A comparison of disaggregated nitrogen budgets for Danish agriculture using Europe-wide and national approaches

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Abstract
Spatially detailed information on nitrogen (N) budgets is relevant for the identification of regions N pollution needs to be reduced. However, the availability of consistent reliable data is generally lacking. Therefore most models applied in Europe use national or even European scale data as model input. To gain insight in the reduction in uncertainty that could be achieved by using higher resolution input data, spatially disaggregated agricultural N budgets for Denmark for the period 2000-2010 were generated by the European scale model Integrator, being fed with high spatial resolution national data for Denmark (Integrator-DK) and compared with results obtained by using the default data (Integrator-EU). Here we focus on the year 2010, for which the quality of the regional Danish input data was considered best. Results show that clear differences exists for the national budgets calculated by both versions of the model but comparison with an independently derived Danish national budget appeared to be better with Integrator-EU results. However, the spatial distribution of manure distribution and N losses from Integrator-DK are closer to the observed distributions than those from Integrator-EU.

Key Words
nitrogen, budgets, agricultural soils, modelling, national

Introduction

Spatially detailed information on nitrogen (N) budgets is relevant to identify regions with a high need to significantly reduce N pollution. Moreover, to be relevant for regional policymakers, there is a need to disaggregate national budgets to the scale of administrative regions responsible for e.g. health and business development, and of municipalities responsible for e.g. local environmental regulation. Furthermore, disaggregation to smaller areas (landscapes and/or catchments) is relevant since implementation of the Water Framework Directive and to a lesser extent the Nitrates Directive will lead to significant changes in land use and land management at this scale. A crucial question regarding the assessment of agricultural N budgets within a country is the most appropriate scale in view of the impact of N inputs on air quality and water quality. With respect to nitrous oxide (N_2O), information on the spatial distribution of the emissions is less relevant, because N_2O is a long-lived gas with strong atmospheric dispersion, leading to an averaging of its concentration. For NH_3 emissions, and related N deposition, and for N leaching and N runoff, accurate information on their spatial distribution is, however, crucial in view of eutrophication impacts on terrestrial and aquatic ecosystems close to its source (Cellier et al., 2011). Here, aggregation of input data for large areas may cause accurate average N deposition and N leaching levels, but a strong deviation in the area exceeding critical N deposition loads or critical N concentrations in ground water and surface water (De Vries et al., 2010). This effect holds for all spatial levels and may especially affect the results of European scale model predictions. For this reason, many countries in Europe have developed modelling tools at national and sub-national scale.

One model that has been used at European scale to assess high spatial resolution N budgets is the model Integrator (Kros et al., 2012). Despite using this detailed information, the model might still be quite inaccurate at the regional level within countries. To gain insight in the reduction in uncertainty that could be achieved by using higher resolution input data, spatially disaggregated agricultural N budgets for Denmark for the period 2000-2010 were generated by the European scale model Integrator, using high spatial resolution national data for Denmark (Integrator-DK) and compared with results obtained by using the data at the EU scale (Integrator-EU). Here we report the approach and results of this study, focusing on the year 2010, for which the quality of the regional Danish input data was considered best. The results provide insight in the quality of European scale model results at regional scale (within country level).

Methods

The Integrator-EU model (Kros et al., 2012), developed to assess N-flows for EU-27 for the period 1960-2030 in response to various scenarios related to changes in climate, land use and land management, was used to assess N flows for Denmark. Integrator-EU comprises 27 member states (EU-27), including Denmark, that were subdivided into so-called NitroEurope Classification Units (NCUs). These NCUs, about 40,000, are composed of multipart polygons, each of the polygons being a cluster of 1 km × 1 km pixels. Integrator includes various sub-models for the prediction of N (NH_3, NO_x, N_2O and N_2) emissions and N leaching from (i) housing and manure storage systems and agricultural soils, (ii) non-agricultural terrestrial systems, and (iii) an emission deposition matrix for NH_3 and NO_x, based on the EMEP model (Simpson et al., 2003). Integrator-EU calculates the total manure production for each NUTS3 region (i.e. county level) using Eurostat data on animal numbers at NUTS3 level from Eurostat and excretion rates from CAPRI. Fertilizer N application is based on national fertilizer consumption rates for the year 2010. For each country, the mineral fertilizer is distributed over crops using weighing factors that are based on the N uptake of the crop. The emission of gaseous N compounds (NH_3, N_2O, NO and N_2) accounted for in the model include includes emission (i) from faeces and urine during storage in housing and manure storage systems, (ii) by grazing animals, (iii) after application of manure and fertilizers to agricultural land and (iv) due to atmospheric deposition, N fixation and crop residue input (not included for NH_3). Losses of N from agricultural systems to ground- and surface waters accounted for in the model include: (i) leaching from stored manure to groundwater, (ii) surface runoff to surface waters, (iii) subsurface runoff to surface waters, and (iv) leaching to groundwater.

