et al. (2012) found a NMB between -24% and -55% in Europe depending on seasons with the CMAQ model, with winter having the worst score.
3) NMB of -44.39% in $PM_{2.5}$ concentrations in comparison with rural stations, and of -53.39% with urban stations were found using WRF-CMAQ in the UK (Im et al., 2015).
4) Despite improvement in CMAQ shown in Appel et al. (2017), persistent underestimation in $PM_{2.5}$ (in the US) remained. This is shown with the low correlation and high RMSE at early and late hours as shown in their figure, while our correlation (annual r =0.58) and RMSE (annual RMSE=5.14 μg/m^3) are better:

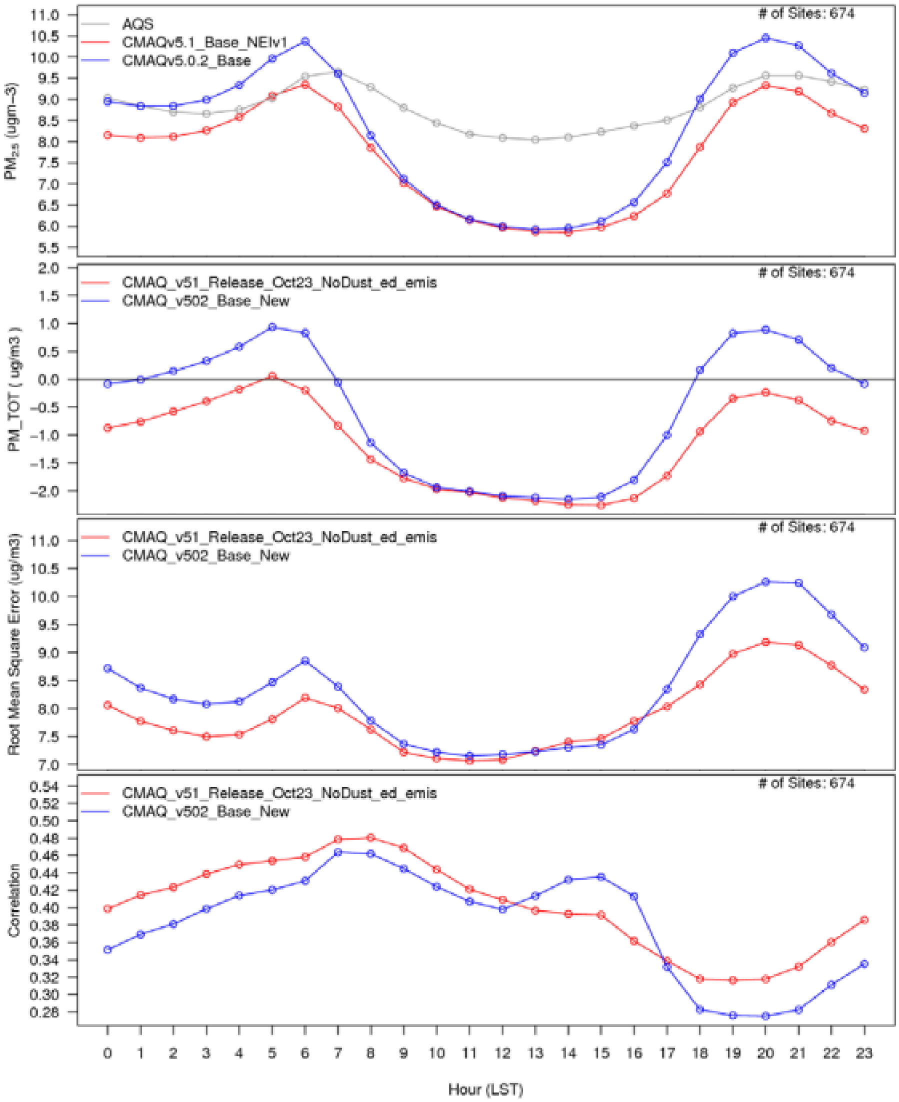


Figure S5: Diurnal time series of spring $PM_{2.5}$ from AQS observations (grey), CMAQv5.0.2_Base (blue) and CMAQv5.1_Base_NEIv1 (red) for concentration (top), mean bias (top middle), root mean square error (bottom middle) and correlation (bottom). All units are in µgm^{-3} except for correlation.

5) Zhang et al. (2020) found, with monthly $PM_{2.5}$ concentrations in the US, NMB values of −24%, −48%, and −20% for GEOS-Chem, WRF-Chem, and CMAQ, respectively. They also applied a postprocessing correction based a Kalman filter to improve these results.
6) Tao et al. (2020) found a NMB near -30% in China despite using a finer scale modelling (1km^2) compared to our carse resolution (10 km×10km).
7) Stocker et al. found an underestimation of $PM_{2.5}$ in Ireland near -30% despite using a finer scale modelling (1km^2).

References:

- Im, U., Bianconi, R., Solazzo, E., Kioutsioukis, I., Badia, A., Balzarini, A., Baró, R., Bellasio, R., Brunner, D., Chemel, C., Curci, G., Denier Van Der Gon, H., Flemming, J., Forkel, R., Giordano, L., Jiménez-Guerrero, P., Hirtl, M., Hodzic, A., Honzak, L., Jorba, O., Knote, C., Makar, P. A., Manders-Groot, A., Neal, L., Pérez, J. L., Pirovano, G., Pouliot, G., San Jose, R., Savage, N., Schroder, W., Sokhi, R. S., Syrakov, D., Torian, A., Tuccella, P., Wang, K., Werhahn, J., Wolke, R., Zabkar, R., Zhang, Y., Zhang, J., Hogrefe, C., and Galmarini, S.:

Evaluation of operational online-coupled regional air quality models over Europe and North America in the context of AQMEII phase 2. Part II: Particulate matter, Atmospheric Environment, 115, 421–441, https://doi.org/10.1016/j.atmosenv.2014.08.072, 2015.

