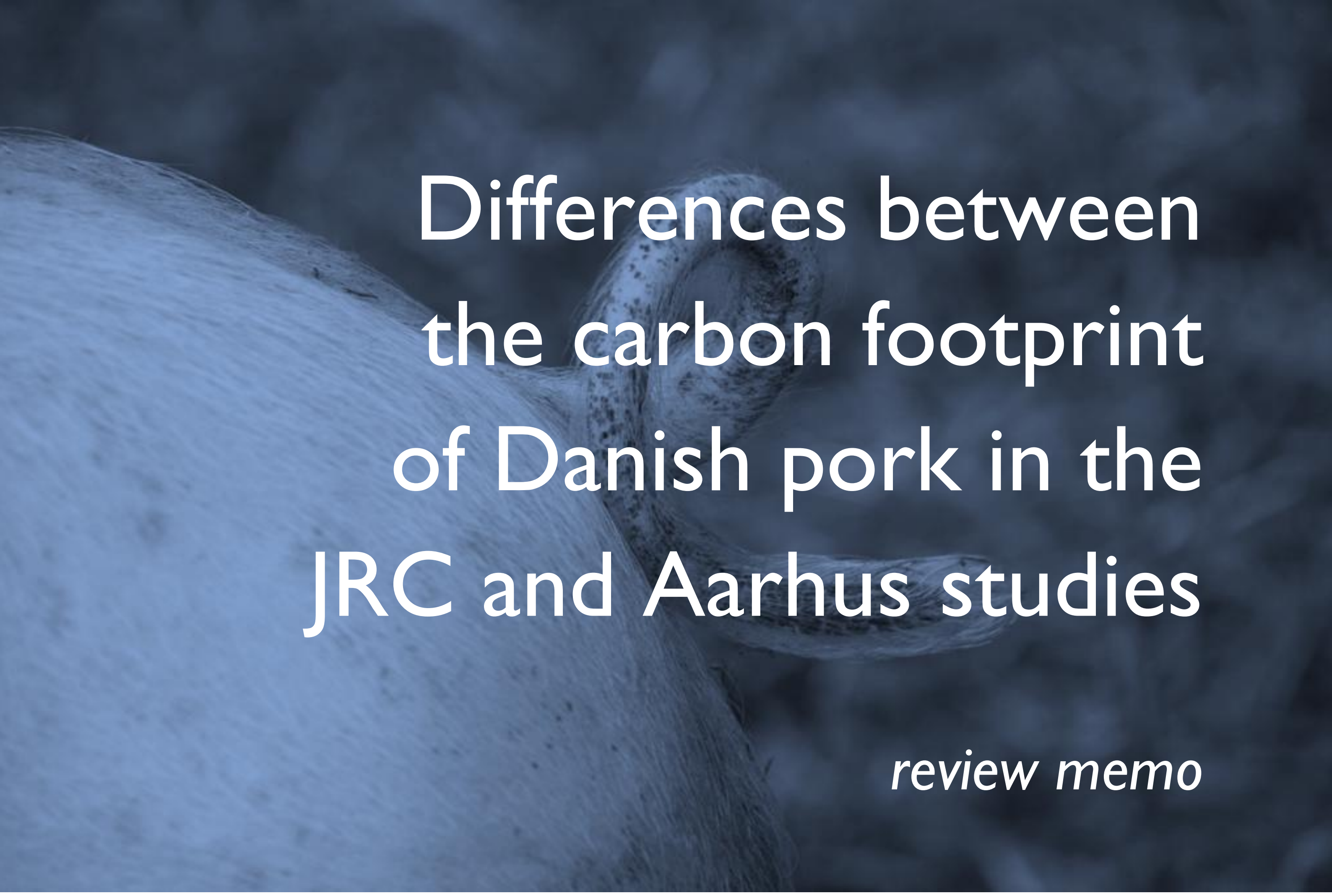

Differences between the carbon footprint of Danish pork in the JRC and Aarhus studies

review memo

Anton Kool
Jasper Scholten
Hans Blonk

May 2013

blonk consultants

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Jasper Scholten
Hans Blonk

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Blonk Consultants
Gravin Beatrixstraat34
2805 PJGouda
The Netherlands
Telephone: 0031 (0)182 579970
Email: info@blonkconsultants.nl
Internet: www.blonkconsultants.nl

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1 Introduction

According to a study by Aarhus University (Nguyen et al., 2011), the carbon footprint for Danish pork is 3.1–3.4 kg CO_2-eq per kg pork (carcass weight). This figure is significantly different from the carbon footprint calculated by the JRC (Leip, et al., 2010), which is 5.0 kg CO_2-eq per kg pork.

The aim of this review is to explain the differences in the carbon footprint of Danish pork calculated by the JRC and Aarhus University. The review was commissioned by the Danish Agriculture and Food Council and accompanied by Danske Slagterier. The review was carried out by Blonk Consultants.

2 About the studies

2.1 The JRC study

The objective of the JRC study (Leip, et al., 2010) was to provide an estimate of the net greenhouse gas (GHG) emissions for animal products in the EU-27 countries using a food chain approach. Besides pork, the study also assessed the carbon footprints of cow's milk, goat's milk, sheep's milk, beef, lamb/mutton, goat's meat and eggs. The GHG emissions were calculated from cradle (including the production of inputs such as fertilisers and feed) to farm gate. The calculations were made using different models, such as CAPRI, GAINS and MITERRA-EUROPE. The inputs and outputs were calculated at the national level; for example, feed intake was calculated by dividing the national feed consumption between all animal categories.

2.2 The Aarhus study

The Aarhus study (Nguyen et al., 2011) is a life cycle assessment (LCA) of a single animal product: Danish pork. The assessment was based on information representative for this specific product chain. Greenhouse gas emissions, energy use, land use, acidification and eutrophication were calculated for pork production from cradle to slaughterhouse gate. The study compared two approaches – attributional and consequential – to show the differences between the results obtained. In this review we only consider the attributional approach, as this is more comparable with the methodology used in the JRC study.

3 The differences analysed

We analysed the differences in approach and data used and asked the respective authors to explain their assessments (see Annex 1 for details of these communications). The causes of the biggest share of the difference between the results of the two studies are discussed more in detail in the next chapter.

Besides methodology and data used, the JRC and Aarhus studies differ in several other aspects as well. First, the aims of the studies differ: the JRC study aims to provide insight into the contribution made by different kinds of livestock production in Europe to greenhouse gas emissions, whereas the Aarhus study focuses on a single animal product from one country: Danish pork. The JRC study therefore uses a top-down approach: primary data, such as feed use, are based on national and European figures, derived mainly from statistics. In contrast, the Aarhus study is a bottom-up case study: primary data are based on average technical performance figures derived from Danish pork production.

At several points in the pork production chain there is co-production. One such point is at the pig farm, where sows produce piglets and live weight for slaughter. In such cases, upstream impacts have to be divided between the different co-products. The JRC study uses allocation, whereas the Aarhus study uses a consequential approach in which the avoided products from co-production are subtracted from the total impact. In the JRC study, impacts are allocated between the co-products sows and piglets. However, no further details about this allocation are provided, such as how impacts are allocated between exported piglets and piglets for fattening.

