Emissions from manure management and application of organic and mineral fertilizer- comparisons of methods

AUTHORS YEAR

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1. Introduction

In this report current assessment methods for manure management and application of organic and mineral fertilizer (IPCC, NIR or national) applied in Nordic countries were reviewed in case studies and compared between PEF methodology. Differences were evaluated by applicability. Also, the effect of manure management technologies was included as one case study for pork.

The report has been prepared by the NordPEF group which works on issues regarding the implementation of Product Environmental Footprint (PEF) in agricultural sector in the Nordics. The group consist of Anna Woodhouse, RISE (Sweden); Sanna Hietala, LUKE (Finland); Troels Kristensen, Aarhus University (Denmark) and Hanne Møller, NORSUS (Norway). The work is funded by the Nordic Council of Ministries and national ministries (MMM/FI) and environmental protection agencies (EPA/SWE) via the Nordic Environmental Footprint (NEF) group. This report is not exhaustive within this topic and descriptions are based on experiences that the participants of the group have as LCA practitioners.

2. Manure management emissions- IPCC vs PEF

For the assessment of emissions from manure management, the PEFCR guidance v 6.3 does not have a recommendation for method, as the recommended approach is presented only for the application of organic and mineral fertilizer.

The current PEFCR for dairy products and the draft version of PEFCR for red meat, however, require manure storage and pre-treatment to be calculated according to IPCC. Methods according to PEFCR draft for red meat are presented here in Table 1. Some differences can be seen between the recommended tier levels to be applied when methods are compared between different livestock product PEFCRs. In this report the focus was on the PEFCR draft of red meat products and observations made in recent case studies. In the following chapters case studies using the methodologies and comparing them is described.

Table1. Accounting of manure management emissions related to GWP according to PEFCR draft for red meat in LCA.

Substance	Process	Minimum requirement	Optional
Methane (CH4), emitted to air	Manure storage	IPCC Tier 2	IPCC Tier 3
Direct nitrous oxide (N2O), emitted to air	Manure storage (and pre-treatment)	IPCC Tier 2, (Tier 1 with penalty in DQR)	IPCC Tier 3
	Manure excretion on pasture		
Indirect nitrous Oxide due to N volatilization (ammonia and nitric oxides) emitted to air	Manure storage (and pre-treatment)	IPCC Tier 2, (Tier 1 with penalty in DQR)	IPCC Tier 3
	Manure excretion on pasture		
Indirect nitrous Oxide due to N leaching, emitted to air	Manure excretion on pasture		
Ammonia (NH3) and nitric oxides (NOx), emitted to air	Manure storage (and pre-treatment)	EMEP/EEA Tier 2 (Tier 1 with penalty in DQR)	Country specific EFs as in national monitoring etc., in accordance to EMEP/EEA
	Manure excretion on pasture	EMEP/EEA Tier 2 (Tier 1 with penalty DQR)	Country specific EFs as in national monitoring etc., in accordance to EMEP/EEA

3. Case studies

3.1 Assessing manure emissions according PEFCR red meat compared to national inventory reports for Finnish pork and broiler chicken production

In a recent life cycle assessment of pork and broiler chicken production in Finland, the analyses were conducted according to the draft version of PEF guidance for red meat. This was done in parallel with general PEF guidance as poultry is not in scope of the red meat PEFCR and as the draft version of red meat PEF guidance is deviating in some parts from the general PEF guidance. In contrast to full PEFCR assessment, the study included only the impact categories global warming potential (GWP) and water scarcity, of which the focus here is on GWP. For the livestock LCA, one of the important life cycle stages is "digestion of feed, housing and manure storage". This life cycle stage is contributing largely to GWP, and it is in focus in this chapter.

Besides the recommendations on assessment methods, the PEFCRs' also set requirements on data quality. While the PEFCRs requirements for primary data are mainly narrowed to those operations which are managed by the company conducting the assessment, on farm activities are also to be modelled mainly according to primary data. The PEFCR draft for red meat is requiring 75% of primary data directly from farms. Much of the decision-making regarding feed composition, feed quality and origin, manure management and storage are done on farms independently. For pork production, the feed composition is highly variable and due to lack of adequate national statistical data on feed composition, primary data collection from farms was required. Thus, assessment of manure management of pork production was depending on primary data collected from farms.

The farm activities data was collected from the farms supplying each of the slaughterhouses that were included in the study. The average annual herd composition was divided into weaners, weaned piglets, fattening pigs and adult animals (sows, boars) and for each of these groups primary data from farms was collected for feed ration composition and animal growth. Details on manure management system was also collected from farms. For Finnish production, studies on typical manure management systems were also available, but in this case primary data was prioritized. The collected data was needed for applying the mathematical models of nitrogen excretion for each animal type.

For broiler chicken production in Finland, the feed composition is fully known and available from meat producing companies. Thus, the primary data collection was more easily facilitated without surveys to farms, while the original data was collected from the farms by meat companies.

The primary data for manure management systems was available only from farms directly but it was also known that all broiler chicken farms providing broilers to two market leading meat companies use similar manure system (litter) in the broiler houses. Only how the manure is used may differ between farms. For broiler chicken egg production, the feed data was only available from the farms, and was collected via questionnaire.