- Appel K. W., Chemel C., Roselle, S. J., Francis, X.V., Hu, R.-M., Sokhi, R. S., Rao, S.T., Galmarini, S., Examination of the Community Multiscale Air Quality (CMAQ) model performance over the North American and European domains, Atmos. Env., 53, 142-155, https://doi.org/10.1016/j.atmosenv.2011.11.016., 2012
- Appel, K. W., Napelenok, S. L., Foley, K. M., Pye, H. O. T., Hogrefe, C., Luecken, D. J., Bash, J. O., Roselle, S. J., Pleim, J. E., Foroutan, H., Hutzell, W. T., Pouliot, G. A., Sarwar, G., Fahey, K. M., Gantt, B., Gilliam, R. C., Heath, N. K., Kang, D., Mathur, R., Schwede, D. B., Spero, T. L., Wong, D. C., and Young, J. O.: Description and evaluation of the Community Multiscale Air Quality (CMAQ) modeling system version 5.1, Geosci. Model Dev., 10, 1703–1732, https://doi.org/10.5194/gmd-10-1703-2017, 2017.
- Zhang, Y., Gautam, R., Pandey, S., Omara, M., Maasakkers, J. D., Sadavarte, P., Lyon, D., Nesser, H., Sulprizio, M. P., Varon, D. J., Zhang, R., Houweling, S., Zavala-Araiza, D., Alvarez, R. A., Lorente, A., Hamburg, S. P., Aben, I., and Jacob, D. J.: Quantifying methane emissions from the largest oil-producing basin in the United States from space, Science Advances, 6, eaaz5120, https://doi.org/10.1126/sciadv.aaz5120, 2020.
- Tao, H., Xing, J., Zhou, H., Pleim, J., Ran, L., Chang, X., Wang, S., Chen, F., Zheng, H., and Li, J.: Impacts of improved modeling resolution on the simulation of meteorology, air quality, and human exposure to PM$_{2.5}$, O$_3$ in Beijing, China, Journal of Cleaner Production, 243, 118574, https://doi.org/10.1016/j.jclepro.2019.118574, 2020.
- Stocker, J., Jonhson, K., Hood, C., Bien, B., Hamilton, V., Aves, C., Jackson, R.: Regional-to-local scale air quality modelling of the Republic of Ireland, CERC report for EPA, FM1297/T5.3, https://www.epa.ie/publications/monitoring--assessment/air/20230710-CERC-EPA-Eire-AQ-modelling---Final.pdf (last access on 23.01.2026), 2023

However, despite many studies in this topic and our additional test on increasing significantly the NH$_3$ emissions, the reasons of these underestimations in the CMAQ model are still unclear.
It will be unreasonable to think that our study alone will find the root causes of these discrepancies.

Most of the studies converge to a misrepresentation of the secondary inorganic aerosols or biases in the anthropogenic emissions (e.g. AQEG, 2012).
We have added this text in Section 3.1.1:
“Overall, research consistently highlights the difficulties in accurately modelling SIA concentrations, which are frequently underestimated in the UK (e.g. AQEG, 2012, Kelly et al., 2023) while Norman et al. (2025) found very large NMB in Europe (up to 71% for SO$_4$ and 376% in NO$_3$).”

It is worth noting that we undertook a study in Wales for the Welsh Government, we adjusted PM$_{2.5}$ concentrations from the CMAQ results for bound water and secondary inorganic aerosols with a scaling factor of 1.279. This led to increase total annual mean PM$_{2.5}$ concentrations by around 15%.

We have added the following sentences in the manuscript:
“This bias in PM2.5 concentrations is however in agreement with the literature since Appel et al. (2012) found a NMB between -24.2% and -55% in Europe depending on seasons with the CMAQ model. A NMB of -44.39% in PM2.5 concentrations in comparison with rural stations, and of -

53.39% with urban stations were found using WRF-CMAQ in the UK (Im et al., 2015). Despite improvement in CMAQ introduced from version 5.1 shown in Appel et al. (2017), persistent underestimation in PM2.5 (in the US) remained, with lower correlation (from ~0.32 to 0.47) and higher RMSE (from 5.8 to 9 µg/m3) than our results. These biases could remain important in few stations and with a low correlation coefficient in a more recent version (5.3.1 – Appel et al. 2021). Tao et al. (2020) found a NMB near -30% in China despite using a finer scale modelling (1 km2) compared to our spatial resolution (10 km × 10 km). A modelling study in Ireland with a similar finer scale modelling (1 km2) with the EMEP model has also shown a bias of ~-30% , while the coupling with the urban version of ADMS had allowed to reduce the bias to ~-20% (Stocker et al., 2023). Zhang et al. (2020) applied a postprocessing correction based a Kalman filter to improve the PM2.5 concentrations in the US but still found important NMB with different models. They found, with monthly averages, NMB values of −24%, −48%, and −20% for GEOS-Chem, WRF-Chem, and CMAQ, respectively."

- Conclusions (in bold):

"**Although this bias aligns with findings in the literature, particularly when no emission corrections or post-processing adjustments to modelled concentrations are applied, this suggests** that key atmospheric processes influencing $PM_{2.5}$ formation may not be fully represented in the model, leading to an underestimation of $PM_{2.5}$ concentrations by approximately 50%."

2. There is a notable inconsistency in the magnitude of ammonia emission reductions presented between the regional and local scales that requires further clarification. While the regional scenarios project relatively minor reductions for the UK even under the high uptake scenario (12.9%) the local modeling indicates substantial reductions for specific farms, with decreases in concentrations reaching up to 80% as shown in Table 3. The manuscript currently lacks a clear explanation for this divergence. The authors should provide a dedicated figure or table to explicitly contrast the scenario assumptions and implementation rates used for the single-point reductions versus the national-scale parameterization to explain why the local efficacy does not translate to the regional scale in the current modeling framework.

Yes, it is right there is a different approach in the emission scenarios between the regional and local modelling.

Firstly, as clarification, in the regional modelling, the high2030 scenario has a national NH_3 reduction up to 12.9%, however this decrease can be larger over specific area (in 10km x 10km grid cell), for example where the studied farms are located, since it reaches up to 23.8% (Pommier al., 2025).

Thus, we have added these sentences in Section 2.3.2:
"These farms have very high reductions in emissions because of their nature and the impact of specific measures (Table 2). However, overall, at a national level, the reductions are on average more modest, even if these farms are located were larger reduction in national NH_3 emissions were calculated (Pommier et al., 2025). In the local modelling, the emission reduction scenario reflects the maximum achievable reduction at the individual farm level depending on their characteristics, whereas the regional modelling evaluated a range of progressively increasing reduction scenarios (Figure 1)."

We have also added a new figure 1 with the following text in Section 2:

"Whereas the regional modelling assumes a progressively higher national adoption of measures across these low to high scenarios, the local modelling applies only those mitigation strategies that are relevant to each individual farm. This approach is summarised in Figure 1."