For the application of Integrator-EU with high spatial resolution national data for Denmark (DK) we made the following changes: (i) adaptation of the boundaries of the NCU, (ii) adaptation of the manure implemented module and (iii) linking Integrator with detailed Danish data. This resulted in a new version of Integrator: Integrator-DK. Based on the boundaries of the Danish municipalities, NCUs that were crossed by a municipal boundary were split such that they are bound by the municipal borders. The overlay with municipalities resulted in 558 NCUs for DK as a whole, an increase of 172 NCUs compared to Integrator-EU. Although detailed estimates of manure applications rate were available for Denmark, we used the Integrator-EU manure distribution module to calculate the manure distribution. This was done to cover the entire N chain from excretion to application. When starting with application it is not possible to calculate gaseous N emission from housing and storage systems and grazing in a consistent way. We calculated the animal manure produced within an NCU, based on the DK animal numbers at NCU level. The manure produced was distributed over the available agricultural land within an NCU, while taking the maximum permissible N manure application rates into account. The detailed Danish data concerning the crop types and livestock types used in Denmark were assigned to Integrator categories for crop types and animal types and the Danish data, usually available at municipality level, were assigned to NCUs.

Results

National N budgets for year 2000 and 2010

Annual N budgets for the entire Danish agriculture for the years 2000 and 2010, based on the original Integrator version (Integrator-EU) and the disaggregated Danish version (Integrator-DK), are presented in Table 1. Furthermore, Table 1 also presents the national budgets as calculated by Hutchings et al. (2014). Relatively large differences exist between Integrator-EU and Integrator-DK results. Integrator-DK calculated N inputs are 7% (in 2000) to 10% (in 2010) lower than those from Integrator-EU. These differences were mainly due a lower excretion and a lower mineralisation rate calculated by Integrator-DK, mainly caused by differences in excretion rates and land use. It is notable that for 2000, Integrator-EU calculates a higher manure excretion than Integrator-DK, whereas in 2010 the situation is reversed. Furthermore, Integrator-DK calculates an increase between 2000 and 2010 in manure excretion, whereas for Integrator-EU the manure excretion remain constant. Most notable differences for the outputs exist for the N uptake. Integrator-DK calculated an uptake which is 25% (in 2000) to 20% (in 2010) lower than those from Integrator-DK. As a result Integrator-DK calculated higher N losses, mainly as leaching and runoff, since the reduction in inputs (7 to 10%) is larger than the reduction in uptake (20 to 25%). Large differences also exist when comparing the model results for both levels with the recently derived national N budgets (DK budgets). It is noteworthy that the total N inputs as calculated by Integrator-EU were closer to those from the DK budget. Another remarkable difference is that the ratio N_2 emission (due to denitrification) to leaching and runoff is about 1 to 1 for both models, whereas it is about 1 to 3. As a result both Integrator models calculated losses to groundwater and surface water which are much less than those estimated by the DK budget.

Table 1 National N balance for DK in 2000 and 2010 based on Integrator EU (Int-EU) simulations with default European data and Integrator DK (Int-DK) simulations with disaggregated Danish data. The table also present the national Danish N budgets based on an independent study (DK budget)

Source	N budget for Denmark (kton N yr^{-1})					
	Int-EU	**Int-DK**	**DK budget** [1]	**Int-EU**	**Int-DK**	**DK budget** [1]
	2000	2000	2000	2010	2010	2010
Manure excretion	247	232	255	247	251	238
Fertilizer	233	234	251	197	194	190
N biosolids	-	-	9	4	-	7
Deposition	37	34	28	36	34	21
Fixation	17	14	38	17	14	41
Mineralisation	86	48	52	84	48	84
Total input	620	561	633	584	542	581
Uptake	383	282	304	356	284	302
Emission NH_3	63	58	63	57	61	51
Emission N_2O	6	6	13	6	6	11
Emission NO_x	3	2	13	3	2	11
Emission N_2	86	107	63	85	85	55
Leaching + runoff	77	106	179	78	85	151
Total output	620	561	633	584	542	581

1) See Hutchings et al. (2014)

Disaggregated budgets at NCU level for 2010

Figure 1 presents XY-plots based on 113 plots of Integrator-EU versus 558 plots of Integrator-DK for the year 2010, where the Integrator-EU results for the 113 plots were compared with the mean of the corresponding Integrator-DK plots.

