Review of scientific underpinning of ammonia emission factors and ammonia models

This report summarizes the finding of our review of the scientific underpinning of the ammonia emission factors and ammonia emission models used in the Netherlands. In the review we have been asked to focus on the following four questions:

1) Are the emission factors for application of manure as used in the Netherlands based on scientifically sound research?
2) Is the scientific underpinning for the differences between broadcast application and other application techniques, such as sod injection, deep injection, and tailing shoe, sufficient to use different emission factors for these techniques?
3) What are the gaps in knowledge in the scientific underpinning of ammonia emission factors, which demands for field measurements of ammonia emission?
4) Is the scientific underpinning of the Dutch modelling of the dispersion and deposition of ammonia sufficient and scientific sound?

As basis for the review we received:

1) Documents on emission factors
2) Documents on deposition
3) Documents from the Sintermann discussion
4) The results from the Dutch review team

General observations:

With respect to the emission factors, the Dutch material has special attention to slurry based manure systems with focus on pig and cattle manure. Application of solid manure is not taken into consideration as well as ammonia emission from grazing although these sources also have an influence on the measured ammonia concentration in the air. Since slurry based systems are dominant in the Netherlands for both cattle and pigs, it has been assumed that this cover the main aspects when comparing the ammonia emission from manure application to the fields and the implication/relation/comparison with the results obtained by the OPS-system and related correlation with measured ammonia concentration in the air.

The Dutch review committee has provided a 20 page document summarizing their findings on ammonia emission and deposition research in the Netherlands. This review is kept at rather general level, it contains much repetition as the various questions have been addressed separately, and the review is not proving much technical detail in the discussion. It is, however, not clear to us whether this is based in the character of the task provided to the Dutch review committee.

In the following we are discussing the four questions that were raised one by one:

1) *Are the emission factors for application of manure as used in the Netherlands based on scientifically sound research?*

Integrated Horizontal Flux (IHF) measurements are probably the most reliable method for measuring the ammonia emission from field applied husbandry manure if a proper set up is made, taking into account the variation in wind, wind direction, background concentrations, and proper concentration profiles downwind the manure application area. Chamber measurements are less reliable as the chambers are under influence from altered radiation and mechanical aeration to keep the temperature down. These are factors which change the boundary conditions in the chambers. As most of the EF used in the Dutch ammonia inventory are based on IHF measurements, the average EF, as given in e.g. Table 7 in Huijsmans and Schils (2009) can be seen as approximate values.

2) *Is the scientific underpinning for the differences between broadcast application and other application techniques, such as sod injection, deep injection, and tailing shoe, sufficient to use different emission factors for these techniques?*

The Dutch EF are solely estimated from trials conducted in the Netherlands and do therefore not benefit from investigations that have been made under similar conditions in other countries. E.g. is the data collection in the ALFAM-model not included, although the Netherlands has contributed a substantial amount of data to this emission model.

Only few studies on ammonia emissions from field application in Europe have been made after 2003. When comparing the Dutch EF with Danish and international literature, there is a fair compliance with the currently used EF in the Dutch ammonia inventory for the same application technique. The Danish ammonia inventory is also based on TAN and partly based on ALFAM data, but also a few newer Danish measurements and Dutch data from Huijsmans et al. (2003). A small difference can be found in surface incorporation in arable land where the Dutch value of 22 % is higher than the currently used Danish values of 5-12 %. This could be attributed to different soil types as the Danish soils are lighter where surface incorporation is easier.

For the purpose of estimating the ammonia emission on farm level, local or national level is the Dutch EF given in Table 7 (Huijsmans and Schils, 2009). The EF differ only between grassland and arable land and in the application technique. Differences in origin of the manure/slurry and in dry matter content are not taken into account.

The Danish ammonia EF for manure application differ furthermore between pig and cattle manure with a lower EF for TAN for pig manure than for cattle. This is partly because the data in the ALFAM-model has shown lower emissions for slurry with a lower dry matter (DM) content, and are explained by a faster infiltration rate in the soil. This is not included in the Dutch estimates when estimating local or national NH3 emissions.