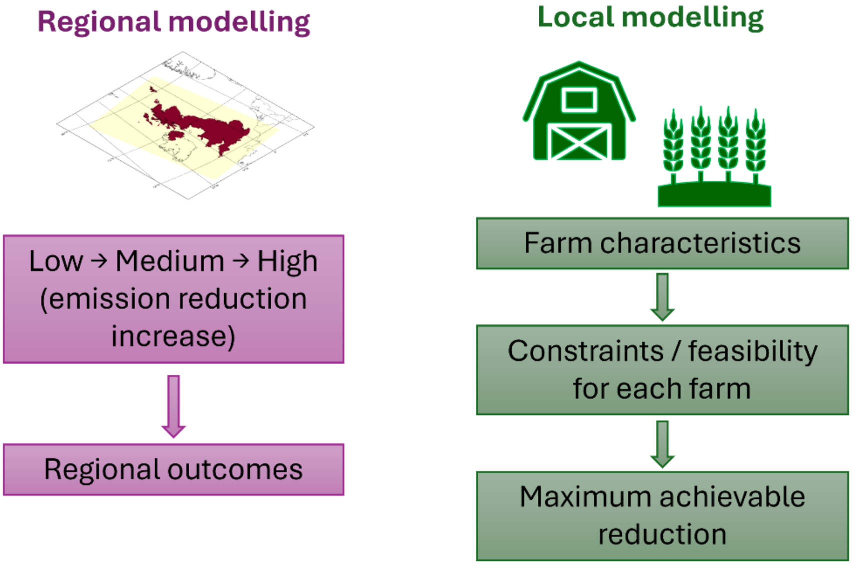


Figure 1: Schematic workflow for designing the emission scenarios.

In the manuscript we also explained the difference between 2 approaches, e.g. 1st paragraph in Section 2.3.2. The emissions in the regional modelling have been calculated with the SMT, based on national emissions. These scenarios are based on mitigation measures described in Appendix A.
Whereas the local modelling includes the relevant measures to each farm.

However, we have also rephrased a sentence in Section 3.2 to clarify the difference, as follow:
"In the local modelling, the mitigation scenario incorporates all measures from the low2030, medium2030 and high2030 scenarios. While the regional modelling assumed progressively higher national uptake from low to high scenarios, the local modelling applied only those mitigation measures relevant to each specific farm."

3. The assessment of ammonia mitigation across the UK appears to possess limited novelty compared to existing literature; however, the single-farm investigation presents a more compelling and original contribution that warrants further depth. I strongly recommend that the authors expand the local scale analysis, perhaps by assessing the specific impacts of mitigation measures on air quality in the immediate vicinity of farms and utilizing field observational data to support these conclusions, or by further evaluating the health benefits for residents living near these farms. Alternatively, the authors could organically integrate the two modeling tools by upscaling the intensive mitigation measures applied at the farm level to the national scale to assess the theoretical maximum potential for air quality improvement across the UK, rather than relying on the currently conservative uptake scenarios.

Since there are different topics in this reviewer's comment, we have split our reply on different points:

1) **impacts of mitigation measures on air quality in the immediate vicinity of farms**

We thank the reviewer for the insightful suggestion to expand the local-scale analysis and to further explore the specific impacts of mitigation measures on air quality in the immediate vicinity of farms. We agree that the single-farm modelling offers valuable opportunities to deepen the discussion.

As recommended, we revisited the ADMS modelling files to assess the feasibility of extracting additional, comparable conclusions across farms. However, the local modelling setups differ substantially between sites. Some farms include very large numbers of emission sources (in some cases more than 70), incorporate complex building effects, and use differing receptor configurations. Because of these structural differences, simple cross-farm comparisons of local concentrations would not be directly meaningful without also presenting detailed information on source characteristics, emission rates, building layouts, and model geometries. These factors strongly influence near-source concentrations and largely explain the orders-of-magnitude differences observed between farms.
Despite these constraints, our review of the modelling reinforces a general conclusion that is consistent across sites: the highest NH_3 concentrations occur in very close proximity to emission sources. This is driven by the low release heights typical of agricultural emissions and, in several cases, by the enhancement of near-field concentrations due to building-induced flow effects. Concentrations decline rapidly with distance, and beyond very short distances the influence of farm-level emissions diminishes sharply.

To address the reviewer's comment and strengthen the paper, we have added the following text to clarify these consistent near-field patterns, highlight the role of release height and building effects, and better contextualise the local-scale concentration results already presented:
"The highest NH_3 concentrations occur in the vicinity of the emission sources as shown in Figure S6 for the farm three. This is driven by the low release heights (< 6m) typical of agricultural emissions and, in several cases, by the enhancement of near-field concentrations due to building-induced flow effects. Concentrations decline rapidly with distance, and beyond very short distances the influence of farm-level emissions diminishes sharply."

However, given the heterogeneity of farm configurations and modelling inputs, expanding the analysis to include cross-farm quantitative comparisons would risk misinterpretation without substantial re-modelling, which is beyond the scope of the present study.

We have also updated the Figure 5 (which is now Figure 6) for more clarity as shown hereafter:

