An LC inventory based on representative and coherent farm types

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Abstract

There is a need for valid and representative data regarding the production, resource use and emissions from typical farming systems in Denmark for analysis of the environmental impact of different systems and as input to product oriented analyses such as Life Cycle Assessments of basic food items. An inventory of 31 farm types was constructed on the basis of 2138 farm accounts from 1999 selected and weighted to be representative for the Danish farming sector. The farm accounts were grouped according to the major soil types, the number of standard working hours, the most important enterprise (dairy, pig, different cash crops) and the stocking rate (livestock units per hectare). For each group the account data on the average inputs and outputs, land use and herd structure was used to establish a farm type model with coherency between livestock production, total feed use, land use, yields, imported feed, home-grown feed, manure production, fertiliser use and crop production. The set of farm types were scaled up to national level thus representing the whole Danish agricultural sector for the included products. The sum of area and yield by crop, number and production by livestock type and the use of fertiliser, energy and concentrated feed was checked against national level statistics and corrected accordingly across all farm types. Resource use and emissions in each farm type was established using standard nutrient concentrations and models for nutrient cycling, energy use and emissions of e.g. ammonia, nitrous oxides and methane. For LCA the product oriented inventory was established using system expansion rather than allocations to account for the secondary enterprises in the livestock farm types. Data are made available on a web-based database and may be used for analyses of the primary production systems or as input for LCA across the whole production chain.

Background

For most products the primary agricultural food production is an important determinant of the total resource use and environmental impact, which is why life cycle assessment (LCA) of food products must carefully address the question of data quality for agricultural production.

Many existing Inventories for LCA of agricultural products have used case studies, based on recordings on a limited number of farms. However, there is a large variation in the resource use and environmental impact between farms with the same main enterprise (Halberg, 1999; Weidema et al., 2002). Thus, an LCA that aims at a more general validity must be based on a larger sample of farm data being representative for the systems in question (average or marginal depending on the purpose of the LCA) and preferably be checked against statistical information from the level the sample will represent (e.g. regional or national).

This paper present an LCI which is based on representative farm accounts and is used to model the input and production of typical farms using a method that allows to check that the models are consistent with higher level statistical information following ideas described by Halberg et al. (2000).

Objective

The objectives of this paper is:

- To present a method for establishing LCI for important farm types based on representative data for the Danish agricultural sector and farm models.
- To give examples of LCI data and discuss problems and advantages in using representative statistical farm data for LCI.

Methods

All Danish farms are obliged to keep detailed records of purchases and sales for tax purposes and the yearly accounts are made with professional help. A representative data set of these accounts, 2138, are reported by the advisors to the Danish Research Institute of Food Economics (DRIFE) and constitute the basic empirical data input to the model of representative farm types presented here. The accounts include besides economical data, technical data on the land use, livestock numbers in different groups and cash crop yields including cereals. The representative data set was based on farm accounts from 1999, sampled as to present the total Danish agricultural sector of the main livestock and crop production. Thus, each farm account is given a weight to allow for division into sub-populations/groups and for scaling up the sample to national level (Larsen, 2003).

The accounts in the data set were divided into 31 groups. Each group contained from 5 to 185 accounts and represented one of the 31 farm types according to soil type (loamy vs. sandy), main enterprise (dairy, beef, pig, poultry and different cash crop types), organic vs. conventional and animal density (e.g. livestock units per ha). For each farm type a detailed model was established partly based directly on the average accounts data within each group and partly on general knowledge as explained in the following: Step 1: Modelling coherent farm types which have a realistic balance between crop and livestock production, use of inputs and sale of products. Step 2: Modelling the emissions (CH_4, CO_2, NO_3, HPO_3, NH_3 and N_2O) from the individual farm types.