The authors of the Aarhus study say they take an attributional approach, although they use important consequential elements, including avoided emissions (for example, fertiliser use avoided by the application of manure).

The JRC study uses different Global Warming Potential (GWP) figures for methane (CH_4) and dinitrous oxide (N_2O) than the Aarhus study. Nevertheless, the effect of the higher GWP for N_2O is almost cancelled out by the effect of the lower GWP for CH_4.

Both studies analyse the production chain of pork. The Aarhus study includes processing of the pork at the slaughterhouse, but this is not included in the JRC study, although the results of both studies are expressed per kg carcass.

The main differences in approach and data are summarised in Table 1. The effect of resolving these differences is quantified where possible and summarised in Table 2 and expressed in figure 1. The three most important differences are related to nitrogen excretion, N_2O emissions from ammonia (NH_3) reducing housing systems, and capital goods.

The emissions from the manufacture of buildings and machinery (capital goods) are included in the JRC study, but not in the Aarhus study. This explains 0.5 of the 2.0 kg CO_2-eq/kg pork difference in impact and is one of the main differences explained in more detail in Chapter 4.

Table 1. Differences in methodology, system boundaries, functional unit, data and results between the JRC and Aarhus studies

		JRC	Aarhus
System boundaries	Processing animals at slaughterhouse	Not included	Included
	Transport of pork	Not included	Impact is calculated and presented separately
	Capital goods	Included; emissions from manufacture of buildings and machinery	Not included
Functional Unit		Per kg carcass	Per kg carcass
Allocation rules	Piglet production sows	The impact from sow husbandry (and upstream impacts) is allocated between piglets and sows for slaughter, based on N content	The meat from slaughtered sows is included in the meat production from pigs. The impacts from sow husbandry (and upstream impacts) are therefore fully allocated to piglets, whereas 3.2% of the total meat is derived from sows (without impact).
	Manure transport and application	Emissions from manure application are allocated to pig production. Impacts of avoided artificial fertiliser are subtracted only for manure applied to non-feed crops.	All emissions from transport and application are allocated to pig production; impacts of avoided artificial fertiliser are subtracted.
	Slaughtering	100% of upstream impacts are allocated to carcass. No avoided impacts from co-products.	Avoided impacts from slaughtering co-products are subtracted from impacts of slaughtering.
Emission factors	GWP N_2O	310	298
	GWP CH_4	21	25
	N_2O emissions from manure management: NH_3 reducing systems	5%	0.5%
	CF feed, kg CO_2-eq/tonne compound feed	Cannot be determined	546
Data	Kg carcass/kg live weight	0.78	0.757
	N excretion, kg N/per kg meat	0.17	0.06
	Feed use, kg/kg live weight	3.09	2.81
	Manure N avoiding fertiliser N	100%	75%
Results	On-farm energy use, kg CO_2/kg live weight	0.718	0.148

The JRC study assumes N_2O emissions from NH_3 reducing animal housing systems are 10 times higher than from traditional animal housing, based on the GAINS model. The Aarhus study does not make this distinction, in line with IPCC 2006. The JRC study assumes that 24% of Danish pigs are kept in NH_3 reducing animal houses. The combined emission factor for direct N_2O emissions from animal houses in the JRC study is therefore 1.6%, whereas the emission factor used in the Aarhus study is 0.5% (more than three times less). This is one of the main differences explained in more detail in Chapter 4.

The Aarhus study assumes that a slightly lower percentage of the live weight is processed into carcass: 75.7% compared to 78% in the JRC study. This results in a relatively small difference between the studies.

The nitrogen (N) excretion per unit pork is almost three times higher in the JRC study. This results in also almost three times higher N_2O emissions from manure management, volatilisation, manure application and grazing. This higher N excretion explains more than half of the difference in the carbon footprint between the studies: 1.18 kg CO_2-eq/kg pork (see Table 2). In the JRC study N excretion is calculated as the difference between N intake and N retention in the animal. The N intake is based on the previously mentioned top-down approach; the feed consumption is derived from Danish figures in EUROSTAT statistics, which are somehow allocated across the different Danish animal production systems. The relatively high N excretion is one of the main differences and is explained in more detail in Chapter 4.

Table 2. The effect of resolving some of the differences in Table 1 on the carbon footprint of pork (in first row)

		JRC	Aarhus
Original result carbon footprint of pork	**Kg CO_2-eq/kg pork (carcass)**	**5.04**	**3.1**
Excluding capital goods		-0.5	
Excluding impact of slaughtering (including avoided co-products)			-0.2
N excretion at 0.06 kg N/kg meat	Calculated by multiplying the sum of 'manure management, manure application, grazing, volatilisation' from Table A6.22 by 35% (0.06/0.17)	-1.18	0
Equal GWPs	N_2O: 298	-0.09	0
	CH_4: 25	+0.13	0
EF N_2O manure management NH_3 reducing system at 0.5%	JRC: Approx. 24% of pigs kept in NH_3 reducing animal housing	-0.75	0
Carcass% to 75.7%		+0.15	0

The Aarhus study allocates all emissions from the application of manure to the pig production sector. In addition, the avoided use of artificial N fertiliser application is subtracted, assuming that 100 kg N in manure avoids 75 kg fertiliser N (75% efficiency). The JRC study takes a partly comparable approach. It allocates all emissions from manure application to the manure producing chain, but only subtracts the artificial N fertiliser avoided by the application of manure to non-feed crops (crops which are not used as feed ingredients in animal compound feed).

Feed use per kg live weight is about 10% higher in the JRC study than in the Aarhus study. The JRC figures are based on the CAPRI model, which uses data derived from market balances and requirement functions. The data on feed consumption used in the Aarhus study are based on information from the Danish Agriculture and Food Council.