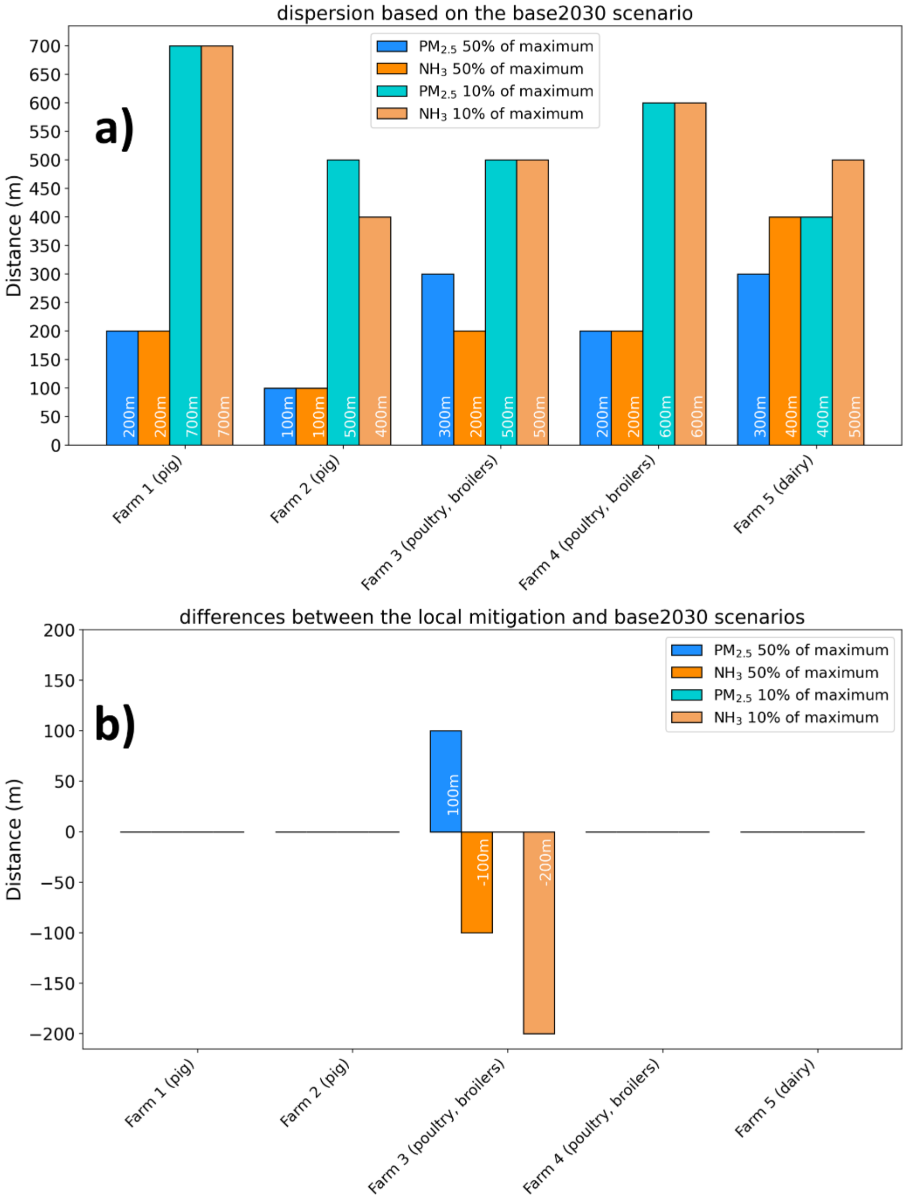


Figure 6: a) Farm's contributions of NH_3 and primary $PM_{2.5}$ given as a distance in meters where the concentration if 50% or 10% of maximum for the base2030 scenario (a) and the difference between the local mitigation scenario and the base2030 scenario (b).

We hope the reviewer will find that the additional discussion meaningfully enhances the local-scale component of the work, while remaining faithful to the limitations of the available modelling.

2) utilizing field observational data to support these conclusions

As explained at the beginning of Section 2.3.2, "emission rates derived from measurements undertaken as part of this project (Leonard and Wiltshire, 2025)".
Thus, field measurements were used to estimate emission rates feeding the local modelling.

3) evaluating the health benefits for residents living near these farms

> The reviewer will surely be interested to know that a specific study on health impact is part of the project. But this health impact focuses on national scale. It has never been the scope of this study to look at local health impact near farms. This local heath analysis was also mentioned as a perspective (see initial text in the Conclusions: "As the UK population is concentrated in urban areas a substantial distance from farms, further work could explore the health benefit of mitigation on communities in the local vicinity of farms (from 1 to 10km).")

The study focusing on national health impact is accepted for publication, but it has not been available online (no DOI) yet. Thus, we could not include it in the list of references.
"Mueller W, Carson F, Dubey J, Gutierrez A, O'Hare E, Cowie H. Agricultural interventions to reduce $PM_{2.5}$ *in the UK: impacts on health and the economy, accepted, NIHR journal"*

This study calculated the percentage change in all-cause mortality for the low, medium and high scenarios, subdivided by devolved administration as shown here:

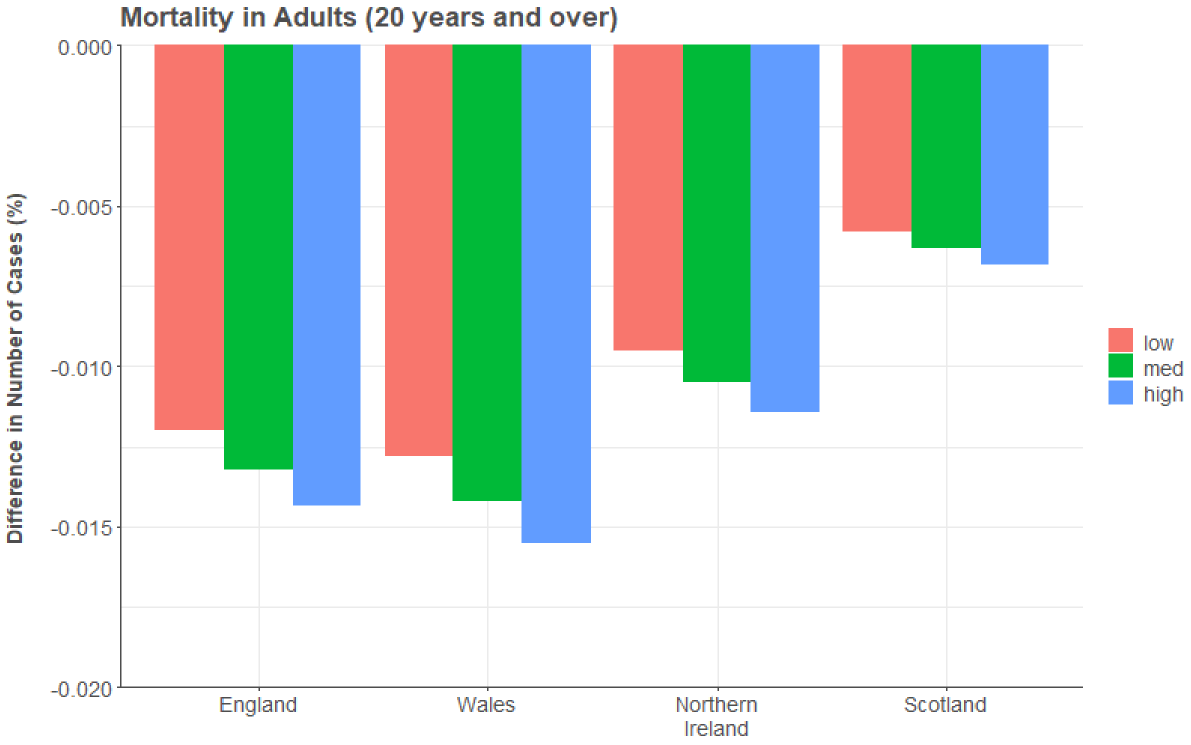


Figure The prevented deaths for all causes associated with the three scenarios in the individual countries.