Step 1. Modelling farm types

The average partition of land with different crops and the number of livestock in each group was used to establish the production of each farm type. The accounts also gave information on crop yields and amounts of cash crops (e.g. cereals, rape seed, potatoes, grass seeds) and livestock products sold (milk, meat, live animals). This information was thus used to establish the level of production within each type and the general crop-livestock interaction (e.g. how much grassland was used for cattle). However, because the use of external inputs like purchased feed and fertiliser was only available in monetary units the exact feed and fertiliser use was modelled using standards. Due to the public regulation of manure and fertiliser use in Denmark representative average values for feed efficiency in livestock production (e.g. feed use per kg live weight pig) and the production of Nitrogen (N) and Phosphorus (P) in manure by livestock types is well established (Poulsen et al., 2001). Moreover, each farm has a fertiliser quota based on official crop-N norms deducted the plant available manure-N produced or imported. Thus, the fertiliser use on the farm types was calculated using these norms. As part of Danish compliance with the Nitrates Directive the use of manure-N is limited (e.g. 140 kg manure N per ha on pig farms) why some farms are obliged to export manure to cash crop farms. This was modelled as transfer of manure from farm types with high stocking rate to other types, which then reduced the fertiliser input accordingly.

This way a coherent model of crop-livestock interactions was established for each farm type with a consistent relation between livestock production, use of home-grown vs. imported feed and export of cash crops. Energy use for traction was modelled following Dalgaard et al. (2001) where each crop is assigned a number of field operations multiplied by diesel use per ha. Electricity use was estimated directly from the accounts. The total land use and yields of each crop, the number of livestock, imported feed and fertiliser etc. across all farm types were then checked against national level statistical information (Agricultural Statistics, 2000) to make sure that the typology as whole was consistent and representative for Danish agricultural sector. As shown in table 1 the data set based on farm accounts is in good agreement with the Danish national statistics (Agricultural Statistics, 2000) for land use and for pig and milk production. The total area and yield of major cash crops (not shown) also fits to national statistics.

Table 1. Selected data from the typology of farm models scaled up to national level and compared with the Danish national statistics (Agricultural Statistics, 2000)

	Typology of farm types	Danish national statistics	Deviation from nat. stat.
Slaughtering pigs [1]produced, 1000	20639	20801	-1%
Sows (yearly basis) 1000	1083	1052	3%
Milking cows[2], 1000	633	661	-4%
Milk production, 1000 tons	4624	4455	4%
Agricultural area, 1000 ha	2585	2644	-2%
Area with cereals, 1000 ha	1395	1448	-4%
Area with roughage, 1000 ha	567	570	-1%
Fertiliser N, 1000 tons N	226	252	-10%
Soybean meal, 1000 tons N	142	156	-9%
Grain, 1000 tons	6571	6728	-6%
Diesel and fuel, PJ	13	14	-18%

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[1] Living weight = 100 kg

[2] Milking cows

The typology of farm models did, however, not account satisfactorily for the total use of fertiliser. Therefore, the farm models were adjusted using some of the slack in the determination of individual fertiliser quotas per farm and finally the still unexplained difference was corrected using an overall factor on the input to all farm types. The model also underestimated the total use of diesel and fuel by 20%, and therefore the farm models were adjusted accordingly.

Use of medicine is not considered and pesticide use was not included in the first version. Resource use and emissions related to the construction and maintenance of buildings and machinery used on the farm was not included.

Step 2. Modelling emissions

The emissions of gasses and other substances relevant for LCA impact categories were calculated based on the established resource use and production including land use and herd structure. The emissions of green house gasses were calculated using standard IPCC methodology for methane production from livestock and nitrous oxide production from soils and all relevant manure and fertiliser compartments (IPCC, 1997; 2000). Following the TIER 2 of the IPCC principles specific data for Danish crops and manure handling were used. The CO_2 emission was calculated from the use of fossil fuel for traction and stables. Emissions related to the production of farm inputs like fertiliser and soybean meal, which happen outside the farm may be included in a second step and have been established as separate processes in the LCI database (Nielsen et al., 2003).