As both pork and broiler chicken production both rely on commercial feed products it was necessary to attain nutritional information on feed compounds. Compound feed data was collected from feed producers and included the PEFCR recommended information such as bill of ingredients, their origins and nutritional data. Feed nutritional data is important for evaluating manure N emissions and this data was either collected from feed producers directly or calculated from bill of ingredients using nutritional data sheets for feed ingredients in Finland or with Feedipedia, which are both publicly available (Luke 2021, Heuze et al. 2013). Based on the diet composition per animal group, the feed nitrogen content was determined per diet:

$$N_{feed} = N_{content/protein} \sum CP_{feed\ ingredient} * m_{feed\ ingredient} \qquad \textbf{Eq. 1}$$

where $N_{content/protein}$ is constant for nitrogen amount in protein (16%), $CP_{feed\ ingredient}$ is protein content of each feed ingredient, $m_{feed\ ingredient}$ is the amount of feed ingredient in diet.

Here, for the Finnish pork, retention of the nitrogen in feed proportion was calculated for swine by applying equation 10.33c from IPCC 2019 refinement with country specific growth factors for swine from Sevón-Aimonen (2002), and this was conducted separately for growing pigs and piglets and adult pigs. The method is the country specific method applied also in the Finnish NIR and the calculation method is close to the one presented by Fernández et. al 1999.

N retention was thus determined for Finnish pork:

$$N_{retention} = 0.026 * LW_{end} - 0.025 * LW_{initial} \qquad \textbf{Eq. 2}$$

Where LW_{end} is the live weight at end of the period and $LW_{initial}$ is the live weight in the beginning of the period. Values 0.026 and 0.025 are nitrogen retention of growing pig and piglet, respectively. Comparison to IPCC (2006) method, which provides the retention rate for swine as 0.3 kg N from every kg N in feed as a ratio, and to 2019 IPCC refinement report, which gives nitrogen gain rates for different growth phases is presented in Table 2.

Nitrogen excretion was calculated as presented in PEF guidance and according to IPCC 2006:

$$N_{excretion} = N_{feed} - N_{retention} \qquad \textbf{Eq. 3}$$

Table 2. Comparison of methods of nitrogen retention of growing swine, Finnish NIR, IPCC 2006 and IPCC 2019 refinement. Final live weight in this example was 120 kg and initial live weight 30 kg. For this comparison, 85-day growth period was assumed. Nitrogen intake in feed in total was set for this example at 8 kg N per period.

	Finnish NIR	IPCC 2006, eq.10.31	IPCC 2019 refinement, eq. 10.33c
N gain, growing	0.026	0.3 kg N for N intake kg	7-20 kg 0.028 20-40 kg 0.025 40-80 kg 0.024 80-120 kg 0.021
N gain, piglet	0.025		
N feed intake, kg N per 85 d period	8		
N retention, calculated	2.37	n/a	2.05
N excretion, calculated	5.67	5.6	5.95

In the example, it is seen that the national method is resulting a lower excretion rate than the current IPCC 2019 method. This is due to the actual differences between the animal models, as the IPCC 2019 retention is based on rather old data and for different swine type with higher fat content than the current typical Finnish production (Shields et al. 1983). For Finnish pig production higher N retention is more accurate and IPCC 2019 would underestimate this and would be yielding higher excretion.

In Finnish NIR nitrogen intake for poultry is estimated with feed consumption per kg of eggs, per one slaughtered or full-grown bird. The feed utilisation values are obtained from commercial poultry breeders and several Finnish feeding experiments. The nitrogen content of feed is determined like for pork and nitrogen excretion with the same equation as for pork ($\boldsymbol{N_{excretion}} = \boldsymbol{N_{feed}} - \boldsymbol{N_{retention}}$ Eq. 3).

For poultry the retention was determined as:

$$N_{retention} = a * Number\_of\_Birds\_Slaughtered * Liveweight \qquad \textbf{Eq. 4}$$

Where a = 0,0296 (N content of a bird according to Lukes experiment data, and which is in line with Finnish NIR).

The national inventory report for Finland has included estimations of annual excretion rates for farm animals, including pigs and broiler chicken. These are presented in Table 3 and were used as default reference values. Actual values for the assessment were calculated based on feed portion N content and N retention rate. Yet, when Nordic NIR methods were compared, large differences could be observed in nitrogen excretion rates especially for growing pigs. As each of the Nordic NIRs were applying national methods defined for the conditions in each country and excretion rates determined based on typical feed compositions, the observed differences can be actual differences in excretion rates. Yet, methodological differences in approach can be also partly explaining the variation.

Table 3. Excretion rates according to Nordic NIR submissions 2020.