The cost-effectiveness of the intervention scenarios was also estimated based on the changes in health outcomes from this health impact assessment. For example, they found the largest avoided costs from prevented health impacts occur in England, driven by its larger population and greater reductions in exposure. Annual values range from £68.9 million in the low scenario to £82.4 million in the high scenario.
The impact on ecosystems has been also calculated. These impacts on ecosystem were cited in Pommier et al. (2025).

Moreover, the synopsis study (also accepted but not published yet) provides an overview of the whole project. This project can be summarised with this figure, highlighting the different outcomes:

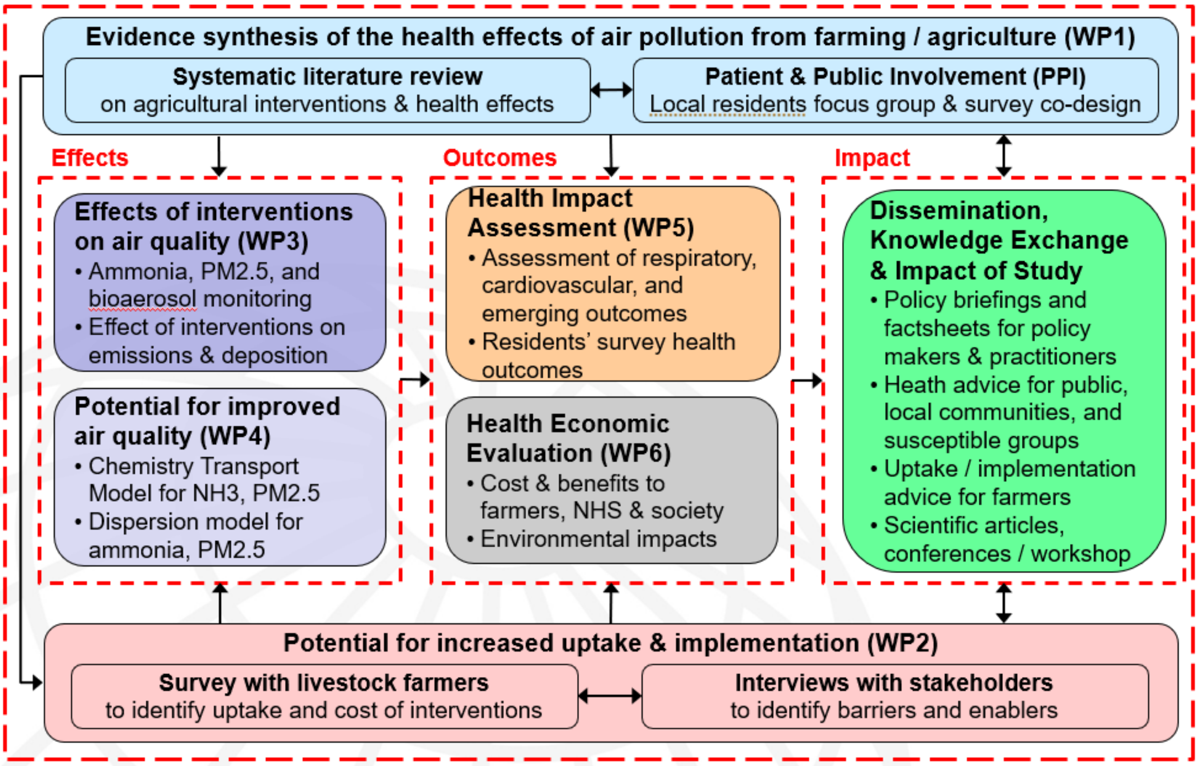


Figure 1: Diagram representing the study approach and interlinks between the WPs as presented in Cowie et al. (2025).

Cowie, H. et al.: AIM-HEALTH: Effectiveness of agricultural interventions to minimise the health impacts of air pollution, accepted in NIHR journal, 2025.

4) **integrate the two modeling tools by upscaling the intensive mitigation measures applied at the farm level to the national scale**

It's an interesting comment, however as explained in our reply to the comment (2), both modelling follows a different approach since the regional modelling analyses the progressive implementation of measures at national scale, while the local modelling focuses on specific measures for each farm.
It will be challenging or unrealistic to apply specific measures for each individual British farm.

The difficulty we would have is lack of data on the population of livestock, by livestock type (e.g. dairy, beef, pigs, etc.) and by management system (e.g. whether the livestock are housed, the type of housing, the manure management system, etc.). Such data would be necessary to scale up to a national level by assuming adoption of mitigation practices. The approach we have taken, using estimates of mitigation measure uptake, is a reasonable alternative, given the lack of data. Uptake values were based on a mix of (1) information from farmers (e.g. focus groups) and (2) the interpretation of information from farmer engagement by experts with industry and technical knowledge.

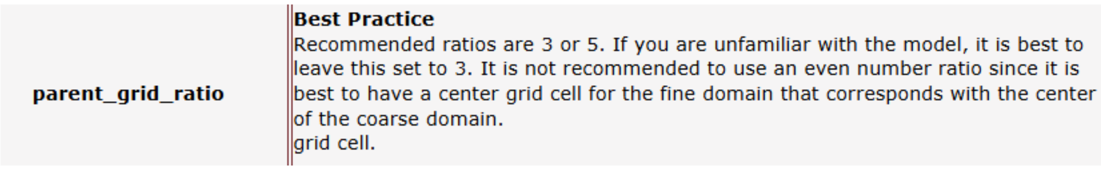
Reviewer 4's comments:

The goal of the paper is relevant and addresses an open question about mitigating PM and NH_3 emissions from the agricultural sector. However, the manuscript has many critical issues. Substantial revisions and improvements are needed before it can be considered for publication. Below are the requested minor and major changes.

We would like to thank the reviewer for his helpful comments. We have replied to the different comments in green below and amended the manuscript accordingly.

General approach

Why are separate models used instead of a downscaling approach (from 10×10 to 1×1 km^2)? Regional models can operate at 1×1 km^2 resolution.
The modelling system has been designed following the best practise in designing the WRF (and CMAQ) nested domain. Indeed, a ratio of 1:3 or 1:5 is recommended as shown hereafter:



parent_grid_ratio	**Best Practice** Recommended ratios are 3 or 5. If you are unfamiliar with the model, it is best to leave this set to 3. It is not recommended to use an even number ratio since it is best to have a center grid cell for the fine domain that corresponds with the center of the coarse domain. grid cell.

source: https://www2.mmm.ucar.edu/wrf/users/namelist_best_prac_wps.html

We well applied a 1:5 ratio for our domains (EU at 50 km and UK at 10 km).