The observed EF from shallow injection on grassland have increased from 1989 to 2002 (Huijsmans and Schils, 2009). Based on the provided material the reviewers have not been able to analyse and verify which manure types have been included in the emission estimates in these trials. The observed increase in the EF is most likely caused by changes in incorporation depth due to changed equipment, other manure types and other conditions which is not accounted for. It has furthermore not been possible to get a more informative view based on the more detailed data in Huismans et al. (2001) and Huismans et al. (2003).

It is the opinion of the reviewers that there in many cases is sufficient scientific underpinning for the differences in the emission between broadcast application and other application techniques, such as sod injection (shallow), deep injection, and trailing shoe, and that is sufficient to justify use of different ammonia emission factors for these techniques. It should however be noted that due to the high variability in the measurements, it may be difficult to distinguish between sod injection and trailing shoe as the emission from sod injection may be very shallow due to local conditions such as wet and heavy soils, low injection deep to avoid plant damages in growing crops, fouling of plants and small coverage with soil of the applied manure.

- It is recommended that the Netherlands analyse and include relevant international literature in the EF in order to strengthen the statistical power of the EF.
- It is recommended to analyse the current data set for possible interactions of the manure effects of differences in DM content, crop height, temperature and soil conditions during application as well as the likely incorporation of the slurry in different crop types and on different soil types.

3) *What are the gaps in knowledge in the scientific underpinning of ammonia emission factors, which demands for field measurements of ammonia emission?*

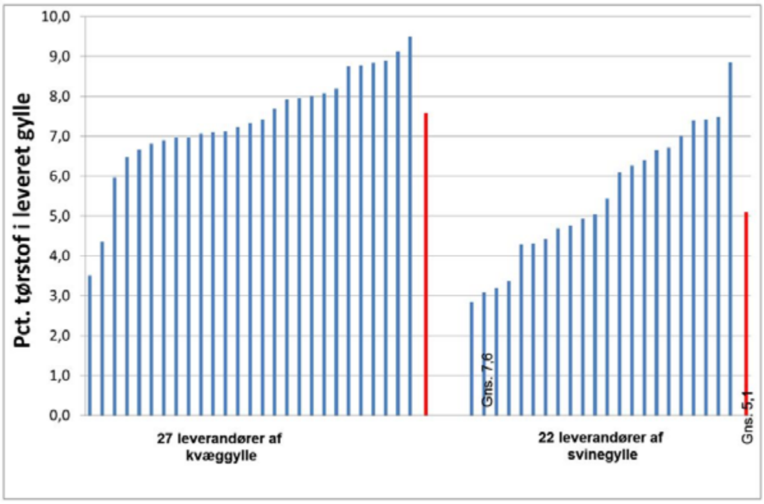
The reported Dutch content of total N, TAN and DM used in the emission estimates can be found in http://www.bemestingsadvies.nl/bemestingsadvies/1-Bemestingsplan/132-Samenstelling%20organische%20meststoffen_%202012.pdf

Tabel 1-7 Gemiddelde samenstelling van organische meststoffen in kg per 1000 kg produkt, dichtheid in kg/m^3

	Droge stof	Org. stof	N_{tot}	N_{min}	N_{org}	P_2O_5	K_2O	MgO	Na_2O	Nmin /Ntot *	Ntot/ P_2O_5 *	Dichtheid
Gier												
Rundvee	25	10	4,0	3,8	0,2	0,2	8,0	0,2	1,0	0,95	20,00	1030
Varkens	20	5	6,5	6,1	0,4	0,9	4,5	0,2	1,0	0,94	7,22	1010
Zeugen	10	10	2,0	1,9	0,1	0,9	2,5	0,2	0,2	0,95	2,22	-
Dunne mest												
Rundvee	85	64	4,1	2,0	2,1	1,5	5,8	1,2	0,7	0,49	2,73	1005
Vleesvarkens	93	43	7,1	4,6	2,5	4,6	5,8	1,5	1,2	0,65	1,54	1040
Zeugen	67	25	5,0	3,3	1,7	3,5	4,9	1,4	0,9	0,66	1,43	-
Rosékalveren	94	71	5,6	3,0	2,6	2,6	5,0	1,6	1,2	0,54	2,15	-
Witvlees kalveren	22	17	2,6	2,1	0,5	1,1	4,5	1,7	1,6	0,81	2,36	-