	NIR FI kg N / head / year	SE	NO	DK
Fattening pigs	17.2	9.5	3.2[a]	6.2
Weaned pigs	9.2	n/a	n/a	
Sows (with piglets)	32.9	n/a	n/a	n/a
Sows (without piglets)	n/a	18.5	24.4	23.8
Piglets	n/a	1.2	1.4	n/a
Boars	21	13	24.4	n/a
Poultry	0.48	0.29	0.03[a]	0.49

[a]per animal, for these, the lifetime is less than year

For Finnish pork and broiler assessment, emissions from manure were assessed according to PEF guidance. For assessing methane emissions from manure, as presented in Table 1., minimum requirement for red meat PEF study is a Tier 2 method. For assessing methane emissions from manure for swine, country specific emission factors were available from National Inventory Report (Tier 2, Table 4). Red meat PEFCR draft sets penalty for data quality if Tier 1 methods are used for direct and indirect N_2O emissions. Thus, the assessment of Finnish cases was conducted with Tier 2 methods and according to methods used in National Inventory Report. For assessment of direct nitrogen emissions from manure management system, default emission factors were used. Manure emission assessment methods as they were presented in Nordic NIRs are presented in Table 4 and emission factors for manure management systems in Table 5. Methane conversion factors according to studied Nordic NIRs are presented in Table 6.

Table 4. Calculation methods for assessing manure emissions CH_4 and N_2O for cattle, swine and poultry, according to National Inventory Reports of Denmark, Finland, Norway and Sweden. T2 = Tier 2, CS = Country Specific, D = Default (IPCC).

Source	**Emissions reported**	**Method**	**Emission factor**
Dairy Cattle, Non-Dairy Cattle, Swine, Poultry	CH_4	All Nordic: T2	All Nordic: CS
Dairy Cattle, Non-Dairy Cattle	N_2O	DK, FI, NO: T2 SE: CS, T2	DK, FI: D SE, NO: CS, D
Swine	N_2O	DK, FI, NO: T2 SE: CS, T2	DK, FI, NO: D SE: CS, D
Poultry	N_2O	T2	D
Liquid system	N_2O	Tier 2	D
Solid storage and dry lot	N_2O	Tier 2	D
Pasture, range, and paddock	N_2O	Tier 1	D
Deep litter	N_2O	Tier 2	D

Table 5. Default emission factors for MMS as according to IPCC 2006 were in use for all Nordic NIRs (year 2020 submissions).

Manure management system	**Emission factor (kg N_2O-N/kg)**
Slurry with cover (natural or floating)	0.005
Slurry without cover	0
Solid storage (incl. urine)	0.005
Deep litter (cattle & swine)	0.01
Poultry manure with litter	0.001
Dry lot	0.02
Composting	0.01
Pasture, cattle	0.02
Pasture, sheep, other	0.01

Table 6. MCF for manure management according to Nordic NIRs (for year 2018) and IPCC. Grey background indicates default IPCC method.

<table>
<tr><th></th><th>FI NIR, %</th><th>DK NIR, %</th><th>NO NIR, %</th><th>SE NIR, %</th><th>IPCC default</th></tr>
<tr><td>Slurry without natural crust or floating cover</td><td>17</td><td rowspan="2">Non-digesteted slurry:
Cattle: 12.4
Swine: 13.37
Digested slurry:
Cattle: 7.48
Swine: 10.38</td><td rowspan="2">Depending on animal type; e.g. dairy cattle 11.9, non-dairy 12.1, swine 14.3</td><td rowspan="2">3.5, Rodhe et al. 2009</td><td>17</td></tr>
<tr><td>Slurry with natural crust or floating cover</td><td>10</td><td>10</td></tr>
<tr><td>Solid storage (including urine)</td><td>2</td><td>2</td><td rowspan="2">Combined solid and deep litter, according to MMS. Eg. Mature dairy cattle: 8</td><td>2</td><td>2</td></tr>
<tr><td>Deep litter (cattle, swine)</td><td>17</td><td>Weaners: 7.2%
Fattening: 11.4%
Sows: 14.7%</td><td>17</td><td>17</td></tr>
<tr><td>‘Deep litter’ (poultry)</td><td>1.5</td><td>1.5</td><td>1.5</td><td>0.02 kg CH4 per animal per year</td><td>1.5</td></tr>
<tr><td>Other (sheep, goats, horses)</td><td>1</td><td>1</td><td rowspan="2">Combined solid and deep litter; depending on MMS (liquid, solid, dry lot) :
Cattle: 8 – 10.1
Swine: 14.3
Other: 10.5 to 6.0</td><td>0.13, 0.19 and 1.56 kg CH4 per animal per year</td><td>1</td></tr>
<tr><td>Dry lot</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Pasture</td><td>1</td><td>1</td><td>0.5</td><td>1</td><td>1</td></tr>
</table>

In Finnish national inventory report indirect N_2O emissions from manure management are defaults from IPCC and they were utilized in Finnish case studies: FracLeach 0.3, EF for leaching 0.0075, and EF for deposition 0.01.

Manure methane was determined according to IPCC equation 10.23:

$$EF = (Vs * T) * \left[Bo * 0.67 * \sum \frac{MCF}{100} * AWMS \right]$$

Where VS is daily excretion of volatile solids, T is the observed time period in days, Bo is the maximum methane producing potential and MCF methane conversion factor.

