Title

Assessing the Sensitivity and Uncertainty of an NH3 Emission Reduction Calculator for Dairy Cattle Barns by Means of Monte Carlo Analysis Combined with Least Square Linearization

Authors

Mendes LB, Demeyer P, Brusselman E, Pieters J

Affiliations list

IIASA, Institute for Agricultural and Fisheries Research (ILVO), Institute for Agricultural and Fisheries Research (ILVO), Gent University

Abstract

With regard to Natura 2000, the Flemish government (Belgium) established the Programmatic Approach to Nitrogen (PAS: acronym in Flemish), with the aim of reducing environmental overload of nitrogen compounds. This approach will have substantial consequences for livestock farms located next to or within special areas of conservation and will likely result in generic measures to reduce ammonia (NH3) emissions from livestock facilities. An NH3 emission reduction calculator for dairy cattle systems (AEREC-DC) was adapted based on a mechanistic approach. Reduction coefficients estimated with this tool are used to assess the efficiency of “low NH3 emission” techniques which can be implemented in Flanders at a later stage. Field measurements will be made in the future to confirm/correct them. Emission reduction techniques combining processes such as floor scraping, flushing, manure acidification, and different types of floor were modeled. The tool comprises 36 input variables, some of which have values that are based on experimental measurements. Nevertheless, reliable information concerning other relevant variables are scarce in the literature. Hence, model sensitivity analysis is imperative. We hypothesize that the ranking of input variables in terms of their effect on the model outcome will change if different uncertainty ranges are assigned to them. Hence, this study was conducted to combine Monte Carlo Analysis associated with Least Square Linearization in order to perform sensitivity and uncertainty analyses on AEREC-DC. The sensitivity analysis was performed by assigning each input variables’ probability distribution function (PDF) with a relatively narrow variance (1% of mean value). The uncertainty analysis was carried out by gradually increasing the PDF’s variance up to what is considered realistic. The outcomes of this study will help deciding which variables urgently need to be monitored experimentally in order to improve predictions’ accuracy.

Assessing the Sensitivity of an NH_3 Emission Reduction Calculator for Dairy Cattle Barns by Means of Global Sensitivity Analysis

Luciano B. Mendes[1], Peter Demeyer[2], Eva Brusselman[2], Jan G. Pieters[3]

[1]Ecosystems Services and Management & Mitigation of Air Pollution & Greenhouse Gases (IIASA), Laxenburg, Austria, mendes@iiasa.ac.at;
[2]Technology and Food Program, The Institute of Agricultural and Fisheries Research (ILVO), Merelbeke, Belgium, peter.demeyer@ilvo.vlaanderen.be, eva.brusselman@ilvo.vlaanderen.be;
[3]Department of Biosystems Engineering, Ghent University (UGENT), Ghent, Belgium, jan.pieters@ugent.be.

Background

An NH_3 emission reduction calculator for dairy cattle systems was adapted based on the mechanistic approach of Monteny et al. (1998). Reduction coefficients estimated with this tool are used to assess the efficiency of “low NH_3 emission” techniques (fig. 1). It comprises 36 input variables (Mendes et al., 2015), some of which have values that are based on experimental measurements. Nevertheless, reliable information concerning other relevant variables are scarce in the literature. Thus, model sensitivity analysis is imperative.