It is correct that a regional simulation at finer scale such as 1km^2 is possible however:

- It will not allow modelling finer scale distribution.
  1km ×1km is still a coarse resolution for modelling local (farm) scale. ADMS is used at 100 m resolution.
- A finer scale modelling (e.g. 1km^2) does not always lead to an improvement on $PM_{2.5}$ modelling (see our reply to the comment on PM2.5).
- It will lead to a large computing time and to a change of the modelling system.

The written English must be improved (e.g., Lines 271, 360, 431–434, 492, etc.).
The new sentences are:

- For Line 271 "The local modelling has focused on five farms, chosen to represent the locations covered by the measurement campaign."
- For Line 360 (correction in bold): "**This approximate 50% underestimation in the modelled $PM_{2.5}$ concentrations mirrors the uniform 50% increase in NH_3 emissions** (and 60% decrease in SO_2 emissions) applied by Kelly et al. (2023) and Marais et al. (2023) in using a similar emissions inventory (NAEI for the year 2019) in their simulations to obtain a reasonable agreement in their calculated $PM_{2.5}$ concentrations with their global CTM (r=0.66, NMB=-11%)."
- For lines 431-434: "In the local modelling, the mitigation scenario incorporates all measures from the low2030, medium2030 and high2030 scenarios. While the regional modelling assumed progressively higher national uptake from low to high scenarios, the local modelling applied only those mitigation measures relevant to each specific farm."
- For Line 490-493: "Further work is recommended to assess how mitigation measures can affect primary and secondary $PM_{2.5}$ at relevant human exposure locations within 1–10 km

of farms, given that national exposure weighting emphasises locations where most primary pollution has already dispersed."

- For line 494: "Limitations of the local modelling include uncertainties related to the emission measurement data and the associated farm activity data."

The conclusions raise concerns about model validation: if the model does not simulate the system properly, the study is not robust enough for publication.
We agree this underestimation can be a limiting factor in our modelling and will impact the analysis of the emission scenarios. This is for this reason we have been transparent in showing this evaluation of the concentrations.
However, it is worth noting that:

8) we decided to do not tweak the emission inventories to improve the calculation of modelled concentrations while Kelly et al. (2023) and Marais et al. (2023) - two studies cited in the manuscript - homogenously increased the NAEI NH_3 emission by 50% and decrease the SO_2 emissions by 60% in the whole UK. Despite scaling the emissions with large numbers, they only found a correlation of 0.66 and still had a bias of -11% in $PM_{2.5}$.

Our results are consistent with previous studies:

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13) Tao et al. (2020) found a NMB near -30% in China despite using a finer scale modelling ($1 km^2$) compared to our carse resolution (10 km×10km).
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References:

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- Tao, H., Xing, J., Zhou, H., Pleim, J., Ran, L., Chang, X., Wang, S., Chen, F., Zheng, H., and Li, J.: Impacts of improved modeling resolution on the simulation of meteorology, air quality, and human exposure to PM$_{2.5}$, O$_3$ in Beijing, China, Journal of Cleaner Production, 243, 118574, https://doi.org/10.1016/j.jclepro.2019.118574, 2020.
- Stocker, J., Jonhson, K., Hood, C., Bien, B., Hamilton, V., Aves, C., Jackson, R.: Regional-to-local scale air quality modelling of the Republic of Ireland, CERC report for EPA, FM1297/T5.3, https://www.epa.ie/publications/monitoring--assessment/air/20230710-CERC-EPA-Eire-AQ-modelling---Final.pdf (last access on 23.01.2026), 2023

However, despite many studies in this topic and our additional test on increasing significantly the NH$_3$ emissions, the reasons of these underestimations in the CMAQ model are still unclear.
Most of the studies converge to a misrepresentation of the secondary inorganic aerosols or biases in the anthropogenic emissions (e.g. AQEG, 2012).
We have added this text in Section 3.1.1:
"Overall, research consistently highlights the difficulties in accurately modelling SIA concentrations, which are frequently underestimated in the UK (e.g. AQEG, 2012, Kelly et al., 2023) while Norman et al. (2025) found very large NMB in Europe (up to 71% for SO$_4$ and 376% in NO$_3$)."

It is worth noting that a study we undertook in Wales for the Welsh Government, we adjusted PM$_{2.5}$ concentrations from the CMAQ results for bound water and secondary inorganic aerosols with a scaling factor of 1.279. This led to increase total annual mean PM$_{2.5}$ concentrations by around 15%.

We have added the following sentences in the manuscript:
"This bias in PM2.5 concentrations is however in agreement with the literature since Appel et al. (2012) found a NMB between -24.2% and -55% in Europe depending on seasons with the CMAQ model. A NMB of -44.39% in PM2.5 concentrations in comparison with rural stations, and of -53.39% with urban stations were found using WRF-CMAQ in the UK (Im et al., 2015). Despite improvement in CMAQ introduced from version 5.1 shown in Appel et al. (2017), persistent underestimation in PM2.5 (in the US) remained, with lower correlation (from ~0.32 to 0.47) and higher RMSE (from 5.8 to 9 μg/m3) than our results. These biases could remain important in few stations and with a low correlation coefficient in a more recent version (5.3.1 – Appel et al. 2021). Tao et al. (2020) found a NMB near -30% in China despite using a finer scale modelling (1 km2) compared to our spatial resolution (10 km × 10 km). A modelling study in Ireland with a similar finer scale modelling (1 km2) with the EMEP model has also shown a bias of ~-30% , while the coupling with the urban version of ADMS had allowed to reduce the bias to ~-20% (Stocker et al., 2023). Zhang et al. (2020) applied a postprocessing correction based a Kalman filter to improve the PM2.5 concentrations in the US but still found important NMB with different models. They found, with monthly averages, NMB values of −24%, −48%, and −20% for GEOS-Chem, WRF-Chem, and CMAQ, respectively."

- Conclusions (in bold):

"**Although this bias aligns with findings in the literature, particularly when no emission corrections or post-processing adjustments to modelled concentrations are applied, this suggests** that key atmospheric processes influencing PM$_{2.5}$ formation may not be fully represented in the model, leading to an underestimation of $PM_{2.5}$ concentrations by approximately 50%."

Specific points

Line 16: The authors should not state "mainly focused on NH_3 emissions" if the title also includes $PM_{2.5}$; this is confusing.
The text is correct since the title is on **NH3 emissions** and **PM2.5 concentrations,** and the study is on the impact of these NH3 emissions on PM2.5 concentrations.