Actual DM and TAN content in some of the conducted trials can be found in Huismans et al. (2001) and Huismans et al. (2003). For cattle TAN content in the manure is there good accordance with the average content as shown above and the TAN content in the manure used for the ammonia emission trials. For pig manure is the TAN content slightly higher in the ammonia emission trials. This can be explained by that the nitrogen excretion rate per pig has been reduced with 25 % since the trials were conducted in 1989-1993. Based on the available data is it not possible to compare the DM content.

When comparing the current Dutch values DM for cattle slurry with Danish values, the Dutch values is slightly higher whereas the DM content of pig slurry is considerable higher than the reported Danish values and especially for fatteners. This despite both countries is having a very intensive and specialized pig production.



Source: https://www.landbrugsinfo.dk/Energi/Biogas/Sider/pl_11_548.aspx

Table 1. Content of dry matter (DM) and nutrients in an average of 27 samples of cattle slurry from the official Danish trials and compared to the figures in the Danish normative values for dairy cattle slurry.

	Dry matter pct.	Total-N, kg pr. Ton	NH4-N, kg pr. ton	P, kg pr. ton	K, kg pr. ton	NH4-share
Average, 27 samples	6,69	3,11	1,77	0,51	2,46	58
Normative values, slurry dairy cows	10,3	6,03	3,62	0,98	5,65	60
Difference from normative values, pct.	65	52	49	52	44	96

Both the Dutch and the Danish NH3 emissions are based on the TAN content in the manure. Comparing to Danish data are the TAN content in the Dutch manure lower. Eg. the TAN content in Dutch slurry is 49% (when estimating the national emission) and 58-60 % in Danish cattle slurry. For pig slurry is used different values depending on if it fatteners or sows, 66 % and 65 % respectively which can be compared with Danish values of 75 %-79 %. If the TAN content is underestimated there will be a subsequent underestimation in the up-scaling procedure. It is recommended to check the TAN content in farm manure for the purpose of up-scaling procedure.

The Danish EF from manure application can be found here (Nørregaard Hansen et al. 2008): http://web.agrsci.dk/djfpublikation/djfpdf/djfhus84.pdf

The Dutch review does not include a review of the activity data on manure application techniques, how much of the manure is applied as solid or liquid, the shares of the different techniques used, to which crop, on which soil type, the effectiveness of the different injection techniques as ammonia abatement techniques in the conducted research trials and compared to practical farming and region. As injection is costly and difficult to apply on clay soils with a high likely hood for crop damages it is recommended to investigate if the technique used in practical farming with soil coverage etc. is the same as the trials conducted.

As there is a large difference in the EF from different application technologies the up-scaling methodology becomes important when comparing estimated emissions/concentrations in the OPS-model and the observed air concentration of NH3. The review doesn't describe how the up-scaling to local and/or national level is made, only that a correction to the observed concentration is done (to close the ammonia gap). As NH_3 may have a high deposition rate the local application methodologies and – timing may have a significant influence on the total emission estimate.

- It is recommended to investigate if the current used EF are suitable average EF for average Dutch conditions or there should be distinguished between e.g. soil types and timing of the year
- It is recommended further investigations on the effect of soil type, manure type, DM content and plant height/fouling is included in further investigations
- It is recommended that the current TAN and DM content is verified as being the best available data for practical farming if these data are used in the models for up-scaling to local and national emission levels

4) *Is the scientific underpinning of the Dutch modelling of the dispersion and deposition of ammonia sufficient and scientific sound?*

Only a limited part of the provided material on dispersion and deposition of ammonia has been published in peer reviewed papers. This does not mean, however, that the presented work is not of high quality. In many cases the Dutch work represents state-of-the-art in this field.