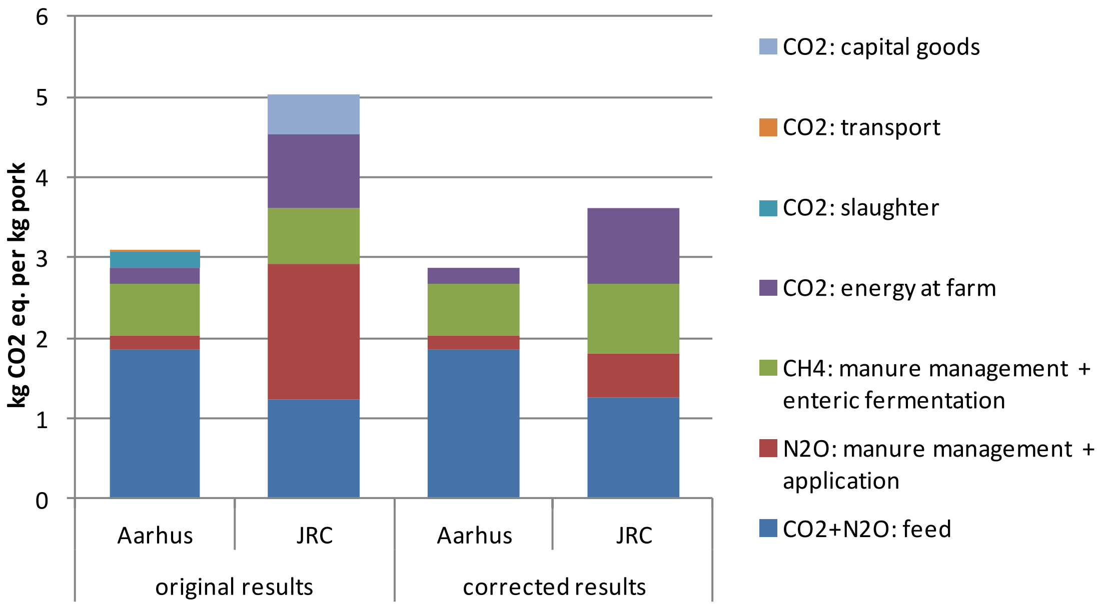

Figure 1. The corrected results (in accordance to the aspects mentioned in table 2) of the Aarhus and JRC studies compared to the original results.

4 The main differences explained in detail

This chapter discusses the issues that account for most of the difference in the carbon footprint of Danish pork between the JRC and Aarhus studies. These issues were first discussed with the relevant researchers. Reports of these discussions can be found in Annex 2.

4.1 Nitrogen excretion

As stated in Chapter 3, the value for N excretion in the JRC study is almost three times higher than the value used in the Aarhus study. In the JRC study N excretion is calculated as the difference between N intake and N retention in the animal. The N intake is based on feed consumption from EUROSTAT statistics.

To understand the underlying data and calculations, we calculated the N content of feed from the productivity and N excretion for Danish pork given in the JRC study. This calculation resulted in a crude protein content of 321 g/kg feed (for details see Annex 2.1). The crude protein content of pig feed (concentrate) usually varies between 160 and 190 g/kg; 321 g is far too high. We also obtained values that were far too high for other countries as well.

In response, the JRC stated that the above calculation is not valid because the value for productivity we used, from Annex 1.2 of the JRC report, is not the value used in the CAPRI model. The productivity given in the Annex refers to a preliminary phase of the study. A different value is used in the CAPRI model, but JRC did not state what this is. In addition, the information on Danish feed use derived from EUROSTAT statistics indicates a remarkably high fish meal content (see Annex 2 at page 18). This may explain the relatively high nitrogen intake from feed.

Second, JRC stated that the calculation of N excretion is based on figures derived from statistics on the number of sows, number of slaughtered pigs and pork output, slaughtering statistics and feed statistics from EUROSTAT. Moreover, requirement functions are used to calculate the requirements for inputs such as crude protein. As these are usually not consistent, the CAPRI model uses a 'Bayesian approach' to alter all these numbers to ensure consistency. The basic assumption behind this approach is that all feed in national balances has to be fed to animals. Although this assumption is theoretically correct, the quality of the data in those statistics and the underlying assumptions and definitions determine the extent to which these data are useful for such an analysis and the quality of the final result. We have not yet been provided with full information on the statistics and values used, neither have we been able to check the values used. Nevertheless, a relatively high fish meal content in feed (as described above) might explain part of the overestimated nitrogen excretion.

4.2 N_2O emissions from NH_3 reducing manure management systems

JRC was consulted about the reasons for the N_2O emission factor for NH_3 reducing measures in animal housing being 10 times higher than for traditional housing. JRC's explanation was that this was based on background information from the environmental impact models MITERRA (Velthof, Oudendag & Oenema, 2007) and GAINS (Klimont & Brink, 2004). We approached IIASA (responsible for GAINS) for an explanation of the use of an increased N_2O emission factor for NH_3 reducing systems in GAINS. From the information we received from them it appears that GAINS does not make a distinction between N_2O emissions from traditional and NH_3 reducing animal housing system at all (Winiwarter, 2005). After confronting JRC with this and following a discussion between JRC and IIASA, it was concluded that it was not correct to increase the N_2O emission factor by a factor of 10 to account for the NH_3 reducing measures in animal housing. JRC confirmed this error in an email on 1 March 2013 (see Annex 2.2).

It is not reasonable to make a distinction between N_2O emissions from traditional and NH_3 reducing animal housing. IPCC 2006 makes no distinction in N_2O emission factors between traditional and NH_3 reducing animal housing systems. From Dutch research it is known that there is not much measuring of N_2O emissions from different animal housing systems, nevertheless no distinction is made by researchers between N_2O emissions from traditional and NH_3 reducing animal housing systems (Oenema et al., 2000; Velthof et al., 2009).

As a result of these investigations, JRC amended the CAPRI model, which calculates greenhouse gas emissions from European agriculture, and sent a note to the CAPRI users mailing list explaining the problem and the changes, and advising them to update their software before new data on GHG emissions are used. In addition, JRC will publish a short document to the AFOLU internet folder (www. http://afoludata.jrc.ec.europa.eu/index.php/dataset/files/236, where most people download the results and the report) highlighting the issues which came up after the publication of the study.

4.3 Capital goods

The emissions from the manufacture of buildings and machinery (capital goods) are included in the JRC study, but are not included in the Aarhus study. Including the emissions from capital goods is not in line with recent guidelines for life cycle inventories, such as PAS 2050. The decision by Aarhus to exclude this from the analysis is in line with PAS 2050 and other guidelines.

The inclusion of the emissions from capital goods in the JRC study explains 0.5 of the 2.0 kg CO_2-eq/kg pork higher impact. The emissions from capital goods and energy consumption at farm level used in the JRC study are based on Kränzlein (2008). The 0.5 kg CO_2-eq/kg pork impact from capital goods represents 10% of the total carbon footprint for Danish pork calculated by JRC, which seems a rather high share. However, the data from which these emissions are derived (such as the type and amount of machinery and buildings taken into account and the emissions factors used) cannot be derived from Kränzlein (2008) nor from the JRC study. The JRC has not yet provided further background data (see Annex 2.3).

5 Conclusions

The difference between the aims of the two studies explains to a certain extent the differences in approach and results. The JRC study provides insight into the greenhouse gas emissions from European animal production. The top-down approach used in this study makes it suitable for providing an overview of animal production systems and animal products at EU-27 level, but less suitable for comparing animal production in different European countries. The Aarhus study takes a bottom-up approach and investigates a single product from one production chain: Danish pork. This makes it more suitable for obtaining information on the specific environmental impact of Danish pork, which can be compared to pork production in other production chains.

From this review it can be concluded that the relatively high N_2O emissions from NH_3 reducing measures at manure management systems in the JRC study is not correct. This explains a major part of the difference in the carbon footprint of pork between the JRC and Aarhus studies. As a result of this review, this error has now been corrected in the CAPRI model used in the JRC study and communicated to users. From now on, calculations of N_2O emissions from manure management systems in the CAPRI model will be in line with accepted methodology, such as IPCC.