For Finland, VS for pigs was set as presented in IPCC (2006) guideline for market swine for Western Europe, 0.3 kg VS per head per day and for breeding swine 0.46 kg VS per head per day. For piglets and weaned piglets, country specific estimates were available from NIR: 0.04 and 0.17 kg VS per head per day, respectively. For comparison of methods, in Sweden, the approach is different: the VS is estimated to be 87% of the excreted manure DM (Dustan 2002). The similar approach was used in Norway, with 90% VS content from manure DM (expert estimate for NIR; Nils Petter Kjos, NMBU). In Denmark, also national method is applied in estimation of VS from manure DM and is set to 80% (Sommer et al. 2013)

B_o was set according to IPCC default in Finnish, Danish and Swedish NIR (0.45 m^3 CH_4 per kg VS). For Norway, country specific value of 0.3 m^3 CH_4 per kg VS was used according to Morken et al. (2013).

An example was built for comparison of breeding swine between Nordic countries, with period of 365 days (Table 7). VS was calculated with IPCC defaults according to Finnish NIR for Finland and country specific VS excretion values were used for Sweden (the excretion per sow per day was given as 0.69 kg VS per head per day), and for Denmark (0.48 kg VS per head per day) and for Norway the excretion was estimated based on estimated DM excretion given in NIR for sows (307.9 kg manure DM per sow). For this comparison, same manure system was set for all as slurry with cover or digested slurry for Denmark.

Table 7. Comparison of emission factor for CH_4 emissions from slurry system with no cover and calculated total emissions of CH_4 according to the emission factors for Finland (FI), Denmark (DE), Sweden (SE) and Norway (NO).

	FI	**DK**	**SE**	**NO**
Kg VS for T=365	167.9	175.09	251.85	277.11
Bo x 0.67	0.30	0.30	0.30	0.20
MCF for slurry with cover	0.1	Digested: 0.1038	0.035	0.143
TOT EF, CH_4 from manure per sow per year	**5.0**	**5.5**	**2.6**	**7.9**

3.1.1 Conclusions

For the assessment of manure emissions from Finnish cases of pork and broiler chicken production, the PEFCR draft for red meat was followed together with the general PEF guidance. The methodological choice was to follow the IPCC Tier levels according to PEF guidance and where country specific methods were prioritised, NIR methods were applied. For Finland the methods used in NIR for manure management emissions had only small differences when compared to default IPCC methods. In other Nordic countries NIR methods give more options also for emission factors. Differences can be found also in determining the retention of nitrogen from feed, while feed ingredient N content estimated should be rather stable. For Finnish pork, the method for retention was based on Sevón-Aimonen (2002), which gave very similar result in comparison to IPCC 2006 for the presented example. Latest method in IPCC 2019 refinement was resulting a slightly higher nitrogen excretion when compared to Finnish and IPCC 2006 methods for the given example. Finnish method is based on data gained from Nordic swine breeds which are typically used in Finland. Thus, the N retention should be similar when compared to Nordic countries and IPCC 2019 method is not describing the retention accurately for these breeds. In contrast to IPCC 2019 retention factors, the current typical breeds in Nordic can actually increase retention rate with growth when meat content is over 60%.

In all Nordic countries a national method was used for determining N retention and excretion. In Denmark is retention per animal (annual or produced) based on yearly updated values for feed intake and efficiency (Danish normative system, https://anis.au.dk/forskning/sektioner/husdyrernaering-og-fysiologi/normtal/). For swine the retention per kg LW is for sows 0.0257 kg N per kg LW, for piglets (7-30 kg) 0.0304 and for slaughter pigs (30-110 kg) 0.0296.

For methane emissions from manure storage, there were more differences in methods between Nordic countries. Comparison of manure methane from similar breeding sows would give rather large differences between countries where similar Nordic conditions apply.

For the harmonization of manure emission assessment methods, harmonized definition for Nordic conditions of the methane conversion factor, amount of volatile solids together with N retention rates would be beneficial.

3.2 Effects of manure management technologies- pig production

It is well known that different technologies available at farm level has potential for reducing the environmental impact of pork production. Hermansen et al (2017) in their report to NEF concluded that technologies such as anaerobic digestion of manure, acidification of slurry, cooling of manure at stable level are important in relation to reducing the environmental impact per kg LW pig meat for slaughter pigs.

In a resent paper the effect was studied not only in the slaughter pig unit (30-110 kg) but also in the for sows and weaners (Olsen et al., 2021). Some technologies, like anaerobic digester, can be used in all parts of the chain, while a technology like frequent removal of slurry – typically once a week – is typically linked to slaughter pig housing systems. As seen in table 8, GWP was reduced in systems using anaerobic digestion of manure, as emissions of methane and N_2O is reduced, but also because it displaces the production of heat and electricity production. Acidification of slurry at stable level is also very effective in reducing CF, while cooling in the stable of the slurry only has minor effect. The combined effect of frequent removal from the stable and use of anaerobic digester in the slaughter pig unit is almost as effective as digester used in the whole chain. These effects will interact with production system, like type of housing, and efficiency, particularly feed efficiency and N excretion, as emission from manure is the major part of the total emission and directly linked to manure technologies.

Table 8. Global warming potential, marine eutrophication and acidification for different manure management systems.