Emissions of nitrate for the eutrophication/nutrient enrichment impact category was assumed to be equal to the farm gate balance minus ammonia losses, denitrification (Kristensen et al., 2003) and net change in soil N status. The ammonia emission from stables, manure storage and handling was calculated using standard values from Andersen et al. (1999). Denitrification was estimated using the method of Winter (2003), and net change in soil N status was modelled using the method of Petersen et al. (2002).

Table 2 shows the aggregated emissions over all farm types compared with national statistics for emissions of green house gasses (Gyldenkærne et al., 2004) and ammonia (Andersen et al., 2001). The difference in nitrous oxide emission was expected since we used more detailed information regarding crop residues than in the national nitrous oxide budget. The methane emission was 10% lower and the ammonia emission was 1% lower than national statistics.

Table 2. Selected emissions from the typology of farm models scaled up to national level and compared with the Danish national statistics (Andersen et al., 2001; Gyldenkærne et al., 2004,)

	Typology of farm types	Danish national statistics	Deviation from nat. stat.
N_2O (1000 tons)	22	20	9%
CH_4 (1000 tons)	160	177	-10%
NH_3 (1000 tons N)	76	77	-1%

Results

The resulting 31 farm type models after correction for national level consistency shows inputs and outputs used to produce specific amounts of livestock and cash crop products with different land use according to major enterprise and livestock density. Detailed results are presented at an open database (Nielsen et al., 2003). Table 3 shows a part of the inputs and outputs associated with production at the different dairy farm types.

Table 3. Main characteristic, inputs and outputs associated with agricultural production at eight different dairy farm types. Data are provided per farm per year.

Farm type	4	5	6	7	16	17	18	19
Characteristics								
Soil type		Loamy (clay)				Sandy		
Stocking rate (Livestock Units/ha)	<1.4	1.4-2.3	>2.3	Organic farms	<1.4	1.4-2.3	>2.3	Organic farms
Pct. of Danish farms[3]	0.9	1.7	5.3	0.2	3.8	7.9	0.7	1.4
Number cows	55	55	82	62	48	67	76	85
Land area (ha)	99	50	44	88	81	65	48	102
Milk yield per cow per year	7227	7288	7053	6811	7431	7429	7125	6866
Pct. of total Danish milk production	4	7	3	1	15	43	4	9
Pct. of cows' feed produced on farm	83	64	36	74	85	66	42	71
Inputs								
Soybean meal, tons	59	70	168	15	49	77	125	24
Spring barley, tons	0	65	177	104	0	92	211	154
Fertiliser, kg N	10689	4486	2096	0	8806	6602	3580	0
Fertiliser, kg P	1016	554	0	0	872	909	758	0
Diesel, MJ	515111	292549	326952	384807	409783	376043	336181	439502
Electricity, kWh	46190	30003	44258	39399	34929	42162	45563	55127
Outputs								
Milk, tons	399	398	576	424	355	499	538	583
Bread wheat, tons	76	17	34	27	37	12	8	8
Beef meat, tons	25	15	20	16	20	21	24	18
Rape seed, tons	8	1	0	0	6	0	0	0

More than 50% of the total Danish milk was produced on the sandy soil types with low and medium stocking rate. There are differences in farm size and the percentage of feed produced on farm between the types. Farm types with high stocking rate produce a smaller part of the feed on the farm and import more soybean meal compared to farm types with lower stocking

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[3] Percentage of Danish farms represented by the farm type

rate. The average organic farm is larger than the conventional farm types, has lower milk yield per cow and crop yields per ha and produces more feed on the farm, especially based on grass-clover leys in crop rotation with cereals. In the model the organic farm import around 20 kg N per ha in manure from conventional farms.

The resulting environmental impact per kg milk produced at farm-gate after system expansion and displacement of cash crops is shown in table 4. Milk produced at farm types with low stocking rates (farm type 4 and 16) shows a tendency to lower environmental impact than milk produced at farm types with medium stocking rates (farm type 7 and 17). The farms with high stocking rate have to export manure according to public regulation, which decreases emissions from the farm. Land use per kg milk increase with higher stocking rate, because the land used for imported feeds are involved.