The input data for the JRC study are based on statistics on production, feed intake, etc. and feed requirement functions. We do not have sufficient information on these statistics to judge how representative they are of animal production in general and Danish pork production in particular. Nevertheless, the figures for N excretion in the carbon footprint calculated in the JRC study are three times higher than expected on the basis of technical performance and feed composition in Denmark, which indicates that the applied statistics can easily lead to overestimation of N excretion. A relatively high fish meal content in feed may explain the high nitrogen input from feed, and consequently the high value for N excretion.

The inclusion of emissions from the manufacture of capital goods (machinery and buildings) in the JRC study is not in line with LCA standards such as PAS 2050. In addition, the figure for the contribution of capital goods to the carbon footprint seems to be relatively high. This has to be taken into account when comparing the JRC study with impact assessments that exclude these emissions.

Based on the findings in this review, we recommend analysing the environmental impact (carbon footprint) of European animal production in an assessment that combines the top-down and bottom-up approach and is in accordance with methodological standards. The outcome will provide an accurate assessment of the total impacts at EU level and impacts at member state level. Combining the top-down and bottom-up approaches will provide more representative primary data. Using methodology standards (such as PAS 2050) as a reference will provide results that are easier to compare with the results of other studies.

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Annex I First round of explanation

Questions regarding the Aarhus study:

Questions from Blonk Consultants in black without shade, answers from Aarhus (Lan Nguyen) in yellow shade

Methodology, system boundaries and functional unit:

- Is the production of capital goods included in the study?

The production of capital goods is not included in our study, assuming that they have a long lifetime (i.e., having a relatively low contribution to the overall impact of pork production).

Methodology, allocation and system expansion:

- At pig production piglets are produced by sows. The piglets are fattened and are brought as pigs to the abattoir. Besides that 'mainstream' of pigs to the slaughterhouse, Sows are also, at their end of life, brought to the slaughterhouse. How does the study deal with this co-production?

In calculating the amount of 'meat produced per sow with offspring' we take into account not only meat from slaughter pigs (after deducting replacement for sow) but also meat from sow replacement. About 3.2% of the total 'meat produced per sow with offspring' is derived from sows (see Table A2).

- Allocation at feed: At section 2.5.2 the allocation in the attributional approach and the system expansion in the consequential approach is explained for soy bean meal. Also at barley and wheat production a co-product (straw) is produced. Can you explain how co-production of straw is accounted for concerning wheat and barley production at the attributional and consequential approach?

In our modeling, we assume that straw of the cereal crops like wheat and barley is not removed but incorporated into the soil (common case). So, there is no question about using ALCA or CLCA to account for the co-production of straw because the straw remains within the crop system.
We also consider that any straw that is not incorportated into the soil is likely to be harvested for use as an animal bedding material. In this case, straw is likely to be mixed with animal manure to form farmyard manure and be applied to soil after a few months, i.e., even though straw is initially removed from a given site, it will be returned to the soil elsewhere afterwards.

Data:

- The Feed Conversion Rate (FCR) (calculated from table 1) is 3.05 and 2.81 for consequential and attributional approach respectively. Why does the marginal kg pig growth in the consequential approach needs more feed than a kg pig growth in the attributional approach? (this difference represents an important share of the differences in impacts between attributional and consequential approach in your study)

This FCR (kg feed per kg pig LW) is calculated based on the amount of protein and energy supplied by the feed ingredients to satisfy the protein and energy requirements of the pigs. In the attributional modeling, we use the information about typical feed composition for sows, piglets and slaughter pigs to calculate the '**actual**' amount of each feed item consumed in kg per 100 kg meat live weight produced (Table A3). In the consequential approach, it is generalised that the pork production is global and draw on global feed resources. Thus producing an extra pig will ultimately draw on a protein source (e.g. oilseed meal) and cereals. The **theoretical** amount of spring barley (assumed to be the marginal energy feed) and soybean meal (marginal protein feed) was calculated based on the amount of protein and energy supplied by the two feed ingredients to satisfy the protein and energy requirements of the pigs. The difference in the amount of feed use per kg meat produced between the two LCA modeling approaches is thus due to the difference in the assumption concerning feedstuff used and the energy and protein content of the feed component.

- Section 2.5.1 At point 2 the use of reduced carbon footprints of nitrogen fertilisers is explained. It is stated that in the attributional approach the figure representing the 'nowadays advanced technology which reduces the carbon footprint by a factor 2 to 4.3' is used which equals 4.25 kg CO2-eq/kg N. This figure is lower than the carbon footprint of N-fertiliser in the consequential approach; 5.44 kg CO2-eq/kg N. From the explanation of the carbon footprint in the attributional approach it can be understood that the carbon footprint of N-fertiliser reduced during the past years due to reducing measures. So as I would expect the carbon footprint of N-fertiliser at the consequential approach would be the same or even lower as the attributional because that figure would represent the extra N-fertiliser production for the extra pig production. And I assume the extra production will be the nowadays advanced technology. So can you explain why the consequential carbon footprint of N-fertiliser is higher than the attributional?

In the attributional modeling, we assume that nitrogen fertiliser is produced by YARA (with advanced technology) having a carbon footprint of 4.3 kg CO2e/kg. The figure complies with the average carbon footprint standard for fertilisers produced and delivered to Nordic countries like Finland, Denmark, Sweden and Norway.
In the consequential modeling, we assume that the marginal nitrogen fertiliser is not produced by YARA but imported from countries which are likely to be marginal producers like Balticum, Poland, Russia, the Netherlands and Germany. The figure of '5.4 kg CO2e per kg marginal nitrogen fertiliser' is derived from (1) reference value (Jenssen and Kongshaug, 2003), and (2) our assumption that the carbon footprint of marginal N fertiliser is improved by 20%.

Questions regarding the JRC study:

Questions from Blonk Consultants in normal text, answers from JRC (Franz Weiss: FW) marked yellow

Methodology, system boundaries and functional unit:

- Just to be sure: The results from the GGELS project represent the animal production till the gate of the farm. So the processing of animals at the slaughterhouse is not included?

FW: Correct!

- The functional unit refers to carcass of the animal. So just to be sure; the results presented in section 6.3 are presented per kg carcass pork?

FW: Yes, it is per kg of carcass.

- Is the production of capital goods included in the study? We derive this from the detailed results presented in Annex 1 to chapter 6, where CO2 emissions from buildings and machinery are included (see table A6.23a for pork) However we can not find it described.

FW: CO2 emissions from the production of machinery and buildings are included.

Methodology, allocation and system expansion:

- Concerning allocation at sow farming: impacts are allocated between piglets and sows for slaughter based on N-content?

FW: Emissions from the production of sows are allovated to piglets and further to pork via N content.

- Allocation at slaughtering: The functional unit is kg carcass. A living pig slaughtered results in carcass and slaughtering co-products. How are impacts allocated to carcass and co-products at slaughtering?

FW: All emissions are allocated to carcass. The relation of carcass to liveweight is supposed to be 78%.