Type of technology	None	Anaerobic digester	Acidification in stable	Cooling in stable	Frequent removal	Frequent removal + digester
Where used		All pigs	All pigs	All pigs	Only slaughter	Only slaughter
Global warming potential (CO_2 eq., kg)	2,67	-0,39	-0,31	-0,03	-0,13	-0,41
Marine eutrophication (N eq., g)	13,87	-0,11	-0,28	-0,05	-0,02	-0,07
Acidification (H+ eq. mmol)	56,6	-3,5	-12,0	-2,5	-0,5	-2,4

The effect at herd level has been investigated by Kristensen et al (2021), based on herd specific data from 8 slaughter pig farms, with a total for 20 different production sites. The report gives detailed information about production and use of technologies, while figure 1 add up the effect of the use of technologies for emission of CH_4 and N_2O respectively. The letter (a,b..) is different unit with each farm (1, 2, …) and to the right weighted average (kg of pigs produced) shows an effect of 0,12 kg CO_2 eq. due to the use of technologies in the slaughter units. At some units, 7a and 7d the effect was up to more the twice of the average due to the combined effect of frequent removal and anaerobic digester. Besides the direct effect on emission of methane and nitrous oxide there is an effect of avoid fossil energy due to the production of biogas equally to 0,14 kg CO_2 eq. per kg LW.

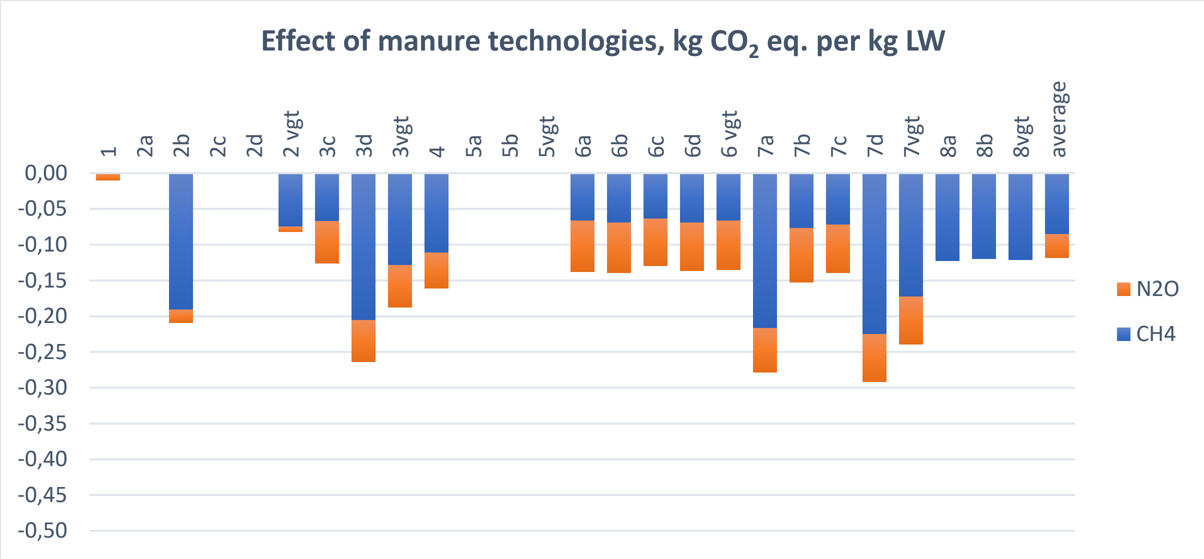

Figure 1. Effect of manure technologies estimated at 8 farms and 20 slaughter pig units.

3.3 Emissions from applying mineral and organic fertilizers- IPCC vs PEF

It is standard to use the IPCC methodology or adopted national methods for calculating biogenic emissions from application of organic and mineral manure and therefore it is interesting to compare the results stemming from these methods with the PEF method. At Aarhus University, Denmark, calculations have been made for application of fertilizer for different crops. Table 9 shows emission factors for PEF guidance and the method used at Aarhus University.

Table 9. Emission factors for feed production recommended in different approaches.

Emission type	PEF feed	PEF General Guidance	Aarhus U methodology
direct N_2O mineral fertilizer and manure	0.022 kg N_2O per kg N applied	0.022 kg N_2O per kg N applied	1% of N manure applied
NH_3 manure	0.24 kg NH_3 per kg N applied	0.24 kg NH_3 per kg N applied	8.7% of N slurry applied* 6% of N deep litter applied*
NH_3 mineral fertilizer	0.12 kg NH_3 per kg N applied	0.12 kg NH_3 per kg N applied	0,025 (Albertsen et al. 2017)
NO_3 manure	1.33 kg NO_3 per kg N applied	0.44 kg NO_3 per kg N base loss mass balance for additiona water	Mass balance (reference?)
P manure	0.05 kg P per kg P applied	0.05 kg P per kg P applied	3% of P surplus

*average for crop rotations and technologies used in Denmark

Table 10 shows the fertilizer input and yield output for five crops grown in Denmark.

Table 10. fertilizer input and yield output for five crops grown in Denmark.