Lines 100–110: Section 2.2 (model validation) should be referenced here.
We have added the information in bold:
"To undertake the study, the CMAQ model, has been used for the regional modelling **and evaluated.**"

Line 177: No details are provided on the deposition formulation and parameterizations, which are especially important for NH_3 simulations.
It is correct the information was missing in the text, even if it was mentioned in Table 1. We have added this sentence:
"Dry deposition of gaseous species is simulated utilizing deposition velocity and the M3Dry aerosol deposition parameterization (Hogrefe et al., 2023)."

Table 1: The vertical resolution of the model should be included.
It has been added.

Lines 193–196: Remove the repetition.
It has been rephrased as follow (changes shown in bold):
"**The air quality simulations were carried out using meteorological data from 2019. This year was selected as the reference because it is classified as a typical meteorological year in the UK** (see Pommier et al. 2025 and references within) and 2019 was also the most recent UK emissions year at the beginning of the project."

Lines 227–229: It is unclear where the CO emission reduction comes from and what "future sources" refers to.
The CO data are more uncertain than the other pollutants as it is not well captured in the SMT.
To give an example, the production of titanium dioxide emitting CO, is not in the projections while it's included in the NAEI baseline. Thus, this source is lost. However, CO does not impact the NH_3 sources.

Line 261: Provide more detail or a reference to support this statement.
The following information has been added:
"This distance is a more conservative threshold than the Good Engineering Practice (GEP) criteria to allow for differences in building shape, wind direction, and wake effects, improving the accuracy of near-field dispersion modelling. The US Clean Air Act (USEPA, 1985) sets a threshold at 2.5 times the height of the nearest structure, measured from ground level at the base of the stack."

With the reference:
U.S Environmental Protection Agency, Guideline for Determination of Good Engineering Practice Stack Height (Technical Support Document For the Stack Height Regulations),

https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000MXYW.txt (last access on 09.12.2025), 1985.

Line 263: Clarify whether this value refers to the entire domain.
The information in bold has been added:
"The CMAQ modelled concentrations **for the corresponding grid cells of the UK10 domain** were used as background concentrations for NH_3 and $PM_{2.5}$."

Lines 274–280: Explain clearly how the reported difficulties were resolved.
We have added these sentences:
"This led focusing the study on these five farms. While some farms had data collected for only part of an animal cycle—requiring assumptions about how representative the results were—the study still gathered high-quality, comprehensive data from these five distinct locations."

Table 2: The last column should be titled "Mitigation measure and emission reduction."
It has been changed as requested.

Lines 301–302: Add a supporting reference.
The following reference has been added:
"An emission rate (g/s) for every hour in a year is the most detailed emission input option in ADMS 6 **(CERC, 2023),** ..."

CERC: ADMS 6, Atmospheric Dispersion Modelling System, User Guide, https://www.cerc.co.uk/environmental-software/assets/data/doc_userguides/CERC_ADMS_6_User_Guide.pdf (last access: 02 January 2026), 2023.

Line 324: Use "emission measurements" instead of "Project measurements."
The whole sentence has been changed (see the reply to the following comment).

Lines 329–331: This paragraph is unclear. Provide an explanation and references.
This paragraph has been rewritten as follow:
"Information on emission sources including dimensions, fan height, diameter, exit velocity were derived from farmer data requests and interviews. Housing temperature data was derived from either farm owned temperature sensors if available, or from project monitoring equipment. **Hourly emission rates of NH_3 and $PM_{2.5}$ were calculated for each hour of the animal (flock) cycle or for the full measurement period, using equations 1 (NH_3) and 2 ($PM_{2.5}$) (Phillips et al., 1998). All calculations were performed on an hourly average basis. The NH_3 emission rate was calculated as:**

$$ER_{NH3} = C_{NH3} \times Q \times R_{molecular} \times c_{mass} \qquad (1)$$

Where ER_{NH3} corresponds to the NH_3 emission rate (g/s), C_{NH3} is the hourly average NH_3 concentration (ppb), Q is the ventilation volumetric flow rate (m^3/s) and $R_{molecular}$ **is the conversion factor from parts per billion to mass concentration based on the molecular weight and molar volume of NH_3,** and c_{mass} **is** the conversion constant (10^6).
The $PM_{2.5}$ emission rate was calculated as:

$$ER_{PM2.5} = C_{PM2.5} \times Q \times c_{mass} \qquad (2)$$

With $ER_{PM2.5}$ being the $PM_{2.5}$ emission rate (g/s), $C_{PM2.5}$ the hourly average $PM_{2.5}$ concentration (µg/m^3), Q the **ventilation** volumetric flow rate (m^3/s) and c_{mass} **the unit conversion factor from micrograms to grams** (10^6)."

With the corresponding reference:
Phillips, V. R., Holden, M. R., Sneath, R. W., Short, J. L., White, R. P., Hartung, J., Seedorf, J., Schröder, M., Linkert, K. H., Pedersen, S., Takai, H., Johnsen, J. O., Groot Koerkamp, P. W. G., Uenk, G. H., Scholtens, R., Wathes, C. M.: The development of robust methods for measuring concentrations and emission rates of gaseous and particulate air pollutants in livestock buildings. Journal of Agricultural Engineering Research, 70(1), 11–24. https://doi.org/10.1006/jaer.1997.0283, 1998.

Line 339: The $PM_{2.5}/PM_{10}$ ratio should not be constant, as it varies in space and time.
The farms are at different rural locations in the UK and for a matter of simplification we have used an average value across the different AURN stations.
Moreover, the modelling analysis has focused on annual concentrations, so a fixed non time dependent conversion factor was applied.
We have added these sentences:
"As the farms are located at different locations across the UK, an average value derived from multiple AURN stations was used for simplification, and, because the analysis considers annual concentrations, a fixed, non–time-dependent conversion factor was applied."

Line 340: This assumption must be well justified and supported.
The sentence has been rephrased:
"A livestock type dependent emission rate was applied to each fan of the corresponding farm buildings, to get the total emission from the farm buildings, and therefore can be scaled up using the building volume."

Line 359: Isn't the bias negative?
It is correct. The minus sign has been added.