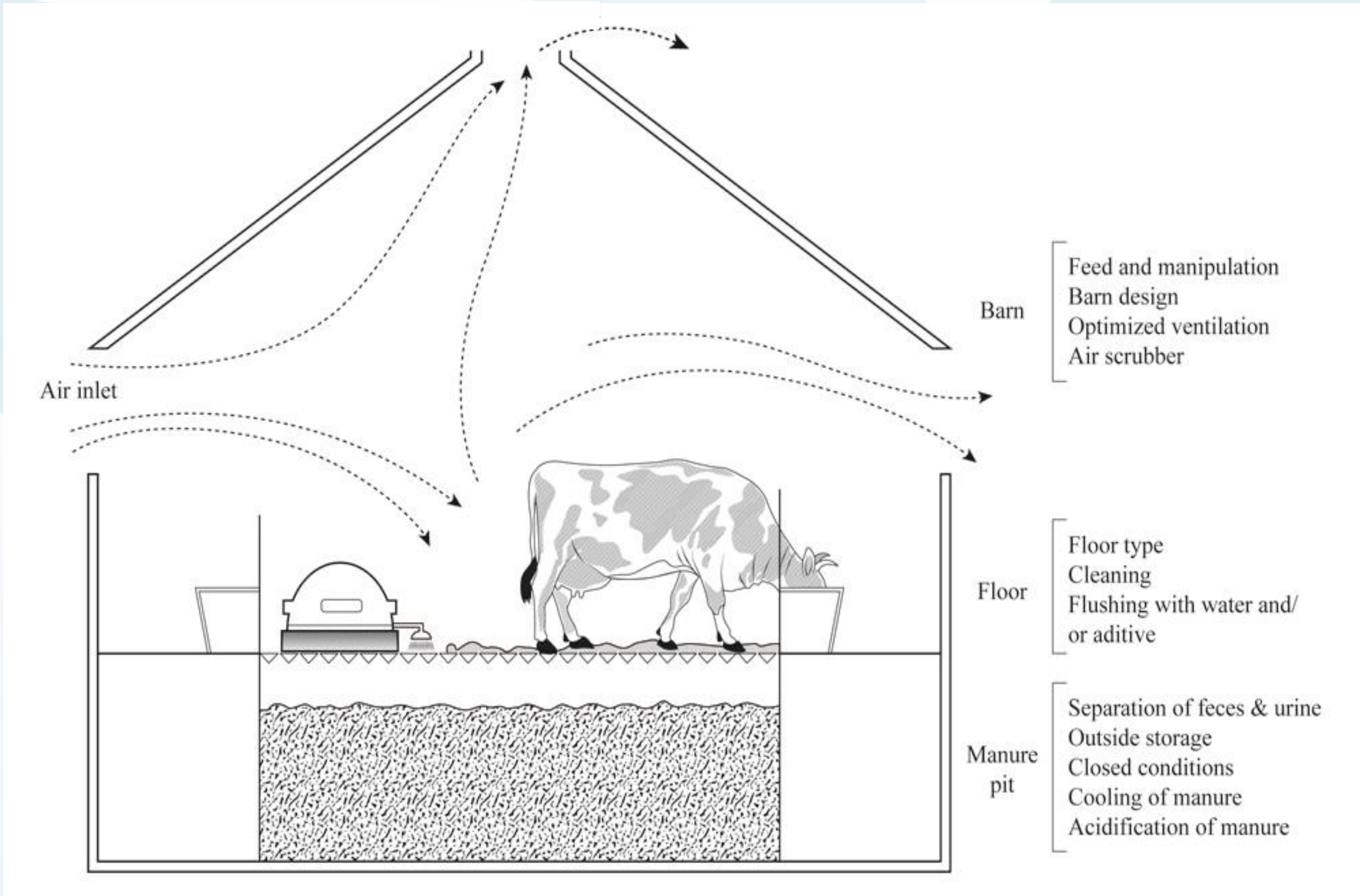

Fig. 1: Decomposition of NH_3 emission sources from a dairy cattle barn and compartments where mitigation strategies can be applied.

Hence, Global Sensitivity Analysis (GSA) was used in this study aiming at explaining the variability of the calculation tool.

Method: Global Sensitivity Analysis (GSA)

A detailed account of the calculation tool is provided by Mendes et al. (2015). In this study, GSA, as represented in fig. 2 and described by Arogo-Ogejo et al. (2010) and used by Snoek et al. (2014) was applied.