Crops		Spring barley	Winter wheat	Oat (spring)	Rye (winter)	Rapeseed (winter)
Input	Unit					
mineral N fertilizer input	kg N per ha	59.2(119)*	89.2(149)*	31.2(91)*	65.2(125)*	106.2(166)*
calcium and boron calcium nitrate	% of N	0.0	0.0	0.0	0.0	0.0
ammonium sulphate (AS)	% of N	2.1	2.1	2.1	2.1	2.1
calcium ammonium nitrate (CAN) & other nitrate types	% of N	42.1	42.1	42.1	42.1	42.1
ammonium nitrate (AN)	% of N	1.4	1.4	1.4	1.4	1.4
liquid ammonia	% of N	2.0	2.0	2.0	2.0	2.0
urea	% of N	0.4	0.4	0.4	0.4	0.4
other nitrogen fertilizers	% of N	7.4	7.4	7.4	7.4	7.4
magnesium fertilizers	% of N	0.0	0.0	0.0	0.0	0.0
NPK fertilizers	% of N	23.3	23.3	23.3	23.3	23.3
diammonphosphate (DAP)	% of N	0.2	0.2	0.2	0.2	0.2
other NP fertilizer types	% of N	1.7	1.7	1.7	1.7	1.7
NK fertilizer	% of N	0.8	0.8	0.8	0.8	0.8
other	% of N	18.7	18.7	18.7	18.7	18.7
mineral P fertilizer input	kg P per ha	3.3	1.3	5.3	0.3	8.3
P2O5	% of P	100.0	100.0	100.0	100.0	100.0
mineral K fertilizer input	kg K per ha	16.1	32.1	28.1	13.1	43.1
K2O	% of K	100.0	100.0	100.0	100.0	100.0
manure input	kg N per ha	80.0 (0)*	80.0 (0)*	80.0 (0)*	80.0 (0)*	80.0 (0)*
manure input	kg P per ha	17.7 (0)*	17.7 (0)*	17.7 (0)*	17.7 (0)*	17.7 (0)*
manure input	kg K per ha	38.9 (0)*	38.9 (0)*	38.9 (0)*	38.9 (0)*	38.9 (0)*
Output						
net yield	kg per ha	5165.0	7282.0	4671.0	5235.0	3632.0
net yield	kg DM per ha	4390.3	6189.7	3970.4	4449.8	3359.6
straw/crop residues	kg DM per ha	2414.6	3404.3	2382.2	3559.8	3023.6
straw harvested	%	69.0	58.0	35.0	57.0	21.0

*in AU methodology, feedstuffs are assumed to be produced only with mineral fertilizers; the figures in parenthesis show this approach.

Figure 2 and 3 highlights a few results, more results can be found in appendix, Table A1.

Figure 2 shows that there are no large differences when using the AU methods compared to the PEF method for direct and indirect N_2O emissions. There are however big differences in ammonia emissions for the AU compared to the PEF method. The AU method generates lower emissions based on the same input data compared to the PEF method.

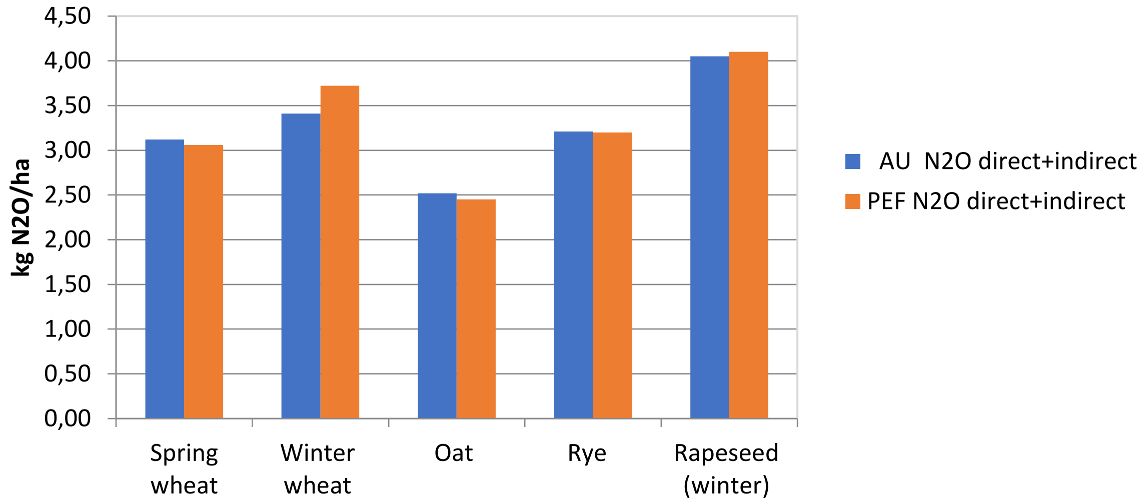

Figure 2. Direct and indirect N_2O emissions from application of mineral fertilizer and organic manure calculated with AU methods (blue bars) and PEF feed (orange bars).