Lines 409–410: The final sentence is too vague. The results are also influenced by high NH_3 emissions during those months.
It is not correct, since the May-July period is not characterized by the higher emissions as shown in Figure S1:

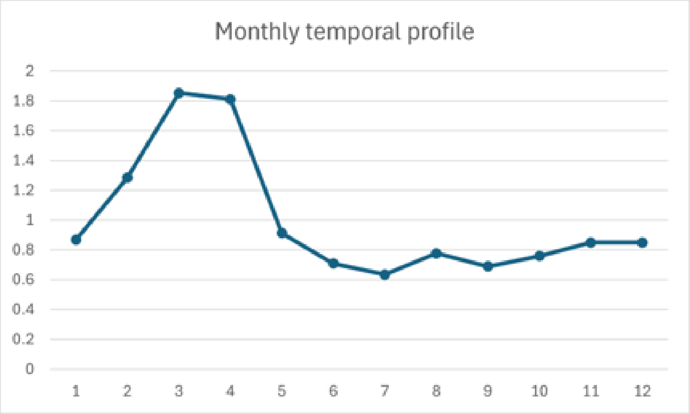

Figure S1. Monthly temporal profile for NH_3 emissions in agriculture sector in the UK.

Lines 418–420: This sentence needs clarification. The advantage of using local-scale modelling is not clear (and "urban modelling" may be a more appropriate term, since "local scale" often refers to resolutions below 1 km).
We have rephrased as below:

“This modelling approach differs from regional modelling, which incorporate atmospheric chemistry to estimate $PM_{2.5}$ from both primary emissions and secondary formation. While the local modelling considered a non-steady state (reactive chemistry) option, secondary formation contributed less than 1% of total $PM_{2.5}$ in the 10 km study area and was ultimately excluded from the analysis.”

We prefer the use of “local scale” modelling than “urban modelling”. Our modelling focuses on farms and there is no urban calculation, so this terms of “urban” will be confusing.

Line 473: What is meant by “subjective feedback,” and how was it used?
We have the text in bold in the following sentence:
“The study has also relied on subjective feedback, **i.e. participants’ perception and understanding,** which can vary widely between individuals or groups.”

To reply to the 2nd question “how was it used?”:
The engagement was done with workshops, focus groups and interviews.
This included questions regarding the key benefits and barriers raised by farmers and what is needed to support uptake in the industry. More details are given in *Jenkins, B.; Wiltshire, J. Farmer perceptions of the benefits and barriers to ammonia mitigation measures. Preprints 2025, 2025082071. https://doi.org/10.20944/preprints202508.2071.v1*

And as described in Appendix A, “*benefits and barriers associated with the mitigation measures to determine a potential future uptake. If a mitigation measure was received positively, it was estimated to have a higher uptake compared to measures that were received negatively by participants*.”

Line 485: Use “can be due to” instead of “is due to.”
It has been changed.

Lines 508–510: Add a supporting reference.
We have updated the text (in bold) and added a reference:
“Whilst there are limitations in data used, replacing emission and flow rate assumptions is unlikely to alter that the majority of pollution is grounded in the nearfield **(< several kilometres)** of farms **(e.g., AFBI, 2025),** since agricultural sources are emitted from lower heights (< 6m) and have low air flow rates relative to other sources such as engine exhausts.”

With the reference:
AFBI, Agri Food and Biosciences Institute. Typical ammonia concentrations in agricultural landscapes, https://www.afbini.gov.uk/page/typical-ammonia-concentrations-agricultural-landscapes (last access: 02 January 2026), 2025.

Conclusions: Two-thirds of this section discusses future work and limitations, which is not appropriate for a conclusions section.
We have renamed the section “Conclusions and Perspectives”.
However, it is not correct saying than 2/3 of the text is on limitations and future work, since the conclusive remarks represent 2/3 of this text, as shown here:
We can split the text by category and the text in blue corresponds to the conclusions and the text in orange the perspectives.

This study highlights the complex interactions between NH_3 emissions from farming activities and $PM_{2.5}$ formation in the UK, with a focus on dairy, pig, and poultry sectors. Using both CMAQ model for regional-scale analysis and ADMS for local-scale dispersion, this work has evaluated the impact of mitigation measures under various uptake scenarios on reducing emissions, especially on NH_3. Although emission reductions, particularly in NH_3, were predicted under high uptake scenario, these changes did not translate into significant reductions in regional-scale $PM_{2.5}$ concentrations, with a maximum decrease of only 1.5%. This outcome is attributed to the NH_3-rich atmosphere, which diminishes the effect of NH_3 reductions on $PM_{2.5}$ mitigation.

The findings also reveal discrepancies between CMAQ model concentrations and ground-based measurements. Although this bias aligns with findings in the literature, particularly when no emission corrections or post-processing adjustments to modelled concentrations are applied, this suggests that key atmospheric processes influencing $PM_{2.5}$ formation may not be fully represented in the model, leading to an underestimation of $PM_{2.5}$ concentrations by approximately 50%. ADMS results further show that NH_3 is rapidly dispersed near the farms, indicating a limited role of these emissions in the formation of $PM_{2.5}$ locally. The study has emphasized the need for integrated modelling approaches and better characterization of SIA formation, as well as the importance of addressing the primary $PM_{2.5}$ and other $PM_{2.5}$ precursors beyond NH_3 to achieve effective air quality improvements.

Overall, this suggested limited impact on potential NH_3-focused mitigation strategies on $PM_{2.5}$ concentrations underscores the necessity of exploring additional emission control measures targeting other precursors and primary $PM_{2.5}$ emissions from the farming sector. Indeed, further work is recommended to review the national benefit of mitigation on primary $PM_{2.5}$ emissions, however benefits of mitigation are likely to be localised on $PM_{2.5}$ as demonstrated by ADMS modelling. Future research should also focus on primary and secondary $PM_{2.5}$ exposure separately near farms, as current air quality studies predominantly assess total $PM_{2.5}$ concentrations, and further work is required to understand the impact of secondary $PM_{2.5}$ on health. This work advocates for a more holistic approach to modelling and mitigation to better inform policies aimed at improving air quality in agricultural regions.

The study has looked at regional exposure to $PM_{2.5}$ from agricultural sources in CMAQ, whereas ADMS has shown that the majority (90%) of emission are dispersed within 700m of farms. As the UK population is concentrated in urban areas a substantial distance from farms, further work could explore the health benefit of mitigation on communities in the local vicinity of farms (from 1 to 10km). To evaluate the potential impact of these emissions on rural populations, one approach would be to map population distribution around agricultural holdings. This would help estimate the number of individuals likely to be exposed to such emissions. Although the study primarily addresses annual estimates, further investigations at finer temporal resolutions (e.g., daily, monthly) could yield deeper insights into exposure impacts. To strengthen understanding of near-field NH3 impacts, future work would benefit from expanded measurement campaigns across a wider range of farm types—not only increasing the number of monitoring sites, but also ensuring balanced representation across key sectors such as poultry, pig, and dairy systems.