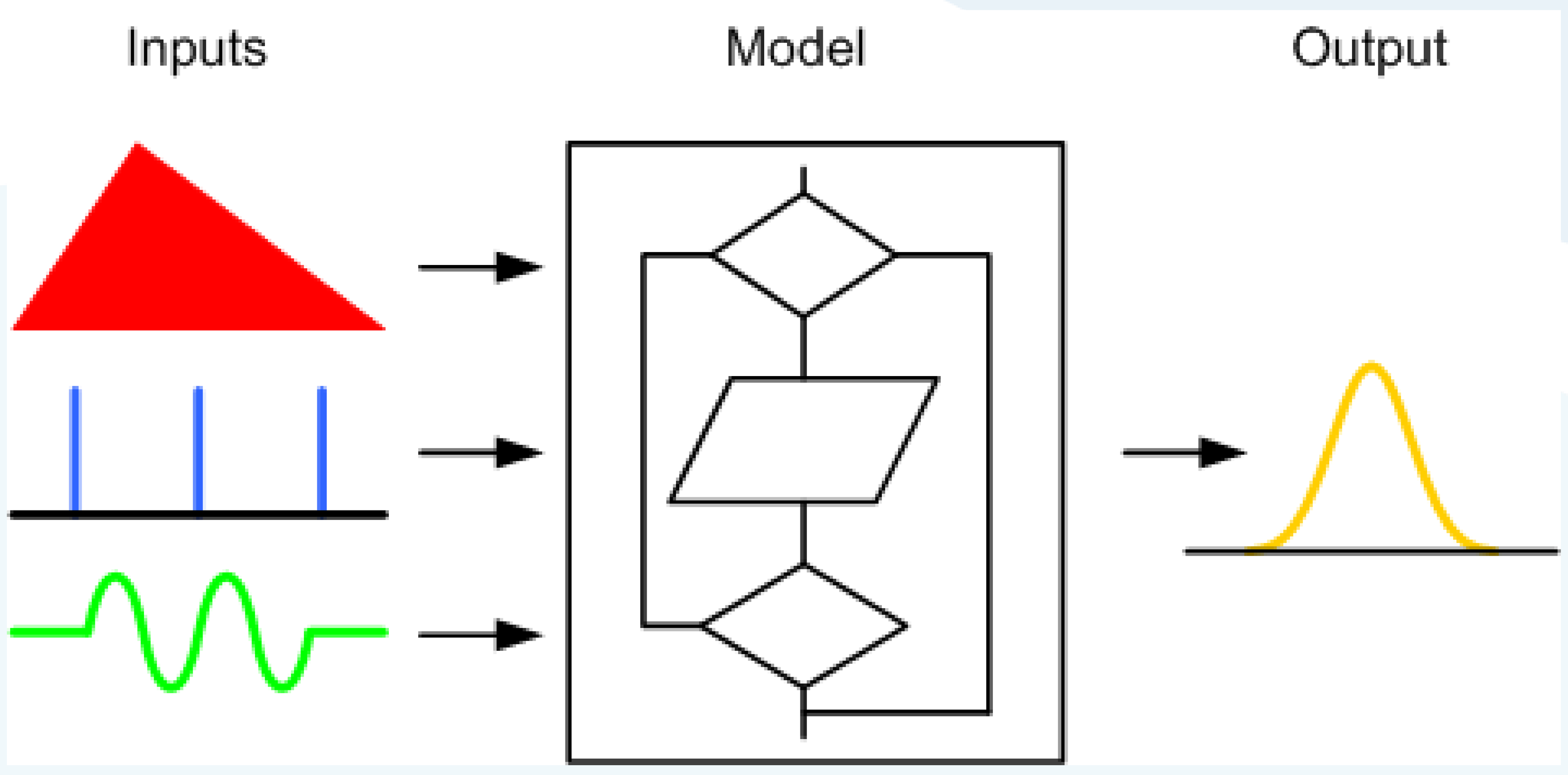

Fig. 2: Graphical representation of the effect of different PDFs assigned to the model inputs on its output.

Results: Unconditional Variance Convergence

Results indicated that a total 5000 simulations sufficed to achieve convergence when full or field variability of input was taken into account (fig. 3).