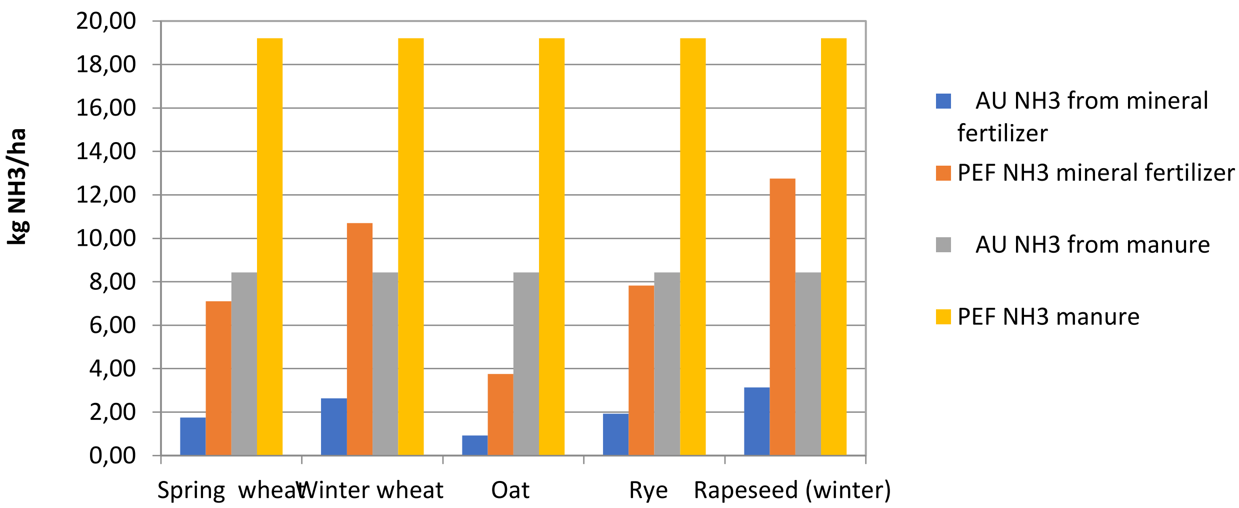

Figure 3. Ammonia emissions, NH_3, from mineral fertilizer and organic manure application calculated with AU methods and PEF feed. Blue bar= AU NH_3 from mineral fertilizer, orange bar= PEF NH_3 mineral fertilizer, grey bar= AU NH_3 from manure, yellow bar= PEF NH_3 manure.

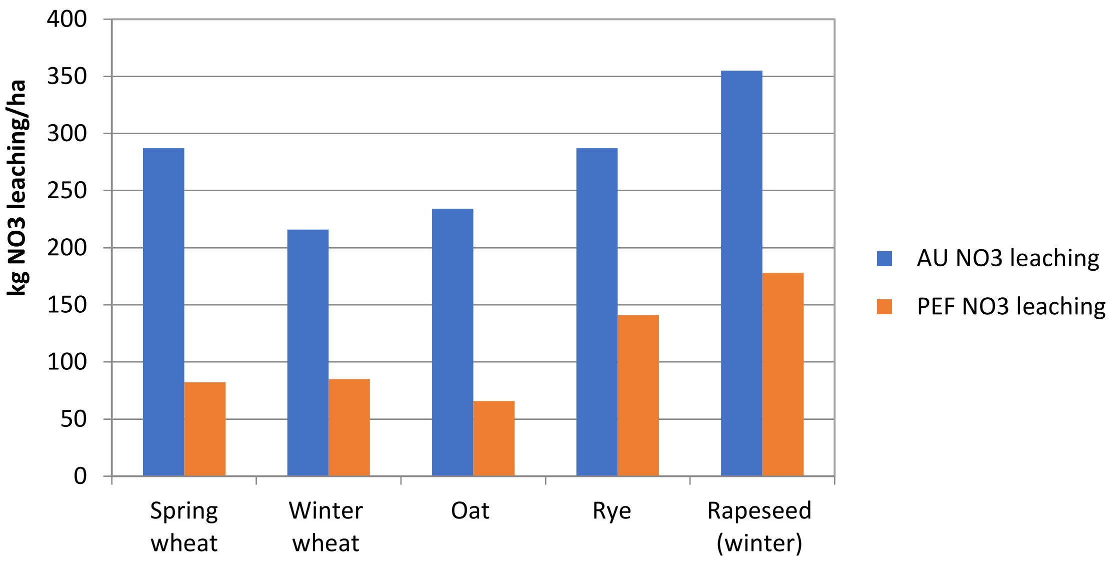

Figure 4. Nitrogen leaching from field application of mineral fertilizer and organic manure according to Au methodology (blue bars) and PEF methodology (orange bars).

For nitrogen leaching PEF methodology generate lower leaching results than AU methodology.

The leaching is average of the 5 crop app 63 kg N (kg N= 0,23 * NO_3) – which is at the same level as Olesen et al (2020) estimated for this type of crop rotations with average input/output for Denmark.