- At section 1.1.5 it is mentioned that manure applied on crops that are not used for feed is avoided by system expansion: How is the share of manure applied at crop for feed and applied at crops not for feed derived?
- Section 4.4 at page 129 says, in contrary to the above mentioned,: 'for manure applied on agricultural land we apply the method of system expansion' Does this mean that for all manure application system expansion is applied?
- And if (pig) manure is applied to a crop which is used as feed ingredient, to which product/system are impacts of manure application allocated? To pig farming/production or to crop/feed production?

FW: We have done it in a maybe not very transparent way, which should be improved for futurestudies. We simply gave a credit for the emissions saved by the application of the manure to the respective category. So, N2o-emissions from manure application remain untouched, but emissions from mineral fertilizer production and application of feed production are reduced by the saved emissions in the non-feed production due to the application of manure. Since manure is homogeneous and does not get a flag from where it comes, we use average shares of manure applied and feed/non-feed relation for each crop. But we use the eact numbers of how much of each crop is eaten by which animals in order to make the allocation.

- What are the assumptions concerning avoided fertiliser use at manure application? Especially at what degree will N, P and K from pig manure avoid N,P and K respectively from fertiliser?

FW: 1 kg N of manure avoids 1 kg of N from mineral fertilizer.

Data:

- Just to be sure: the weight of a pork carcass relative to the weight of a living pig entering the slaughterhouse is 78%? This is assumed to be equal for all European countries in the GGELS study?

FW: Yes.

- What is the share of pig manure in Denmark applied to feed crops and applied to non-feed crops?

FW: It is the same share for all manuer, so no difference has been made between animals. The share in Denmark is around 67% for feed, and 33% for non feed.

- What values are used and from which data source for the carbon footprints of the avoided N, P, K fertiliser?

FW: The method how emissions from the production and apliaction of mineral fertilizers are calculated are documented in the report (pp 88ff, pp 108).

- The feed input per kg pork is 3.965 kg per kg pork (carcass, total from table A4.4a) which equals a Feed Conversion Rate (FCR) of 3.09 (kg feed/kg live weight). This value is 10% higher than the figure of 2.81 which is used in the Aarhus study (and explains a part of the differences between the results of both studies). What is the source/reference for the feed input at Danish pork production as presented in table A4.4a?

FW: It is the feed use which is in the CAPRI data base. This is derived rom the market balances and requirement functions. It is not values from literature.

Results:

- At Table A6.21 – A6.30 GHG emissions of pork production are given.
- The total CH4 emission (excluding LULUC) of Danish pork in Table A6.25 equals 0.70 kg CO2-eq/kg pork which differs from the value calculated from the figures of Danish pork in Table A6.21: 6.18 +26.96 = 33.14 g CH4 X 22.25 (GWP biogenic CH4) = 0.74 kg CO2 eq.

FW: We used the factor 21 for the calculation of CO2eq from CH4.

- A comparable issue concerning N2O: The total N2O emission (excluding LULUC) of Danish pork in Table A6.25 equals 2.24 kg CO2 eq/kg pork. The calculated value of the total N2O emissions from table A6.22 is 7.2 g N2O per kg pork, which equals 7.2 X 298 (GWP N2O) = 2.15 kg CO2 eq/kg pork.

FW: Like above, it is the factor which differs. We used 310 for N2O.

- So the question from the two above mentioned bullet points: How are the CH4 and N2O emissions from Table A6.21 and Table A6.22 calculated to kg CO2 eq in Table A6.25. For instance which GWP emission factors are used?
- At table A 6.23a the CO2 emission factors of pork production from energy use are given. At the life cycle of pork energy is used for production/cultivation feed components, processing feed, animal husbandry and transport. For the sources 'Diesel', 'Other fuels' and 'Electricity' in table A 6.23a it is not clear to which chain in the life cycle it refers. For instance 'Other Fuels' : does this refer to the use of, for instance natural gas for heating pig housing or does it refer to energy used in feed crop cultivation?

FW: The values refer to both, feed and animal production. So, i.e. Diesel is mainly used for crop production and therefore for feed production then used for feeding pigs. Maybe the term Feed production in the table is misleading, what is meant here is the feed processing. Öther fuels"is mainly the heating of stables.

- The GHG emissions of a few sources differ significantly to the results of the 'Aarhus' study:
  - The N2O emissions from manure management at the GGELS study is 3.79 g N2O per kg pork (carcass). At the Aarhus study these emissions are calculated as 0.73 g N2O/kg pork (carcass). A reason for this difference might be the increased N2O emission due to animal housing using NH3 reducing measures. From table 4.8 we understand that the N2O emission from animal housing increases 900% due to NH3 reduction measures. What is the explanation/source for this factor of 900%? And what is the emission factor for direct N2O from N in manure management excluding and including this 900% increase?

FW: It is in fact this assumption of a 900% increase of the emission factor in case of NH3 reduction measures. The default emission factor is the one from IPCC 2006 0.5% for liquid and solid systems (assuming a natural crust cover for liquid systems). For details on the assumption of the 900% increase I refer you to the GAINS group at IIASA. The assumptions have been overtaken from the GAINS model.

  - Another explanation of the relatively high N2O emission from manure management is the amount of N excreted in manure. The amount of N excreted in manure at the GGELS study is based on the CAPRI model which is 22.8 kg N per head whereas the figure from the Danish National inventory is 8.5 kg N per head. So the primary data for N-excretion from CAPRI seems to be relatively high, what is the source reference for this value?

FW: N excretion is calculated as the difference between N intake and N retention in the animal. The N intake is based on the feed item in the production balance (official statistics of EUROSTAT). This is somehow distributed to the animals. If there is a problem with this statistics this would affect the feed intake in CAPRI because it is the main source. We admit that the values seem to be very high compared to other estimates and maybe the feed distribution in CAPRI should be improved. However, on the other hand there is the statistics which obviously is not consistent with the usual assumptions on N excretion in Denmark.

  - The CO2 emissions from 'electricity' and 'other fuels' totals 0.92 kg CO2/kg pork. At the Aarhus study the CO2 emissions from energy use at animal husbandry are calculated as 0.20 kg CO2/kg pork. So the GGELS value is about 4.5 times higher. As already mentioned above energy use at what stage is included in the figures for 'electricity' and 'other fuels' and what are the primary data behind these figures ?

FW: These values are based on the work of Tim Kraenzlein (see references in the report). In his dissertation he describes in detail the calculation of the energy related emissions. Other fuels is related to stable heating.