In the Netherlands the mapping of nitrogen deposition is performed on 1 km x 1 km grid net using the OPS model (van Jaarsveld et al., 2012) with an implementation of the Dutch DEPAC (van Zanten et al., 2010) dry deposition module. The OPS is available in two versions OPS-LT and OPS-ST for long- and short-range transport respectively. The OPS is basically a linear model system for which chemical conversion is calculated assuming pseudo first order reactions.

The local scale version of OPS (OPS-LT) is a steady-state Gaussian plume model computing concentrations and depositions on 0 to 50 km scale. The OPS-ST is in many ways comparable with the Danish Gaussian plume model OML-DEP that is applied in the DAMOS system (Geels et al., 2012; Hertel et al. 2013), and these models represent state-of-the-art in operational local scale deposition models.

The long-range transport version of the model (OPS-LT) is a Lagrangian model type assuming transport from a source to a receptor is taking place in straight, well-mixed sectors of height z_i and horizontal angle of 30^0. Where the first order chemistry of ammonia will often be a somewhat reasonable approximation at local scale, this is more questionable at long-range transport scale. This conversion depends on the atmospheric concentration of acid gases and aerosols, and it thereby it depends on sources of SO_2 and NO_x. The state-of-the-art in pollutant transport modeling is today found in 3-dimensional Eulerian models. The 3-dimensional Eulerian models are furthermore able to account for the interaction between pollutants from different sources and thereby for the non-linearity of chemical conversion.

The Dutch dry deposition module DEPAC represents state-of-the-art in this field and has been extensively described in the report by van Zanten et al (2010). The applied dry deposition parameterisation for ammonia is accounting for bi-directional fluxes by adopting a description of a so-called compensation point in the flux description of stomatal, external leaf surface and soil exchange pathways. Still, various shortcomings of the DEPAC dry deposition module have been addressed (as stated by the Dutch review committee) and these need to be followed up in the future. As stressed by the Dutch review committee ecosystem models addresses a dynamic equilibrium between emission and deposition, but this is not yet standard in concentration - deposition modelling. For some surface types little or no measurement data are available for validation of the parameterisations, but this is a general problem in this field and an area not only for the Dutch but also for the international research community to address.

A very significant part of the uncertainties in modelling of concentrations and depositions is generally related to the emissions. The OPS model system applies correction factors relative to the average emission strength for land-spread manure and animal housing systems as function of temperature. The Danish experience is that applying proper parameterisations of the temporal variation in ammonia emissions (Gyldenkærne et al., 2005) affects strongly the model performance (Skjøth et al., 2004; Skjøth et al., 2011), and this is one of the focus areas of the on-going EU FP7 project ECLAIRE. In the Danish studies it was demonstrated that the ammonia emission models need to account for local agricultural practise in order to describe well the variations in emissions. In the Netherlands there is an agricultural Geographical Information System covering the all animals and their manure production (van Os et al. 2011). It is unclear for the reviewers how this information has been accounted for in the OPS models. A new French study has shown that main soil characteristics, especially soil pH are important (Hamaoui-Laguel, L., 2013, in press). Furthermore, a recent study from the ECLAIRE group (Skjøth and Geels, 2013) shows that the foundation on fixed emission factors that are used throughout the country introduces considerable uncertainty to the emissions. Due to this, then, the general recommendation from the ECLAIRE group is that ammonia emission should be directly related to local weather variables (Sutton et al, 2013, in press) where the emission from stable systems and application of fertilizer and manure can be handled through a uni-directional model as in Skjøth et al (2011).

There are generally few measurement data on dry deposition of ammonia to different types of vegetation available for deriving improved parameterisations and testing of these in dispersion – deposition models. Conducting experiments for providing such measurement data is complex and highly resource demanding, and this calls for cooperation nationally and internationally.

- It is recommended that the Dutch dispersion – deposition modelling is involved in detailed model inter-comparisons testing the local scale and long-range transport calculations separately and in combination.
- Depending on the results of the inter-comparisons it should be considered to substitute OPS-LT with a Eulerian 3-dimensional model for the description of the long-range transport
- A more detailed model for the temporal variations in ammonia emissions over Europe should be applied accounting for local agricultural practise.