Similar results for pig meat and major cash crops on farm level and per kg product ex farm are presented by Nielsen et al. (2003) on the open database: www.lcafoods.dk.

Table 4. Environmental impact from production of 1 kg of milk from six different conventional dairy farm types

	Units (eqv.)	Farm type 4	Farm type 5	Farm type 6	Farm type 16	Farm type 17	Farm type 18
Global warming	g CO_2	754	910	726	943	1030	998
Eutrophication	g NO_3	14.3	36.2	22.7	46.9	52.3	50.6
Acidification	g SO_2	7.6	9.6	10.1	9.0	10.0	10.9
Photochemical smog	g ethene	0.25	0.26	0.24	0.27	0.28	0.30
Land use	m^2year	1.18	1.36	1.48	1.31	1.38	1.57

Discussion and conclusion

The present LCI is based on realistic levels of resources used per unit of produced product and reflects average production levels and efficiency within different farm types. The types are all consistent in terms of crop-livestock interactions. The typology accounts for most input and output of the Danish agricultural production including the exchange of manure between farm types. The factors soil types and livestock density were assumed to be the primary systematic determinants of the level of resource use and emissions from farms. The farm models allow for the calculation of emissions per kg of product using system expansion and displacement as demonstrated by Nielsen et al. (2003). The process of system expansion is, however, not straightforward and involves critical assumptions regarding marginal producers of the avoided products. In the case of exported manure the methodological choice of using system expansion gave a different allocation of ammonia losses than is often used when comparing nutrient balances and losses from farming systems (e.g. Kristensen et al., 2003). Because the exported manure only displaces an amount of N fertiliser equal to the plant available N content (i.e. the part of total manure-N taken up by the crop when compared to fertilizer in trials) the ammonia losses from spreading the manure on the importing farm is still included in the emissions of the manure producing farm.

The basis for the established typology of farm models is a set of representative farm accounts on the form that is used for statistical purpose including the Danish reporting to the Farm Account Data Network (FADN), which again forms part of EU agricultural statistics (Poppe et al., 2000). Thus, this type of data will be available for most European countries, which again could facilitate the development of more uniform methods for LCI establishment across different countries. Another advantage of this method is that it may be updated relatively easily with data for the subsequent years when accounts data are available.

The major drawback of the method from the authors' point of view is that the large variation between farms in e.g. feed or fertiliser use efficiency due to differences in farmers' management skills and strategic choices regarding crop rotation and feed planning is not reflected in differences between the farm types. This was, however, a necessary choice based on the primary purpose: To get representative and statistically valid data for an LCI to be used for comparison of different products and securing a valid baseline for LCA on processed food products. The amounts of feed and fertiliser purchased could have been modelled based on the monetary information using standard prices per unit but that might have introduced another bias because of differences in the actual price per unit paid (e.g. large farms that get discount prices would in reality have used more feed or fertiliser than estimated from average prices). One hypothesis could be that farmers in the marginal types would be more efficient than the average farmers and thus have a lower resource use and emissions per kg product delivered. The results show differences in resource use and emissions per kg product between farm types, but more sensitivity analyses are needed in order to determine if these differences are significant.

Another drawback is the relatively large number of small co-enterprises in the farm types resulting from combining a large number of farm accounts with different co-enterprises (e.g. two dairy farms growing five hectares with cash crops, one bread wheat, the other sugar beets will result in a type growing 2.5 hectares of each). This results in a number of co-enterprises that have to be compensated for through system expansion. A solution to this would be to eliminate some of these co-enterprises in the modelled farm types, which however further would detach the model from the empirical data.

The typology did not initially account for the total use of fertiliser in Danish agriculture why a correction factor was used. While this secures consistency with national level statistics it is not a totally satisfactory solution because the error may in fact belong to underestimation in specific rather than all types. Fertiliser use in Danish farms is strongly regulated presently and it was considered most realistic to adjust all farm types equally in order to fit the national statistic.

It can be concluded that the resulting LCI demonstrates successfully a method to establish coherent and representative inventories of agricultural production based on generally available data.

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