Annex 2 Detailed discussions about main issues

A2.1 N-excretion:

In black the questions / statements of Blonk Coonsultants, in green the answers / reaction of JRC (Franz Weiss)

The N-output per swine used in the JRC study (22,8 kg N per head per year in table 5.2) is a lot higher than expected (for instance the Danish National Inventory states 8.5 kg N per head per year).
In your comment about this you wrote: 'N excretion is calculated as the difference between N intake and N retention in the animal. The N intake is based on the feed item in the production balance (official statistics of EUROSTAT). This is somehow distributed to the animals. If there is a problem with this statistics this would affect the feed intake in CAPRI because it is the main source. We admit that the values seem to be very high compared to other estimates and maybe the feed distribution in CAPRI should be improved. However, on the other hand there is the statistics which obviously is not consistent with the usual assumptions on N excretion in Denmark.
Using the productivity for Danish pig farming (Annex 1.2; kg pork/head/yr), the amount of feed used to produce pork (Table A4.4a; kg feed/kg pork) and N-excretion the crude protein content of feed can be calculated as follows:

Answer: I am sorry for the misunderstanding, but Annex 1.2 does not relate to the numbers used in the CAPRI model. We tried to mention it right at the beginning, but it remains an important source of misunderstandings. The reason why it is there is that the project was divided in two phases. In the first phase there was a conventional assessment of GHG emissions included, not based on CAPRI, while the estimations used as final results were calculated in the second phase. It was not our preferred solution to leave it there but DG AGRI, who has funded the project, wanted to keep it. Therefore, the productivity in CAPRI is not the one in Annex 1.2.

Retention N in pigs: 133 kg (annex 1.2) / 0.78 (kg carcass/kg live weight) = 170.5 kg liveweight * 251 g N/kg (Table 4.36) = 4.26 kg N/head/year
N-excretion = 22,8 kg N /head/year (table 5.2)
N-input = 4.26 + 22.8 = 27.06 kg N /head/year
Feed input: 133 kg pork/head/yr (annex 1.2) * 3.965 kg feed/kg pork (sum of feedstuffs in table A4.4a) = 527.3 kg feed/head/year
N-content feed: 27.06 / 527.3 kg feed/head/year = 51.32 g N/kg feed
Crude protein content feed: 51.32 * 6.25 = 321 g crude protein per kg feed

The crude protein content of pig feed (concentrate) usually varies between 160 – 190 g /kg, 321 g is far too high. We calculated the crude protein content in pig feed for some other countries:

	FCR, kg feed/kg live weight pig	crude protein content feed, g/kg
Germany	3.77	181
Finland	2.70	213
Belgium	3.16	222
Sweden	3.46	225
France	2.78	248
United Kingdom	2.91	249

Denmark	3.09	321
Netherlands	2.64	332
Cyprus	3.15	334
Greece	3.07	533

In general these calculated figures seem to be much higher than usual values in practice which implies that the used statistics do not provide a sound figure for feed and N-intake .

Answer: These are the crude protein values used in CAPRI for Denmark (in kg per kg feed):

	CRPR
Soft wheat	0.12
Durum wheat	0.12
Rye	0.1
barley	0.1
oats	0.11
maize	0.1
other cereals	0.17
rape	0.2
sunflowers	0.17
soy beans	0.41
other oil fruits	0.22
fodder maize	0.02
fodder root crops	0.02
other fodder on arable land	0.032
olives	0.106
pulses	0.26
potatoes	0.021
textile crops	0.35
tomatos	0.187
other vegetables	0.02
apples, pears and peaches	0.03
other fruits	0.014
citrus fruits	0.064
atable grapes	0.11
table olives	0.106
grass	0.02
straw	0.03
cow milk for feeding	0.03
sheep and goat milk for feeding	0.03
rice	0.09
molasses	0.05
starch	0.3
sugar	0.01
rape oil	0.1
sunflower oil	0.1

soy bean oil	0.13
rape cake	0.35
sunflower cake	0.35
soy bean cake	0.45
olive cakes	0.1
othetr cakes	0.32
destilled dried grains	0.26
protein rich feed (fish meal etc.)	0.408
energy rich feed (manioc meal etc.)	0.09

Besides that the FCR (feed conversion rate) seems to be very high for some countries (for instance 3.77 for Germany) and for some countries rather low; NL 2.64 compared to 2.70 in practice (recent Blonk Consultants study)

Based on the above we would like to have more background information about the feed intake based on Eurostat:

- What is the total feed intake and how is this distributed to the different animals?
- What are the Eurostat figures for feed intake for Denmark (and if possible other countries)
- How is the N-intake from feed intake calculated?

Answer: Unfortunately, the feed distribution in CAPRI is not as simple as to be explained in a few lines. On the one hand, there are the official data from statistics. This is for pigs the number of sows in the livestock statistics, the number of slaughtered pigs and pork output according to slaughtering statistics and the feed category of the production balance sheets of EUROSTAT and partly, for example for fish meal, from FAO commodity balance. On the other hand, there are requirement functions which are used to calculate the crude protein, dry matter and energy requirements for the produced pork. Since those numbers, nutrient requirements and nutrient deliveries will generally not fit together, CAPRI applies a Bayesian approach changing all numbers in a way to guarantee consistency (simultaneously for all animal activities). I attach you a simplified version of the approach in the file documentation_fedtrm.doc (however, you won't find the calculation of the theoretical requirements there). The important point, however, is that all the feed in national balances have to be fed to animals, If there is an inconsistency between technical coefficients used i.e. by inventories and the official statistics, CAPRI will close the consistency gap by changing all numbers according to their credibility. But it is not guaranteed that CAPRI identifies and changes the wrong numbers, it will change all numbers a somewhat.

For the original numbers of the production balance I refer you to the respective sources: The supply balance sheets from EUROSTAT (you find there production, imports, exports etc. and also animal feed use), and the commodity balances from FAO for non-EU and Non-agricultural products like fish meal. In the Bayesian procedure CAPRI, due to an oversupply in Denmark, reduces those original numbers. The resulting CAPRI feed supply for Denmark is (in 1000 t):

	FEDM
Soft Wheat	3768.974
Durum wheat	7.509

Rye	69.813
barley	2806.847
oats	308.983
maize	70.57
other cereals	112.48
rape	38.271
sunflowers	3.587
soy beans	84.165
other oil fruits	3.376
fodder maize	4376.356
fodder root crops	433.743
other fodder on arable land	8310.396
pulses	50.159
potatoes	98.674
grass	3491.333
straw	761.914
molasses	103.604
rape cake	363.148
sunflower cake	233.499
soy bean cake	1814.538
destilled dried grains	8.706
protein rich feed	1010.965
energy rich feed	245.5

As you can see, the most likely candidates for the high protein supply in Denmark are soy bean cake and protein rich feed, which is an aggregate of fish meal, by products of milling and brewing industry and corn gluten feed.

For example the Danish numbers for fish meal from FAO commodity balance are much higher than in any other comparable country in Europe:

2003	2004	2005
689.496	586.577	547.332

For more detailed information on exact data sources and which numbers are hided in which aggregate you can also contact directly the University of Bonn who is in charge of these issues in the CAPRI model.

Andrea.zintl@eurocare-bonn.de

We would highly appreciate if you could help us with your national expertise to find the source of the possible overestimation, on the basis of the feed numbers above. In fact, I am currently looking for better data on fish meal use in feeding. If we used EUROSTAT data (Prodcom from farm to fork) corrected by aquaculture consumption instead of FAO data we could reduce the crude protein supply by around 10%, which, however, is not enough. I think we can exclude that the problem is in the feed distribution among animals since all Danish animals seem to be oversupplied compared to technical estimates. It is the total amount of feed which seems too high for the animals in the country.