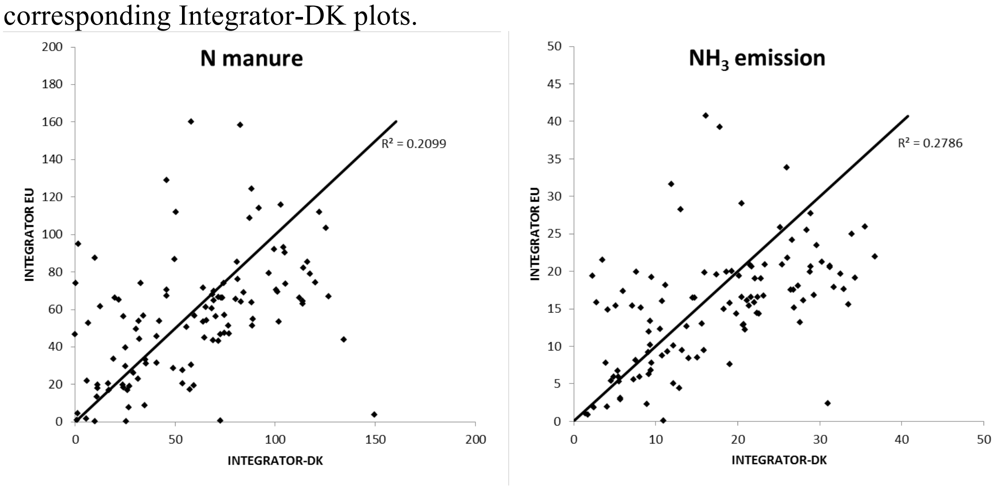

Figure 1 XY-plots for N input by animal manure and NH_3–N emission based on 113 plots of Integrator-EU versus averaged values for the same number base on 558 plots of Integrator-DK for the year 2010. The solid line represents the 1:1 line and the R^2 the coefficient of determination of linear regression between the Integrator-EU and Integrator-DK results

Results show a relatively large scatter around the 1:1 line, and a rather poor correspondence for manure application (R^2 =0.21) to moderate for NH_3 emission (R^2 =0.28). This means that the spatial distributions of Integrator-DK clearly differ from those of Integrator-EU. This is confirmed by Figure 2, which presents the spatial distribution of the N animal manure input and NH_3 emission at NCU level. Results show large differences between the spatial distribution as calculated by both model versions. The inclusion of more detailed data, that is more supported by national authorities, clearly results in a different spatial distribution. The Integrator-DK result show a much larger west-east gradient in manure application and NH_3 emission, which is more in line with the actual animal distribution. This is likely to be due to errors in the procedure to downscale animal numbers to a higher spatial resolution, especially regarding non-ruminants.

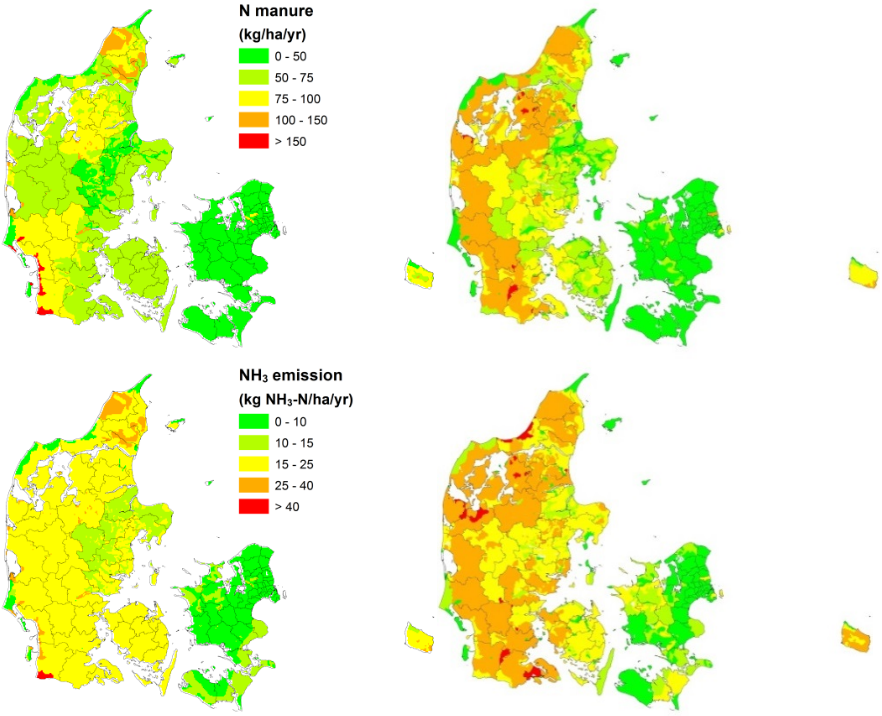

Figure 2 Total N animal manure input (top) and total NH_3 emission (bottom) from agriculture for the year 2010 with Integrator-EU (left) and Integrator-DK (right).

Conclusion

Large differences exist for the national N budgets calculated by both versions of the model. The incorporation of detailed national data rather than less detailed European data does, however, not necessarily result in more reliable national results. Nevertheless, the spatial distribution of manure distribution and N losses from Integrator-DK are closer to observed distributions than those from Integrator-EU. Differences in spatial distribution between Integrator-EU and Danish results are mainly due to differences in the spatial distribution of livestock. This comparative study between spatially detailed data based and generic national data based N budgets clearly illustrates the importance of good spatial resolution in input data. There is clearly a need for collection of high resolution data from all Member States or Member States should submit their own (high) spatial distribution data.

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