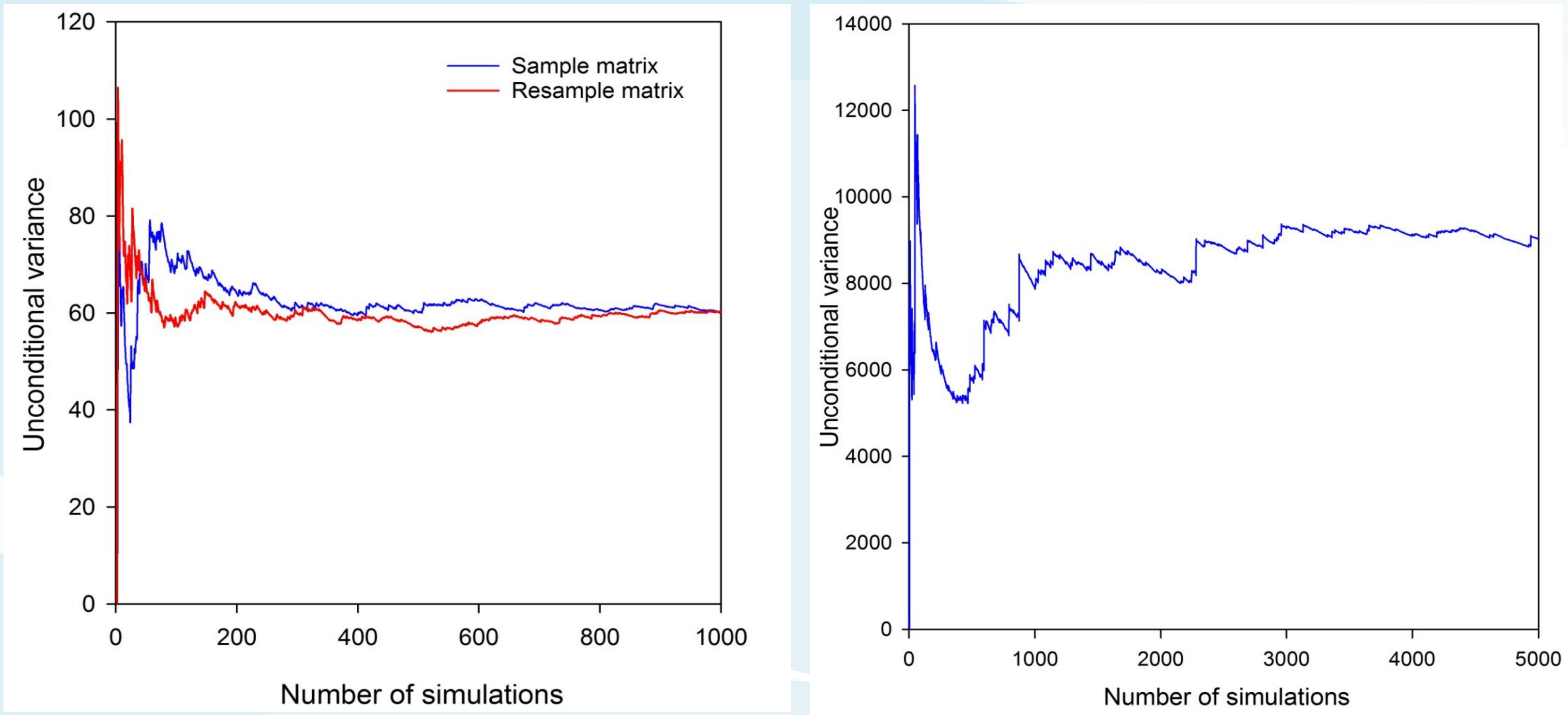

Fig. 3: Convergence of model unconditional variance as a function of the number of simulations and input variability magnitude: 1% variability (left) and full range variability (right).

Results: Preliminary Ranking of Variables

The preliminary results of GSA (table 1) confirmed that model is largely sensitive to the emission source strength (pH, U_0 and μ_{max}) and geometry (urine puddle area and depth).

Tab. 1: Partial results from the ‘Global Sensitivity Analysis’

Variable	First order sensitivity (%)	Rank
Floor area per cow at slats (m^2)	0.8	
Area allocated per cow at manure pit (m^2)	0.5	
Urine puddle depth (mm)	**1.4**	5th
Urine puddle area (m^2)	**1.8**	4th
U_o ($kg \cdot m^{-3}$)	**1.2**	7th
TAN ($kg\ m^{-3}$)	**0.8**	8th
Urination frequency ($animal\text{-}place^{-1} \cdot d^{-1}$)	0.3	
μ_{max} ($kg \cdot m^{-3} \cdot min^{-1}$)	**24.8**	1st
K_m ($kg \cdot m^{-3}$)	**10.9**	2nd
Floor temperature (ºC)	1.0	
Temperature at manure pit (ºC)	**1.3**	6th
pH of urine at floor (dimensionless)	**9.2**	3rd
pH at manure surface at pit (dimensionless)	0.5	
Air velocity near floor ($m \cdot s^{-1}$)	0.5	
Air velocity near manure pit surface ($m \cdot s^{-1}$)	0.2	
Cleaning frequency (d^{-1})	0.5	
Cleaning inefficiency (dimensionless)	0.5	
Flushing rate ($L \cdot animal\text{-}place^{-1} \cdot d^{-1}$)	0.4	
Flushing efficiency (dimensionless)	0.4	
Sum	**56.9**	

Currently, 43.1% of total model variance still remains unexplained. As a next step, second and third order sensitivities will be calculated aiming at further reducing the unexplained variance.

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