A2.2 N2O emission at NH3 reducing housing system

Direct N2O at NH3 reducing housing system

The N2O emission from a NH3 reducing housing system is a factor 10 higher compared to a conventional housing system, based on the GAINS model. I would like to have more information about the backgrounds of this. You refer to IIASA, do you have a contact person who I can consult about this?

Answer: The person responsible for the agricultural part of GAINS at IIASA is Zbigniew Klimont: klimont@iiasa.ac.at

Answer Zig Klimont, 14 feb

Dear Anton,

Thanks for your question. I forward this to Wilfried Winiwarter who is dealing with the N2O component of GAINS.

He should follow up on that shortly.

Answer Wilfried Winiwarter, 26 feb

Dear Anton,

Thanks for investigating into N2O from agriculture. Despite the fact that uncertainties are large, at least there should be consistencies – and you are right being surprised, I also do not find consistencies in what you report from JRC data to those we use in GAINS. The only clear effect I would expect happening is when manure measures include moving from liquid to solid waste systems (note: this is not an option in the GAINS ammonia module, but someone could come up with interpreting that as a measure) there would be N2O emissions increase associated to that. In GAINS (see report attached) we use 2% of N excreted as being emitted as N2O (identical to 31 g N2O for each kg N excreted) for solid manure systems, a figure we derive from the IPCC 2000 GPG.

Sorry I cannot provide you with an explanation of the JRC's result.

Best wishes

Wilfried

Additional answer Wilfried Winiwarter, 27 feb

Dear Anton,

I think it is a good idea to explore this from the detail. But in order to allow Franz understand my response, it may be useful to add your statements that I responded to. I cannot tell if your interpretations of the JRC report fully match the report itself, and I did not attempt to check this.

Best wishes

Wilfried

Answer Franz Weiss, 28 feb:

Dear Anton, Winfried and Zig,

The calculation of NH3-emissions in CAPRI is based on the MITERRA model, which again takes most of the information and assumptions applied from the GAINS model. It has been implemented in co-operation of Heinz Peter Witzke und Diti Oudendag. For N2O-emissions from manure management systems we use the N2O-default-emission factor 0.5% (IPCC 2006, Vol.5, Tab. 10.21) for both solid and liquid systems, assuming a natural crust cover for liquid manure management systems (suggested by Luisa Samarelli). The 0.5% were then corrected by the IPCC default NH3-emissions (since in IPPC all is based on N excretion, while Miterra uses a mass flow approach). Furthermore, MITERRA takes into account several NH3-mitigation measures which seem to be in line with GAINS (among others the adaptation of animal housing systems mentioned by Anton). The cross effects from NH3-mitigation measures are based on table 5.3 in both the attached reports (Miterra and GAINS). For the measure 'animal housing adaptations' this table, according to my understanding, states a 900% increase of N2O emissions in case of application of the measure. In case of Danish pigs a 28% adaptation rate of this measure was assumed for liquid systems (shares: 92% liquid to 8% solid). If our interpretation of the assumptions presented in the above reports is wrong, we would be happy for a clarification. In that case, I suppose, that would also be interesting for the Alterra-team managing the Miterra model.

Thanks and best regards,

Franz.

Answer Wilfried Winiwarter, 28 feb:

Dear all,

Many thanks, Franz – I understand this clarifies the matter and confirms my previous statements. While trying to understand the algorithms and the models, we should however be clear that in reality N2O emissions from manure treatment is quite uncertain and the major part of manure related N2O emissions will occur after spreading to soils anyway.

Both IIASA reports are based on Mosier et al., 1998 and/or 1996 IPCC guidelines, which is more or less the same. This reports distinctive differences of N2O emissions from an anaerobic liquid system (0.1% of N released as N2O-N) to an aerobic solid system (2%). The Klimont/Brink report assume their 'Housing adaptation' measure to include a separation between liquid and solid, with the effect of an overall emission somewhere in between, or an increase of somewhat less than the factor of 20 of the respective 'pure' systems – they thus suggest a factor of 10. Note that introducing such a separation between liquid and solid is not an abatement option in the current implementation of the GAINS model, 'housing adaptation' refers to rapid removal of manure into closed storage, and the shares of solid and liquid manure systems are left untouched by current GAINS abatement options.

Now the MITERRA model seems to apply a 0.5% emission factor from IPCC 2006 for anaerobic conditions of liquid manure under natural crust. Following IPCC 2006, there is no reason to assume a 10-fold increase by moving to an aerobic system (which originally referred to an emission factor change from 0.1% to assumed 1%). So that turns out to be an inconsistent mixture of two quite distinct IPCC approaches to estimate manure emissions.

Best wishes

Wilfried

Answer Franz Weiss, 28 feb:

Hi Winfried,

Thanks very much for the clarification. We did not think about this when changing the N2O emission factors to IPCC 2006. From the text in the report (page 48) explaining the measure 'housing adaptation' for pigs it was not clear to me that the measure included a switch from a liquid to a solid system (see report):

….For pig housing, a 30-40 percent reduction of NH_3 emissions

can be obtained by combining good floor design (partly slatted floor, metal or plastic coated slats,

inclined or convex solid part of the floor) with flushing systems. Even higher reduction

efficiencies can be achieved when flushing systems with clarified aerated slurry or manure

cooling systems are used (UNECE, 1999b)…..

Could you maybe help us out and go through table 5.3 and indicate us for which cross effects there might be impacts from the change to IPCC 2006 factors? Unfortunately, we are not always able to understand the logic behind the GAINS measures and effects on emission factors, and since MITERRA has not been implemented by us to CAPRI there is some kind of stepwise information loss happening from IIASA via Miterra via Bonn to JRC. For the case of animal housing adaptation, would it be correct to set the cross effect on N2O emissions to zero, since we use the same emission factor for solid and liquid systems?

Best regards,

Franz.

Answer Anton Kool, Blonk Consultants, 28 feb:
To summarise:
JRC based the 10 fold increase of N2O emissions from manure management due to NH3 reducing measures on the 900% factor in Klimont and Brink 2004 , Table 5.3

From IIASA (Wilfried Winiwarter) we understand that the 900% factor (or 10 fold increase) in Klimont and Brink 2004 , Table 5.3 is based on N2O emission factors for anaerobic liquid (0.1%) and aerobic solid systems (2%) based on Mosier et al., 1998 and/or 1996 IPCC guidelines.
The 900% factor is, if I understand correctly, an assumption of the effect if housing systems switch in a certain degree from anaerobic to aerobic. The 10 fold increase is the result of the assumption: 'somewhat less than the factor of 20 of the respective "pure" systems'
JRC applies the IPCC 2006 value of 0.5% for N2O emissions from manure management for traditional non adapted animal housing systems.
If I understand correctly they mentioned ammonia reducing measures by JRC apply to something else than the animal housing adaptations in Klimont and Brink 2004 , Table 5.3 . So for that reason and also for the fact that JRC uses the IPCC 2006 value of 0.5% it is NOT correct to apply the 10 fold increase of N2O emissions from manure management due to NH3 reducing measures.
Remaining question: If ammonia reducing measures are applied in a liquid manure management system (and it is NOT switched into a solid manure system) will there be an effect in direct N2O emission from manure management? If yes, please quantify.