In Sweden nitrogen leaching is estimated by modelling of nutrient flows taking into consideration factors that are of great importance, such as soil species (higher N-leakage on light soils), precipitation (higher N-leakage in heavy precipitation in winter), and type of crop (low N-leakage from an embankment (Johnson et al., 2016). A comparison made between PEF feed and the Swedish methodology suggests that a very large difference in results can be expected depending on the method of calculation chosen. The PEF feed method results in many times higher leaching than if the value was selected from/calculated according to the Swedish method (Johnson et al., 2016), up to 5-10 times higher N leakage for a single crop. There are also examples of the opposite relationship, where calculation according to PEF feed would result in half as high leaching. The difference would have been even larger for crops where fertilizer is not applied, such as field bean and pea. According to the PEF feed method, nitrogen leaching from these crops would be 0 kg, although in practice nitrogen leaching also occurs from these crops.

The main differences appear to be at high fertilization applications (PEF overestimates the importance of fertilization), and for grassland crops (PEF does not reflect the effect of a perennial crop and evergreen soil). The PEF method is also unable to reflect local soil and climate conditions.

3.3.1 Conclusions

No further analysis into why the differences occur between methods could be done in this project but it I important to know that there are differences and that they can be significant. The N_2O emissions are a large part of a feed carbon footprint and that the AU methodology and PEF generated similar results is reassuring.

Acidification potential results will differ between the two methodologies as the NH_3 emissions were twice as high for the PEF method compared to AU method. There is a need to investigate why this is to evaluate if the PEF method is overestimating emissions.

Do the differences in nitrogen leakage due to difference in methodology have any impact on the environmental footprint? It only has a minor significance if only the carbon footprint is evaluated. Nitrogen leaching contributes to indirect N_2O emissions that have some impact on the carbon footprint, while phosphorus leaching does not contribute to any climate impact. However, if eutrophication is assessed, the method chosen has a great impact on the result. The main impact on eutrophication for environmental footprints of crops or feed materials is the leaching of nitrogen and phosphorus and can account for up to 90% of the eutrophication potential.

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APPENDIX

Table A1. N emissions calculated according to different approaches.

N emissions		**Spring barley**	**Winter wheat**	**Oat (spring)**	**Rye (winter)**	**Rapeseed (winter)**
AU methodology	Unit					
N_2O (min_fert + manure; direct + indirect)	kg N_2O per ha	3.12 (2.62)*	3.41 (2.92)*	2.52 (2)*	3.21 (2.72)*	4.05 (3.56)*
N_2O (crop residues)	kg N_2O per ha	0.93 (0.93)*	1.98 (1.98)*	1.11 (1.11)*	1.62 (1.62)*	1.33 (1.33)*
NH_3 from mineral fertilizer	kg NH_3 per ha	1.75 (3.52)*	2.64 (4.41)*	0.92 (2.69)*	1.93 (3.7)*	3.14 (4.91)*
NH_3 from manure	kg NH_3 per ha	8.43 (0)*	8.43 (0)*	8.43 (0)*	8.43 (0)*	8.43 (0)*
NH_3 from crop	kg NH_3 per ha	2.43 (2.43)*	2.43 (2.43)*	2.43 (2.43)*	2.43 (2.43)*	2.43 (2.43)*
NO_3 leaching	kg NO_3 per ha	287 (256)*	216 (185)*	234 (203)*	287 (256)*	355 (324)*
PEF feed						
N_2O (synthetic fertilizer and manure; direct and indirect)	kg N_2O per ha	3.06	3.72	2.45	3.20	4.10
NH_3 synthetic fertilizer	kg NH_3 per ha	7.11	10.71	3.75	7.83	12.75
NH_3 manure	kg NH_3 per ha	19.21	19.21	19.21	19.21	19.21
NO_3 (synthetic fetilizer and manure)	kg NO_3 per ha	185.20	225.10	147.96	193.18	247.71
N_2O crop residues**	kg N_2O per ha	0.93	1.98	1.11	1.62	1.33
PEF Gen Guidance-alternative approach						
N_2O (synthetic fertilizer and manure; direct and indirect)	kg N_2O per ha	3.06	3.72	2.45	3.20	4.10
N_2O crop residues**	kg N_2O per ha	0.93	1.98	1.11	1.62	1.33
NH_3 synthetic fertilizer - urea	kg NH_3 per ha	0.04	0.06	0.02	0.04	0.07
NH_3 synthetic fertilizer - ammonium nitrate	kg NH_3 per ha	3.09	4.65	1.63	3.40	5.53

NH_3 synthetic fertilizer - others	kg NH_3 per ha	0.80	1.20	0.42	0.88	1.43
NH_3 manure	kg NH_3 per ha	19.21	19.21	19.21	19.21	19.21
N_2 fixation by crop	kg N_2 per ha	0.00	0.00	0.00	0.00	0.00
N_2	kg N_2 per ha	12.53	15.23	10.01	13.07	16.76
NO_3 (synthetic fetilizer and manure) base loss	kg NO_3 per ha	61.27	74.47	48.95	63.91	81.95
NO_3 (synthetic fetilizer and manure) additional loss water	kg NO_3 per ha	21.09	10.78	17.02	77.36	95.81
Total NO_3 (synthetic fetilizer and manure) emission to water	kg NO_3 per ha	82.36	85.25	65.97	141.27	177.75

*the figures in the parenthesis refer to feed production only with mineral fertilizers

** no specifications are made in the guidelines with regards to the N_2O emissions from crop residues