Answer Franz Weiss, 1 march:

Hi Anton,

I confirm your first four statements. To your fifth statement: The 'animal housing adaptation' measure was implemented based on the work of the GAINS group (so, no difference in the definition). As I said, it was implemented to CAPRI some years ago in co-operation of the University of Bonn and Alterra. We, at JRC, did not sufficiently check what is behind those measures or measure bundles, used the code as it was and changed the N2O-default emission factors from IPCC 1996 to IPCC 2006, which led to the boost of the emission factor for pigs and poultry; but not for all, but just (i.e. in case of pigs of Denmark) for 0.28 * 0.92 * 100% of pigs in liquid systems (92%) supposed to be under the measure animal housing adaptation (28%).

For your remaining questions Winfried or Zig are better qualified to give you an answer (I am an economist). Thanks again for your investigation which helped us to detect an error which can be important for the emissions of some countries.

Best regards,

Franz.

Answer Winiwarter, IIASA, 1 march:

Dear all,

Having discussed the issue in detail with Zig Klimont, there is only little to add.

N_2O emissions are the result of microbial activities, by-product of the main conversion pathways. N_2O is formed and also destroyed by microbes before ever arriving in the atmosphere. Reaction rates depend on temperature, oxygen availability, carbon and nitrogen content, water availability and maybe a lot of other influencing parameters which very strongly on the micro-scale, and this variation itself moreover influencing the outcome. So it becomes clear that any release factor is highly uncertain. Uncertainty ranges, as quoted by the IPCC 2000 GPG's are 'between half and twice the value given'.

With limited measurements available, too, one tries to use theoretical background. It is clear that any N_2O formation needs oxygen, i.e. it can not occur under anaerobic conditions. This is what Mosier et al. (and IPCC, 1996) have been looking into. In consequence, it seemed reasonable to assign from the few available measurements low values to an anaerobic situation, and high values to aerobic emissions. Also in the Klimont and Brink report (which basically repeats here what has been published by Brink et al. already in 2007) refers to that:

(p. 54 of the report sent by Franz yesterday):

The effect on N_2O emissions from pig housing depends

on the efficiency of the separation of manure into a liquid and a solid fraction. N_2O emissions from

manure in aerobic systems appear to be 20 times higher than from anaerobic systems (Mosier *et al*.,

1998). Therefore, emissions from the manure that remains in the liquid fraction and will be aerated

may be up to 20 times higher than without the aeration process. If the solid fraction is stored, it may

start to compost. This may also produce more N_2O than if the slurry is not separated.

So what we see here as an explanation in the effects from altered pig houses is a) separation of solid/liquid and b) aeration of a liquid fraction in storage. If the investigation is on systems that do separate, and that do mix the liquid manure in order to allow oxygen getting dissolved, then you may have a clear increase in N_2O emissions. If the adaptation of animal houses means that manure is frequently washed or scraped away, that open surfaces are kept small and manure is stored in closed tanks, which we understand our measure in GAINS to be like, then we do not know if and how much N_2O would increase – as we remain to be anaerobic here, there is a tendency not to see a reason why emissions should increase (we also do not use any assumed increase in GAINS now).

For IPCC 2006, Table 10.21 in Vol. 4, additional measurements seem to have been covered. It appears to me that for those measurements the level of aeration was not so clear, so one would not be able to clearly differentiate aerobic and anaerobic conditions. In consequence, at least the factor of 10 increase originaly suggested by Brink (for another basis to start from) seems not applicable.

Maybe any of you may find it useful to check with Corjan Brink (still available in this field, working at PBL) is also willing to support this argument, or has followed up later developments. He is the one who originally developed the idea of possible effects / trade-offs due to abatement measures.

Best wishes

Wilfried

Answer Franz Weiss, 4 march:

Dear Winfried and Zig,

Thank you very much for clarifying the issue!

Greetings to Laxenburg,

Franz.

Answer Anton Kool, 5 march:

Dear Franz

And thanks to you for your cooperation

After clarifying this issue what steps will be taken? Will this error made public an erratum or so? and will this be corrected in CAPRI model?

regards

Anton Kool

Answer Franz Weiss, 5 march:

Dear Anton,

I have already corrected it in the CAPRI model and written a comment in the Capri mailing list which explains the problem and the changes, recommending to update the system if new data on GHG emissions are used. Moreover, I spoke with Adrian and we agreed that it might be a good idea to put a short document to the AFOLU folder (where most people download the results and the report) highlighting issues which came up after the publication of the study when discussing the results. So, at least people who download the results in the future could see those issues. However, it is a study which has been made at a certain moment with certain assumptions and the study does not claim to be perfect. The assumptions including the one on the cross effects of reduction measures are documented in the report and the results are the outcome of those assumptions. We continuously try to improve the model and due to the large number of assumptions applied we will, unfortunately, always find issues which in past studies have been done in a certain way but would be done differently in the light of today or tomorrow. In this sense I think it is sufficient if the results of older studies are continuously updated by the output of ongoing research.

Best regards,

Franz.

A2.3 Energy use and manure application:

Capital goods and machinery

CO_2 emissions from production of machinery and buildings are included in the GGELS study. For Danish pork this figure is 0.5 kg CO_2 eq/kg pork and represents about 10% of the total GHG fluxes per kg Danish pork (Table A6.23a). As this is a substantial share can you provide more background information on what figures this result is based on:

- What kind of machinery and buildings are taken into account? Are these machinery and buildings due to feed production as well as due to pig production?
- what is the quantity of machinery and buildings taken into account for feed and pig production?
- What are the emission factors used per unit machinery and buildings to calculate CO_2 emissions?
- What are the sources/references for the assumptions/data used on this topic?

Energy use pig farming

You refer to the work of Tim Kraenzlein Unfortunatly this is a not public available publication. Can you provide the used primary data from this reference or send me this publication?

Answer: Both emissions from the production of machinery and buildings and energy use from pig farming is based on the work PhD of Tim Kraenzlein. I attach it to the email.

Manure application

The allocation of manure application is rather complex. Let me try to describe it in my own words. For instance the Danish pig manure production equals 100 milion kg N. At animal housing 16% N is lost by volatilisation, so 84 milion kg N remains for application at crops. Twothird is applied on feed crops, one third on non feed crops. So the emissions due to application of 56 milion kg N on feed crops is fully allocated to pig production. The emissions due to application of 28 milion kg N on non feed crops is also fully allocated to pig production? And the avoided fertiliser N application at non feed crops of 28 milion kg N is subtracted from the N-fertiliser application in feed crops?

Answer: I agree, it is not very transparent and we will probably change that in the future. For GGELS it is as you said, the whole emissions from manure application would be allocated to the animals. But then, for the feed they ingest, the saved emissions reduce the emissions from mineral fertilisers used for feed production fed to the animal.